Centre for Building Performance Research

EMBODIED ENERGY AND CO_2 COEFFICIENTS FOR NZ BUILDING MATERIALS

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1 INTRODUCTION

1.1 Readership

This report is intended for policy makers, building material producers. environmental engineers, environmental researchers, building designers and specifiers.

1.2 Acknowledgments

It is a great pleasure to thank the Building Research Association of New Zealand (BRANZ) for the invitation to carry out this work, and to acknowledge their funding support for this project, and for the earlier embodied energy research at the CBPR. In particular I should like to thank Roman Jaques for his professional and friendly assistance.

I should also like to thank my colleagues at the CBPR for their support and feedback, especially Mike Donn for his precise grasp of the issues, and Henry Skates for his friendly assistance.

1.3 Introduction

Emerging environmental impacts demand detailed knowledge to progress towards sustainable practices. The embodied energy of human made objects has been used as a defacto scale to assess environmental impact and reduce unsustainable practices. Connected with the pressing issue of climate change, embodied CO_2 analysis is the next step in achieving a better understanding of environmental impacts, and is directly linked with embodied energy analysis by the component of emitted carbon dioxide (CO_2) from most energy sources.

The principal source of CO_2 in building materials is the combustion of fossil fuel in their production, or the use of ingredients or energy sources that in turn required a significant use of fossil fuel. By applying known CO_2 emission rates for various fuels to the use of those fuels in producing individual building materials, an overall embodied CO_2 content can be established for each material. The quantity of each fuel or energy source contributing to the final product is known from an energy analysis of that material. An accurate energy analysis method is thus a necessary precursor to a reliable CO_2 analysis. A process-based hybrid energy analysis was used as the basis of this research. For a discussion of the particulars of hybrid and other analysis methods, refer to Alcorn, 1998.

As part of its effort to reduce CO_2 emissions, New Zealand is intending to ratify the 1997 Kyoto protocol in 2002. Of strategic importance, especially to the building industry, is accurate identification of the CO_2 content of materials used in the built environment, since the energy use of buildings is typically around 50% of total national energy usage in developed countries.

This report details the methods used to take data from previous embodied energy work by the CBPR and to apply CO_2 emission factors to it to derive embodied CO_2 coefficients for New Zealand building materials.

2 METHODOLOGY

Data from a previous study (Alcorn, 1998) is used in this study, and upgraded to include embodied CO_2 coefficients. Energy inputs to each process have been analysed for their CO_2 content. Each material has been re-calculated, with any new readily available data included, and errors or omissions rectified. An example of the changes that have occurred is recycled aluminium, where the energy of collecting scrap aluminium has been added, along with the energy of the capital equipment. No specific data was available for these particular items, but it was decided to include proxies from closely related operations to improve the consistency of the results.

2.1 Analysis Conventions

Embodied energy analysis has been noted during its history for large variation in results. The bulk of the discrepancies come about from the inherent uncertainty, distortions and variations of input-output data when it is used for energy analysis. Input-output analysis uses economic data that typically aggregates disparate materials and often several industries into one category. The (sometimes greatly) varying energy requirements for different production processes that fall within the same category cannot be reflected in the results of an input-output energy analysis unless significant extra work is done to adjust for such variations (at which point the analysis becomes a hybrid one). For example, in New Zealand there is one category for basic metal industries, which includes the production of aluminium and steel. However, because aluminium uses far more energy to produce a kilo of product, and because there is more aluminium production than any other metal in New Zealand, the energy attributed to other metals is exaggerated as they are lumped in with the higher energy use of aluminium.

For all its varied and serious shortcomings, however, input-output analysis continues to be used because it is perceived as producing results quickly and easily, although they may not be any easier than those obtained by a process-based hybrid analysis. It also has the advantage of a 'global' coverage of inputs, as input-output tables account for the entire economy.

Full process analysis or process-based hybrid analysis methods provide much more consistent results (Alcorn and Haslam, 1996). A process-based hybrid analysis has the advantage of being accurate, like a full process analysis, at the same time as being economical with resources, especially time.

In addition to the basic method of analysis used, a number of conventions may or may not be employed that can significantly alter the results for individual materials. The particular conventions used (and why) are often difficult to discover.

2.1.1 Convention Changes - Feedstock Energy

Unless otherwise noted, the methodology of this work follows established embodied energy analysis conventions, with a few departures from usual practice.

One such departure that requires emphasis is that the energy of a feedstock has been treated differently in this study from the method used by the author in earlier embodied energy analyses. The change also differs from the usual methodology used by other researchers for the energy of feedstock.

In this study, the calorific value of an ingredient used as a physical feedstock to a process *is* *not* included. This contrasts with more common practice where, for example, the calorific value of the oil feedstock used to manufacture plastic would be included in the final embodied energy coefficient. This is to eliminate some fundamental inconsistencies that arise from the different treatment of materials depending on their immediate energy source, and to better reflect the underlying aim of embodied energy research, which is to understand energy use and to minimise it for environmental (and economic) reasons.

The principal reason for minimizing energy use, from an environmental perspective, is to minimize emissions with a global warming potential, and to minimize resource use. It is for these reasons that the use of fossil fuels is regarded as problematic. Essentially, the stored solar energy of fossil fuels cannot be released at the current rate without significant environmental impact. Principally this comes in the form of CO_2 emissions contributing to global warming. Thus, energy analysis tracks the use of fossil (and other) fuels so that the impacts can be accurately attributed to the end use. When, however, fossil fuel is acquired from the ground but not burnt, then the same CO_2 impacts do not occur. Likewise, as an energy resource, if it is not burnt, it *remains* as an energy resource which might be burnt later. The only significant difference is that it resides on the surface of the planet, rather than beneath it. There are energy, CO_2 and other environmental impact costs of getting the fossil fuel out of the ground, and converting it into a useable product, but these are accounted for.

Waste plastic or other waste products embodying fossil fuels are sometimes used as fuel sources, eg, in electricity generation from municipal waste. These waste sources are sometimes regarded as having zero energy content, with the assumption that the energy use and CO_2 emissions were attributed to the first use. In this instance the use of the energy potential and the release of the associated CO_2 occurs when the product is burnt, and not before. Thus it is the process that uses such waste products as fuel that should incur the energy and CO_2 'penalties', whereas the first use should only incur the 'penalties' from extraction and conversion of the fossil fuel into a useable product.

In this study, while the calorific value of an ingredient used as a feedstock *is not* included, the calorific value of an ingredient used as a fuel *is* included. Thus, the calorific value of bitumen used in making asphalt *is not* counted, but the calorific value of bitumen used as a bunker fuel *is* counted. (Bitumen, as a separate material, is calculated both as a fuel and as a physical feedstock.) Similarly, the calorific value of oil used as a feedstock to plastic manufacture *is not* counted, but the calorific value of oil used as a fuel for plastic manufacture *is* counted.

2.1.2 Conventions Used

Energy figures, and the consequent CO_2 emissions figures are based on the following methodology:

- **Solar energy** is not included. For example, the solar energy input to the growing of trees is not counted.
- The energy of **human labour** is not included. For example, the muscular energy for people to collect scrap paper for cellulose insulation, or fell trees for timber is not counted.
- The calorific value of an ingredient used as a physical **feedstock** to a process *is not* included. The calorific value of an ingredient used as a fuel *is* included, For example, the calorific value of bitumen used in making asphalt is not counted. (As a separate material bitumen is calculated both as a fuel and as a physical feedstock.) The calorific value of oil used as a feedstock to plastic manufacture *is not* counted. The calorific value of oil

used as a fuel to plastic manufacture *is* counted.

- **Secondary products** have the proportion of energy used to make them included. For example, fly-ash from the steel making process has an energy fraction from the entire steel plant attributed to it.
- The energy of **waste or recycled products** is treated as zero for physical ingredients, but the additional energy of collection or re-processing is attached to them. Waste products with a calorific value that are used as fuels have their calorific value as fuels included plus the energy of collection. For example, the energy of waste steel is treated as zero, but has the energy of collection included. The energy of waste lubricating oil used as a fuel has its calorific value included, as well as the energy of collection, but not the energy of extraction and processing into lubricating oil for its first use.
- The energy for **international transport** of ingredients is included. For example, the energy of transporting gypsum from Australia for use in cement production is counted in the cement figure, irrespective of where the ship was fueled.
- The energy of **local transport** to the material production site is included, but not the energy of transport from the factory gate to the point of use. For example,

  1) The energy of transporting clay to the brick factory is included, but not the energy of transporting bricks to a construction site in Wellington.

  2) The energy of transporting cement from the cement works to a concrete product making factory in Wellington is included, but not the energy of transporting the concrete blocks to a construction site in the Upper Hutt.
- The analysis method used is a **process-based hybrid analysis** as much as possible. This means that individual production processes are first analysed as far as is practical. All ingredients and energy sources used are analysed, with factors included for the production and distribution of energy, the transport of ingredients and the energy of the capital equipment used to make the material. The total energy is then divided by the output of the production facility. (See Alcorn, 1998)
- The **energy to obtain energy** and deliver it to the site is taken from input-output data (unless more specific data is available).
- The **energy of each ingredient** is taken from its own coefficient, or from reliable published sources or from input-output data, with preference in that order.
- The **capital equipment energy** of the production facility is accounted for. If the value of the production plant is known, an allowance based on input-output data for the MJ/$ value of that industry (or for machinery production or for buildings and construction, whichever is most appropriate to that facility) is included. If the value of the plant is not known, input-output data relating the average gross fixed capital formation to total output value for that industry is applied as a percentage of the sub-total for that product. (See Alcorn, 1998)
- The analysis is a “cradle to gate” method. That is, the **limit of the analysis** is the factory gate, with all inputs accounted for upstream of that point.
- All known **physical inputs are included**, unless noted otherwise.

2.2 Energy Input-Output Factor

Each energy source requires energy to produce and deliver it to the factory. A factor to account for this is applied where such an input-out factor is not already included in the ingredient or fuel figure.

2.2.1 Table of Energy Input-Output Factors

Industry Energy Category	MJ / MJ
Coal Mining	1.04
Crude Petroleum and Natural Gas Extraction	1.03
Petroleum Refining	1.25
Electricity Generation and Distribution	1.53
Gas Treatment and Distribution	1.1

Source: Peet and Baines, 1995

2.3 Imported Energy and Imported CO_2

Imported energy and imported CO_2 are noted separately. These figures account for energy or CO_2 that is embodied in ingredients brought into the country. Fuels, such as petroleum products are not included in imported energy.

The IPCC counts CO_2 of international transport at the port of last re-fuelling. It is sometimes not known where ships normally re-fuel. In these cases it is assumed that they re-fuel both in the port of origin and in New Zealand. This makes half the energy "imported" and likewise the CO_2.

2.4 Transport Energy

It is assumed that none of the published transport energy intensities used include an input-output factor tp account for the energy of extracting and processing crude oil into fuel. An input-output factor has thus been factored into transport calculations. The exception to this is the CBPR figure used for “International Bulk Carrier” which does include a factor for fuel extraction and production.

2.4.1 Table of Transport Energy Intensities by Mode.

Type	Energy Intensity MJ / Net t km	Source
Bulk Train	0.3	Collins, 1993
General freight trains	0.6	Collins, 1993
Branchline trains	1.7	Collins, 1993
Coastal shipping	1.4	Collins, 1993
Bulk carrier, international	0.2	CBPR study, 1995
Bulk carrier, mixed cargo	0.4	IDEMAT 96
Utes and panel vans	20	Collins, 1993
Rigid trucks	2.5	Collins, 1993
Articulated trucks	1	Collins, 1993
Rigid plus artics.	2	Collins, 1993
Road trains	0.5	Collins, 1993

2.5 Cement

As with other materials, the figures for cement manufacture have changed. Details on the changes for cement are given here as an example of the sorts of changes that have occurred since Alcorn, 1998 was published, and because cement is an especially significant building material.

In New Zealand cement is produced in two plants, one which uses a wet process and the other a dry process. Dry process cement manufacture typically uses less energy. Data from a detailed analysis of cement processing in New Zealand (Jaques 2001) has been used to update the data used in Alcorn 1998. In particular this affects the results for the wet process New Zealand operation. Changes in the process method and energy sources are incorporated. The figures for wet and dry process manufacture are averaged proportionately to their national usage to arrive at the cement, average figure.

The data from Jaques (2001) is used in the wet process calculations but modified by including the calorific value of waste oil used in the calcining process. The data for acquiring the limestone and marl is used in place of industry wide input-output data. The acquisition of limestone and marl is done by the manufacturer, whereas in the dry process plant, limestone and marl is mined by a separate company.

Changes in the process include the use of slag and its transporting from Australia. The embodied energy coefficient used for slag assumes that slag production equals 28% of steel production, by weight, with energy being apportioned equally between the steel output and the output of the slag that gets used. The slag source is Australia, so a figure for Australian steel (Lawson, 1996) is the basis of calculations. and the use of waste lubricating oil as a fuel for the calcination process.

Waste oil is used in the wet process as a fuel for calcination (Jaques, 2001). The transport energy for the collection of the waste oil is assumed to be similar to that for the collection of waste steel (Alcorn, 1998). The energy of obtaining the oil from fossil reserves is ignored, as this is accounted for in the first use (lubrication) of the oil. However, the calorific value of the oil as a fuel *is* included, as this has been preserved during its use as a lubricant, and would not rightly be included in an embodied energy analysis of lubricating oil. Figures for light fuel oil are used for the calorific value and emission factor.

2.6 Timber CO_2 Absorption

Timber products are calculated in two ways. They are calculated in the normal manner for the energy embodied up to the factory gate, and for the CO_2 emitted in this production process. They are also calculated to account for the CO_2 sequestered by the growing tree. This means that timber products have a negative CO_2 emission coefficient, representing the net CO_2 absorbed by the production of the product, including the growing of the tree (McLaren, 2001).

Products that use waste timber feedstock, such as cellulose insulation, do not have the CO_2 absorption benefits credited to them, as these are accounted for in the first use of that product.

Calculating the net CO_2 emission or absorption allows for the calculation of total emission or absorption balances of whole buildings or building systems.

2.7 Spreadsheet

This study was conducted using an Excel spreadsheet. An example page is given in 4.3.1.

In order to make the methodology and derivation of the coefficients as transparent as possible, details of the figures used, the assumptions and methodologies applied, and the data origin for significant cell entries are noted in the spreadsheet.

To preserve the confidentiality that was a condition of obtaining much of the data, some of the spreadsheet cells are hidden.

3 CO_2 EMISSION FACTORS

3.1 Industry Emission Factors

Where there was no data more specific for a particular ingredient, input-output figures showing the individual fuel types for that particular industry are used. The appropriate New Zealand Standard Industrial Classification (NZSIC) category for a particular building material is broken down by fuel type. (Peet and Baines, 1995) The proportion of each fuel type used in that industry is multiplied by the relevant CO_2 emission factor to arrive at an average CO_2 emission factor for that industry on a grams of CO_2 per MJ basis. Only a selected number of industry categories were analysed. These were selected to suit the types of building materials and the gaps in the process analysis data for those materials. For example, in the case of the CO_2 emissions from mining bauxite for aluminium production, a New Zealand input-output figure and consequent NZSIC emission factor for mining and quarrying (category 023A) was applied to the Australian mining operation, since no appropriate Australian figure was available.

3.1.1 Table of Selected Input-Output Based Industry Emission Factors

NZSIC Category	Code	Emission Factor g CO_2 / MJ
Other Mining and Quarrying	023A	56.18
Machinery manufacture	038B	50.74
Water Works and Supply	042A	19.03
Building and ancillary building services	051A	63.9
Other construction	052A	65.57
Non-metallic Minerals Manufacture	036A	73.25
Basic Chemicals Manufacture	035A	52.41
Basic Metal Industries	037A	61.72
Fabricated Metal Products Manufacture	038A	70.11

3.2 Derivation of CO_2 Emission Factors

Each fuel source has a quantity of CO_2 emissions associated with it. These are not always available in a form that is complete for the end-use of these energy sources in New Zealand. CO_2 emission figures were taken from three sources: the *New Zealand Energy Data File* (Dang, January 2001); *New Zealand Energy Greenhouse Gas Emissions 1990-1999* (Ministry of Economic Development, June 2000); and the *New Zealand Energy Information Handbook (*Baines, 1993)

Figures for emissions from **coal, petroleum products** and **LPG** are taken directly from Baines, 1993. Figures for **biogas** and **wood** are taken from Ministry of Economic Development (MED, 2000). A combination of information from MED and Dang, 2001 was used to establish emission factors for **natural gas**. A combination of Dang, 2001; MED, 2000 and Baines, 1993 was used to arrive at emission factors for **electricity** and **geothermal** energy.

3.2.1 Coal

Coal has various emission factors for the different grades. These are given in the table of Energy Emission Factors. While there are fugitive emissions of other greenhouse gases (CH_4) associated with coal production, there are no other CO_2 emissions.

3.2.2 Gas

The CO_2 emission factor used for gas as a fuel, 51.8 g CO_2/MJ, is not that from Baines, but from Ministry of Economic Development, which averages daily flow statistics, and is thus more up to date (MED, 2000). Extracted gas shows a varying composition over both the short (daily) and long term. There has been a trend for the CO_2 component of the gas stream to fall over recent years as the composition of the gas extracted changes over time (MED, 2000). Other fuel types do not display this variation in CO_2 emissions.

CO_2 in high concentrations in the gas stream is removed from some distributed gas. Incomplete combustion while flaring, and any leakage during maintenance and distribution lead to 'fugitive' emissions of CO_2 associated with the production and distribution of gas (MED, 2000). Energy used to extract and distribute gas through pipelines is derived from gas and is responsible for 'own use' emissions.

Flaring/venting and distribution/transmission account for 286 kt CO_2 p.a. (MED, 2000). Extraction and processing account for 363 kt CO_2 p.a (Ibid.), but this must be apportioned to gas *and* oil in the ratio 2/3 gas and 1/3 oil (Dang, 2001). Thus 286 + (363 X 0.667) = 528 kt CO_2 p.a. of fugitive and own use emissions attributable to gas.

The final CO_2 emission factor for gas is the sum of emissions for combustion of the gas, and the 'fugitive' and 'own use' emissions. Gas demand is 218.21 PJ p.a. Emissions for gas from flaring/venting and distribution/transmission are 528 / 218.21 = 2.42 kt CO_2 / PJ, or
2.42 g CO_2 / MJ.

The final emission factors for gas are thus:
Maui: 51.8 + 2.42 = 54.22 kt CO_2 / PJ = 54.22 g CO_2 / MJ
Treated gas: 52.4 + 2.42 = 54.82 kt CO_2 / PJ = 54.82 g CO_2 / MJ
Average gas: 52.1 + 2.42 = 54.52 kt CO_2 / PJ = 54.52 g CO_2 / MJ

3.2.3 Geothermal

Because there is CO_2 in the water/steam flow from geothermal fields, CO_2 is released in the use of geothermal heat for electricity generation.

Total CO_2 emissions from geothermal energy are 386 kt CO_2 p.a. (MED, 2000). Total energy use from geothermal energy is 103.94 PJ (Dang, January 2001). Thus, the overall emission factor for geothermal energy is 386 / 103.94 = 3.7 g CO_2 /MJ.

3.2.4 Electricity

CO_2 emissions in electricity generation result from the combustion of gas and coal, from the geothermal gas stream, from flaring and transmission of gas, and from the use of gas in the extraction and processing of gas.

Energy sources for electricity generation are:
- Gas 23.3 %
- Coal 3.9 %
- Geothermal energy 6.4 %
- Hydro 63.2 %

Other renewables (biogas, industrial waste, wood and wind) have negligible CO_2 emissions (less than 1 %) (Dang, January 2001).

3.2.4.1 Coal

Coal for electricity generation (sub-bituminous) has an emission factor of 91.2 g CO_2 /MJ (Baines, 1993). There are emissions of other greenhouse gases (CH_4) associated with coal production, but no other fugitive CO_2 emissions.

The final emission factor for coal associated with electricity generation is thus: 91.2 x 0.039 = 3.56 g CO_2 /MJ

3.2.4.2 Gas

Gas for electricity generation is virtually all Maui gas (Baines, 1993) so has an emission factor of 54.22 g CO_2/MJ. The final emission factor for electricity from burning gas is thus: 54.22 X 0.233 = 12.63 g CO_2 /MJ

3.2.4.3 Geothermal

Geothermal energy accounts for 6.4 % of electricity generation (Dang, Jan.2001, p100).

The final emission factor for geothermal energy associated with electricity generation is thus: 3.7 X 0.064 = 0.24 g CO_2 /MJ

3.2.4.4 Electricity Emission Factor

The total emission factor for electricity is thus 3.56 + 12.63 + 0.24 = 16.43 g CO_2 / MJ

3.3 Table of CO_2 Emission Factors

Energy Source	g CO_2 / MJ	g CO_2 / l	Source of Data
Coal, bituminous	88.8		Baines, 1993
Coal, sub-bituminous	91.2		Baines, 1993
Coal, lignite	95.2		Baines, 1993
Coal, All NZ production	90.4		Baines, 1993
All Petroleum Products	68		Baines, 1993
Petrol	66.6	2298	Baines, 1993
Diesel	68.7	2618	Baines, 1993
Heavy Fuel Oil	74.8		Baines, 1993
Light Fuel Oil	72.5		Baines, 1993
Electricity	16.43		Baines, 1993; MED, 2000; Dang, 2001
Gas, average	54.52		MED, 2000; Dang, January 2001
Gas, Maui	54.22		MED, 2000; Dang, January 2001
Gas, treated	54.82		MED, 2000; Dang, January 2001
LPG	60.4	1601	Baines, 1993
Geothermal	3.7		Baines, 1993; MED, 2000; Dang, 2001
Biogas	101		MED, 2000 (IPCC)
Wood	104.2		MED, 2000 (IPCC)

4 EXAMPLE ANALYSIS - RECYCLED STEEL

The method of calculating the coefficients follows that used to calculate the embodied energy coefficients in Alcorn, 1998. The materials appearing in this report have, however, all been freshly calculated, and any new data that was available has been included. Additionally, any errors or omissions that were discovered have been corrected. The resultant changes in the embodied energy coefficients for some materials are recorded by notes appended to the materials database on an Excel spreadsheet. For example, recycled aluminium shows an embodied energy coefficient of 9 MJ/kg in comparison to the figure of 8.1 MJ/kg appearing in Alcorn, 1998. This is due to the inclusion of diesel for scrap collection, and an allowance for the energy of capital equipment, both of which were missing in the 1998 study.

Recycled steel reinforcing and sections provides a typical example material to illustrate the method used. Calculations were done using an Excel spreadsheet.

4.1 Methodology

This study treats the whole process of producing a material as one operation. It organizes the analysis into ingredients, energy inputs, transport, capital equipment, outputs, and extra information. This differs from other methods which breakdown the analysis into production stages (eg. raw materials extraction, transportation and various production stages).

The ingredients, energy inputs, and transport are listed. Embodied energy coefficients for ingredients are calculated or taken from other sources. The majority of materials in this study use embodied energy coefficients from Alcorn, 1998. Where necessary, an input-output factor is applied to account for any incomplete portion of a process analysis. The embodied energy coefficient for an ingredient is converted to a coefficient per kilogram of product by relating it to the output of the operation studied. Emission factors are applied, using the method described in section 3, to arrive at an emission per kilogram of product for each ingredient. Where some or all of this is from imported energy or imported ingredients it is noted separately.

A sub total of the energy and CO_2 coefficients is used to calculate the capital equipment energy. This is the energy to build and maintain the plant used for the manufacturing operation. The gross fixed capital formation column of the input-output tables is calculated as a percentage of the total output for a particular industry. Applying this percentage to the sub total of energy and CO_2 coefficients is a crude calculation but is better than no figure where there is no useful information available on the energy or economic value of the plant. The percentage is generally less than 5%.

Other available information is noted.

4.2 Recycled Steel in New Zealand

In New Zealand steel is produced by BHP New Zealand Steel from local iron sands. Pacific Steel Ltd. produces steel from mainly New Zealand sourced scrap. Between 80% and 90% (allowing for annual variations) of structural steel for building is imported.

The collection and recycling of steel within New Zealand is an involved process. Alcorn, 1998 includes a detailed energy analysis of the scrap collection process.

In New Zealand scrap steel is collected countrywide for recycling into reinforcing bars, structural sections (angles, channels and flats) and wire rod which is subsequently re-manufactured into wire products, such as nails and reinforcing mesh.

Some of the scrap is shredded by machines at Christchurch and Auckland. Larger scrap items are gas cut to a size suitable for the furnace. Balers compress the scrap ready for transporting from collection points.

4.3 Ingredients

For discussion of the recycled steel calculation, references to cells in this section (e.g. B5) refer to **4.3.1**

The embodied energy of scrap, entirely due to the collection and transporting of the scrap, comprises 80% liquid fuels (diesel and bunker fuel) and 20% electricity. The CO_2 emission factor (F9) used to derive the CO_2 emissions for the scrap component of recycled steel is the emission factor for All Petroleum Products (Table 3.3) times 0.8, plus the emission factor for Electricity (Table 3.3) times 0.2. The total CO_2 emissions from scrap for one kilogram of recycled steel (G9, Fig.1) is the product of the CO_2 emission factor (F9) and the embodied energy coefficient of recycled steel for scrap (E9).

Calculation for Silico-Manganese (SiMn), Ferro-Silicon (FeSi), Lime and Burnt Lime follow the same pattern as scrap.

A factor taken from input-output data for coal mining (Table 2.2.1) is applied to the carbon input to account for the energy of extracting the carbon for use in the process. The embodied energy coefficient for one kilogram of product from carbon is the quantity of carbon (B14), times the embodied energy coefficient for carbon (C14), times the input-output factor for extracting the coal (D14), all divided by the output from the steel plant (B21). This is then multiplied by the input from the steel plant to the bar mill (B17), since the bar mill is producing the reinforcing bars and sections, and divided by the output from the bar mill (B44) and then divided by 1000 to get from units of tonnes (used in the quantities of inputs and outputs) to kilograms for the final units.

CO_2 emissions for the carbon ingredient are treated in the same way as for the earlier ingredients.

Oxygen is treated in the same way as carbon, except that an input-output value (D15) is used in MJ/$ (Peet and Baines, 1995), since there was no data available on the energy to produce a cubic metre of oxygen. The value of oxygen per cubic metre is placed in the embodied energy coefficient column (C15). The rest of the calculation for oxygen is the same as that for earlier ingredients.

Water is calculated using only an input-output value, since only the dollar value of the water used was known.

4.3.1. Spreadsheet for Recycled Steel Reinforcing and Sections

	A	B	C	D	E	F	G	H	I
1	Steel, recycled, reinforcing and sections								
2			Total Energy			Total CO_2		Total Imported	
3			MJ/kg:	8.55		g/kg:	352.4	CO2,	87.5
4			MJ/m3:	67143.70		kg/m3:	2766.0	MJ/kg:	1.6
5			EE coefficient of	I/O factor	EE coefficient	CO2 emission	CO2 emissions	Imported	Imported
6		Quantity	ingredient		of product	factor	of product	energy	CO2
7			(MJ/kg)(or other)	(MJ/MJ)	(MJ/kg)	(g/MJ)	(g/kg)	(MJ/kg)	(g/kg)
8	**Ingredients**								
9	Scrap steel (t)	157500	704		0.7	57.7	41.7		
10	SiMn (t)	4200	42700		1.2	56.2	65.6	1.2	65.6
11	FeSi (t)	1400	42700		0.4	56.2	21.9	0.4	21.9
12	Lime (t)	2170	1280		0.0	56.2	1.0		
13	Burnt Lime (t)	750	7430		0.0	73.3	2.7		
14	Carbon (t)	1800	29700	1.04	0.4	90.4	32.7		
15	Oxygen (m3)	1900000	1	43.71	0.5	52.4	25.5		
16	Water ($)	1700		6.27	0.0	19.0	0.0		
17	Billets, steel plant to bar mill (t)	116270							
18									
19	**Output from steel plant**								
20	Slag (t)	5020							
21	Billets to rod and bar mills (t)	170510							
22									
23	**Energy sources**								
24	Electricity (kWh/t)	520	4	1.53	2.9	16.4	48.4		
25	Electricity (MJ)	31000000		1.53	0.5	16.4	7.4		
26									
27	Natural Gas (MJ)	134000000		1.13	1.5	54.5	79.1		
28									
29	**Transport**								
30									
31	**Sub Total**				8.0		326.1		
32									
33	**Capital equipt. energy**								
34	Steel plant (MJ)	30517200			0.2	50.7	10.1		
35	Bar mill (MJ)	33410000			0.3	50.7	16.2		
36	CFC								
37	GFCF, as percentage								
38									
39	**Total**				8.6		352.4	1.6	87.5
40									
41	**Other Information**								
42	Prices ($)								
43	Annual Output, NZ (t)								
44	Output, bar mill (t)	104680							
45	% of National Output								
46	Density of Material (kg/m3)	7850							
47	Other Physical Characteristics								
48	Manufacturers/Players								
49	Manufacturing Process								
50	Age of Data	1995							
51	Source of Data	Pacific Steel							
52	Confidentiality	No							
53	Comparative Data								
54	Other notes								

4.4 Energy Inputs

For recycled steel reinforcing and sections two plants are utilized. For the initial steel plant electricity was known in kWh/t, while for the bar mill electricity was known in MJ per annum. Consequently there are two entries, with separate units, for electricity to the production of recycled steel reinforcing and sections (B24, B25). The kWh/t figure is converted into MJ (C24). Both electricity figures are multiplied by an input-output factor (D24, D25) to account for the energy of generating and distributing the electricity to the factory (Table 2.2.1).

To calculate the embodied energy coefficient per kilogram of product due to electricity (E24), the electricity to the steel plant (B24 times C24 times D24) is multiplied by the sum of the steel plant output of billets and slag (B20, B21), since, as an energy per tonne input, there is an equivalent input of electricity to produce a tonne of output, be it steel or slag. The electricity input is divided by the output of steel only from the steel plant (B21), since all the energy used needs to be attributed to the useful product. If the slag were used as a material, it would attract an embodied energy coefficient reflecting the inputs to the steel plant. The electricity input is finally divided by 1000 to translate tonnes to kilograms for the units of the final coefficient (MJ/kg).

Electricity to the bar mill is already in MJ. The rest of the procedure is the same as for the steel plant electricity calculations, except that the result is divided by the out put from the bar mill, and slag is not considered.

Natural gas is used in the bar mill. It is calculated in the same way as electricity to the bar mill.

The CO2 emissions due to electricity and gas (F24, F25, F27) come from Table 3.3. The CO_2 emissions per kilogram of product (G24, G24, G27) are a simple product of the relevant embodied energy coefficients (column E) and the CO_2 emission factors (column F)

4.5 Transport

For the calculation of recycled steel the energy of transport is included in the embodied energy coefficient of scrap.(C9)

4.6 Capital Equipment

For the calculation of recycled steel a MJ figure for the two plants was available from Alcorn, 1998, based on good estimates of the value of the plants in dollars.

4.7 Outputs

For recycled steel, outputs for the steel plant are recorded, with a breakdown for steel billets and slag (B20, B21). For most materials, where only one plant is used in the manufacturing process, there is only one output. The output from the bar mill (B44) is used to divide the energy of each ingredient or energy source to arrive at a MJ/kg figure.

4.8 Totals

Subtotals for the embodied energy coefficient and CO_2 emissions coefficient are used to calculate the capital equipment energy where this is a percentage figure. This is the case for most materials, but not for recycled steel.

Totals are the sum of the subtotal and capital equipment energy. The final coefficient is the total with decimal places reduced to one significant figure.

The final embodied energy coefficient is expressed in terms of MJ/kg (D3) and MJ/m^3 (D4). The final CO_2 emissions coefficient is expressed in g/kg (G3) and kg/m^3 (G4).

Imported energy is expressed in MJ/kg and imported CO_2 in g/kg.

4.9 Other Information

Other information is recorded as available. For recycled steel the output of the bar mill (B44) and density (B46) are used for calculating other figures. The age of data (B50), source of data (B46) and confidentiality status of the information for this material (B52) are recorded for reference.

5 CONCLUSIONS

Energy has been used as a de-facto measure of environmental impact, on the basis that whenever a process is undertaken, there is some consequent impact, and energy used for the process. However, some energy sources have less environmental impact than others. In particular, with the current focus on global warming and consequent climate change, it is important to know the CO_2 implications of each energy source, since this is globally the principal greenhouse gas. CO_2 emission associated with individual processes and operations may thus be regarded as a superior de-facto measure of environmental impact. Given that in developed countries the energy use associated with buildings is in the region of half the total energy usage, it is valuable to know the status of CO_2 emissions embodied in building materials.

This report provides, by use of a process-based hybrid analysis technique, embodied CO_2 coefficients for building materials that reflect the specific inputs of ingredients and energy sources and the CO_2 emissions associated with them. This, in association with the embodied energy coefficients, provides a basis for detailed analysis of buildings and building elements beyond the simple, and inaccurate, stand-by of converting national energy figures into CO_2 figures, or making inevitable but misleading assumptions about fuel types for particular materials. The embodied CO_2 coefficients show a different pattern from the embodied energy coefficients, with less of a gap between the highest group and the next highest, and at the other end of the scale some materials having negative values.

5.1 Notable Materials

In a comparison of materials analysed for embodied energy and embodied CO_2, aluminium stands out less when considered for CO_2. While aluminium in various forms (raw, extruded, painted, anodized) occupies the top four positions in both embodied energy and embodied CO_2, there is a smaller gap back to the next entry, copper sheet, in the CO_2 index. In the energy index, there are another five materials that may be considered at the high end of the range, above 50 MJ/kg: HDPE; extruded PVC; stainless steel; copper wire and rod; and copper sheet.

In the CO_2 index there are eight materials, all timber products, that have negative values, representing a net absorption of CO_2, which may be regarded as having low embodied CO_2. At the top of the CO_2 index the aluminium products, apart from recycled aluminium, again stand out. In addition, another seven materials, above 2000 g CO_2/kg, may be regarded as having high embodied CO_2: polystyrene; HDPE; LDPE; extruded PVC; stainless steel; copper wire and rod; and copper sheet. Bitumen as a fuel also falls within this range, but is excluded, as are other fuels.

5.2 Further Research

The range of materials included in this report covers the most common and significant building materials used in New Zealand. Further research is needed to extend the materials covered to include the majority of commonly used building materials. Statistical analysis of the relative importance of each material in the wider context of New Zealand's energy usage and CO_2 emissions position is needed. As other data on environmental impacts becomes available from manufacturers, this needs to be collected and analysed to form a more precise perspective of the impacts of building materials in New Zealand. The impacts that need to be covered would include other greenhouse gases; resource depletion; emissions to air causing effects other than the greenhouse effect; acidification of water and soil; eutrophication of water and soil; emission of toxins to soil, water and air; waster disposal, and other site-specific effects. Still further work is needed to adapt weighting and rating systems for comparing these effects to the New Zealand context.

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APPENDIX

Embodied Energy and CO_2 Coefficients of New Zealand Building Materials

Material	MJ /kg kgkgkg	MJ / m^3	g CO_2 / kg	kg CO2 /m3	Imported	
					MJ/kg	g CO2 /kg
Aggregate, general	0.04	65	2.3	3.5		
river	0.03	46.7	1.6	2.4		
virgin rock	0.06	83.3	3.1	4.6		
Aluminium, virgin	192	517185	8000	21600	57.9	4294
extruded	202	544685	8354	22555	57.9	4294
extruded, anodized	226	611224	9359	25270	57.9	4294
extruded, powder coat	218	587940	9205	24855	57.9	4294
Aluminium, recycled	9	24397	622	1679		
extruded	14.6	39318	721	1946		
extruded, anodized	23.8	64340	887	2393		
extruded, powder coat	15.2	40928	731	1975		
Asphalt (paving)	0.2	335	14.6	22.8		
Bitumen (feedstock)	2.4	2475	171	176		
Bitumen (fuel)	44.3	45632	3020	3111		
Cellulose pulp	19.6	1057	612	33		
Cement, average	6.2	12005	994	1939	0.2	14.5
dry	5.8	11393	967	1885	0.2	10.9
wet	6.5	12594	1021	1990	0.3	17.9
Cement fibre board	9.4	13286	629	894		
Ceramic brick, new tech.	2.7	5310	138	271		
brick, old tech, av.	6.7	13188	518	1021		
brick, old tech, coal	7.6	14885	684	1348		
brick, old tech, gas	5.8	11491	353	695		
Clay, unfired	0.07	69	4.7	4.7		
Concrete, block, 200	0.9	12.5/unit	106	1.6/unit		
block fill	1.2	2546	156	345		
block fill, pump mix	1.2	2732	163	375		
precast double T	1.9	4546	214	526		
grout	1.5	3496	209	496		
17.5 MPa	0.9	2019	114	268		
30 MPa	1.2	2762	159	376		
40 MPa	1.4	3282	189	452		
Copper, virgin, sheet	97.6	872924	7738	69173	97.6	7738
virgin, rod, wire	92.5	827316	7477	66844	92.5	7477
recycled, tube	2.4	21217	112	1002		

Material	MJ /kg kg	MJ / m3	g CO2 / kg	kg CO2 /m3	Imported	
					MJ/kg	g CO2 /kg
Glass, float/tint	15.9	40039	1735	4372	12.7	1500
laminated	16.3	41112	1743	4391	12.7	1500
toughened	26.4	66605	1918	4834	12.7	1500
Gypsum plaster	3.6	8388	218	501	3.6	218
plaster board	7.4	7080	421	404	3.6	218
HDPE	51	48166	3447	3257	45.6	3440
Insulation, cellulose	4.3	146	140	4.7		
fibreglass	32.1	1026	770	24.6		
polystyrene, expanded	58.4	1401	2495	59.9	52.9	2495
LDPE	51	45872	3540	3186	37.7	3533
MDF	11.9	8213	-568	-392	0.6	42.1
Polystyrene, expanded	58.4	1401	2495	59.9	52.9	2495
extruded	58.4	1868	2495	79.8	52.9	2495
PVC, extruded	60.9	80944	4349	5784	60.9	4349
Sand	0.1	232	6.9	15.9		
Steel, virgin, structural	31.3	245757	1242	9749	30	1148
recycled, reinf, sections	8.6	67144	352	2766	1.6	87.5
recycled, wire	12.3	96544	526	4129	1.5	82.9
stainless	74.8	613535	5457	44747	68.3	5105
					MJ/m^3	$g\ CO_2/m^3$
Timber, pine, r. sawn, air d rough-sawn,	2.8	1179	-1665	-699	0.6	43.5
pine, air dri, rough, treat	3	1252	-1657	-696	62.5	3288
pine, air dried, dressed	3	1273	-1662	-698	0.6	43.5
pine, gas dried, dressed	9.5	3998	-1349	-567	0.6	43.5
pine, bio dried, dressed	4.1	1732	-1644	-690	0.6	43.5
pine, gas dried, dressed	9.7	4060	-1342	-564	62.5	3288
glulam	13.6	5727	-1141	-479	954.6	50042

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ABSTRACT

In 1995 and 1998 the Centre for Building Performance Research (CBPR) conducted research on the embodied energy coefficients of building materials in New Zealand. Reports containing tables of the coefficients were published in 1995, 1996 and 1998. (Alcorn, 1998) This report details the methods used to take data from those embodied energy coefficients and to apply CO_2 emission factors to them to derive embodied CO_2 coefficients for New Zealand building materials. The conventions used and departed from are listed. Tables are included for: input-output factors for energy sources; transport mode intensities; CO_2 emission factors for some NZSIC industries; CO_2 emission factors for energy sources; and an appendix of embodied energy and CO_2 emission coefficients.

Tables & References provided.

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