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Embodied Carbon in Natural Building Stone in Scotland

Prepared for Historic Scotland

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We would also like to thank the quarry and processing facility owners and managers in Scotland, England, Northern Ireland and the Republic of Ireland who gave their time and participated in this project. For reasons of confidentiality we do not name any participants, but we would like to emphasise the contribution of each individual to our project and results.

Summary

Historic Scotland commissioned SISTech and Heriot-Watt University to undertake a research project to understand the carbon embodied in natural stone used in the construction and repair of Scotland's buildings. The main aims of the study were to quantify a carbon footprint of sandstone, granite and slate produced in Scotland and the UK, and the footprint of imported stone.

An initial literature review found that although there are databases of embodied carbon values for most building materials, the range of results for natural stone are varied and inconsistent. Discrepancies among existing literature include the system boundaries used and the embodied energy results for different stone types. In particular, the review highlighted that previous work is of comparatively little use in understanding the impact of quarrying and processing of natural stone in Scotland and this justifies this research, which aims to collect as much primary data as possible.

A process-based life cycle methodology was developed to understand the embodied carbon in Scottish natural stone, and the system boundaries chosen were aligned with PAS 2050, the current UK standard for embodied carbon accounting. A sample of Scottish and UK quarries and stone yards were selected to take part in this research and each was contacted with the survey materials. Primary data collected were supplemented with secondary data from official sources and embodied carbon footprints of each stone type were quantified.

Due to the lack of existing data on footprints of stone in stone exporting countries, an investigation into the structure, transport modes and stone producing areas within each country was carried out. This information was used to model the carbon associated with transporting stone from Spain, Poland, India and China to Scotland.

The results of this research show that the carbon footprint of UK sandstone and granite are lower than those of other building materials (64 and 93 kgCO_2e per tonne respectively), but the carbon embodied in UK slate is significantly higher (232 kgCO_2e per tonne stone). While the overall footprint is directly influenced by stone processing, transport of stone to site and volume of waste, the processing stage of the lifecycle is the most significant contributor. The size of the slate footprint is due to the physical properties of slate as a stone, which result in large volumes of scrap stone associated with the quarrying and production processes.

The results of the transport model show that the footprint of stone increases with distance from the country of origin. Whereas importing stone from China results in an over 550% increase in the sandstone footprint, importing slate or granite from Spain is comparable to transporting stone from south east England to Scotland.

The main conclusion of the study is that sandstone and granite are low carbon building materials compared to others, though the footprint of slate is comparable to brick or concrete. For stone imported from outwith the European Union, transport is by far the largest component of the carbon footprint.

1 INTRODUCTION

Natural stone plays an iconic role in Scotland's built environment and cultural heritage. The use of stone in construction has a long history in Scotland, beginning with the earliest recorded settlements, peaking in the 19th century with the increase in Scotland's industry and subsequently declining in the 20th century. This decline has been attributed to a demand for cheaper building materials such as brick and concrete, in preference to building stone; and increasing imports of building stone, facilitated by cheaper, improved global transport infrastructure. However these changes come at a cost in terms of environmental impact and, in particular, carbon dioxide emissions.

The Climate Change (Scotland) Act 2009 lays out the Scottish Government's commitment to reduce greenhouse gas emissions in Scotland by 80% in 2050. Historic Scotland's Technical Conservation Group is currently carrying out a programme of research into a range of issues relating to energy use in traditionally constructed buildings, in order to understand their potential contribution to mitigating climate change. For new buildings, there are clear guidelines and regulations regarding the thermal performance and material make-up of building components, and there is established data about the broad environmental impacts of a variety of building materials; a similar data inventory does not exist for traditional structures. In particular, there is little existing information on the carbon impact of dimensional stone used for the repair of traditional buildings and construction of new buildings.

Recognising this gap, the Technical Conservation Group commissioned SISTech and Heriot-Watt University to undertake this research to understand the carbon embodied in natural stone used in the construction and repair of Scotland's buildings.

1.1 Aims and objectives of the study

The main aim of this study was to understand the impact, in terms of energy use and greenhouse gases, of the quarrying and processing of natural stone used in the repair of traditional buildings and construction of new buildings.

Specifically, the project objectives included:

- To conduct a literature review of relevant existing studies
- To develop a life cycle analysis based approach to embodied carbon accounting as applied to natural stone
- To collect necessary data from quarries and stone yards
- To calculate the carbon embodied in sandstone, slate and granite dimensional stone

Through discussions with the project steering group it was decided that the main emphasis of the study would be on sandstone used as building stone. This was partly due to the wide use of sandstone in repairing historic buildings in Scotland and also due to the lack of operating granite and slate quarries in Scotland. A wider geographic sample of quarries and processors throughout the UK would be used to understand the impacts associated with the use of granite and slate as building stone.

1.2 Overview of the Scottish stone industry

The natural variation in the geology of Scotland defines the distinct cultural identity throughout the land both in terms of stone type used to construct and repair buildings as well as the construction methods employed. Two main markets for Scottish stone currently exist: stone for new buildings and stone for repairing Scotland's historic buildings. Due to the diverse range of stone used in Scotland's built heritage, many of the stone types required for maintenance are no longer available from their original source quarries, including Scottish slate which has not been quarried since the 1950s. These issues are being addressed by the Scottish Stone Liaison Group (SSLG), a body established to raise awareness of the requirement for traditional Scottish stone.

There are approximately 53 building stone quarries in Scotland today, the majority of which produce building stone only upon demand for specific projects or for a few months each year. Of the Scottish quarries still regularly producing building stone, output is variable. Operations range from between 0.5 – 50 ha sites, with the smaller producers catering for local and niche markets with production rarely exceeding 500 tonnes, and the larger producers operating a number of quarries with production averaging 5,000 – 10,000 tonnes per annum (Scottish Government, 2007). A more detailed description of the Scottish and UK stone industry is given in Appendix A.

1.3 Energy use in the stone production process

The processes used to extract and produce building stone are relatively uniform around the UK.

Quarrying of stone, or extraction, consists of removing large blocks of the building stone from its setting within a larger geological formation. The ease or difficulty of extraction depends largely on the nature and structure of the geology of the area and the physical properties of the stone being quarried. The quarrying process also varies with stone type. For example, quarrying slate, which occurs as a thin layered, largely linear structure, requires a different method of breaking the bed (only along one plane) to that used for quarrying larger bedded sandstone or granite.

In general, the process includes removal of any overlying rock and sediment exposing the desired bed, the creation of minimal damage to the rock, the use of heavy machinery to remove the stone, and transport of the stone to a storage or processing facility. The main sources of energy used at a dimensional stone quarry include diesel and petrol for drills, excavators, front end loaders and dump trucks (see Figure 1), and a limited amount of explosives.

Figure 1: Removal of rough block within a UK quarry.

The processing of stone is much more varied across stone operations. Generally, rough blocks of stone from the quarry undergo primary processing, which involves the block being cut into more usable sized blocks by very large primary or frame saws (See Figure 2). After this, the primary block is cut again into sizes required for projects or products by diamond tipped secondary saws. These are then 'finished' or completed either by hand, or increasingly, by 3-D profiling machines.

The main uses of energy in the stone yard are electricity for the stone-processing machinery, pumping of water and extraction of dust; diesel and gas oil / fuel oil for finishing and shrink wrapping of products; LPG or diesel for heating the yards; and diesel or petrol for transporting the finished stone. Electricity is also used in any office or retail buildings attached to the yard.

Figure 2: ***(clockwise from top left)*** **Primary sawing of granite rough block; sandstone block during secondary processing; stone finishing by 3-D profiling machinery; hand finishing.**

2 LITERATURE REVIEW

2.1 Overview of Life Cycle Analysis (LCA) and embodied carbon accounting

'Carbon footprinting' - accounting for the carbon impacts of an entity - has become an important tool for climate change mitigation initiatives in the last decade. Measuring greenhouse gas (GHG) emissions is a crucial step towards changing behaviour within organisations as these assessments highlight areas where they can curb carbon intensive activities and incorporate carbon impacts into decision making (BSI, 2008b).

When considering the built environment, carbon footprinting can either focus on the 'operational' emissions of a built asset (those produced as a result of the asset's current and future operations), or on the emissions 'embodied' in the asset (those associated with the production and distribution of the asset). Where operational emissions include direct energy requirements of an organisation, focusing on embodied carbon emissions widens the scope of the GHG accounting exercise and incorporates supply chain GHG impacts into the carbon footprint. This 'embodied' carbon associated with a material or built asset can be defined as 'the total carbon dioxide equivalent that is emitted during the different stages of extraction, processing, use and disposal of the material' (UKWIR, 2008). By definition an embodied carbon analysis originates from a life cycle analysis (LCA) approach.

Boundary setting is an essential part of any LCA study. When undertaking a study of embodied energy and/or carbon, boundaries must be established within which the quantity of energy used is analysed, and subsequent carbon emitted. The most common boundary definition is 'cradle to grave', where all energy involved from the extraction of raw material to the end of the products' lifespan is accounted for. Boundaries may also be established to analyse subsets of the overall life cycle, including 'cradle-to-gate' studies that account for all energy from raw material extraction through to the point the product leaves the factory gate and 'cradle-to-site' studies that also include energy used for retail and transport of the product to the final location of its use. Table 1: outlines three common system boundaries used in LCAs and embodied carbon studies.

Table 1: The types of boundaries used in LCAs (Howard, Edwards and Anderson, 2004).

Profile type	Life Cycle stages can include
Cradle-to-gate	Production stage: raw material supply, transport, manufacturing of products, and all upstream processes from cradle to gate.
Cradle-to-site	Product stage: raw material supply, transport, manufacturing of products, and all upstream processes from cradle-to-gate. Construction process stage: transport of materials to the building site and wastage from building installation/construction only (including transport and disposal of waste).
Cradle-to-grave	Product stage: raw material supply, transport, manufacturing of products, and all upstream processes from cradle-to-gate. Construction process stage: transport of materials to the building site and wastage from building installation/construction only (including transport and disposal of waste). Use stage: repair, replacement, maintenance and refurbishment including transport of any materials and disposal of waste over the sixty year study period. Demolition: expected to occur any time at or after the end of the study period. It includes transport and disposal of waste.

The variation in system boundaries used by different studies is discussed in section 2.2 below.

The ISO 14040 series specify guidelines for general LCAs. A recent development in life cycle carbon accounting is the PAS 2050 'Specification for the assessment of the life cycle greenhouse gas emissions of goods and services' developed by the Carbon Trust and published by the British Standards Institute (BSI) in 2008.

2.2 Overview of relevant work in this area

In recent years there have been a number of efforts to document the environmental impacts (including energy and carbon impacts) of different materials used in the building industry. Most of the results of these studies are incorporated in the comprehensive LCA databases for materials and processes currently used in commercial LCA applications (such as Sima Pro and Gabi4).

In the UK, the Building Research Establishment's (BRE) database of materials and their environmental impacts is published in the form of books such as the Green Guide to Specification (Anderson, 2002; Anderson, Shiers and Steele, 2009), websites (www.greenbooklive.com) and tools (e.g. BREEAM) and are widely used by academia and industry. The 'Environmental Profiles' database for materials, produced by BRE, is based on process based LCAs of different UK construction materials in an effort to produce standardised environmental data on construction materials in the UK (Anderson, Shiers and Steele, 2009).

The precursor to embodied carbon studies, Life Cycle Energy Analysis (LCEA) has also become popular as an indicator of environmental performance. Initial publications on embodied energy coefficients of materials originate from the Buildings Research Association in New Zealand (Alcorn, 1998; 2001; 2003). Current LCEA work in the UK includes the Inventory of Carbon and Energy (ICE) developed by the University of Bath's Sustainable Energy Research Team (Hammond and Jones, 2008a; 2008b). The ICE summarises embodied energy and carbon coefficients for building materials, using data collected from secondary sources in the public domain, and employs a cradle-to-gate analysis for the majority of the materials included. Though the ICE includes results for stone (Table 2), these exclude some stone types (e.g. sandstone).

In contrast to work on other building materials, there are fewer studies in the public domain that focus on the carbon impacts of natural stone. Alshboul & Alzoubi (2008) and University of Tennessee (2008a; 2008b; 2008c) are two non-UK studies that have published some figures on natural dimensional stone in Jordan and the United States respectively. The latter is an ongoing LCA study, funded by the Natural Stone Council, the main industry body for natural stone in the US. It has collected industry data from 15 stone quarries and operations across the US and has published results for granite, limestone and slate (Table 2). In Scotland, as part of a Master's dissertation project, Venkitachalam (2008) conducted an embodied carbon analysis of a sandstone quarry in the Scottish Borders and found that transportation emissions were 31% and 90% respectively of the total embodied emissions associated with local and imported stone used in Scotland.

The values for embodied energy and/or carbon associated with stone published in these studies vary greatly, reinforcing Hammond and Jones (2008b) who state that the data for stone LCA results are 'generally poor'. Table 2 sets out the embodied energy and carbon values from the different studies and databases discussed above.

Table 2: Variation in embodied energy and carbon values

Source Study	Type of stone	Embodied Energy (MJ/kg)	Embodied Carbon ($kgCO_2/kg$)	Boundaries
Alcorn (2003)	General	0.656	n/a	Cradle-to-grave
Alshboul and Alzoubi (2008)	General	0.309	n/a	Cradle-to-site
Venkitachalam (2008)	Sandstone	0.122	0.0095	Cradle-to-site
University of Tennessee (2008a)	Granite	5.908	0.621	Cradle-to-gate
University of Tennessee (2008b)	Slate	0.208	0.028	Cradle-to-gate
University of Tennessee (2008c)	Limestone	0.964	0.105	Cradle-to-gate
University of Bath ICE (2008b)	Granite	0.1 to 13.9	0.006-0.781	Cradle-to-gate
University of Bath ICE (2008b)	Limestone	0.3	0.017	Cradle-to-gate

Another discrepancy between most existing studies are the sources of energy included within the defined system boundaries. Different standards and studies scope in or out various upstream supply chain impacts depending on the inventory methodology used and practicability of data collection. A comparison of activities included within the system boundaries of relevant studies and standards is given in Table 3.

Table 3: LCA System Boundaries used by different standards/studies

	ISO 14040	**PAS 2050**	**BRE Material Profiles[1]**	**University of Tennessee studies[2]**	**Stone Study: Scotland[3]**	**Stone Study: Jordan[4]**
Boundaries include	*Cradle-to-grave*	*Cradle-to-grave*	*Cradle-to-site*	*Cradle-to-site*	*Cradle-to-site*	*Cradle-to-gate*
Materials (used in the production process)	✓	✓	✓	✓		
Energy generated onsite	✓	✓	✓	✓		✓
Use of electricity	✓	✓	✓	✓	✓	✓
Use of fuels on site	✓	✓	✓	✓	✓	✓
Use of fuels off site (transport)	✓	✓	✓	✓	✓	✓
Energy embodied in fuels	✓	✓				
Energy use in offices and factories	✓	✓	✓			
Treatment and disposal of waste products	✓	✓		✓		
Recovery of used products (including reuse, recycling and energy recovery)	✓	✓				
Manufacture of ancillary materials	✓					
Manufacture, maintenance and decommissioning of capital equipment	✓					
Manufacture, maintenance and decommissioning of capital infrastructure	✓					
Any other processes within the life cycle which are associated with GHG emissions		✓				

[1] Anderson, Shiers and Steele, 2009; [2] University of Tennessee 2008a; 2008b; 2008c; [3] Venkitachalam, 2008; [4] Alshboul and Alzoubi, 2008

Although most practical studies have focused on first and second order impacts (Alshboul and Alzoubi, 2008; Venkitachalam, 2008), the standards ISO 14040 and PAS 2050 recommend the use of wider boundaries. As can be seen in the table above, one main theme across the LCAs and embodied carbon studies investigated is the exclusion of embodied energy associated with the manufacture and maintenance of capital equipment and infrastructure.

3 METHODOLOGY

In order to quantify the carbon embodied in the extraction and processing of natural stone used for construction and repairs of buildings in Scotland, a process-based LCA approach has been used. The boundaries and guidelines specified in PAS 2050 have been followed as far as practicably possible so as to ensure that the results of this research are comparable to other future work in this area. Any deviations from the PAS 2050 methodology have been clearly defined.

3.1 Developing a process map

The initial step in developing the LCA was to identify all of the materials, activities and processes that contribute to the production of stone, and to investigate any carbon impacts associated with these. These were mapped out as a process diagram in order to define the flows of energy through the stages in the life cycle of stone (see Figure 3).

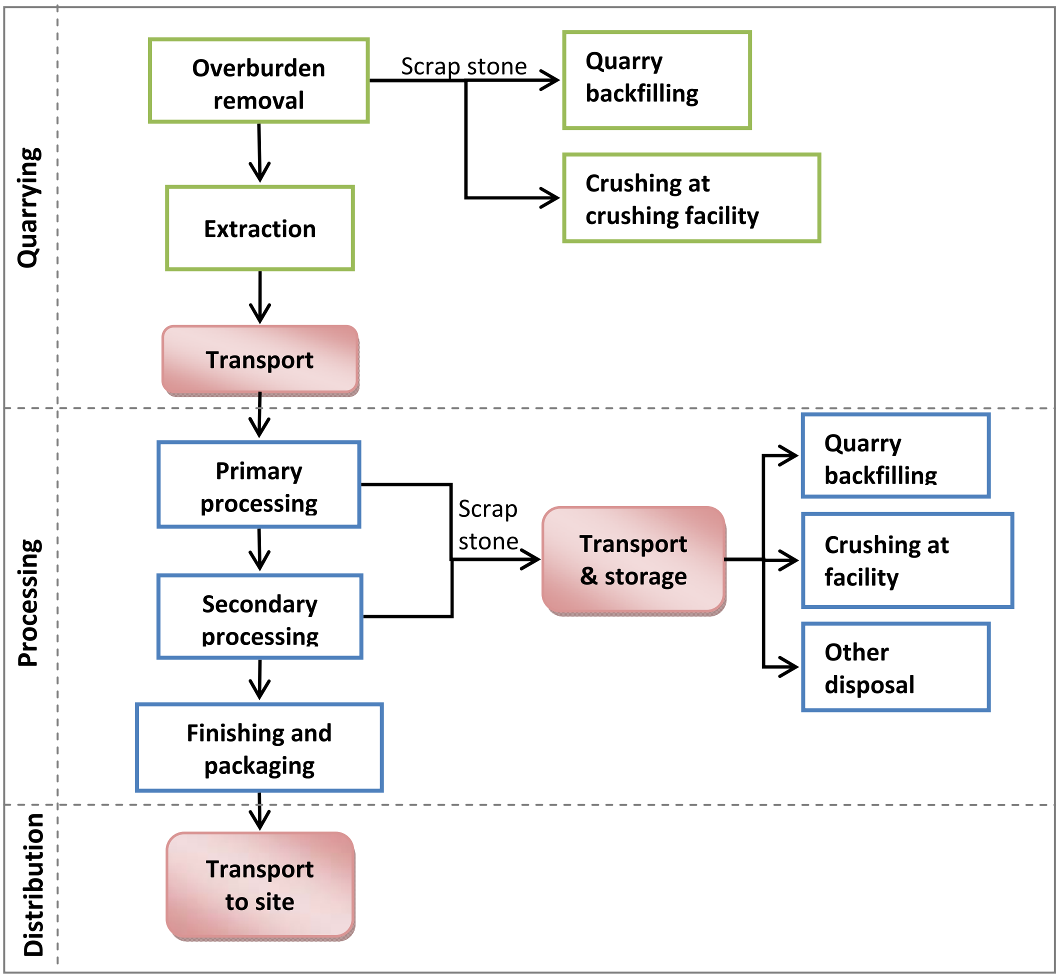

Figure 3: Process diagram of the life cycle of natural stone

The initial map was based on information gathered during the literature review and during discussions with project stakeholders. This map was then verified in discussion with quarry and stone yard owners.

3.2 System boundaries and functional unit

The overall objective of this research was to understand the embodied carbon associated with the production of natural stone, and the carbon impacts associated with the transport of finished stone to the building site. To this end, the analysis utilised two system boundaries:

- Cradle-to-gate
- Cradle-to-site

The boundaries of the cradle-to-gate analysis conducted in this research are consistent with the Business-to-Business (B2B) approach outlined in PAS 2050. The main inputs included in this analysis are as follows:

- All direct energy use from fuels at the quarry and at the processing site
- All indirect energy use from electricity
- Energy used to dispose of waste
- Energy use associated with the running of offices on site
- Off-site energy use related to transport of the stone
- Energy embodied in the fuels and electricity used
- Process emissions associated with the combustion of ‘black powder’, an explosive material used at the quarry

According to the boundaries chosen, and in line with PAS 2050, some sources of energy use were excluded from this work. These are as follows:

- Energy embodied in the manufacture and maintenance of machinery and vehicles used
- Energy embodied in water used on site
- Energy embodied in buildings (e.g. office/factory buildings)
- Energy embodied in the production of black powder / explosives

The exclusion of energy embodied in the production of black powder was due to lack of existing information on explosives. As the amount of the materials used at the quarry (compared to the energy use) is minimal this exclusion has not made a material difference to the results of this work. This exclusion was deemed to be in accordance with PAS 2050.

Figure 4 outlines each of the main inclusions and exclusions within the boundaries of this work.

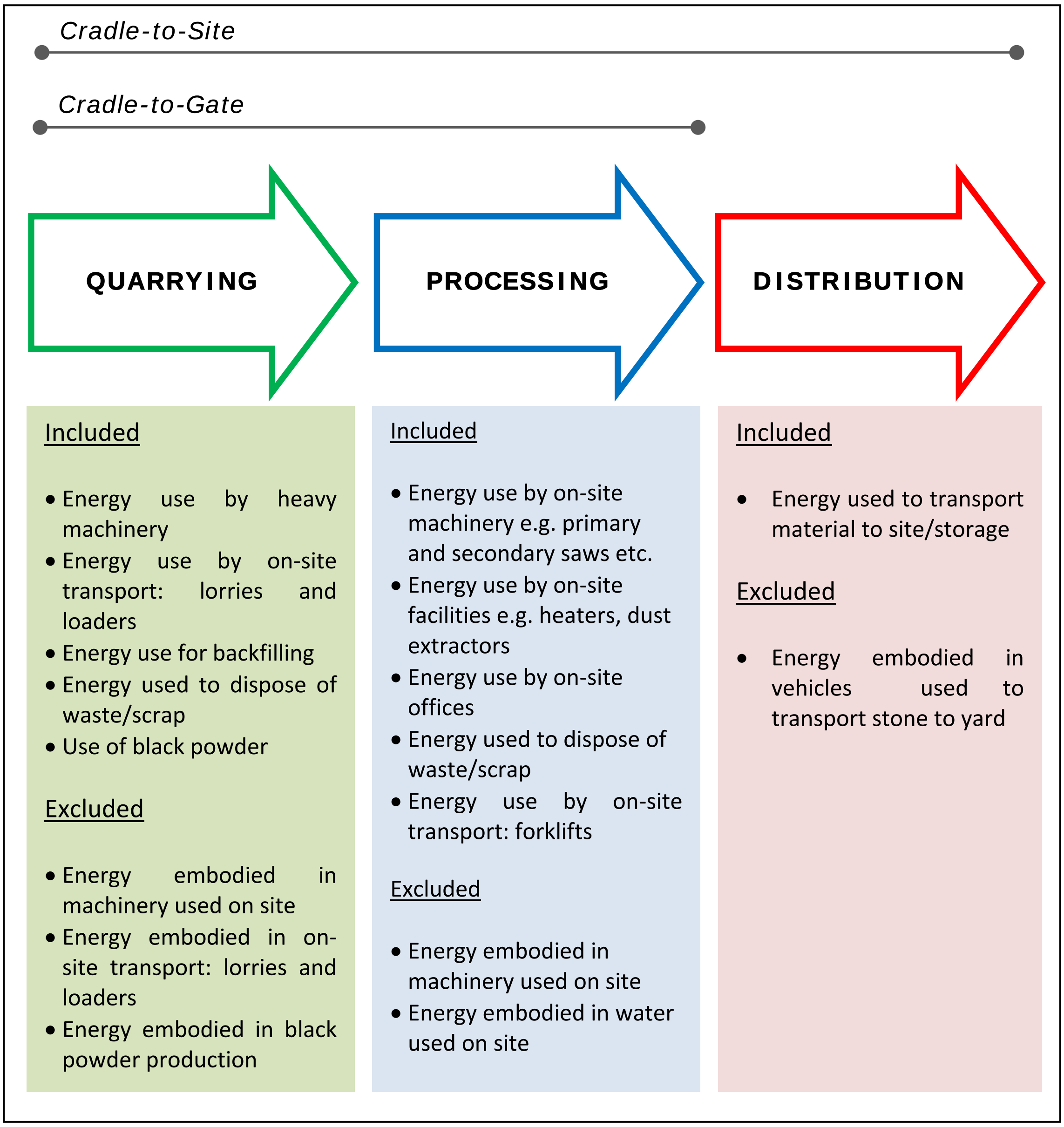

Figure 4: System boundaries - Inclusions and exclusions in each stage of the life cycle

For the cradle-to-site analysis, the cradle-to-gate figures have been supplemented with additional data associated with the transport of stone to a number of example destinations in Scotland. This additional analysis only includes direct fuel use associated with the transport of stone by ship or road. A detailed account of how these emissions were calculated is given in Section 3.4.

3.2.1 Functional unit

The functional unit defined for this work is kilograms of carbon dioxide equivalent per tonne of natural stone (kgCO_2e/tonne). The only process emissions associated with the production of stone are those from the combustion of black powder at the quarry. Emission factors for fuels and electricity used within this analysis include N_2O and CH_4 emissions associated with the combustion of fuel.

3.3 Data collection method and materials

3.3.1 Primary data – energy use during quarrying and processing

The data on energy and materials use was collected using survey questionnaires developed for quarries and stone processing facilities, and based on the process map shown in Figure 3. These surveys requested that owners submit annual fuel use and production information (for 2008), as well as to state the main destinations of their stone products i.e. the sites at which the stone is used. Copies of these questionnaires are available in Appendix D.

A list of the main stone operations in Scotland was drawn up based on information from the Scottish Stone Liaison Group and the Natural Stone Directory (Natural Stone Specialist, 2008). Due to the small number and limited variety of Scottish stone quarries and processing facilities, this list was extended to include granite and slate quarries elsewhere in the UK and in the Republic of Ireland. Where possible, only quarry operations that produce stone throughout the year were included, rather than those producing stone on demand for particular projects. Each quarry and stone yard shortlisted was contacted by phone initially and materials were sent through email and by post. As sandstone was identified as the priority for the study by the project Steering Group (due to the wide use of sandstone for the repair of buildings), the main efforts in collecting data were directed at sandstone quarries and stone yards. The numbers of operations contacted and of those who responded are shown in Table 4.

Table 4: Number of UK stone operations contacted and responses received

Type of stone	No. of operations contacted		Responses received		Location
	Quarry and yard	*Stone yard*	*Quarry and yard*	*Stone yard*	
Sandstone	13	6	4	3	Scotland and Derbyshire
Slate	6	n/a	2	n/a	Cumbria and Wales
Granite	6	n/a	3	n/a	Cornwall and Ireland

The project team visited a subset of those contacted for the survey (8 operations) in order to gain a deeper understanding of the processes involved and the type of data being submitted. The quarries and stone yards visited included all three stone types and a range of scale of operations.

The number of responses received compared to the number of operations contacted was relatively low as shown in Table 4. This was partially due to the smaller scale of some of the operations contacted and seasonality of operations. Some operations were reluctant to participate due to the time involved in collecting the required information.

3.3.2 Secondary data – combustion and life cycle emission factors

All the activity data in this study is based on primary data collection. The main secondary datasets used were databases of emission factors used to calculate the emissions arising at each stage of the quarrying and production process. Wherever possible, emission factors were drawn from the most robust sources, as specified in

PAS 2050. These included Defra, LCA databases collated by the European Commission, and industry-specific sources. The only exception to this was the emission factor for black powder which was developed stoichiometrically. See Table 5 for details of the sources of the emission factors utilised in this study.

Table 5: Sources of secondary data used in this study

Emission Factors	Type of factor	Applied to	Source
Fuels: diesel, gas oil, fuel oil, LPG	Combustion factor	Cradle-to-Gate analysis	Defra / DECC - 2009 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting.
Fuels: diesel, gas oil, fuel oil	Life-cycle factor	Cradle-to-Gate analysis	European Commission - European Reference Life Cycle Database (ELCD) Version II (2008).
Fuels: LPG	Life-cycle factor	Cradle-to-Gate analysis	World LP Gas Association – World Gas, 2008. An Energy Solution for a Low Carbon World: A comparative Analysis demonstrating the Greenhouse Gas Reduction Potential of LP Gas.
Freight Transport: road (UK)	Tonne.km factor	Gate-to-site analysis	Defra / DECC - 2009 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting.
Freight Transport: road (worldwide)	Tonne.km factor	Gate-to-site analysis	Institute for Energy and Environmental Research (IFEU) – IFEU, 2008. Ecological Transport Information - Update 2008. (This work was commissioned by various EU freight and rail organisations).
Freight Transport: sea	Tonne.km factor	Gate-to-site analysis	Defra / DECC - 2009 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting.
'Black Powder' explosive	Combustion factor	Cradle-to-Gate analysis	Developed stoichiometrically from process chemistry.

3.3.3 Quality of primary and secondary data

In order to understand the quality of the primary data collected, each quarry owner / operator was asked to specify the source of data being submitted i.e. whether these were from official records and bills or had been estimated. Of the 20 data returns received (from both quarries and stone yards) the majority of the activity data including energy use, annual quarry / yard dimensional stone production and waste production was based on actual records kept by the organisation. The data on main destinations for stone products was based largely on estimates.

Table 6: Percentage of data returned based on actual records and bills

	Overview of operations[1]	*Use of Energy/Fuel*	*Transport to site / yard*
Quarries	78%	78%	89%
Yards	91%	91%	9%
Both	85%	85%	45%

1 Includes quarry / yard gross and net production figures

3.4 Development of embodied carbon footprints

The primary data collected from each quarry and stone yard included details of annual energy use by fuel type and production figures. Each operator was also asked to submit details of the main destinations for their stone product in 2008 and the amount of product sent to each destination.

In order to calculate the embodied carbon footprint of each stage in the life cycle of stone, the energy used for each activity (e.g. use of different fuels, transport for distribution) was multiplied by the appropriate emission factor, and these were added together. The overall operations footprints were allocated among products and by-products using the system expansion method described in PAS 2050. The carbon footprints per tonne of stone from each quarry and stone yard were then quantified using the total tonnage of quarried stone or stone product. A detailed illustration of the calculations used in this report is given in Appendix C.

Overall Scottish and UK footprints per stone type have been produced using a weighted average of all the quarries and stone yards included.

3.5 Modelling transport impact of imported stone

One of the main aims of the study was to understand the magnitude of the carbon impact of transport of natural stone. This was identified as particularly important by Historic Scotland due to the volume of stone now being imported into the UK and Scotland from around the world. During initial research into the UK stone industry it was found that although HM Revenue and Customs maintains detailed data on imports and exports, there is very little collated, published information on the volume of stone imports into the UK. Based on industry reports (Natural Stone Specialist, 2006) and interviews with project stakeholders the main countries exporting stone to the UK were identified as Portugal, Spain, Italy, Poland in the EU and Brazil, India and China outwith the EU (Scottish Stone Liaison Group, Harrison Stone Consultants). As the magnitude of carbon emissions associated with transport is expected to rise proportionally with distance (for any given mode of transport), a subset of four representative countries were chosen for this study – Spain, Poland, India and China. A short description of the stone industries in each of these countries is given in Appendix B.

It was initially hoped that top-down footprint figures could be developed for the stone industries in each of these countries based on disaggregated industrial energy consumption data in each country. Due to the lack of consistent disaggregated data and the variability in the quality of data in each country, this was deemed unfeasible and an investigation was launched into the nature and scale of the industry in each country. The following information was collected for each country through an internet search followed up with phone interviews with industry professionals in the UK and each of the chosen countries:

- structure and scale of the stone industry,
- types of stone produced in and exported from each country,
- identification of the main stone producing areas in each country,
- modes of transport within each country for the transport of stone,
- main transport routes for the export of stone including identification of ports and main roads,
- main modes of transport used from the country to the UK.

The average road and shipping distances were calculated using Google Maps and PortWorld mapping tools using the information collected above and supplemented with Defra / DECC (2009) and EcoTransIT (IFEU, 2008) emission factors. These were used to model the carbon associated with the transport of stone into the UK. For the purposes of this study two hypothetical destinations in Scotland have been used as end points for imported stone. These were Edinburgh, for all three stone types, and Aberdeen, for granite. The main assumptions associated with the transport modelling are as follows:

- Stone processed from a particular country has been quarried and processed within the country (within the same area of the country) before being transported to the UK for use on site.
- The shortest transport routes have been followed, e.g. for stone from India and China the route followed is assumed to be through the Suez Canal, rather than around the Southern African coast.

4 RESULTS

4.1 Carbon embodied in natural stone from the UK

The results in Table 7 below present the embodied carbon associated with sandstone, granite and slate produced by quarries and stone processing facilities in the UK. The overall footprint figures for each operation investigated have been weighted by their tonnage output in order to produce overall figures for each stone type. The footprints are based on data collected for the calendar year 2008.

Table 7: Cradle-to-gate and cradle-to-site embodied carbon

Stone type	Embodied carbon (kgCO_2e/tonne)	
	Cradle-to-gate	*Cradle-to-site*
Sandstone	64.05	77.42
Granite	92.91	107.48
Slate	231.99	251.77

The cradle-to-gate values in Table 7 reflect the energy used in quarrying and processing of the stone, while the cradle-to-site figures reflect the transport of stone from Scottish and UK stone operations within the UK.

As shown in Table 7, of the three stone types studied, slate has the largest cradle-to-gate and cradle-to-site footprint. The cradle-to-gate footprint can be attributed largely to the amount of scrap stone associated with the quarrying and processing of slate. Within this study it was found that during slate production approximately 85% scrap stone is produced, whereas in the production of sandstone and granite the production of scrap is 29% and 47% respectively. This volume of scrap slate can be attributed to the thinly bedded and easily breakable nature of slate, which means that larger tonnages of bed rock are quarried and a larger volume of rough stone is processed in order to produce slate product, as compared to granite and sandstone.

The cradle-to-site figures are based on data collected from each stone yard on the mode of transport and destinations for stone processed in the yard in 2008, and therefore reflect the average footprint of transport of stone to construction sites (mostly within the UK). This component of the slate footprint is slightly higher than granite and sandstone comparators due to the clustering of slate quarries in the study (Cornwall and Cumbria) and the UK wide distribution of the slate product from these operations (and associated carbon cost of transport). For most of the Scottish sandstone operators, distribution is largely regional or local.

Figure 5 shows the disaggregated footprints for each stone type and the allocation of carbon to the main stages in the life cycle of the stone.

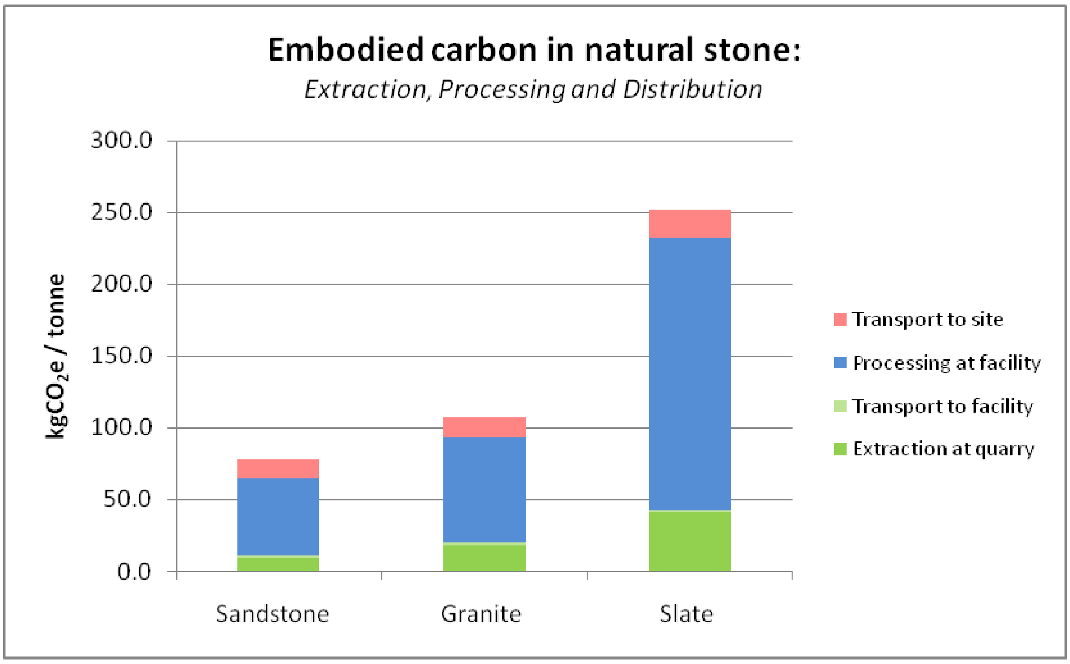

Figure 5: Disaggregated results for carbon embodied in UK natural stone

As can be seen in Figure 5, the largest component of each stone footprint is attributable to the processing stage of the life cycle, mostly due to the different stages of processing (i.e. primary processing, secondary processing, finishing) and the variety of machinery associated with each stage. The largest source of emissions in the processing phase of the life cycle is electricity to run stone preparation machinery, dust extraction devices and water pumping machinery.

4.2 Carbon associated with the import of natural stone

Due to the lack of data on stone quarrying and processing in each country of comparison, UK values have been supplemented with modelled gate-to-site carbon figures representing the transport of stone from various parts of the world to Scotland. Hence the results in this section assume that the carbon impact associated with quarrying and production in the four countries investigated is equal to the footprint of stone production in the UK. In reality this is unlikely to be the case. For example, a smaller per unit footprint could be expected in Spain due to the sheer size and capacity of much larger Spanish operations. In Indian and Chinese operations the footprint of quarrying and production would expected to be lower than the UK footprint due to greater dependence on manual labour. However, as can be seen in Figure 6, in the absence of country specific footprints it has been useful to use the UK quarrying and production figures in order to understand the magnitude of impacts associated with transport.

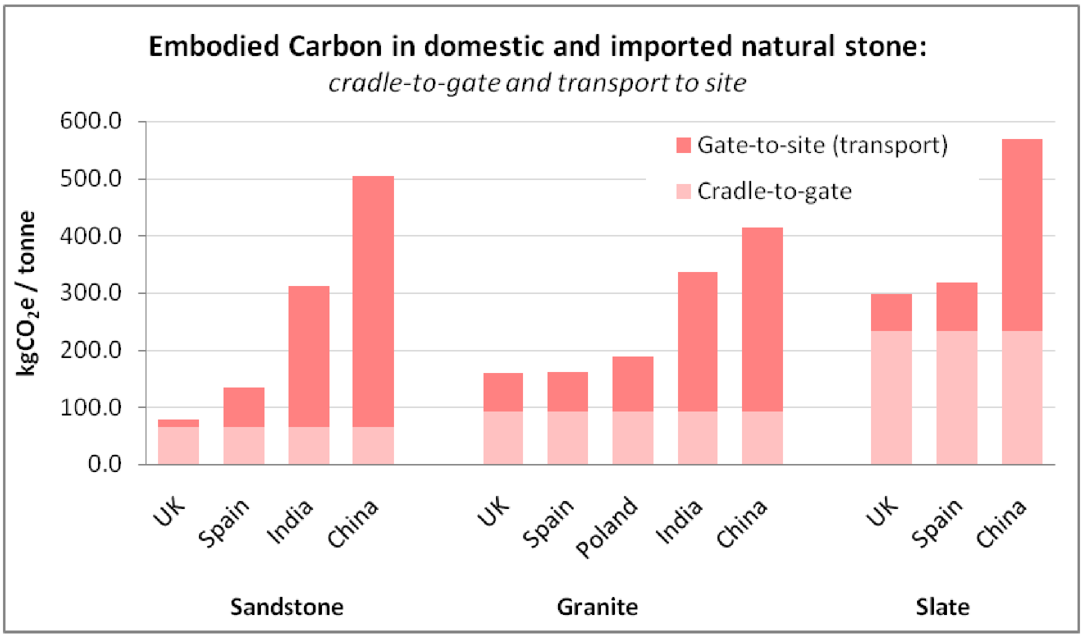

Figure 6: Embodied carbon footprints of natural building stone imported from different countries

The countries used in this analysis are the major exporters for each stone type. The results for each country are based on average carbon impacts from different stone producing regions within each country to hypothetical destinations in Scotland. Table 8 presents the results of the transport modelling as a percentage increase or decrease in the embodied carbon footprints for different stone types due to transport from various countries of origin.

Table 8: Percentage increase in cradle-to-site values for carbon embodied in natural stone due to transport from different countries of origin

Stone type	UK Cradle-to-Site* ($kgCO_2e$/tonne)	% Increase in Cradle-to-Site embodied carbon values			
		Spain	*Poland*	*India*	*China*
Sandstone	77.31	73%		304%	552%
Granite	158.00	2%	19%	113%	163%
Slate	297.42	7%			91%

*The UK Cradle-to-Site figures in this table are based on transport to hypothetical development sites used for the transport modelling in this study, and do not reflect distribution of atone and associated transport impact from UK quarries and processors. These are given in Table 5.

As seen from these results, the impact of transport from imported stone increases with an increase in the distance from the point of origin. As expected this impact is much larger when stone is sourced from India or China resulting in an over 550% increase in the footprint of sandstone from China. Importing stone from Spain, however, only increases the embodied carbon of the stone by 7% and 2% in the case of slate and granite which is equivalent to transporting stone from one end of the UK to the other.

For stone sourced from Spain and Poland, most of the transport footprint is attributable to road journeys within each country from yard to port, and although the journey by sea to the UK is almost 4 - 5 times the road distance in some cases, the carbon impact is lower, due to the significantly lower carbon impact (per tonne-kilometre) of shipping. For stone sourced from India and China, the largest proportion of the footprint is attributable to shipping due to the long distances travelled. However, even in the footprints of Chinese and Indian stone, the road transport has a higher per kilometre carbon impact per tonne of stone.

Though the results presented here are estimates, they highlight the very large carbon impact associated with transport of imported stone. In each of the results above the shortest route and simplest scenario has been assumed, whereas in reality the transport impacts associated with the global stone trade may be even higher due to the reported practice of shipping rough stone from Europe to India or China for processing (taking advantage of lower labour costs) before exporting it back to the EU.

4.3 Uncertainty of results

The quality of any LCA is directly related to the quality of the inventory data. Weidema and Wesnaes (1997) describe data quality indicators based on reliability, completeness, and temporal, geographical and technological correlation. They give definitions for five levels of data quality from ‘excellent’ to ‘unreliable’. A high proportion of the input data for the UK study was based on bills and records kept by the actual quarry operators for 2008 for the area of study, and this data is based on a small but representative sample of quarries. Therefore the confidence that can be attached to this part of the work is high and the data quality excellent under this classification.

The results for production and processing in other countries are necessarily less reliable because of differences in methods between countries. As shown in Figure 6, even if the cradle-to-gate component in India and China could be reduced to zero, the transport to site would still exceed the total for UK production.

5 DISCUSSION AND CONCLUSIONS

5.1 Natural stone compared to other UK construction materials

Natural stone is a low carbon building material compared to other construction materials. The main carbon impacts associated with UK stone are related to processing of the stone, transport of the stone to site and volume of waste stone produced. As detailed in Section 4, quarrying and processing of the sandstone and granite are not very energy intensive compared to the production processes of other materials like brick or concrete. Provided the stone is locally or domestically sourced the carbon emissions associated with it are less than other building materials as detailed in Table 9.

Slate, on the other hand, has a comparable footprint to materials like brick and concrete. The size of the slate carbon footprint is directly related to the amount of scrap stone (used for by-products like aggregate and inert filling material) produced by slate quarries and yards. In some cases the tonnages of this scrap stone far outweighs the architectural slate produced from these operations, but the amount of energy used in processing large amounts of rough slate to produce the dimensional slate product is still very high.

Table 9: Embodied carbon associated with common construction materials (adapted from the University of Bath ICE)

Material	Embodied Carbon ($kgCO_2$/tonne)	Source
Sandstone	64	This work
Granite	93	
Marble	112	ICE
Concrete - 1:2:4 Cement:Sand:Aggregate (4)	129	
General Concrete	130	
Cement Mortar - (1:2:9 Cement:Lime:Sand mix) (1)	143	
Cement Mortar - (1:1:6 Cement:Lime:Sand mix)	163	
Concrete - 1:1.6:3 Cement:Sand:Aggregate (3)	169	
Cement Mortar - (1:1/2:4 1/2 Cement:Lime:Sand mix)	196	
Concrete - 1:1:2 Cement:Sand:Aggregate (2)	209	
General Clay Bricks	220	
Slate	232	This work
Timber: Sawn Softwood	450	ICE
Timber: Sawn Hardwood	470	
Facing Bricks	520	
General Building Cement	830	
Steel: Bar and Rod (5)	1710	
Steel: Galvanised sheet (6)	2820	

All figures are for Cradle-to-gate, (1) This is the closest mortar to those used for traditional stone listed in the Inventory, (2) High strength, (3) Load-bearing structures, columns, floor slabs, (4) Typical in construction of buildings under 3 stories, (5) Typical values, (6) Primary steel

There is potential for further reducing the emissions of stone production by using electricity generated from renewable sources. For example the cradle-to-gate embodied carbon of sandstone (64 $kgCO_2e$/tonne – see Table 7) includes approximately 116 kWh/tonne of electricity. The current UK emissions factor for network electricity is 0.52 kgCO_2e/kWh. If all this were replaced by renewable energy at a very low emission factor, it would be possible to reduce the footprint of sandstone to 15 kgCO_2e/tonne. Even without much progress towards a zero carbon UK electricity supply network this could be achieved by local installations at quarries and stone yards. An example of where this has been achieved at a sandstone quarry and stone yard in Spain is described in Appendix B.

Finally, most of the quarries and yards investigated produced virtually no waste material. Most operators have found ways of using all scrap stone produced during the processing stage so that almost nothing goes to landfill. Sandstone and granite operators use larger scrap stone to produce rough walling stone for local farms, while finer scrap is used to produce aggregate. Slate scrap is also used by operators to produce other products such as landscaping material.

5.2 Impact of importing stone to Scotland

As expected at the start of this research, the transport of imported stone has a very big impact on the overall footprint of stone. The results presented in this report show that for imported stone the carbon footprint can increase by 90% to 550%, by transporting it from India or China to Scotland. As shown in Section 4, even if cradle-to-gate emissions embodied in stone were to reduce to a minimum or zero, the transport to Scotland would still have a significant carbon impact.

The estimates presented in this report are also conservative in that they assume the shortest transport route between the country of origin and Scotland, and the simplest scenario, whereby stone that is quarried in one region is processed in the same region before being transported to the UK. In reality rough blocks can be transported long distances before being processed, and then transported further distances before being used at a construction site. For example, Internazionale Marmi e Macchine (2009) shows that the rise in Chinese imports of raw granite and marble block in 2008 were higher than exports of finished stone. The main countries exporting this raw stone to China were Italy, Egypt, Iran, Brazil and India. This stone, processed in China, was then exported back to countries in the EU and the United States of America. This particular trend of exporting rough block to the Far East and Brazil for processing only to import the processed stone in the EU and the US is well established in the global stone trade, as reported by industry organisations and publications like Internazionale Marmi e Macchine (2009), AIDICO (2008) and Natural Stone Specialist (2009).

It is logical to assume that the cradle-to-gate carbon footprints of stone from countries like India, China and Brazil would be lower than the UK footprints presented in this report due to economies of scale and an expected dependence on manual labour. However, the investigation of the main stone producing and processing areas in China and India during this research highlights that transporting rough block from one area to be processed in another by road would increase carbon footprints of the stone significantly. This is true of Brazil, China and India, where the distances between regions are considerable and stone producing areas are spread all over the country. As described in Natural Stone Specialist (2009) granite is extracted from 27 different areas in eastern, central and northern China, whereas processing hubs are restricted to two or three areas in south China. These distances (and associated carbon impacts of transport) would be extensive – for example, the distance between Shandong, a sandstone producing area in China, and Xiamen, the main Chinese port used for exports, is twice the length of the UK.

5.3 Vulnerability of this study

One potential limitation of this work is that there is no differentiation between stone products. The functional unit was chosen as a tonne of stone production, and the results given are for the weighted average of all dimensional stone products produced at the stone yards which took part. The use of stone in repairs could be specified as square meter (m^2) of façade replacement, for example, and the weight of the stone used will depend upon the thickness required. It seems reasonable to expect that more processing per tonne will be needed for thinner stonework, and that the carbon emission per tonne would also be higher for a thinner product. This of course is unlikely to affect the transport element of any stone product.

The study explicitly excluded any consideration of the technical suitability of the stone concerned. Hyslop (2004) pointed out that selection of masonry repair materials involves more than simple aesthetic matching, as performance of the stone repair depends on factors like porosity, grain size and texture. This adds another factor to be considered by the specifier and could be a further stimulus to policies fostering the use of indigenous stone in Scotland.

5.4 Future areas of work

Another important factor to consider when understanding the environmental impacts of stone as a building material is the lifetime of stone used in construction. Future efforts in this area of research could quantify the carbon associated with the repair and maintenance activities over the lifetime of the building in order to better understand the impacts of repairing and replacing stone.

Other possible work in this area could compare the carbon impacts of stone replacement with so-called plastic repair (this is a lime-sand mortar that is patched into the damaged stone) which is discouraged for significant buildings but still widely used in general work on traditional stone buildings.

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Appendix A Profile of the UK and Scottish stone industry

Market for UK stone

Two markets for indigenous UK stone currently exist, for new building for repairing traditional buildings. This second market is particularly relevant to this study due to the number of historic buildings and structures in Scotland. High profile examples of the recent resurgence in the use of Scottish stone for new buildings include the Scottish Parliament, the Museum of Scotland and the Weston Link at the National Gallery of Scotland.

Structure of the Stone Industry in the UK

During peak activity in Scotland's stone industry circa the mid 1800s, in excess of 750 quarries operated throughout Scotland (Wilson, 2005). In recent times, the number of operational building stone quarries in the country has seen a sharp decrease to approximately 53 (Scottish Government, 2007). Improvements in overseas transport infrastructure and a decrease in local supply and architectural preference has led to cheaper imports from a variety of sources. This situation is true for the rest of the UK as well as can be seen in Table 1 below.

Table 1: Distribution of active building stone quarries in the UK, March 2007. Source: British Geological Survey, 2007.

	England	*Scotland*	*Wales*	*Northern Ireland*	*Isle of Man*	**Total**
Building sandstone	173	16	16	1	0	**208**
Building limestone, incl. chalk	118	5	10	2	2	**137**
Granite & other igneous rocks	15	26	4	2	1	**48**
Slate & marble	18	1	15	0	4	**38**

Output is variable from the Scottish quarries still producing building stone. Operations range from between 0.5 – 50 ha areas, the smaller producers catering for local and niche markets with production rarely exceeding 500 tonnes, while the larger producers may operate a number of quarries with production averaging 5 – 10,000 tonnes per annum (Scottish Government, 2007). The structure of the UK industry as a whole is characterised by a large number of relatively small operations, where over half the entire industry output is driven from only 15 sites (BGS, 2007).

Imports and Exports of stone

The low cost of imports due to economies of scale in European operations and low costs of labour from countries further afield compared to prohibitively expensive domestic UK building stone means that the UK is a major importer of building stone.

The main imports of slate and flagstones have traditionally been from Portugal, though recently these have been overtaken by imports from India and China as well. Granite and sandstone too, are imported from India and China, and within Europe from Spain and Italy (Natural Stone Specialist, 2009). Annual production, imports and exports in natural stone from the UK are given in Table 2.

Table 2: Annual production, imports and exports of building and dimension stone in the UK (adapted from BGS, 2007).

tonnes	**Imports**	**Exports**	**Production**
Marble and other calcareous stone	148443	6967	320000
Granite and other igneous rock	557878	8063	50000
Sandstone	322530	1081	419000
Other stone	133336	15950	1000
Paving stone and flagstone	297099	3716	Not available
Total	**1162187**	**32061**	**790000**

Appendix B Profiles of foreign stone industries

Based on industry reports (Natural Stone Specialist, 2006) and in conversation with project stakeholders (Scottish Stone Liaison Group, Harrison Stone consultants) the main countries of import to the UK were identified as Portugal, Spain, Italy, Poland in the EU and Brazil, India and China outwith the EU. The four countries chosen for this study are Spain, Poland, India and China.

Apart from Poland, all the countries in this study are among the top global producers of natural stone (see Table 3).

Table 3: The world's ten largest raw natural stone producing countries in 2007 (adapted from AIDICO, 2008)

Country	Production of raw material (million tonnes)
China	22.0
India	21.5
Iran	11.1
Italy	10.0
Turkey	9.5
Spain	8.0
Brazil	7.5
Egypt	3.5
Portugal	3.0
France	1.2

The following sections describe the stone industries in each of the countries in this study.

Spain

The Spanish stone industry is one of the world's largest industries and Spanish granite, marble, slate and sandstone are exported worldwide both in raw and processed form. According to AIDICO (2008) in terms of exports by weight, China receives the largest quantity of Spanish stone (26%), although the EU overall remains the country's main export destination, accounting for 58% of the total. The countries showing greatest demand within the EU for Spanish natural stone are France (20%) and the United Kingdom (10%).

The main exporting provinces are Valencia and Galicia (78% of all exports) followed by Castile, León, Andalusia, Cataluña and Murcia.

Box 1 presents an example of renewable energy adopted in Spanish sandstone production.

Box 1: 'Carbon Neutral' Spanish sandstone

Areniscas, a large Spanish sandstone producer, has adopted an environmental policy that combines investment in renewable energy production with waste and pollution management and claims to have achieved the overall environmental impact of 0.00kw-h/m^2 of stone they produce.

In 2003 the company installed photovoltaic panels which now produce 123,517 kWh per annum, enough to offset a majority of the carbon impact of their extraction and processing energy usage. Areniscas claims to have reduced their annual carbon impact by 63,734 $kgCO_2$.

Source: Arensicas Environmental Statement, 2008.

Poland

The Polish natural stone industry is based largely on granite and sandstone – 90% of the stone excavated in the country is composed of these types. Internal demand has occupied the largest proportion of the Polish stone market in recent years, and stone export destinations have been mainly Germany and Switzerland (Kamien Polski, 2009).

The main areas for the extraction of granite are Strzegom, Sobótka, Strzelin and Nysa, while sandstone is largely extracted in southern Poland around Bolesławiec, Kłodzko Valley, Świętokrzyskie region, the Beskids and near Szydłowiec.

India

India has recently become a major player in the international stone trade, and though Indian operators do not import stone to process within the country, Indian exports of raw stone (especially granite) to countries like China and the US have grown steadily in recent years (IMM, 2009).

Marble, sandstone, granite and slate are produced from a range of Indian states. The states of Karnataka, Andhra Pradesh, Tamil Nadu and Uttar Pradesh are the main centres for granite, especially for raw block that is exported. Over 90% of Indian deposits of sandstone are located in the Rajasthan area (CDOS, 2003).

China

China is the world's largest producer of dimensional stone with an output of over 25 million tonnes, two thirds of which is exported. The steady growth in exports of Chinese stone over the last decade (see Figure 1) has been driven by the cost of Chinese stone offering a lower price alternative to manufactured stone from the EU and other parts of the western world. As shown in Figure 1 Chinese imports of rough block far outweigh their export of finished stone. Much of the finished stone that is exported is processed rough block imported from various countries.

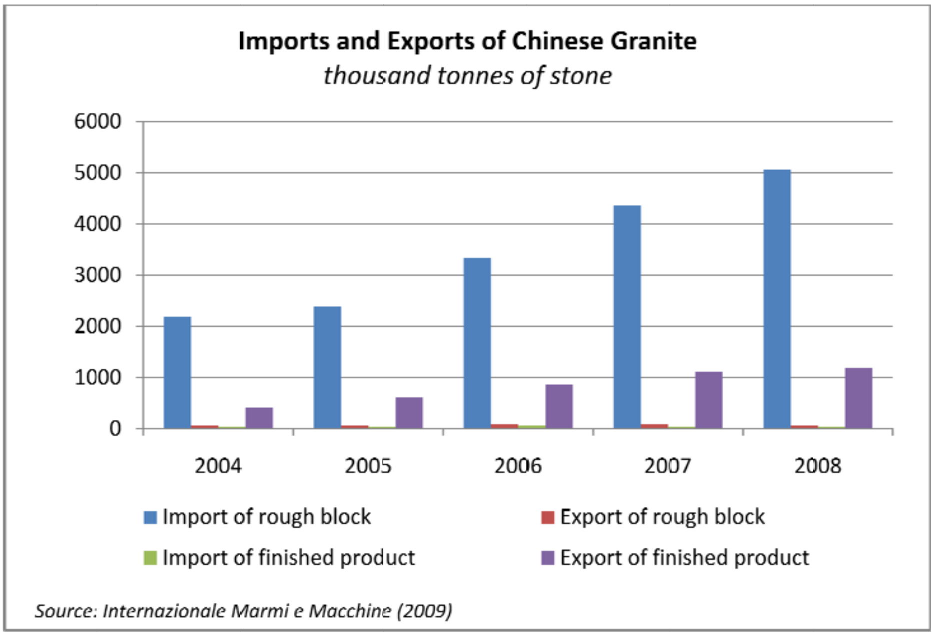


Figure 1: The rise in imports and exports of Chinese granite from 2004 to 2008

The three main areas with respect to stone production in China include Fujian, Guangdong and Shandong provinces. Xiamen, located in Fujian, is the main port for importing / exporting of stone (Natural Stone Specialist, 2009).

Appendix C Illustration of footprint calculations

Calculating carbon footprints

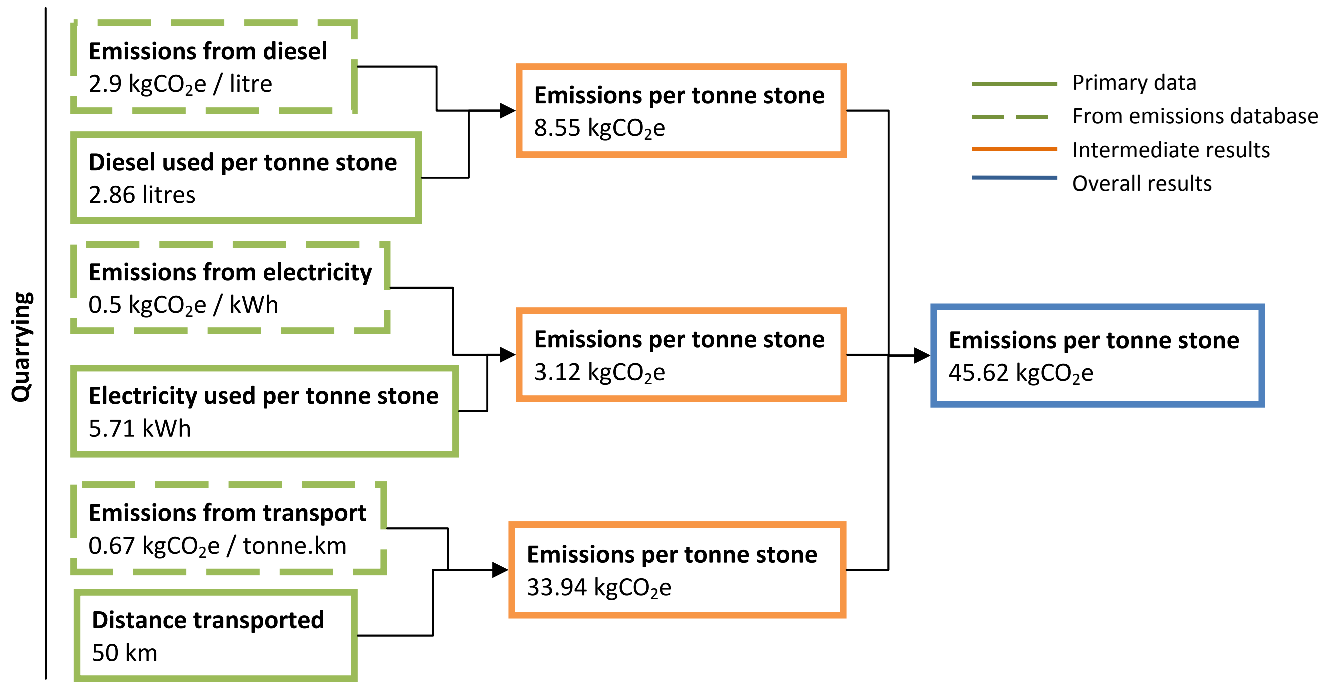
BSI (2008a; 2008b) describes the calculations necessary to develop a carbon footprint according to the PAS 2050. The main equation for calculating the carbon footprint of any activity can be described as:

Carbon footprint of a given activity = Activity data (mass/volume/kWh/km) × Emission factor (CO_2e per unit)

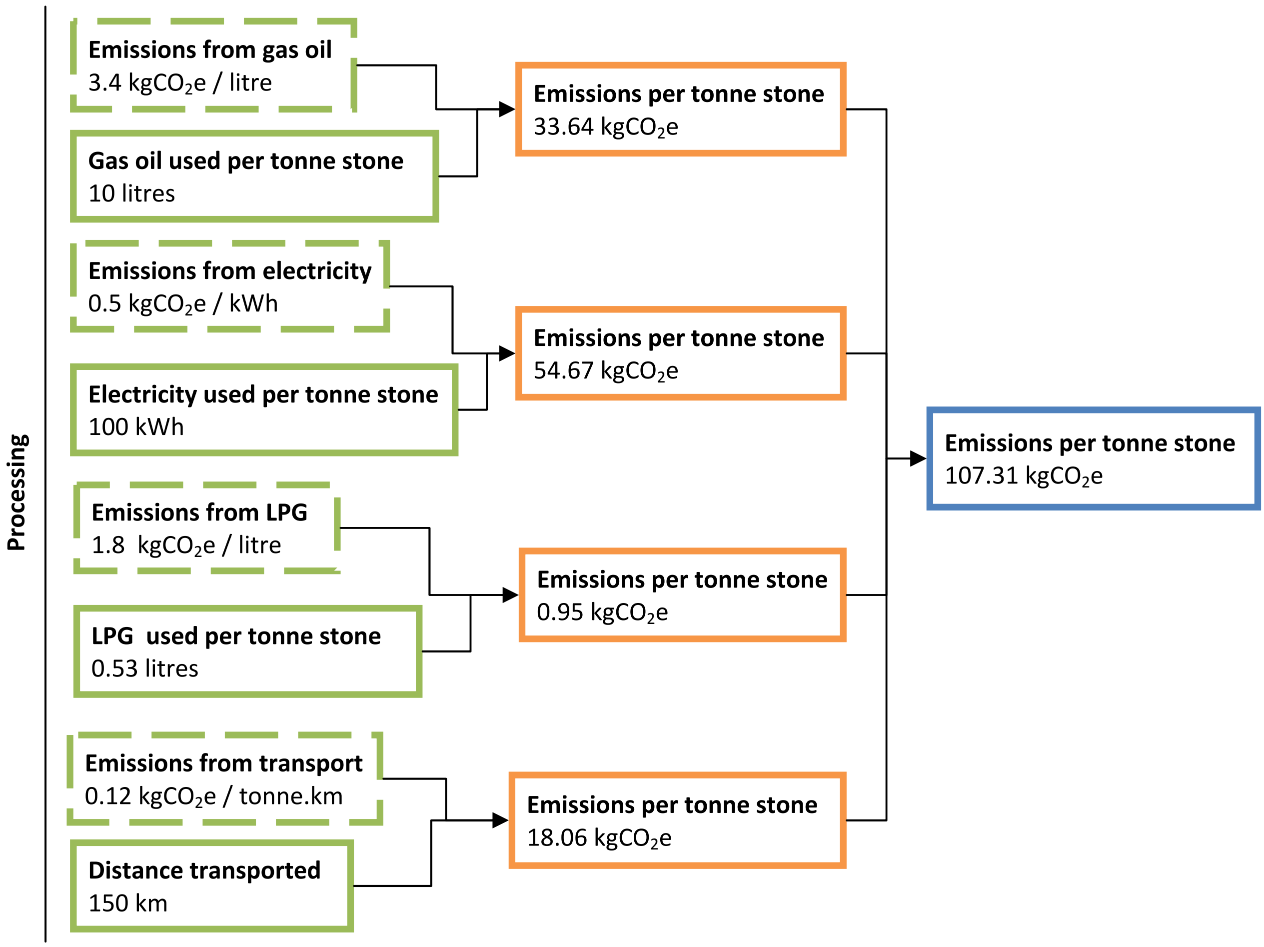
The following flow diagram illustrates the calculations in this report. The UK cradle-to-site footprint in the illustrated example is 152.93 kgCO_2e per tonne stone. In this example, the increase in the footprint to site if the stone were originating in Spain is 84.51 kgCO_2e per tonne stone.

The numbers used are not representative of the data collected, and are provided only as an example of how the footprint model used in this study operates.

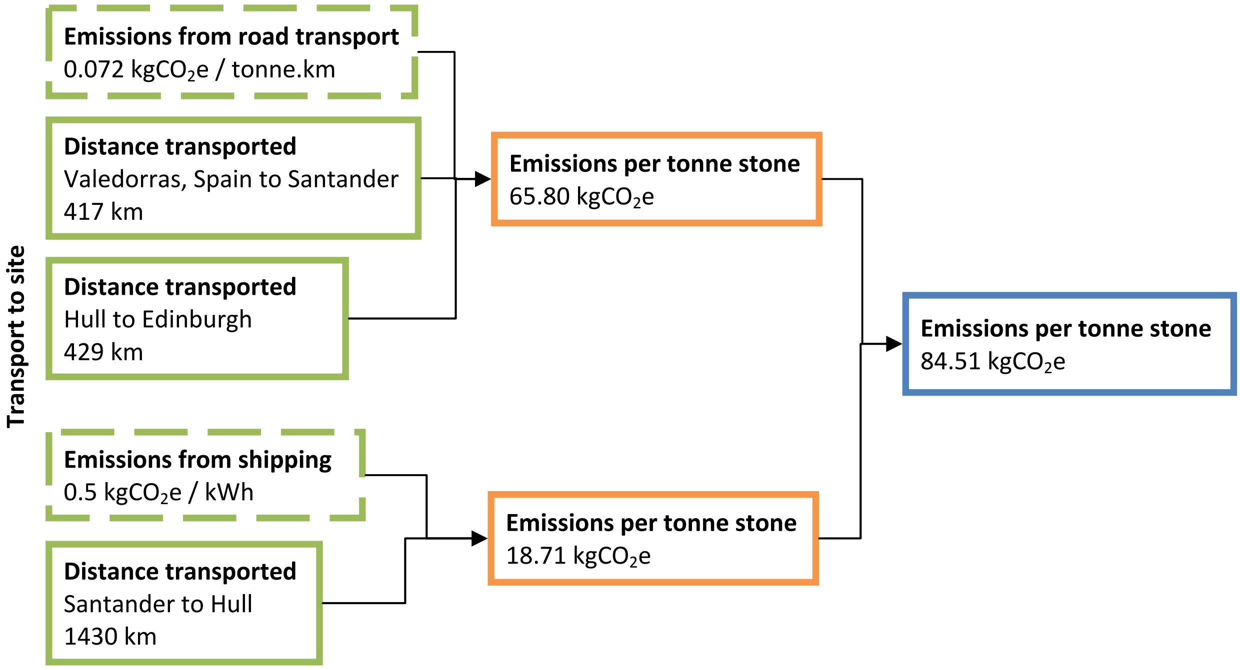
Developing the footprint of quarried stone



Developing the footprint of processed stone



Developing the transport footprint of stone from other countries



Appendix D Data collection material

RESEARCH INTO EMBODIED ENERGY AND CARBON OF STONE

Data Collection Survey - Quarry

1 INTRODUCTION

Thank you for agreeing to take part in the Historic Scotland research project to measure the 'carbon footprint' of building stone in Scotland. The project is being carried out by the Scottish Institute of Sustainable Technology (SISTech) in conjunction with the Scottish Stone Liaison Group. It will measure the greenhouse gas emissions associated with the production of stone here in Scotland, and compare those results with the carbon footprint of imported stone.

If you have any questions during the completion of the survey, please do not hesitate to ask. Any questions should be directed to the Project Manager, Dr. Suzy Goodsir of SISTech by telephone: 0131 451 8161 or by email: suzy.goodsir@sistech.co.uk.

2 QUARRYING OPERATIONS

The purpose of this survey is to gather information about a quarry, to help measure the 'carbon footprint' of building stone. Please use the following tables to provide details of the operations undertaken during stone extraction within the quarry. Where possible, use recorded data to input information. If no such data is held, please attempt to provide accurate estimates. All data should be for 2008.

Please note that if your company operates more than one quarry, a separate survey should be completed for each of them. **Please submit separate forms for individual quarries.**

2.1 Quarry Details and Overview

Please only provide details relating to the quarry facility. Details of secondary processing facilities are not required in this survey.

a. Name of quarry	
b. Quarry address/location	
c. Type of stone quarried	
d. Gross quarry production in 2008 (tonnes)[1]	
e. Net amount of usable stone removed from quarry (tonnes)[2] in 2008	
f. Destination of waste products/scrap stone[3]	
g. Size of quarry (acres/hectares)	
h. Working days in 2008	
i. Number of full-time equivalent (FTE) employees	

[1] Gross Quarry production – total amount of stone quarried including waste
[2] Net quarry production – total amount of stone quarried to be used for product
[3] E.g. backfill, landfill, recycling, resale

2.2 Overall Use of Energy/Fuel

Please detail fuel consumption in units specific to fuel type, e.g. diesel expressed in litres, electricity in kWh. This question is only about quarrying operations - do not include transport to or from the quarry.

Energy Type	Consumption in 2008 (include units[4])
a. Diesel	
b. Electricity	
c. Natural Gas	
d. Gas Oil	
e. Petrol	
f. Fuel Oil	
g. Burning Oil	
h. Industrial Coal	
i. Domestic Coal	
j. Wood Pellets	
k. Coking Coal	
l. LPG	
m. Petroleum Coke	
n. Explosives/black powder	
o. Other:	

[4] Include appropriate units, e.g. kWh, litres, kg, etc

3 TRANSPORT FROM QUARRY TO PROCESSING FACILITY

This section asks about the transport of the unworked stone from the quarry to its destination processing facility (stoneyard).

3.1 Stone Transport to Processing Facility/Facilities in 2008

In the table below, please tell us about where the unworked stone is sold to, indicating the percentage (or weight) destined for each location. Please state the mode of transportation used, and the distances the stone travelled.

If your unworked stone is processed at more than one stoneyard, please tell us about all of them, including any that are owned by your company. For guidance, refer to the example provided.

Processing facility name	Location or address	Processing facility ownership[5]	Mode of transport (road/rail/sea)[6]	Distance travelled[7] (if known) (miles)	Total amount sent to facility (tonnes/%)
Rockall Stone	*Nr. Rockall Quarry, Isle of Rockall*	*Rockall Stone*	*Road – 100%*	*6*	*60%*
Londonderry Stone Processors	*Londonderry, Northern Ireland*	*Londonderry Stone Processors*	*Sea – 80%* *Road – 20%*	*303*	*40%*

3.2 Type of Road Transport

Tick the type of road transport used to take the unworked stone to its destinations.

Rigid	☐	**Articulated**	☐	**Any other type of vehicle/comments:**
>3.5-7.5t	☐	>3.5-33t	☐	
>7.5-17t	☐	>33t	☐	
>17t	☐		☐	

[5] Please insert the company name by which the processing facility is owned.
[6] If numerous methods of transport are used, please provide estimated percentage of the total journey undertaken by individual methods.
[7] This is the distance between the quarry and the stone processing facility.

4 SOURCES OF INFORMATION

Please indicate where you obtained data input into the above tables. Tick the appropriate box depending on your source data.

Question	Data Sourced From Record	Data Based on Estimation
1.1 *Quarry Details and Overview*		
1.2 *Overall Use of Energy/Fuel*		
1.3 *Use of Heavy Equipment*		
2.1 *Stone Transport to Processing Facility/Facilities in 2008*		
2.2 *Type of Road Transport*		

RESEARCH INTO EMBODIED ENERGY AND CARBON OF STONE

Data Collection Survey - Stoneyard

1 INTRODUCTION

Thank you for agreeing to take part in the Historic Scotland research project to measure the 'carbon footprint' of building stone in Scotland. The project is being carried out by the Scottish Institute of Sustainable Technology (SISTech) in conjunction with the Scottish Stone Liaison Group. It will measure the greenhouse gas emissions associated with the production of stone here in Scotland, and compare those results with the carbon footprint of imported stone.

If you have any questions during the completion of the survey, please do not hesitate to ask. Any questions should be directed to the Project Manager, Dr. Suzy Goodsir of SISTech by telephone: 0131 451 8161, by fax: 0131 451 8150 or by email: suzy.goodsir@sistech.co.uk.

2 STONE PROCESSING FACILITY

The purpose of this survey is to gather information about a stoneyard, to help measure the 'carbon footprint' of building stone. Please use the following tables to provide details of the processing operations conducted on unworked stone at the processing facility. Where possible, use recorded data to input information. If no such data is held, please attempt to provide accurate estimates. All data should be for 2008.

Please note that if your company operates more than one stoneyard, a separate survey should be completed for each of them. **Please submit separate forms for individual stoneyards.**

2.1 Overview of Stone Processing Facility

Please only provide details relating to the stone processing facility. Details of primary quarrying are not required in this survey.

a. Name of processing facility	
b. Address/location	
c. Type(s) of stone processed	
d. Total amount of unworked stone entering the facility in 2008 (tonnes)	
e. Total amount of stone product produced by the processing facility in 2008 (tonnes)[1]	
f. Types of stone product produced	
g. Quantity of waste/scrap stone produced (tonnes) and its destination[2]	
h. Quantity of useful by-product produced and its destination[3]	
i. Working days in 2008	
j. Number of full-time equivalent (FTE) employees	

[1] Only include product directly manufactured from unworked stone supplied to the processing facility. Do not include output of pre-worked stone product supplied to the facility.

[2] E.g. backfill, landfill, recycling.

[3] E.g. irregular shaped stone, sand.

2.2 Overall Use of Energy/Fuel During Processing

Please detail fuel consumption in units specific to the fuel type, e.g. diesel expressed in litres, electricity expressed in kWh. This question is only about processing on site - do not include transport of unworked stone to or from the facility.

Energy type	Consumption in 2008 (include units)
a. Diesel	
b. Electricity	
c. Natural Gas	
d. Gas Oil	
e. Petrol	
f. Fuel Oil	
g. Burning Oil	
h. Industrial Coal	
i. Domestic Coal	
j. Wood Pellets	
k. Coking Coal	
l. LPG	
m. Petroleum Coke	
n. Other:	

3 TRANSPORT FROM PROCESSING FACILITY TO RETAILER/SITE

This section asks about the destinations of the processed stone products.

3.1 Destinations for Stone Processed in 2008

In the table below, please tell us about where the products are sold to, indicating the percentage (or weight) destined for each location. Please state the mode of transportation used, and the distances the products travelled. For guidance, refer to the example provided.

Main destination/site (name and location)	**Mode of transport (Road/rail/sea)**	**Distance travelled[4] (if known) (miles)**	**Total amount sent to site (tonnes/%)**
Londonderry Stone Retail Yard, Londonderry, Northern Ireland	*Sea – 80%* *Road – 20%*	*303*	*50%*
Rockall Stone Retail Yard, Isle of Rockall	*Road – 30%* *Rail – 70%*	*6*	*30%*
Edinburgh Building Site	*Sea – 50%* *Road – 50%*	*?*	*15%*
Collection by locals	*Road*	*All collectors based within a 15km radius*	*5%*

3.2 Type of Road Transport

Tick the type of road transport used to take the products to their destination.

Rigid	☐	**Articulated**	☐	**Any other type of vehicle/comments:**
>3.5-7.5t	☐	>3.5-33t	☐	
>7.5-17t	☐	>33t	☐	
>17t	☐		☐	

[4] This is the distance between the stone processing facility and the destination (retailer, site, etc).

4 SOURCES OF INFORMATION

Please indicate where you obtained the data input into the above tables. Tick the appropriate box depending on your source data.

Question	Data from records	Data based on estimate
1.1 *Overview of Stone Processing Facility*		
1.2 *Overall Use of Energy/Fuel During Processing*		
1.3 *Use of Heavy Equipment*		
2.1 *Destinations for Stone Processed in 2008*		
2.2 *Type of Road Transport*		

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