AGGREGATE CARBON DEMAND: THE HUNT FOR LOW-CARBON AGGREGATE

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Abstract

Construction projects are increasingly concerned with environmental sustainability. Schemes such as the Building Research Establishment Environmental Assessment Method (BREEAM) Green Guide include 'mineral resource extraction' as part of their environmental impact rating of construction materials, such as aggregate. One means of assessing environmental impact is to determine the 'embodied energy' used (or 'embodied CO_2' emitted) to produce aggregate; this is equivalent to the 'carbon footprint' of an operation. This 'energy audit' takes into account everything from extraction and processing through to offices and workshops, and waste and water management.

The Mineral Products Association publishes embodied CO_2 (as kilograms per tonne, kg/t) figures for aggregate, crushed rock, sand and gravel, ready mixed concrete, asphalt and cement. The leading aggregate producers report embodied energy (as kilowatt hours per tonne, kWh/t) or embodied CO_2, or even both.

Research at the British Geological Survey has been carried out to quantify the likely embodied energy of aggregate resources without the use of an energy audit. A modified work index ('crushability') test device has been used to determine the embodied energy of aggregate resources. The initial research has focused on Carboniferous limestone as worked in central and northern England. This research is ongoing and in the future will include different rock types used to produce construction aggregate such as basalt, dolerite, granite and sandstone.

The ultimate aim is to provide baseline information on the likely 'carbon demand' of as yet unworked aggregate resources. This could be presented as spatial data complementary to existing, digital, mineral resource maps. These data will assist in future spatial planning for crushed rock resources. They will also bring a fresh perspective to Mineral Policy Statement 1, which requires that the environmental benefits and constraints of working mineral resources are considered.

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Introduction

Most aggregate quarrying companies report the amount of energy and/ or carbon consumed in the production of construction aggregate and related products. This is a result of the pressure to address climate change by society as reflected by national and international agreements. The quarrying industry has taken up this challenge as it is keen to demonstrate its environmental credentials.

Internationally, the UN Framework Convention on Climate Change (UNFCC, 2010) in 1994 was one of the first significant treaties designed to tackle global warming by reducing Green House Gas (GHG) emissions. It lead to the Kyoto Protocol (UNFCC, 2010) in 1995, which bolstered the original agreement. The Green House Gas Protocol Initiative (GHGP, 2010), founded in 1998 by the World Resources Initiative and the World Business Council for Sustainable Development, provided an accounting tool for GHGs, which is now widely used internationally. The UN Global Compact (UN Global Compact, 2010) established in 2000 provided a strategic policy for businesses, and committed to ten universally accepted principles in the areas of human rights, labour, environment and anti-corruption.

In the UK, the Climate Change Levy (HMRC, 2010) was introduced in 2001. This is a tax on non-domestic energy users that was designed to encourage energy efficiency. Energy-intensive industries, such as the cement industry, receive an 80% discount on this levy by negotiating Climate Change Agreements. The levy funds energy efficiency initiatives including The Carbon Trust. The Carbon Reduction Commitment (CRC) Energy Efficiency Scheme (Environment Agency, 2010) came into being via the Climate Change Act in 2008. This is a mandatory energy saving and carbon reduction scheme administered by the Environment Agency. The Sustainable Construction Strategy (BIS, 2010) is a joint Government (Department of Energy and Climate Change) and industry initiative that aims to clarify policies and set standards on sustainability. In 2007, the Quarry Products Association (now part of the Mineral Products Association) declared its 'Carbon Reduction: statement of intent' (Mineral Products Association, 2010) and committed to ensuring that the quarrying industry was fully engaged with the need to reduce its carbon consumption.

In light of these initiatives, construction projects are becoming increasingly focused on the environmental sustainability of the materials they use. In response to this, the Building Research Establishment Environmental Assessment Method (BREEAM) certification scheme was introduced. This complies with the Framework Standard for the Responsible Sourcing of Construction Products BES 6001 (Building Research Establishment, 2009). As part of this, the BREEAM Green Guide was produced to enable project designers to select construction materials based on their environmental impact rating (Building Research Establishment, 2010). This rating ranges from A+ to E, from those with the least environmental impact to those with the highest. It is determined by creating an environmental profile for building components; this profile consists of thirteen elements, including 'Climate Change', 'Water Extraction' and 'Mineral Resource Extraction'. For example, the new William Smith Building at the British Geological Survey (BGS) headquarters in Nottinghamshire, achieved a BREEAM rating of 73.7% which is equivalent to the 'Excellent' standard (Figure 1).

Figure 1. *William Smith Building, British Geological Survey (BGS), Nottinghamshire. This building achieved a BREEAM excellent rating. BGS©NERC.*

The rating for construction aggregates is usually part of that for concrete and other construction components. The clearest example that relates to construction aggregate is in the domestic landscaping category for lightly trafficked areas, where 'gravel over prepared sub-base' can be compared with 'gravel over a prepared recycled sub-base'. The rating given to each for 'Mineral Resource Extraction' is very different, with an 'E' rating for the former (as it uses primary aggregate) and an 'A' rating for the latter (as it uses recycled aggregate). This highlights the importance of quantifying the environmental impact of primary aggregate production. Better information would enable environmental rating systems, such as the BREEAM Green Guide, to refine their profiles based on more accurate data.

Carbon Footprint

In 2008, the UK construction aggregates sector produced 207 million tonnes of primary aggregate and was responsible for 0.46% of the total carbon emissions in the UK, excluding transport (Mineral Products Association, 2009). Based on the official estimate of total UK net emissions of carbon dioxide of 532.8 million tonnes in 2008 (Department for Energy and Climate Change, 2010) this equates to an estimated 2.45 million tonnes of CO_2 emitted by the UK aggregate sector.

One of the chief means of assessing the environmental impact of a quarrying operation is to determine the 'embodied energy' of aggregate production. This is calculated by carrying out an 'energy audit' of a quarrying operation. This calculates the energy input at each stage of production, including stripping of overburden, drilling and blasting, haulage, primary crushing, surge stockpiling, transfer/ conveying, crushing, screening, stockpiling, loading and transport off site. All other site operations that consume energy, such as offices, workshops, waste handling and storage, dust and other environmental controls, water management and site remediation work, are also included. Energy values are typically quoted in kilowatt hours per tonne (kWh/t) or megajoules per tonne (MJ/t) of production. The carbon dioxide emissions are calculated from the energy values using greenhouse gas conversion factors, and are typically quoted in kilograms of carbon dioxide per tonne (kg/CO_2/t). Defra (2010) gives the CO_2 emission per kilowatt hour for different fuel types, including national grid electricity (0.500kg), natural gas (0.185kg), fuel oil (0.265kg), industrial coal (0.317) and LPG (0.214). The values calculated are equivalent to the 'carbon footprint' of a quarrying operation.

Many companies produce annual reports which tell us how well they are progressing towards the basic tenet of Sustainable Development, which is to ensure that our needs can be met now and in the future while at the same time protecting the environment. These reports use a template that conforms to the internationally recognised Sustainability Reporting Guidelines, produced by The Global Reporting Initiative (GRI) (GRI, 2010). These reports detail the performance of the company, including improvements in business, products and workplace, contribution to tackling climate change and society, and protection of the environment. These reports also include the 'embodied energy' and/ or the 'embodied CO_2' per unit volume of production for their products, as shown in Table 1. The 'embodied energy' (or 'embodied CO_2') information is aimed at society in general; it enables a year-on-year demonstration that companies are working to minimise their carbon footprint.

Mineral product	Carbon* kg/CO_2/t	Energy** kWh/t
Ready Mixed Concrete	0.95	1.76
Sand & Gravel	4.28	8.30
Crushed rock	4.32	9.70
Asphalt	34.4	98.11

Table 1. *Embodied carbon and embodied energy for typical aggregate products. * Carbon data is from the Mineral Products Association 2009 Sustainable Development Report; kg/CO2/t is kilograms of carbon dioxide per tonne. ** Energy data is from the Tarmac 2009 Sustainable Development Report; kWh/t is kilowatt hours per tonne. All data is for 2008.*

In order to minimise the amount of energy used, the efficiency of a quarrying operation can be assessed by carrying out a production review. In most cases, this is carried out by regional performance managers, consultants or experts working for equipment suppliers. A performance review requires a thorough audit of the production process; as part of this, a process flowsheet is devised which summarises the throughput tonnage figures, crusher and screen settings, and product gradings. Flowsheet analysis is aided by the use of proprietary computer software, such as AggFlow 2006 (aggflow.com) and JKSimMet (www.jktech.com.au), or in-house software developed by equipment suppliers (such as Bruno as used by Metso Minerals). These software tools enable the planning and simulation of the crushing process, with the ability to use different machine combinations and settings. The software models the behaviour of crushers and other process equipment with different rock types, based on laboratory and process plant data. The simulation can be fed with theoretical or real information on the feed material; the accuracy of the simulation can be increased by the use of real feed variables. Adjustments made to the settings or by changing the type of equipment may optimise the process to give the maximum aggregate production and minimise energy consumption. An example of where process optimisation has lead to a reduction in energy consumption is shown in Table 2. This shows that Luck Stone quarries (Bealeton, Virginia and Pittsboro, North Carolina, USA) achieved energy reductions of up to 5% using the Mine-to-Mill optimisation method (Adel *et al*, 2006).

Process stage	Energy consumption before optimisation	Energy consumption after Mine-to-mill optimisation
Primary (Jaw crushers), kWh/t	0.35	0.29
Secondary (Cone crushers), kWh/t	0.26	0.24
Tertiary (Cone crushers), kWh/t	1.17	1.05
Total, kWh/t	1.77	1.57

Table 2. *Comparison of energy consumption at Luck Stone Quarries before and after Mine-to-Mill optimisation. kWh/t is kilowatt hours per tonne. Data from Adel et al, 2006.*

Baseline Information

In the UK, decisions to permit new quarries or extensions to existing quarries are made by the Mineral Planning Authorities (MPAs). As part of the decision-making process, information on the nature of the available mineral resources, other land uses and environmental designations is taken into consideration. The BGS has produced county and regional mineral resource maps for England to help inform decision makers (MineralsUK, 2010).

Information on the likely energy required to produce aggregate from different rock types is currently not available to decision makers. Typically, the amount of energy required to produce aggregate is calculated after it has been produced or after the decision has been made to go ahead with a quarry in a specific location. MPAs have an obligation to sustainable development as laid out in the Government's mineral policy statement MPS1 (Communities and Local Government, 2006). This states that MPAs should use the best available information on mineral resources and consider the environmental benefits and constraints of working them. Information on the likely energy of production of aggregate from different rock resources would be a valuable addition to the existing information, especially as energy use is likely to become of greater significance to construction projects and decision makers in the near future. It would enable MPAs to make a more informed decision regarding the likely 'carbon footprint' of a planning proposal.

Crushability Index Testing

In an attempt to provide more information on the likely energy required in the production of aggregate, research has been carried out at the BGS involving the physical testing of rock resources. Many different tests were considered in the initial stages of this research. Quarrying companies use Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV) to determine the suitability of aggregate for use in roadstone and concrete (Mathers *et al*, 2000). The ACV and AIV test methods use aggregate in the size range 10-14mm, and determine the amount of material that is broken into fines (<2.36mm). Geotechnical testing is carried out to determine the properties of near-surface rocks and building stones, including Uniaxial Compressive Strength (UCS), compressive Point Load, Brazilian (splitting tensile strength), Triaxial Compressive Strength and ring shear tests. The values produced are in MegaPascals (MPa), which is a measurement of the force required to break the rock. The Schmidt Hammer field test correlates with the UCS (Aydin, 2009). There is no clear correlation between these tests and the energy of production (Wallis, 2009).

Mineral processing tests are used to calculate the Bond Work Index, which is the energy required to crush and grind rock to liberate valuable ore and industrial minerals to enable them to be separated and concentrated. Tests include the Bond Rod Mill and Ball Mill Index, otherwise known as the 'grindability' index (Wills & Napier-Munn, 2006), and the Bond Crushing Work Index, otherwise known as the 'crushability' index (Metso, 2007). These produce energy values in kilowatt hours per tonne (kWh/t). Non-destructive ultrasonic testing can be correlated with the 'grindability' index (Deniz & Ozdag, 2003). The 'crushability' index was selected as the best test for the BGS research, as it produces energy data and provides the closest approximation to the crushing technology used by the quarrying industry.

A crushability test device was designed and built by the BGS workshops (Wallis, 2009); the currently used device is shown in Figures 2 and 3. It consists of twin pendulums, each 'free-swinging' with a 10 kg 'hammer' at the end. These can be raised outwards from their resting position (where the pendulums are vertical) to their maximum height of 0.5m (where the pendulums are horizontal). Test samples are cut into 60mm cubes (Figure 4) and placed between the hammers when the pendulums are at rest. When at maximum height the potential energy of the combined hammers is 95.7 Joules. When released, the maximum impact force of the hammers on the test samples is up to 0.5 MPa. This compares with the impact force on a rock of up to 2MPa in an industrial scale jaw crusher and up to 40MPa in an industrial scale cone crusher. In the BGS Aggregate Crushability Test method, the test is repeated on the same sample until the largest piece remaining is less than half of the mass of the original sample cube. The combined potential energy for each release of the hammers is calculated in Joules and then converted to kilowatt hours per tonne.

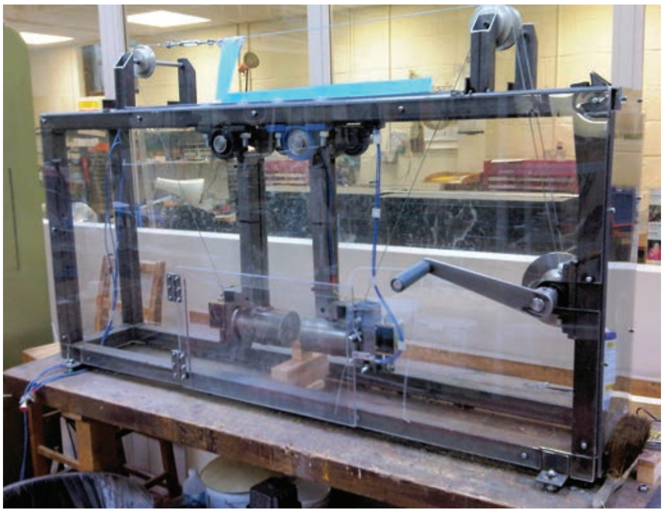

Figure 2. *BGS crushability test device. BGS©NERC.*

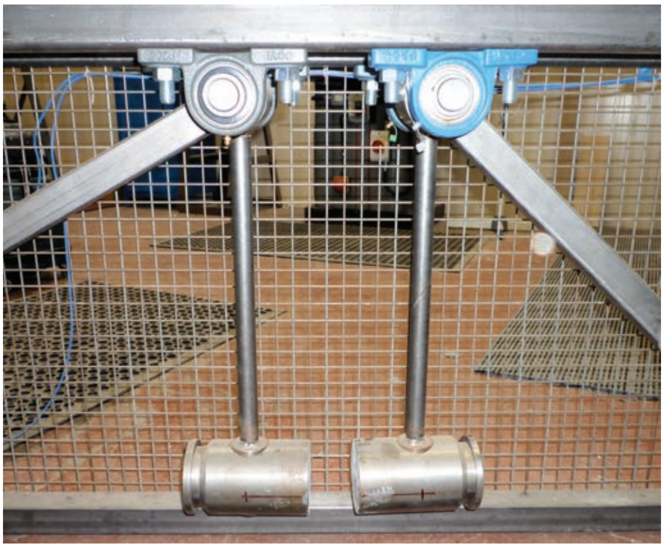

Figure 3. *Close up of the BGS crushability test device. BGS©NERC.*

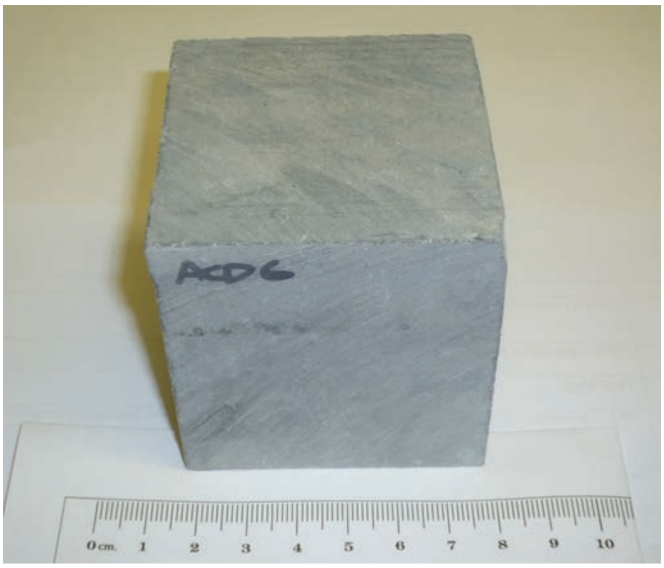

Figure 4. *BGS crushability test cube (60mm). BGS©NERC.*

Samples from limestone quarries across northern and central England were tested using the BGS Crushability Test. Figure 5 shows a sequence of photographs of a test in action and Figure 6 shows a close up just after the point of impact. The results are shown in Table 3. Selected samples (where there were more than five test samples per quarry) are plotted against the known energy of production, as provided by the quarrying company (Figure 7). The data produced represents the energy required to break the rock. It does not represent the energy required to produce construction aggregate. However, this data does show a positive correlation between the crushability test data and the actual energy of production. As a note of caution, this research is in its early days and more test data is required to confirm if this correlation holds true for other quarries. As the next stage of the research, additional limestone quarries will be sampled and tested. Also, testing of different rock types is needed to demonstrate that the crushability method has a wider application. Future research will include the testing of other rock types commonly used for construction aggregate such as basalt, dolerite, granite and sandstone.

The energy values produced are independent of operational factors and will enable a reliable comparison with other occurrences of the same rock type and even with different rock types. Also, the data produced would be complementary to the standard resource quality characteristics, such as mineralogical and chemical composition, physical properties and other geological information. Spatial presentation of the data on Geographical Information System (GIS) resource maps could be themed by 'aggregate energy' and/ or 'aggregate carbon'. Figure 8 is a mock-up of an 'Aggregate energy' resource map for the Carboniferous limestone of the Peak District National Park (the values used are not real and no additional quarrying is implied). Maps such as this would provide more information on the quality of rock resources for decision-makers. This may become more important in the future as the potential 'embodied energy' of primary construction materials is likely to become a more significant factor in the search for, and approval of, new quarries or extensions to existing quarries.

CONCLUSIONS

The wide acceptance of the need to address climate change is increasingly affecting the way that the UK quarrying industry operates. Construction projects, such as those that comply with the Building Research Establishment Environmental Assessment Method certification scheme, will increasingly demand construction materials that have the lowest environmental impact. As a result, the 'embodied energy' or 'embodied carbon' of construction aggregate will become a more important consideration.

Currently, decision makers such as the Mineral Planning Authorities (MPAs) do not have information on the likely energy required to produce construction aggregate from different rock resources. Research has been carried out at the British Geological Survey (BGS) in an attempt to calculate the likely energy of production of different rock resources. A crushability method was used to test rock samples of limestone and calculate the

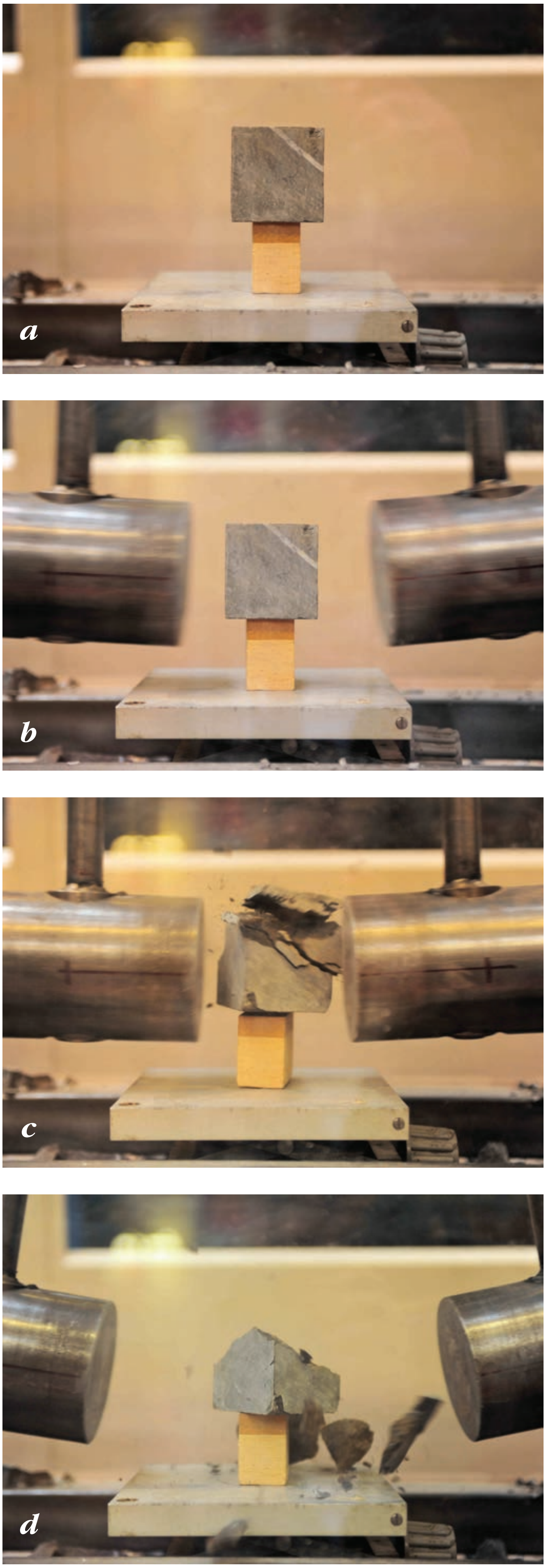

Figure 5 (a,b,c,d). *BGS crushability test in action. BGS©NERC.*

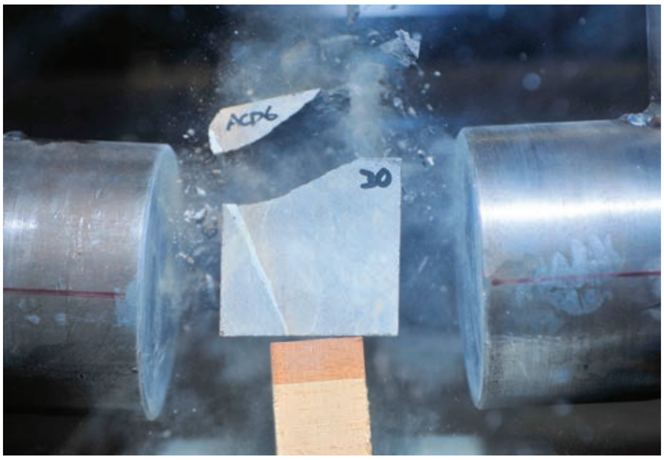

Figure 6. *Close up of the BGS crushability test in action. BGS©NERC.*

Quarry	Number of test samples	Average (kWh/t)	Maximum (kWh/t)
1	n/a	n/a	n/a
2	1	0.044	0.044
3	2	0.013	0.017
4	8	0.036	0.061
5	10	0.045	0.060
6	9	0.028	0.053
7	14	0.033	0.079

Table 3. *BGS crushability test data. kWh/t is kilowatt hours per tonne. The rows highlighted are those used in the plot shown in Figure 3.These were chosen as they have more than 5 test samples per quarry.*

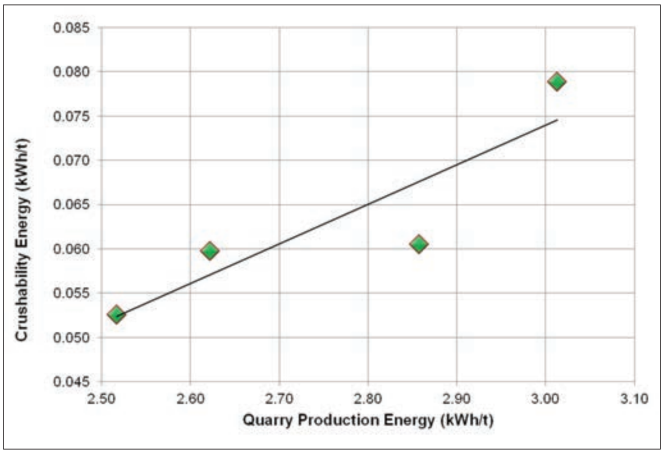

Figure 7. *BGS maximum crushability energy (Table 3) and quarry production energy. kWh/t is kilowatt hours per tonne.*

energy of breakage. The initial test work indicates that the BGS crushability method can be related to the energy of production, and may prove to be a useful means of categorising resources for decision makers.

Geographical Information System (GIS) resource maps with an 'Aggregate Energy' theme could be produced that would provide decision makers with information on the likely energy requirements of exploiting different rock resources. This would essentially enable the 'carbon footprint' of a planning proposal to be calculated. Such information would then be taken into consideration alongside the standard technical and economic criteria used to assess the suitability of resources for producing construction aggregate.

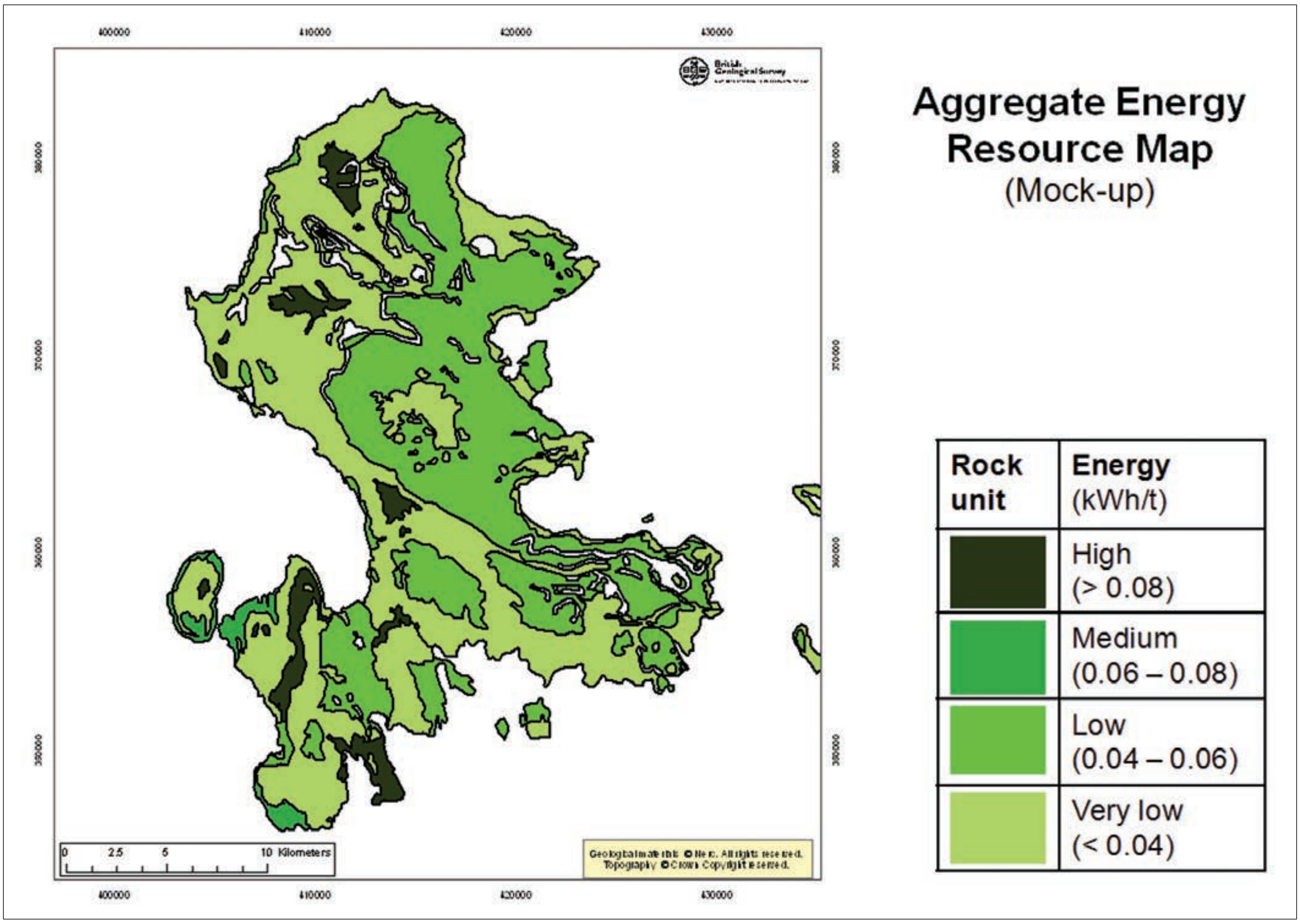

Figure 8. *Mock-up of an aggregate energy resource map for the Carboniferous limestone of the Peak District National Park. BGS©NERC.*

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REFERENCES

Adel, G., Kojovic, T. and Thornton, D. 2006. Mine-to-Mill optimization of aggregate production. US Department of Energy, DE-FC26-04NT42084, Pp.157. http://www.osti.gov/bridge/servlets/purl/914568-TIDTd7/914568.pdf

Aydin, A. 2009. ISRM Suggested method for determination of the Schmidt hammer rebound hardness: Revised version. International Journal of Rock Mechanics & Mining Sciences, 46, 627-634.

BIS (Department for Business, Innovation and Skills), 2010. Sustainable Construction. http://www.bis.gov.uk/policies/business-sectors/construction/sustainable-construction.

Building Research Establishment, 2009. BRE Environmental & Sustainability Standard BES 6001.http://www.greenbooklive.com/filelibrary/responsible_sourcing/BES_6001_Issue2_Final.pdf

Building Research Establishment, 2010. Green guide to specification. http://www.bre.co.uk/greenguide/podpage.jsp?id=2126

Communities and Local Government, 2006. Mineral Policy Statement 1: Planning and Minerals. http://www.communities.gov.uk/documents/planningandbuilding/pdf/152993.pdf

Deniz, V. and Ozdag, H. 2003. A new approach to Bond grindability and work index: dynamic elastic parameters. Minerals Engineering, 16, 211-217.

Department for Food and Rural Affairs, 2010. 2010 Guidelines to Defra /DECC's GHG Conversion Factors for Company Reporting. http://www.defra.gov.uk/environment/business/reporting/pdf/101006-guidelines-ghg-conversion-factors.pdf

Department of Energy & Climate Change, 2010. UK Climate change sustainable development indicator: 2008 greenhouse gas emissions, final figures: Statistical release. http://www.decc.gov.uk/assets/decc/statistics/climate_change/1_20100202104722_e_@@_ghgnatstats.pdf

Environment Agency, 2010. Carbon Reduction Commitment (CRC) Energy Efficiency Scheme. http://www.environment-agency.gov.uk/business/topics/pollution/98263.aspx

GHGP (Green House Gas Protocol Initiative), 2010. Home page. http://www.ghgprotocol.org/

GRI (Global Reporting Initiative), 2010. G3 Guidelines. http://www.globalreporting.org/ReportingFramework/G3Guidelines/

HMRC, 2010. Climate Change Levy – Introduction. http://customs.hmrc.gov.uk/channelsPortalWebApp/channelsPortalWebApp.portal?_nfpb=true&_pageLabel=pageExcise_InfoGuides&propertyType=document&id=HMCE_CL_001174

Mathers, S.J., Harrison, D.J., Mitchell, C.J. and Evans, E.J. 2000. Exploration, evaluation and testing of volcanic raw materials for use in construction. British Geological Survey, NERC, pp116.

Metso, 2007. Metso minerals research and its services. http://www.metso.com/miningandconstruction/MaTobox7.nsf/DocsByID/F7AA7725C48E81E4C225714D004566DC/$File/Research_english.pdf

Mineral Products Association, 2009. Sustainable Development Report 2009. http://www.mineralproducts.org/documents/MPA_SD_Report_2009.pdf

Mineral Products Association, 2010. Carbon Reduction Statement of Intent. http://www.mineralproducts.org/documents/cstate.doc

MineralsUK, 2010. Minerals Information Online. http://www.bgs.ac.uk/mineralsuk/maps/maps.html

Tarmac, 2009. Sustainable Development Report 2009.

UNFCC (United Nations Convention on Climate Change), 2010. Essential background. http://unfccc.int/essential_background/items/2877.php

UN Global Compact, 2010. Home page. http://www.unglobalcompact.org/

Wallis, H.C. 2009. Development of equipment to investigate Aggregate Carbon Demand. Sheffield Hallam University B. Eng thesis, 14030462, unpublished, pp72.

Wills, B.A. and Napier-Munn, T. 2006. Wills' Mineral Processing Technology: An introduction to the practical aspects of ore treatment and mineral recovery. Butterworth-Heinemann, Pp.110-112.