Embodied Carbon of Natural Stone in Scotland:
A Methodology

A report for Historic Environment Scotland

Report Authors:
Jim Hart and Dr Francesco Pomponi, for JH Sustainability Ltd, December 2020.

Contact: jhart@jhsust.co.uk

Embodied Carbon of Natural Stone in Scotland:
A Methodology

1. Introduction

This report presents a methodology for the calculation of embodied carbon of natural stone products used in Scotland. The work is intended to be a practical demonstration of what can be achieved, and how. As such, the scope of the work was limited to dimensional sandstone for walling: whilst the methodology outlined here will be applicable to other types of stone and usage, further work will be required to implement it more widely, potentially including data gathering.

As well as defining the methodology, this report provides an overview of the short project funded by Zero Waste Scotland on behalf of Historic Environment Scotland to develop the methodology and benchmarks. Additional outputs from the project consist of a demonstrator embodied carbon calculator, and instructions for its use.

Although the results of studies do vary, an analysis of the few studies of the life cycle emissions and embodied carbon of sandstone suggests that greenhouse gas emissions of around 62 kgCO_2e per tonne[1] is a reasonable assumption for the extraction and production of dimensional sandstone in the UK, with some variation if produced outside of the UK. On the other hand, emissions from transport are widely variable depending on the relative locations of the quarry, the production facility, and usage, potentially ranging from a few kgCO_2e/t to well over 1000 kgCO_2e/t.

Context to the Study

The status of the natural stone industry in Scotland is well covered elsewhere, by the British Geological Survey for instance [1], and is not revisited here. However, it is clear that natural stone can be one of the most sustainable and lowest carbon construction materials if it is procured near to where it is to be used. Specifying and procuring domestically quarried and processed stone for projects in Scotland is seen as a way of achieving the lowest possible embodied carbon, as well as meeting wider social, ethical and environmental objectives.

If embodied carbon is to be a criterion for choosing between different suppliers of stone, then a good basis for such decision-making is needed, and the calculation should account for all legs of its journey from quarry to construction site. Then, where sustainability and climate inform procurement, locally produced product is likely to be favoured.

This is the need addressed by this report and associated outputs.

System boundary

The scope of this study and associated methodology is from the quarry to the construction site (known more generally as ‘cradle-to-site’). The full product life cycle, using standard terminology as in EN15978, is shown in figure 1, with the stages relevant to this study highlighted.

In the context of the stone industry these stages can be summarized as follows.

---

[1] Greenhouse gas emissions in terms of kg of ‘carbon dioxide equivalents’, which also takes account of any non-CO_2 greenhouse gas emissions. Reported per tonne of product, and abbreviated to kgCO_2e/t.

- A1 – extraction of stone at the quarry.
- A2 – transport of the stone to the processing site, including any stone wasted at A3. Note that the processing site may be co-located with the quarry, in which case A2 would be zero.
- A3 – cutting and finishing of stone at the processing site / sawing yard.
- A4 – transport to the construction site where the stone is to be installed.

Building life cycle information														Supplementary info beyond building life cycle
Product stage			Construction process stage		Use stage					End of life stage				
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	D
Raw material supply	Transport	Manufacturing	Transport	Construction & installation process	Use	Maintenance	Repair	Refurbishment	Replacement	De-construction / demolition	Transport	Waste processing	Disposal	Reuse, Recovery, Recycling; Benefits & loads beyond system boundary
					B6 Operational energy use									
					B7 Operational water use									

Figure 1. Life cycle stages classification, as defined in EN 15978 and used throughout this article. The stages addressed in this study are shaded.

The resource inputs considered within the system boundary are governed by the scopes of the three studies that this methodology draws on (or any additional studies in future). For stone extraction (A1) and processing (A3), the following items are included.

- Electricity use.
- Fuel use (diesel, natural gas, fuel oil, etc.).
- One study [2] explicitly includes fuel used for heating the workshop in A3.
- The life cycle impacts of energy use, beyond the direct emissions associated with combustion. i.e. taking account of the impacts associated with the provision of the fuels.

The main exclusions, as noted by Crishna et al. [3] are the life cycles of the buildings and machinery used for the extraction and processing of stone. Consumables (e.g. saw blades and explosives) are part of this exclusion.

For the transport stages (A2 and A4), the principles are the same. The full life cycle greenhouse gas (GHG) emissions associated with vehicle fuel use (combustion emissions and well-to-tank emissions) are included, but the vehicles themselves are outside of the system boundary.

2. Previous Work

Extraction and Processing

There are relatively few reliable and relevant sources of data and information on the life cycle inventory and embodied carbon of natural stone building materials from sources typically accessed by the construction industry. This applies to natural stone in general, as well as to the specific case of sandstone.

One of the most prominent sources, globally, is in fact the study published by Historic Scotland in 2010 in Technical Paper 7 (TP7) [4], and the associated academic publication [3] which assesses embodied carbon of sandstone, granite and slate. Other sources include the University of Tennessee Center for Clean Products study in 2009 for the US National Stone Council, which has provided documents including summaries of the embodied energy of various stone products including one specifically for sandstone [5]. The Tennessee studies are, in turn, the primary data sources for stone that have been picked up by the widely used Inventory of Carbon and Energy (ICE) [6].

There are a small number of academic publications that allow a value for embodied carbon to be deduced. However, only two more were found that allowed this for dimensional sandstone without going through a detailed life cycle assessment (LCA), and these are shown in table 1. A small body of literature also exists that provides life cycle inventories of stone industry processes that would facilitate LCA studies. Where possible, these figures represent the embodied carbon associated with each stage if the same processes were carried out in the UK, using the UK electrical grid in its current state (as opposed to its more fossil-fuel dependent state in 2010 for instance). For instance, the data from the Tennessee 2009 study shows the embodied carbon of the quarrying and processing systems used, per tonne of finished stone, if the same systems were to be used now in the UK. This is reasonable since stone extraction and processing systems are broadly similar throughout the industrialised world.

The exception to this, in table 1, is the case of South Africa, as the study refers to the 'artisanal' stone industry, where extraction and much of the processing is done by hand.[2] The South African study is included in the table for interest only, as it is assumed that responsible sourcing will prefer more mechanized systems.

Study	**A1**	**A2**	**A3**	**Total kgCO_2e/t**	**Ref**
ICE				60	[6]
Tennessee[1]	25.0	-	61.2	86.2	[5]
Scotland[2]	8.9	1.3	38.2	48.4	[3,4]
Switzerland[1]	21.4 – 27.0	-	24.0 – 30.4	45.4 – 57.4	[2]
South Africa	0	11.7	1.5	13.2	[7]

Table 1. Cradle-to-gate embodied carbon, kgCO_2e/t, results for sandstone, disaggregated into stages, either presented in or derived from published works. Notes. [1]Values presented here are calculated from embodied energy data, using the most up-to-date UK grid emission factor [8] for electrical energy. [2]The values for Scotland have been recalculated, using the up-to-date UK grid emission factor. Further details in Appendix.

Several environmental product declarations (EPD) for natural stone products exist, but none were found for dimensional sandstone. The EPD that appeared as close as any – in terms of relevance – is an expired EPD from EUROROC (a membership group of ten European companies), for which 64% of the product mix

---

[2] Not recalculated in the table, but using the UK grid emission factor would take A3 down to about 0.4 kgCO_2e/t.

assessed is sedimentary rock [9]. However, the fact that the average thickness of the slabs and tiles covered by the assessment is only 40mm limits its relevance, and the average density of 2.74 tonne/m^3 suggests that little of the sedimentary rock is sandstone. In this case, the A1-A3 emissions amount to 255 kgCO_2e/t. A more recent document from the same source [10] concludes with a slightly higher number for A1-A3, despite employing the artifice of subtracting 112 kgCO_2e/t from the emissions to account for the carbon stored in the wooden pallets used to transport the product.

Freight Transport

Most of the studies identified above have something to say about freight transport of the stone, which is here classified as follows.

- A2 Transport of the quarried stone from the quarry to the processing site
- A4 Transport of the finished stone from the processing site to the construction site.

Note that more stone is moved at A2 than at A4, as a proportion of the stone taken from processing is reduced to lower-grade by-products and is therefore not part of the functional unit of 1 tonne of finished dimensional sandstone, although the impacts of transporting it must be taken into account.

According to TP7, the GHG emissions attributable to A2 (transport between quarry and processing site) amount to less than 2 kgCO_2e/t, for domestically produced stone. The low average distance behind this figure is partly down to the fact that in some cases A2 emissions are zero, as the quarry and processing facilities are co-located. Emissions for A4 for domestically produced stone are higher, at 13.4 kgCO_2e/t. It is worth pointing out that whilst A2 emissions will frequently be zero, it is also possible for them to be the dominant contributor to emissions for instance when extracted stone is moved long distances to access lower-cost processors.

With reference to A4 emissions, TP7 estimates cradle-to-site emissions for stone imported from various countries to Scotland, by assuming the same cradle-to-gate values as for domestically produced stone, and then adding a component for transport. The report indicates[3] that cradle-to-site emissions are as follows:

- domestically produced sandstone: 77 kgCO_2e/t
- sandstone imported from Spain: 134 kgCO_2e/t
- sandstone imported from India: 312 kgCO_2e/t
- sandstone imported from China: 504 kgCO_2e/t.

One other source of information implies higher values for imported sandstone, but without any supporting information. In its online offer of commercial products Marshalls indicates country of origin and carbon footprint of various paving products. For example, some of the sandstone imported from India is shown as having embodied carbon from 101.5 kgCO_2e/m^2 [11]. This appears to be for 50mm paving: so assuming a density of 2200 kg/m^3, this is equivalent to 920 kgCO_2e/t. Whilst higher than the values suggested in TP7, the methodology presented in this document can yield similarly high values for embodied carbon when a quarry is located a long way from the nearest port, which is often the case.

Apart from in TP7, A2 emissions are only covered and separately identified in two of the other cases referred to above. The South African study reports a relatively high figure (11.7 kgCO_2e/t) for a short 12km trip from quarry to stone yard, but a small (< 6 tonne payload) and apparently inefficient truck has been assumed. In the later EUROROC EPD [10], A2 contributes just 0.43 kgCO_2e/t.

[3] Values calculated from the percentage increases reported.

3. Proposed Methodology

Introduction

The focus of the methodology is for dimensional sandstone for use in Scotland, and the production data underpinning the methodology as implemented in the calculator are derived from three studies [2,4,5].

The methodology is capable of incorporating updates to that data, and also developments in the specificity of the data – for instance in relation to stone type (geologically), product type (dimensional stone, thin façade materials, etc.), and technology (e.g. mechanized or artisanal). In other words, although the calculator[4] would need adaptation, the methodology can be used for any type of natural stone for which data exists on energy use in quarrying and processing, and on wastage rates in processing.

Life cycle stages

The cradle-to-site embodied carbon of stone can be disaggregated as follows:

- Stage A1 – Quarrying at location 1 (L1)
- Stage A2 – Transport
- Stage A3 – Processing at location 2 (L2)
- Stage A4 – Transport to site, at location 3 (L3, which is somewhere in Scotland).

The discussion of methodology is grouped into two parts: transport (A2 and A4) and production (A1 and A3).

Transport: A2 and A4

A simple observation is that if the three locations (L1, L2 and L3) are known, then if realistic assumptions are made about transport modes, an informed (albeit with uncertainties) assessment of the transport emissions A2 and A4 can be reached. It is impossible, however, to provide a robust assessment of transport emissions without full view of the supply chain.

Simply stated, the methodology requires the user to divide the journey of the stone from quarry to construction site into legs of known distance. Then, to each leg of the journey, apply a relevant emission factor reporting GHG emissions for moving one tonne of stone one km (kgCO_2e/t.km). Note that for the leg(s) of the journey from quarry to processing site, more stone is moved than is incorporated into the final product, and this larger quantity of stone is what must be assessed.

The calculator implementation of the methodology requires the user to follow the process below.

- Identify locations L1, L2 and L3.
- Divide the journey into legs and using online mapping tools, calculate the length of the land and the sea components of each journey: L1 to L2, and L2 to L3.
- For each component of the land journey, report distances within and outside Europe separately, as different emission factors are used to take account of the difference in vehicle emission standards in Europe and the countries outside of Europe responsible for much of the UK's stone supply such as India and China.

The calculator, multiplies each of these distances by set emission factors and – for A2 – a waste factor (Appendix B), and combines the results to produce an overall sum of the GHG emissions, per tonne of product, for the journey.

---

[4] See Appendix C.

Quarrying and Processing: A1 and A3

The methodology for calculating the GHG emissions associated with life cycle stages A1 and A3 is underpinned by the following values.

- Electricity consumption benchmarks per tonne of finished product at each of stages A1 and A3: kWh/t
- The GHG emission benchmarks associated with all other fuel use (excluding electricity),[5] per tonne of finished product, for A1 and A3: $kgCO_2e/t$.
- Emission factors for electricity consumption (see Appendix B) in the country or countries in which quarrying and processing take place.

It is then a question of multiplying each figure for electricity consumption by the appropriate emission factor and adding to the GHG benchmarks for other fuels.

The current sources for data on quarrying and processing GHG emissions and energy consumption are the most relevant studies highlighted in table 1 [2,4,5]. These should be supplemented or supplanted by data from any new and relevant studies as they emerge.

This process has already been followed for the three studies identified above, and distilled down into single values for each of: electricity and other fuels, for A1 and for A3: the results are embedded in the calculator associated with this report, so the only inputs needed from the user are the locations of the quarry and processing site. See also table 1 and Appendices.

4. Further work and conclusions

The methodology as presented here is reliant on embodied carbon values for sandstone that are all more than five years old. A case might be made that as the absolute values of the extraction and production embodied carbon (A1 and A3) are relatively small compared to the variation in transport emissions depending on origin, then accuracy in the A1 and A3 figures is not at a premium. However, appearances matter, and ensuring that all significant underlying data is still relevant and accurate is a worthy objective. The transport emissions (A2 and A4) are automatically kept up-to-date with the methodology, but it may be time to obtain new data to support A1 and A3. Two approaches might be adopted for this.

The first option is to re-survey the Scottish industry using a similar approach to that employed in the 2010 study.

The more rigorous method is to take a bottom-up approach, and undertake life cycle assessments of specific categories of stone product. This would entail developing a life cycle inventory (LCI) of processes for each unit of finished product: for instance, for a specific cutting method, quantifying the m^2 of cut face per tonne of product, and determining the inputs for each cut. To an extent, such work will be supported by LCI databases and data in the literature (e.g. a recent paper on LCI of techniques for stone quarrying and processing [12]), but it is also possible that significant effort into quantifying the inputs to some processes would be required.

[5] If the system boundary extends beyond fuel and power (e.g. to include machinery), then such emissions can also be included. This is not the case for any of the studies reported here.

Bibliography

1. Gillespie, M.R.; Tracey, E.A.. Scotland's building stone industry: a review Minerals & Waste Programme. **2016**.
2. Ioannidou, D.; Zerbi, S.; Habert, G. When more is better - Comparative LCA of wall systems with stone. *Build. Environ.* **2014**, *82*, 628–639.
3. Crishna, N.; Banfill, P.F.G.; Goodsir, S. Embodied energy and CO2 in UK dimension stone. *Resour. Conserv. Recycl.* **2011**, *55*, 1265–1273.
4. Crishna, N.; Goodsir, S.; Banfill, P.; Baker, K.J. *Historic Scotland Technical Paper 7. Embodied carbon in natural building stone in Scotland.*; 2010;
5. The Natural Stone Council *A Life-Cycle Inventory of Sandstone Quarrying and Processing. Version 2.*; 2008;
6. Jones, C.; Hammond, G. Inventory of Carbon and Energy v3.0 Beta 2019.
7. Agwa-Ejon, J.F.; Pradhan, A. Life cycle impact assessment of artisanal sandstone mining on the environment and health of mine workers. *Environ. Impact Assess. Rev.* **2018**, *72*, 71–78.
8. DBEIS; DEFRA UK Government GHG Conversion Factors for Company Reporting 2020.
9. EUROROC *Environmental Product Declaration. Tiles and Slabs from natural stone*; 2014;
10. EUROROC *Environmental Product Declaration. Natural stone – Massive slabs*; 2018;
11. Marshalls Commercial Sandstone Paving Available online: https://www.marshalls.co.uk/commercial/product/brackendale-sandstone (accessed on Dec 9, 2020).
12. Bianco, I.; Blengini, G.A. Life Cycle Inventory of techniques for stone quarrying, cutting and finishing: Contribution to fill data gaps. *J. Clean. Prod.* **2019**, *225*, 684–696.
13. Carbon Footprint Country Specific Electricity Grid Greenhouse Gas Emission Factors: v1.4 2020, 1–10.
14. Bednar-Friedl, B.; Wolkinger, B.; König, M.; Bachner, G.; Formayer, H.; Offenthaler, I.; Leitner, M. Transport. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; 2015; pp. 279–300.

Appendix A - Table 1 Data

The following offers more information on the data shown in table 1. In particular, it allows the embodied carbon of each stage to be recalculated using different grid emissions factors, for the electrical contribution, appropriate to the time and place.

Tennessee study

The value derived from the Tennessee study (which reports embodied energy as MJ/ft^3 of stone) is higher than the value quoted in ICE, despite the use (almost certainly) of a lower grid emission factor to convert embodied energy in electricity to embodied carbon. The reason for the difference is unclear. The density of sandstone was taken to be 2200 kg/m^3.

The breakdown is as follows:

A1: 24.8 $kgCO_2e/t$ + 0.8 kWh_{el}/t

A3: 48.0 $kgCO_2e/t$ + 46.0 kWh_{el}/t.

Scotland study

This paper reports embodied carbon (A1-A3) of 64 $kgCO_2e$/tonne. There are some challenges with interpretation, but this is now recalculated as 48.4 $kgCO_2e$/tonne using the current UK grid emission factor. The assumed breakdown is as follows:

A1: 8.9 $kgCO_2e/t$ + zero kWh_{el}/t (this is assumed from a reading of the report, but any inaccuracy would be automatically compensated by the same amount in A3)

A2: 1.3 $kgCO_2e/t$

A3: 4.8 $kgCO_2e/t$ for non-electrical embodied carbon + 116 kWh_{el} /t.

Switzerland study

The breakdown is as follows:

A1: 19.1 – 24.1 $kgCO_2e/t$, plus 8.0 – 10.1 kWh_{el}/t

A3: 17.7 – 22.5 $kgCO_2e/t$, plus 21.7 – 27.5 kWh_{el}/t.

In each case, the electrical energy figure (kWh_{el}/t) can be converted to embodied carbon by multiplying by the appropriate emission factor, which – to take account of full life cycle emissions – should include any relevant data available on transmission and distribution (T&D) and on 'well-to-tank' emissions. These are included in the UK Government GHG Conversion Factors, for the UK and – to an extent – for other countries.

Appendix B – Conversion Factors

A number of conversion factors are required to turn distance travelled, energy consumed, etc. into GHG emissions. These are all variable to greater or lesser extents, and should be updated as the supporting data sources are updated.

The most useful single source is the annual (2020 version currently) UK Government GHG Conversion Factors for Company Reporting [8]. For electricity consumed outside of the UK, this is supplemented by suitable international data. These are summarized, not exhaustively, in table B1 below. Additional conversion factors are shown in table B2.

Item	Value	Note / source
Electricity consumed in UK	0.29 $kgCO_2e/kWh$	[8]
Electricity consumed overseas. Example: India	0.84 $kgCO_2e/kWh$	Direct emissions from [13]; WTT estimates from [8]
Fuels. Example: diesel	0.31 $kgCO_2e/kWh$	[8]
Sea freight	0.019 $kgCO_2e/t.km$	Average container ship [8]
Road freight (in EU)	0.10 $kgCO_2e/t.km$	Large artic truck, average laden [8]
Road freight (outside EU)	0.19 $kgCO_2e/t.km$	Top end of range for largest delivery vehicle category. Rounded up to allow for non-CO_2 GHG emissions [14].

Table B1. A selection of emission factors and sources. Note that in every case the basic combustion-related emission factor has been supplemented with additional life cycle factors: so the numbers presented here are the sums of more than one value in the data source. In the UK Government spreadsheet the life cycle factors are identified on separate worksheets using the terminology WTT (well-to-tank) for all cases below, and – additionally – for electricity, T&D (transmission and distribution).

Item	Value	Note
Sandstone Density	2.20 t/m^3	Typical value. Range can be as wide as 1.9-2.3
Waste factor (mass of stone moved in A2 per mass of stone in finished product)	1.29	Values for granite and slate, for instance, are higher [4].

Table B2. Other conversion factors required by the methodology.

Appendix C – The Calculator

The calculator has been developed as a coded spreadsheet that can work both offline and online (e.g. potentially hosted on HES website in the future when more materials are included).

It has been developed in two variants: a simplified version for quick initial appraisals, and a more detailed version demanding more rigour and knowledge of the supply chain. The graphed results in both cases include indicative error bars, to promote the idea that all the outputs come with significant levels of uncertainty. The main reason for this is that the results are based on averages, with significant variations possible in terms of efficiency and fuel mix at all stages.

Simplified Calculator

The simplified version of the calculator requires only a quick selection of the region[6] for each of the locations L1, L2, and L3 explained in the report, and the input of the overall quantity of sandstone to be assessed. The calculator produces results both per tonne, and the total as shown in figure C1 below. This simplified calculator is expected to be used for a quick sense-check at early stages in the design/procurement process to understand the hotspots and enable meaningful mitigation strategies.

The A2 and A4 calculations are driven by an editable matrix of distances (land, then sea, then land again) between and within the regions identified. These distances are based on reasonable worst case assumptions, rather than an assessment of where quarries and production facilities are actually located. South Africa is used as a proxy for the 'rest of the world', as it is another stone supplier, distant from Scotland, with a notably high emission factor for electricity.

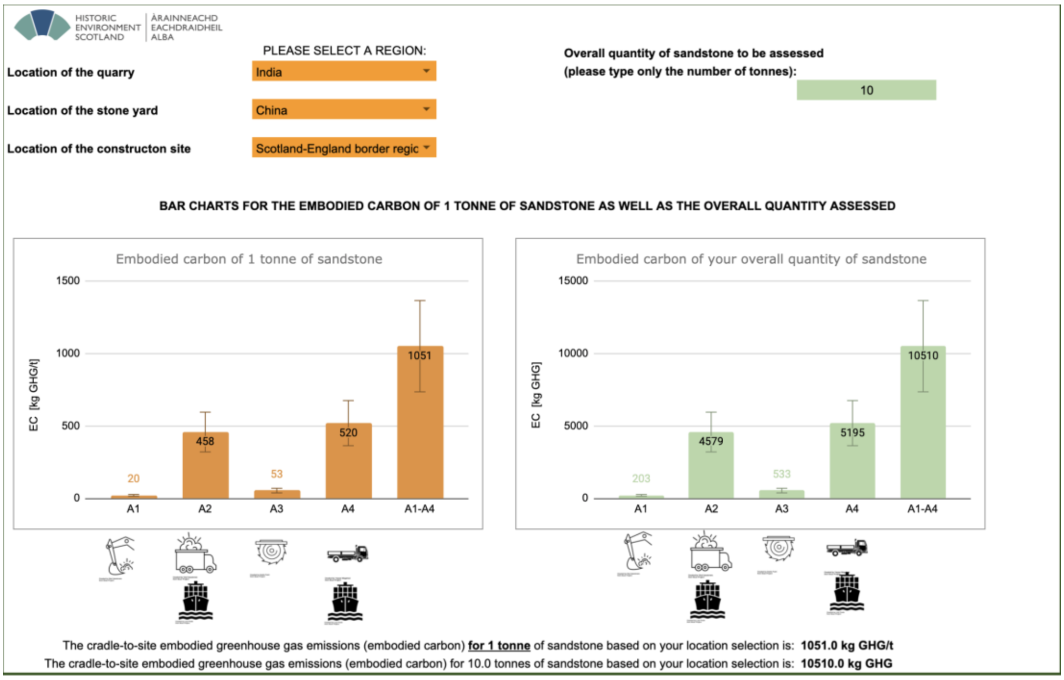

Figure C1. View of simplified calculator.

---

[6] Great Britain is divided into the following Scotland-centric regions for this purpose, along Council boundary lines.
(1) Northern Scotland (Highlands, Islands, Moray, Aberdeen & Aberdeenshire).
(2) Central Scotland North (other areas north of the Forth-Clyde: Argyll & Bute, Stirling, Clackmannanshire, Fife, Perth & Kinross, Dundee, Angus).
(3) Central Scotland South (all local authority regions between those listed in (2) and (4)).
(4) Scotland-England border area (Scottish Borders, Dumfries & Galloway, Cumbria and Northumberland.
(5) Rest of England and Wales.

Detailed Calculator

For the detailed version of the calculator, more information (and work) is required to the user. Specifically, the user needs to disclose exact details of the stone supply chain such as:

- exact locations of the quarry and the stone yard / processing site
- exact distances in km travelled by road both in Europe and outside Europe with inputs calculated through Google maps
- ports of departure and arrival for any sea-leg of the stone 'journey'
- exact distances in nautical miles if a sea trip takes places, calculated through one of the several websites available.[7]

In this second case the visualization is similar (in the sense that the two graphs with overall numerical quantities remain the main output for the user) but the additional information is also captured for reporting and auditing purposes. An example of the result produced is shown in the figure C2.

As said, the calculator offers only two freight transport modes, with land journeys by road, and sea freight by container ship.

If other modes are to be considered then the relevant calculations will have to be done outside of the calculator, or an appropriate workaround devised and implemented with a record of what has been done and why. For instance, in the case of rail freight, it might be found that the relevant emission factor (per tonne.km) is only (for example) 35% of the factor for road transport. In that case, to force the calculator to produce the right answer, the length of the relevant leg of the journey could be input as 35% of its true value. As another example, Channel and Minch crossings, for instance, may be by Ro-Ro ferry instead of container ship. If the GHG emissions for Ro-Ro ferry are near enough to the emissions of HGV road travel, then it would be reasonable to reallocate that particular sea journey to the land category, especially if the sea leg of the journey is a relatively small part of the total; alternatively a similar approach to the rail option could be adopted, although in this case an increased sea distance would be entered in the calculator as emissions per tonne.km are greater for ferries than they are for container ships.

Calculator maintenance and upgrade

As suggested in section 3, the data underpinning the calculator should be reviewed from time to time. In terms of implementation within the spreadsheet, the most simple task is to update the emission factors for electricity generation and transport (rows 5 and 10 in the 'input values' worksheet). The UK Government emission factors are updated annually, every summer.

The other relatively manageable task if relevant data becomes available would be to replace one of the three studies underpinning the A1 and A3 data with data from a new study, which would involve careful replacements of numbers in the B2:C9 range of the same worksheet.

Many other changes are possible, but would mostly be classed as development work. These might include addition of more studies for A1 and A3 data (as opposed to replacement of studies); inclusion of a wider range of options and emission factors to cover, accurately, more situations (e.g. processing locations and transport modes); and extension to other stone types.

[7] Note that 1 nautical mile = 1.85 km, in case a sea distance is found in units other than nautical miles. A search for 'sea distance calculators' reveals several options. One that currently does not require registration is ports.com/sea-route/

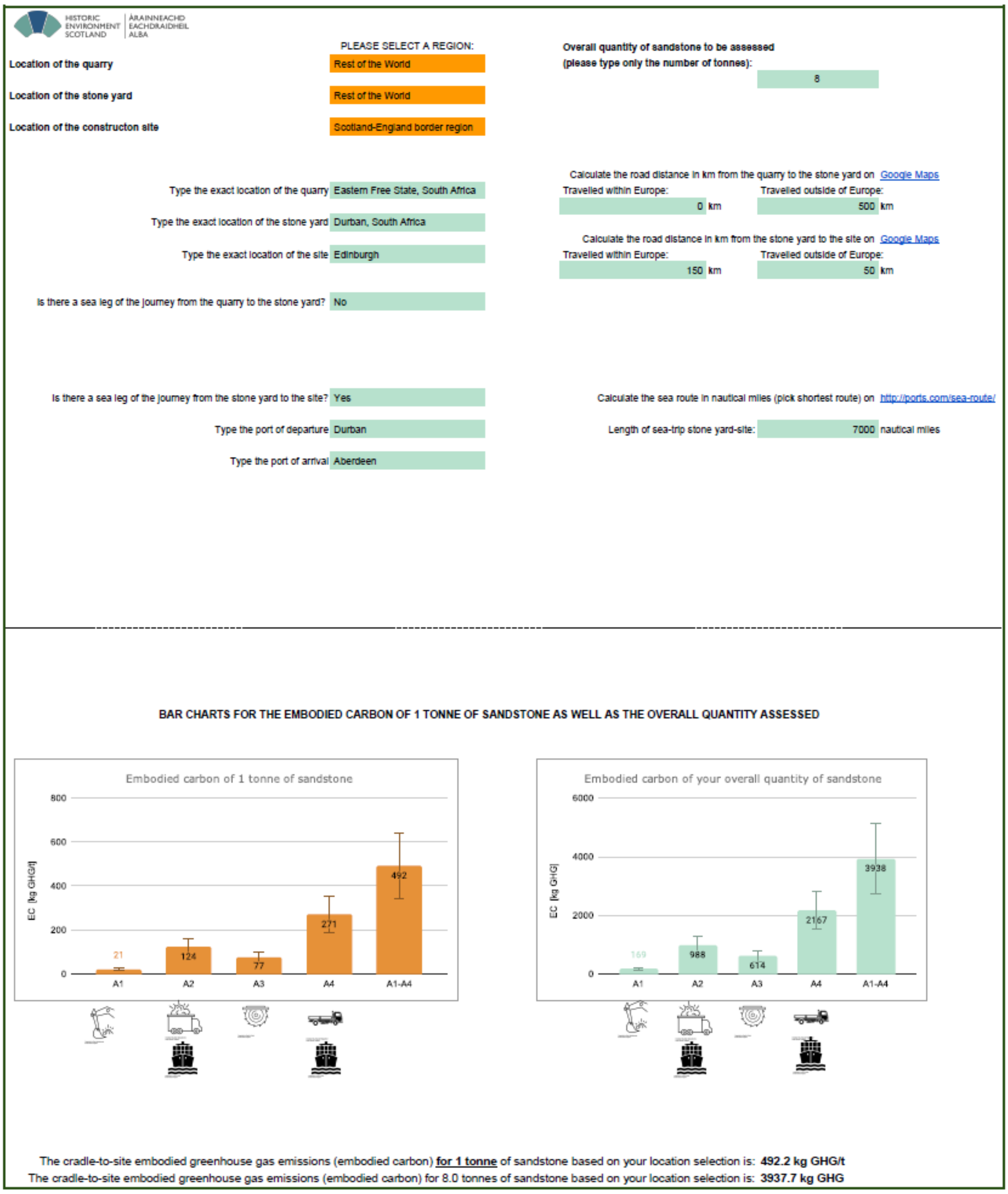

Figure C2. View of detailed calculator. Input locations and values are illustrative only.