Reality-based carbon assessment for resource-constrained materials

Dominic Munro, **Miriam Graham**, **Grace Di Benedetto**, **Malcolm Turpin** and **Fragkoulis Kanavaris** introduce the concept of a 'global availability fraction' and explain how it can enable engineers to understand the real-world carbon implications of specifying GGBS or scrap steel.

Are the 'easy carbon wins' of high volumes of ground granulated blast-furnace slag (GGBS) and scrap steel really wins at all? While high quantities of these materials currently make a project look great on paper, using more on your project may have no net effect on global carbon emissions due to their constrained supply chains.

This article provides a recommended method to adjust carbon calculations to reflect this frequently overlooked implication, enabling options to be chosen which minimise global emissions. The article summarises a research paper recently published in *Structures* that presents the detail of the method (Munro *et al.*)[1] and builds on an article by Poole *et al.*[2] as well as cross-industry papers led by the IStructE on seeing the bigger picture of project-level embodied carbon with regard to GGBS[3] and scrap steel[4].

What is a resource-constrained material?

A *resource-constrained material* describes materials for which the supply volume is limited, is less than the current demand, and does not readily increase in response to further increases in demand. Therefore, if larger amounts of the constrained material are used on one project, there is less of that material available for other projects **(Figure 1)**. This means there is no net reduction in global emissions – just a shift in who claims the benefit.

If this effect is not usually accounted for in our options assessments, designs may even be selected which actually have higher global emissions, despite designers thinking that emissions are being reduced.

This article explores two major materials which are examples of resource-constrained materials: GGBS and scrap steel.

GGBS

GGBS is a by-product of blast-furnace iron production, commonly used to replace Portland cement in concrete. Because it is a by-product, its supply fundamentally depends on how much iron is being made – not how much the construction industry demands. The IStructE's cross-industry review concluded that around 90% of all iron slag produced globally is granulated into GGBS and that it is fully utilised, demonstrating how this is a resource-constrained material[3].

Explore the research in more detail

For a more detailed explanation of the method summarised in this article, read the original research paper by Munro *et al*. at www.sciencedirect.com/science/article/pii/S2352012425009890?dgcid=author.

Scrap steel

Ferrous scrap recovery rates are already high – driven by steel's commercial value – with the IStructE reporting these at 80–85%; the remaining 15–20% is currently uneconomical or impractical to recover[4]. The conclusion is that increasing demand for scrap steel will not improve recovery rates.

It is worth distinguishing between recycled steel (melted down and reformed) and reclaimed steel sections (directly reused). Efficient reuse of reclaimed steel can genuinely lower carbon emissions, provided total steel weight does not increase by more than approx. 20–40%[5] where reclaimed steel is used. This is because there is an opportunity for increasing amounts of redundant steel to be reclaimed as opposed to recycled, with the process of recycling being more energy-intensive than reclaiming.

Calculation methodology

To ensure options are compared based on actual global impacts, the methodology presented in the research paper[1] incorporates the impact of global resource constraints when assessing embodied carbon. This 'consequential life-cycle assessment (LCA)' thinking acknowledges the wider systemic impacts of material choices, practically applying an essential aspect of PAS 2080[6]. Resource-constrained material impacts are known present-day emissions occurring beyond the project system boundary. They replace end-of-life emissions (Module D), which are assumed to be excluded from the LCA.

Rebound material

When demand for a resource-constrained material increases, the supply of that material cannot increase as it is

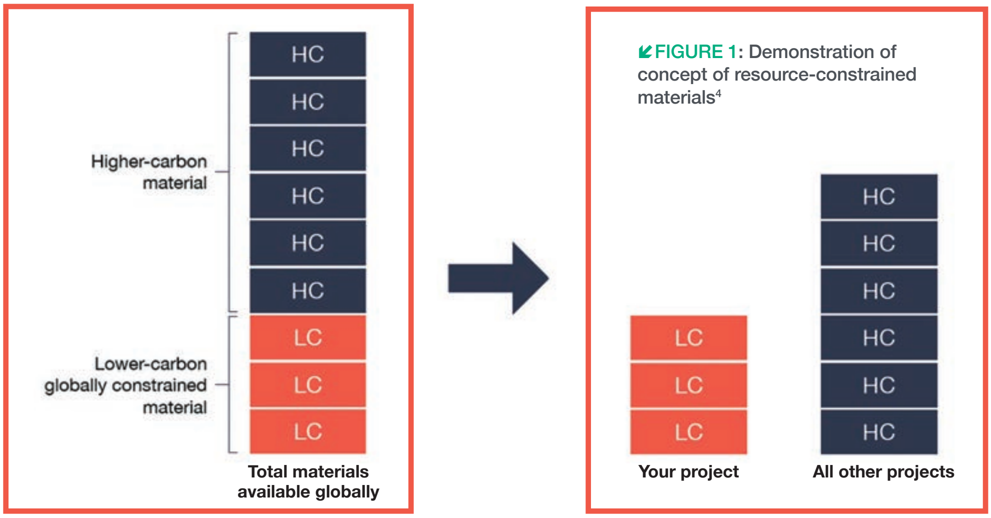

FIGURE 1: Demonstration of concept of resource-constrained materials[4]

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constrained. Therefore, an alternative material's supply must increase its global production to meet this demand; this is the *rebound material*. The rebound material is typically the most commonly supplied alternative to the resource-constrained material.

Primary pig iron is assumed to be the rebound material for scrap steel demand, making up any shortfall or excess of demand for scrap steel. For GGBS demand, the rebound material is assumed to be an average Portland cement, with a clinker content of 88% and the remaining 12% being gypsum, limestone and other supplementary cementitious materials.

Global availability fraction

The *global availability fraction* reflects the proportion of the total demand for a material that can be met by the resource-constrained material. This is the relationship between the resource-constrained material and the rebound material.

The current global availability fractions determined for GGBS and scrap steel are:

- **GGBS:** 7% of total cement production
- **scrap steel:** 35% of total steel production.

Please see the full paper[1] for details of their derivation.

Rebound emissions

If every project used the global availability fraction of a resource-constrained material, supply would meet demand and there would be no material impact outside the project boundary, representing a balance point.

If a project specifies more of a resource-constrained material than the global availability fraction, it is important to ask, 'how would the resource have otherwise been used?' Given the nature of resource-constrained materials, if this material would have been used in a similar way elsewhere, then there is no net benefit.

This means that when a project specifies more than 7% GGBS or 35% scrap steel, projects (or other uses) outside the system boundary which would have used these materials must use the rebound material instead **(Figure 2)**. Equally, when a project uses less than the global availability fraction, the rebound emissions are negative.

Therefore, this additional rebound material has additional, present-day *rebound emissions*.

The total adjusted emissions are calculated using **Equations 1 and 2**, representing the rebound emissions added to the impact from conventional LCA, which does not account for the impact of resource-constrained and rebound materials. This essentially recalibrates the embodied carbon to the scenario so that every project can only take benefit from the global availability fraction of the resource-constrained material. Rebound emissions factors are presented in **Table 1**.

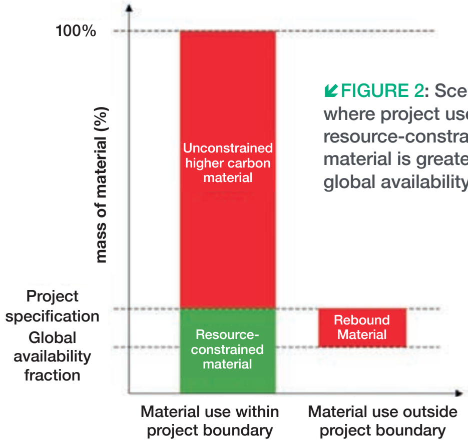

FIGURE 2: Scenario where project use of resource-constrained material is greater than global availability fraction

Total constrained impact
= A1 to A3 emissions
impact as per LCA (1)
+ rebound emissions factor ×
rebound material demand

Rebound material demand
= resource-constrained
material input (2)
– total cement or steel product ×
global availability fraction

Generic materials tables

In **Tables 2, 3, 4 and 5** the methodology is applied to typical materials used in industry. Note that as current calculations are based on ICE database v.4.0[7], these values will require updating over time.

Please see the full paper[1] for detailed derivation of rebound emissions factors **(Table 1)**, derivation of the generic rebound emissions **(Tables 2, 3, 4 and 5)**, case studies, and a more detailed exploration of this concept.

Frequently asked questions

When can I use this methodology?

This methodology is ideal for options appraisals, as it accounts for the real-world implications of material choices, ensuring decisions are based on global carbon impacts rather than potentially unrealistic localised impacts.

Note that this methodology is not yet (as of September 2025) incorporated into official standards or targets and should be communicated as a below-the-line adjustment.

Table 1: Rebound emissions factors as of 2025

Resource	Rebound emissions factor (A1–A3) ($kgCO_2e/kg$)	Source
Portland cement used in place of GGBS	0.735	ICE database v4.0, 2024[7]
Pig iron used in place of ferrous scrap	1.720	ICE database v4.0, 2024[7]

Table 2: Estimated rebound emissions (A1–A3) for concrete mixes containing GGBS

Strength class	Rebound emissions $kgCO_2e/m^3$									
	0% GGBS	10% GGBS	20% GGBS	30% GGBS	40% GGBS	50% GGBS	60% GGBS	70% GGBS	80% GGBS	90% GGBS
C20/25	-14	6	26	46	67	90	117	150	185	226
C25/30	-16	6	28	51	73	98	128	164	206	259
C30/37	-18	7	32	57	82	112	146	190	241	302
C35/45	-20	8	36	64	92	125	167	222	289	
C40/50	-21	9	39	69	99	136	183	245		
C45/55	-23	9	42	74	106	147	200			
C50/60	-25	10	45	80	115	159				

How can GGBS and recycled steel be resource-constrained when I have no issues with procuring them on projects?

The ability to procure these materials does not mean they are not globally resource-constrained – they remain commercially available and may have increased availability in certain regions compared with others.

What if I need to use more for functional requirements?

Resource-constrained materials are ideally used where they present functional benefits and prevent the use of additional materials. For example, GGBS has durability benefits where chlorides are present, allowing for reduced cover, or in cases requiring temperature/crack control. The benefit of specifying GGBS in such cases can be demonstrated by using this methodology to compare the carbon impact of functionally equivalent

Table 3: Estimated total constrained impact (A1–A3) for concrete mixes containing GGBS

Strength class	Total GWP including rebound emissions kgCO$_2$e/m^3									
	0% GGBS	10% GGBS	20% GGBS	30% GGBS	40% GGBS	50% GGBS	60% GGBS	70% GGBS	80% GGBS	90% GGBS
C20/25	250	249	248	248	247	254	264	283	297	315
C25/30	270	269	268	267	266	273	288	306	328	358
C30/37	302	301	300	299	298	308	323	349	379	412
C35/45	334	333	332	331	329	340	366	403	448	■
C40/50	358	357	356	354	353	367	397	442	■	■
C45/55	382	381	379	378	377	395	432	■	■	■
C50/60	410	409	407	406	404	426	■	■	■	■

Table 4: Estimated rebound emissions (A1–A3) for steel products using different proportions of scrap input

Steel product	Rebound emissions kgCO$_2$e/kg										
	0% scrap	10% scrap	20% scrap	30% scrap	40% scrap	50% scrap	60% scrap	70% scrap	80% scrap	90% scrap	100% scrap
Rebar	-0.60	-0.43	-0.25	-0.07	0.11	0.30	0.49	0.68	0.88	1.07	1.28
Section	-0.60	-0.43	-0.25	-0.07	0.11	0.30	0.49	0.68	0.88	1.07	1.28
Plate	-0.60	-0.43	-0.25	-0.07	0.11	0.30	0.49	0.68	0.88	1.07	1.28
Hot-rolled coil	-0.60	-0.43	-0.25	-0.07	0.11	0.30	0.49	0.68	0.88	1.07	1.28
Cold-rolled coil	-0.60	-0.43	-0.25	-0.07	0.11	0.30	0.49	0.68	0.88	1.07	1.28
Seamless tube	-0.60	-0.43	-0.25	-0.07	0.11	0.30	0.49	0.68	0.88	1.07	1.28
Welded pipe	-0.60	-0.43	-0.25	-0.07	0.11	0.30	0.49	0.68	0.88	1.07	1.28

Table 5: Estimated total constrained impact (A1–A3) for steel products using different proportions of scrap input

Steel product	Total GWP including rebound emissions kgCO$_2$e/kg										
	0% scrap	10% scrap	20% scrap	30% scrap	40% scrap	50% scrap	60% scrap	70% scrap	80% scrap	90% scrap	100% scrap
Rebar	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02
Section	2.27	2.27	2.27	2.27	2.27	2.27	2.27	2.27	2.27	2.27	2.27
Plate	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02
Hot-rolled coil	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93
Cold-rolled coil	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13
Seamless tube	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38
Welded pipe	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97

systems. It should be noted that, due to its technical merits, all available GGBS should be utilised in concrete construction, but in a rather efficient way.

Why is a global approach taken?

The materials considered (GGBS and scrap steel) are traded on a global scale. Where there is a surplus or deficit locally, this is met through international trade, making a global model most appropriate. It is also worth noting that, compared with the A1–A3 impact of these materials, transport emissions are comparatively very low.

What if global utilisation of these materials falls or availability increases?

If utilisation falls, or availability increases, such that demand no longer exceeds supply, the material would no longer be classified as 'resource-constrained' as it is not fully utilised. Therefore, this methodology would no longer apply. However, this scenario is thought to be highly unlikely for GGBS and scrap steel[3,4].

Doesn't specifying these materials help the business case for low-carbon alternatives by demonstrating a strong demand?

This proposes GGBS and recycled steel as transitional solutions; however, this argument does not reflect reality. Using higher quantities of a resource-constrained material on a project to meet embodied carbon targets can potentially delay the exploration, investment and use of long-term solutions for low-carbon materials that are not constrained resources.

Why should projects adopt this thinking if it makes it more difficult to meet carbon targets?

In line with the aims of the IStructE and Structural Engineers Declare (www.structuralengineersdeclare.com/), we have a responsibility to reduce the environmental impact of the structures we design. Understanding and reporting on global impacts is an important part of this to achieve effective emissions reductions. We also expect this thinking to be integrated into industry standards within the timescales of many projects that we are designing today, so adopting this approach now can avoid the risk of future recalculations that threaten certifications and access to green finance.

What alternatives are there for reducing embodied carbon emissions?

The most effective way to reduce embodied carbon is to use less material. Some strategies include challenging project briefs, reusing existing structures, reclaiming materials, and optimisation for efficiency of material usage in design.

There are, and will increasingly be, new technologies and approaches which are less carbon-intensive and are scalable. For these materials, increases in demand will increase supply over time and the resource-constraint methodology will not directly apply. For example, for concrete, multicomponent cements, mixes with a high proportion of limestone fines, calcined clays, beneficiated fly ashes and other emerging supplementary cementitious materials may present more scalable solutions going forward.

Are there other resource-constrained materials?

There are likely to be other materials which meet the coined definition of being 'resource-constrained'. For example, there is some evidence to suggest this for fly ash and other industrial byproducts used as cement replacements, as well as high-grade recycled aluminium. Further research is needed to establish this and to determine the global availability fraction for these materials.

Conclusion

This methodology ensures carbon calculations reflect the resource constraints of materials like GGBS and scrap steel. By adjusting to the global availability fraction, options can be identified that truly minimise global emissions. This consequential approach represents essential progress to align project carbon accounting with planetary reality.

For detailed implementation guidance and comprehensive derivations, see the full paper by Munro *et al*.

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