A tool for measuring resource scarcity

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Abstract

A resource use indicator is presented that focuses on availability to future generations. This resource indicator should only be used as part of a suite of indicators that cover the three pillars of sustainability and used within an analysis taken over the complete lifecycle (cradle to grave). So that users may make informed decisions, the residual lives of the resources are calculated and reported, but to facilitate comparisons, the mineral, fossil fuel and water use are converted into a Current Scarcity Score using a characterization model derived from a hyperbolic function. The resource use indicator is expressed as this Current Scarcity Score.
This indicator provides information needed to support the Construction Products Regulation, Basic Requirements for Construction Works 7: *Sustainable use of natural resources*
One result from the Raw materials Initiative (RMI) should be to use less of resources that are classified as being 'critical' or 'of concern' to Europe. To help with this process, the supply risk and economic risks defined in the RMI have been converted to an equivalent residual life and incorporated into the calculation of the Current Scarcity Score.

Keywords

Sustainability, environment, indicators, water, fuels, European Union, primary resources, secondary resources.

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1. INTRODUCTION

The Current Scarcity Score (CSS), a resource use indicator, described in this paper was developed for construction products and construction, but the principles are application to other products.

Construction is the largest single user of resources and, therefore, it is not surprising that the European Commission introduced into the *Construction Products Regulation* (European Commission, January 2011) a new Basic Requirement for Construction Works 7 (BRCW7): *Sustainable use of natural resources.* BRCW7 requires the construction works to be designed, built and demolished in such a way that the use of natural resources is 'sustainable', with a definition of sustainability including at least the following:

a) Use of environmentally compatible raw and secondary materials in the construction works.

b) Durability of the construction works.

c) Recyclability of the construction works, their materials and parts after demolition.

Using resources that are recyclable and durable will help preserve primary resources, so the main thrust of providing information with respect to BRCW7 should be a measure of whether the resources used will be available to future generations. In a NOTE on the implementation of BRCW7 (Moore, 2011), it was stated:

'*It is important to note that the title is "Sustainable use of natural resources". It is not "sustainable construction works", which is a much broader concept. The underlying objective of BWR7 is to ensure that natural resources are available to future generations.'*

The CSS is a means by which information about the sustainability of the use of resources in a product, functional unit or structure may be provided to users.

The European Commission is also concerned about the availability of key resources to European manufacturers. The Raw Materials Initiative (European Union, June 2010) identified a number of resources that are 'critical' or 'of concern' to Europe. Reducing the use of such resources is a sound strategic objective. The CSS provides a means by which information on the use of these resources may be provided to users.

At the strategic level, Europe is doing a great deal to improve resource efficiency. Eurostat is collecting data so that informed decisions can be made and the impact of decisions can be measured. Nobody is likely to question the need to be more resource-efficient (less resource per unit of output). However collecting statistics will not change practice. Practice will only change significantly if resource use can be measured and reported in a fair, understandable and consistent way as part of an environmental product declaration (EPD) for products, which in turn is used to determine the resources used to produce a functional unit, then the structure and then the structure over the complete life-cycle.

CEN/TC350: *Sustainable construction* is busy generating European standards to facilitate this process for construction and these standards will cover not just environmental aspects, but also the other two pillars of sustainability, namely the social and economic aspects of sustainability. However the activities of CEN/TC350 should be regarded as work in progress and the current versions of its standards are limited by the availability of indicators with wide support, e.g. an indicator for impact on bio-diversity has not yet been included in an EPD conforming to EN 15804 (CEN, 2011).

2. NOTATIONS

a	allocation of impacts for co-products applied in accordance with EN15804 (CEN, 2011)

ADP_i	Abiotic Depletion Potential of resource i
b and c	constants
CSS	Current Scarcity Score (indicator)
DR_i	extraction rate of resource (kg yr^{-1})
DR_{ref}	extraction rate of the reference resource R_{ref} (kg yr^{-1})
EI	economic importance score
m_i	quantity of resource i extracted (kg)
R_i	ultimate reserve of resource i (kg)
RMI	European Union's Raw Materials Initiative
R_{ref}	ultimate reserve of the reference resource, antimony (kg)
S_{NRi}	Current Scarcity Score for natural resource NR_i per material unit
S_{Pi}	Current Scarcity Score per unit of product
SR	supply risk score
TMR	total material requirement (a method of measuring resource use)
V_{NRi}	volume of resource Ri used to the manufacture product
w	Current Scarcity Score per unit volume of resource

3. RESOURCE USE INDICATORS

There are several systems for reporting resource use (JRC, 2008). In practice the Total Material Requirement (TMR) and the Abiotic Depletion Potential (ADP) are the systems most widely in use. Before reviewing these systems, it is essential to understand the role and function of a resource use indicator. Firstly it should be a single indicator in a suite of environmental indicators, e.g. as given in an environmental product declaration, and its impact should never be assessed in isolation from the other environmental indicators and the indicators from the other pillars of sustainability. For example, mono-culture has a negative impact on biodiversity, but this impact should be taken into account in the bio-diversity indicator. On the other hand, certain types of resource extraction may increase or protect bio-diversity. For example in the UK, 700 current or ex-mineral extraction sites are classed as 'Sites of Special Scientific Interest' (The Concrete Centre, 2009) and this positive impact should also be taken into account along with other considerations of resource use. Diverting food crops, e.g. maize, palm oil and sugar, in third world countries to the production of bio-fuels has significant social and economic impacts and these should be taken into account in the social and economic indicators, not in the resource indicator.

The prime purpose of the resource indicator should be a measure of availability of the resources to future generations. The indicator should include all resources (primary and secondary, abiotic and biotic) and the resources used to provide energy.

Current EPDs such as those conforming to EN 15804 (CEN, 2011) have separate resource indicators for material (mineral) resources, fossil fuel resources and water resources (biotic resources are usually regarded as being available to future generations). Across products, the relationship between these three resource indicators will not be uniform and one objective of the CSS is to combine these three types of resources into a single indicator. At some time in the future, Europe will have to agree a way of combining all the indicators for the three pillars of sustainability into a single impact. Developing a single resource indicator instead of three resource indicators is a small step in this direction.

3.1 Total Material Requirement

As the name implies this system is simply the sum of the resources by mass used regardless of their availability to future generations. A tonne of iron is given the same impact as a tonne of rock. In practice BRE (BRE, 2007) only applies the indicator to mineral resources and not other materials (fossil fuels and water are covered by separate indicators, but biotic resources are not covered). The EcoPoint system (BRE, 2007) contains 13 indicators, three of which relate to material use and when this system is applied to heavy building materials, unreasonable results are obtained. For example, with a structural concrete, the fossil fuel depletion impact is less than 2% of the total impact, yet these are some of scarcest natural resources with no recyclability when used as fuel. The water extraction impact is around 3% to 4% of the total impact, which seems reasonable for the UK. Surprisingly climate change is not the greatest impact: over 50% of the total environmental impact comes from the mineral resource depletion category, which is assessed on the mass of the materials used in the product. These are mainly the rock, gravel and sand to provide the aggregates and the limestone, clay and gypsum to make Portland cement, all of which are plentiful and available to future generations ((European Union, June 2010)).

For these reasons, CEN/TC350 rejected the use of the TMR in its suite of standards.

3.2 Abiotic depletion potential

The formula for calculating abiotic depletion potential for non-fossil energy carrying resources is (Van Oers et al., 2002):

$$\textit{Abiotic depletion potential} = \sum_i ADP_i \times m_i \qquad \text{[Eq. 1]}$$

with:

$$ADP_i = \frac{\dfrac{DR_i}{(R_i)^2}}{\dfrac{DR_{ref}}{(R_{ref})^2}} \qquad \text{[Eq. 2\}}$$

The baseline ADP values which are expressed as kg Sb eq., are usually based on a measure of reserves that includes all that is contained in the Earth's crust, but ADP values have also been calculated based on other measures of reserves (Van Oers et al., 2002). The reference resource is antimony and when the known reserves of antimony change, as they have, the ADP changes for every resource. Current ADP values range from 1.20E+20 kg Sb eq. for radon to 1.94E-17 kg Sb eq. for neodymium (Van Oers et al., 2002). As the name implies, the approach is limited to abiotic natural resources and is in general based on chemical elements. Converting many natural resources to a single chemical element is not appropriate, e.g. rock, clay, as they are used as a whole and not used to derive a single chemical element, e.g. a metal. However the system now covers such resources.

Unravelling the ADP values show that the main source of data is from the USGS (USGS, 2009).

A recent development (Schneider et al, 2011) has extended the ADP to include resources that are already in the economy. They call this the anthropogenic stock and it comprises stock in use, stock not in use but not yet discarded, deposited stock in landfill/recycling plants and stock that is lost to recycling. They recognise that the stock lost to recycling should be excluded from the anthropogenic stock. This approach is right in that the stock of material is more than that in nature, but it over-estimates what is available. For example, if a resource is depleted in nature the only stock available is the anthropogenic stock, but only a part of this is available at any time, namely the stock not in use but not yet discarded, and deposited stock in landfill/recycling. For materials used in structures, which have long lives, this may represent a small part of the anthropogenic stock. In addition such a concept could only work for resources that are recycled in the same form, e.g. some metals. From a strategic level, society needs to know how rapidly resources are depleted in nature and what amount of demand is satisfied from recycling. These objectives can be achieved more easily using the indicator described in this paper.

The European standard, EN15804, uses the ADP system. In addition to having the ADP applied to abiotic resources, they have a second ADP indicator linked to fossil fuels. The characterisation factors for ADP (elements and fossil) are to be taken from CML (Institute of Environmental Sciences Faculty of Science University of Leiden, Netherlands). The characterisation factors for ADP-fossil fuels are the net calorific values at the point of extraction of the fossil fuels. The ADP is the best of the fully-developed systems but prEN15804 (CEN, 2011) noted:

'*The indicator describing the depletion of abiotic resources is subject to further scientific development. The use of this indicator is intended to be reviewed during the revision of this standard.*'

The downsides of the ADP system are:

● It is limited to abiotic resources and it is wrong to assume that all biotic resources are infinite.

● The relationship between the impacts of the two ADP indicators will never be a constant across different products/systems and therefore a single resource indicator is a better solution. To be able to compare solutions over the life-cycle, it is necessary to combine the various indicators into a single score. Having a single indicator for resource use will help this process.

● The numbers generated by the ADP system are meaningless to most users and consequently there will be no emotional bond to improve performance. For example the ADP value for tungsten based on the reserve base is 2.54E-01 which means nothing to most users, but a residual life of 103 years will certainly focus attention on the need to improve.

NOTE. An ADP of 2.54E-01 will not always equate to a residual life of 103 years.

● The ADP does not provide a method for implementing the recommendations of the Raw Materials Initiative.

3.3 Other systems

There are a range of other systems used locally and these have been reviewed (JRC, 2008). In addition it has been proposed that resource availability for concrete is treated as a local issue (Habert et al, 2010). While this may be useful in helping secure local planning consents for aggregate extraction, you cannot have competing solutions compared using different criteria. As concluded by CEN/TC350, there is room for an improved resource indicator.

4. CSS INDICATOR

4.1 Objectives

The objectives of the CSS indicator are:

● Provide information on resource use related to availability to future generations, i.e. the residual lives of the resources.

● Include in a single indicator all resources (primary and secondary, abiotic and biotic, water) and the resources used to provide energy.

● Provide a means by which the recommendations given in the RMI (European Union, June 2010) on the criticality of certain resources to Europe can be incorporated into the SNR indicator in a way that will shape practice.

● Provide a means by which the residual lives are combined into a Current Scarcity Score (CSS) for a product, functional unit or structure over part or all of the lifecycle.

● Provide a measure of resource efficiency when compared using national/European average values.

The CSS does not include land use, but land use is more significant for the bio-diversity indicator and indicators within the social and economic pillars of sustainability.

4.2 Outline of the system

The system is a refinement of the system described by Harrison and Collins (Harrison and Collins, 2011). While a number of the original concepts are retained, users did not like the sudden jumps caused by having stepped changes in the characterization per unit of resource and so a continuous characterization model is introduced.

A cause-effect diagram is shown in Figure 1.

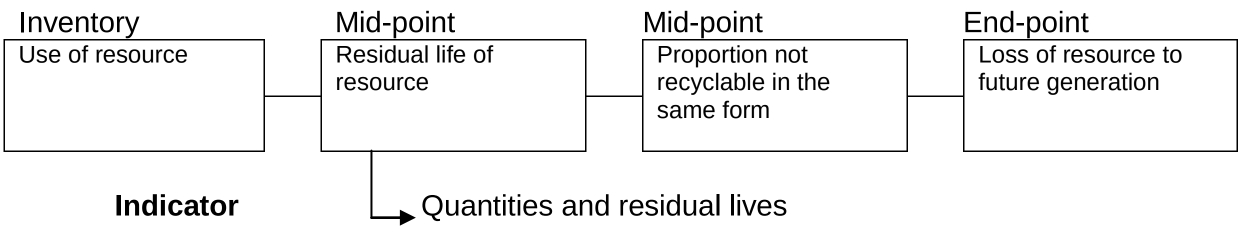


Figure 1: Cause-effect diagram

To enable comparisons between solutions, the quantity used of each resource is converted into a Current Scarcity Score using a characterization model, which is a function on the residual life of the resource. The sum of these Current Scarcity Scores gives the score for the solution. The solution with the lowest score has the lowest impact with respect to this particular indicator.

5. RESIDUAL LIVES

The concept of residual lives is the starting point for the ADP system and therefore, this concept may be taken as being an established starting point. The residual life is the reserves of a resource divided by the rate of extraction. There are various measures of resource availability, Table 1 (European Union, June 2010). Mineral reserve is clearly inappropriate as mining companies only determine if extraction is commercially sound and 'scarcity' rapidly changes the economics of extraction. Speculative and hypothetical resources may over-estimate what is available. 'Mineral resource' is taken as being an (conservative) appropriate value for the purposes of the CSS. The expectation is that this measure of residual life will under-estimate what in time is proven to be available, but the judgement of the authors is that it is better to err on the side of safety.

The report of an ad hoc group concluded (European Union, June 2010):

'The uncertainties associated with resource estimates are very large. Nevertheless over the past the reserves have been constantly replenished from undiscovered and identified resources. As a consequence, over the past 50 years, the extractive industries sector has succeeded in meeting global demand and the calculated life time of reserves and resources has continually been extended further into the future'.

They also concluded:

'*The Group considered that geological scarcity is not an issue for determining the criticality of raw materials in the time horizon considered in this study*.'

Elsewhere in the report they state:

'*Therefore it was decided that the analysis would look into the supply risks that may arise within a time period of 10 years. It is thus on this basis that – depending on data availability – the future demand and supply of the raw materials was taken into account*.'

With a 10 year period, total resource availability is not an issue. However this time scale is less than our generation, not future generations, and resource availability will become an issue over the next few centuries. It is highly probable that new sources will be discovered and technical improvement will increase the rate of extraction, but the idea that extractable reserves will continue to increase over the next few centuries is highly questionable, particularly with respect to fossil fuels which are not distributed uniformly through the 35 km of the continental crust.

Table 1: Measures of a mineral resource

Mineral reserve	Part of the resource that has been fully geologically evaluated and is commercially and legally mineable
Reserve base	Mineral reserve plus those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics
Mineral resource	All identified resources that have a natural concentration of the mineral or a body of rock that is, or may become, of potential economic interest as a basis for the extraction of a mineral commodity
Hypothetical resources	Unidentified resources which are similar to known mineral bodies and may be reasonably expected to exist in the same producing district or region under analogous geological conditions
Speculative resources	Unidentified resources that may occur either in known types of deposits in favourable geological settings where mineral discoveries have not been made, or in types of deposits as yet unrecognised for their economic potential

The 'mineral resource' used in this indicator should be regarded as the current best estimate of primary resources.

The use of a resource is the sum of the extracted resource plus the resource obtained from recycling less the resource placed in strategic stockpiles. For primary resources it is the rate of extraction that matters as this is the measure of depletion of reserves. While the reserves of key resources have increased over the last 50 years (European Union, June 2010), so has the rate of use.

Predicting future rate of use is fraught with difficulties:

● Will it be a function of the increasing population?

● Will we become more resource efficient?

● Will there be alternative materials?

● Will innovation create new demands or replace existing demands?

● Will economics force changes?

A mere 500 years ago we did not have computers, telephones, planes or cars and it is not possible to determine what will be the true rate of use of a resource in another 500 years. In this methodology, the recent historical rate of use is applied.

Determining the residual life of biotic resources can be more difficult. For example, according to the website Bagheera (Bagheera, 2011) there is only 2.5 million square miles of tropical rain forests left and these are being lost at a rate of 93000 square miles per year. Most of this loss will be permanent loss due to farming and human use giving a residual life of 27 years. With proper land care and use, biotic resources have very long residual lives. For these resources the minimum characterization per unit of resource should be applied to the quantity of resource grown.

Biotic resources take up land and land use is not part of the proposed indicator. This is because the impacts of land use are more appropriately addressed in the bio-diversity indicator and the indicators linked to social and economic aspects of sustainability.

Water is a resource where, with rare exceptions, the concept of residual life is not appropriate. With mineral and fossil fuel resources, residual life has been based on global availability or with a few resources, availability to Europe. Water availability is a local issue. This suggests that the CSS should be set at a national level or at the European level. Within Europe there will be regions where water availability is, and is not, an issue. Water with different CSSs will lead to identical products having different CSSs, but this will also be true for power taken from the national grid as the fuel mix in the different European countries is not the same.

A resource indicator should take account of water use. The system boundaries for water use are shown in Figure 2 and net water use is the quantity reported, i.e. the sum of the potable water plus extracted water less the water returned to the water system either directly or after processing. Consequently for manufactured products the water use is the sum of the water included in the product (e.g. mixing water for concrete) and process water that is not returned to the water system. Water that is simply used for cooling and then returned to the source is not taken into account. Any effect of the rise in water temperature on biodiversity should be taken into account under the biodiversity indicator.

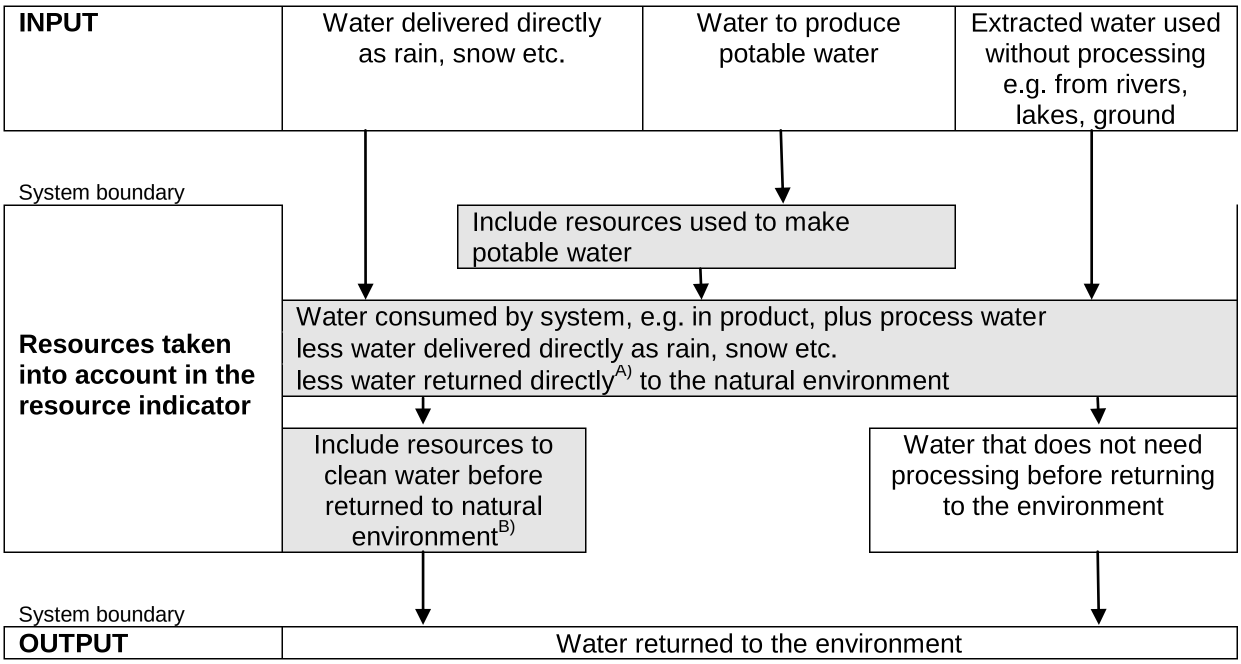
For biotic resources, water supplied directly by nature (e.g. rainfall or snow) is excluded from the calculations. All water used for irrigation is included in the calculations. It could be argued that some of this irrigation water evaporates and returns as rain or goes into the ground and adds to groundwater, but such links are tenuous and excluded from the calculation. Water intended for other applications and polluted by run-off from crop production cannot be easily measured. Such water is excluded from the calculations of the water use and the CSS, but its impacts could appear in other indicators.

When water use is considered over the lifecycle, water consumption during the in-use phase is likely to be the dominant quantity. Applying the principle defined above, results in water consumed by users and water, for example, used for watering the garden are part of the water use, but the designer of the structure has little real control over these uses. However the bulk of the water use during the in-use phase of life is returned to the system for reprocessing and therefore excluded from the calculation of water use. In for example, showers, the difference between water in and water out will be the same (effectively zero) regardless of whether water efficient showers and appliances are used. These aspects of water use are best addressed by placing requirements on the water efficiency of appliances and by water cost. Consequently in general it is proposed that water use during in the in-use phase of life is excluded from the calculation of the CSS. There may be a few exceptions such as the water used in the air-conditioning system, which is something the designer has control over.

The production of potable water takes resources and these resources need to be taken into account. To avoid double counting, the resources used to convert process water that originated as potable water back into potable water are not taken into account. However, the resources used to process water before returning to source, e.g. a river, are included, as this may be taken as being equivalent to the starting point for producing potable water.

The residual lives used in the methodology, and in other accepted methodologies, are the current 'best estimates' and not 'tablets of stone'. It should be accepted that these values must be periodically reviewed and updated. A review of the residual lives should be undertaken every few decades or when there is a significant change in reserves or rate of use.

Consequently the current estimates of reserves and rates of extraction have been used for the determination of the residual lives in this methodology. The reality is resource availability will, in the view of the authors, be an issue over the next few centuries and we should start now to use less of resources that are predicted to become scarce over the next centuries.



A) This excludes water that is evaporated and water lost into the ground as the link to the local water cycle is tenuous.
B) Excluding the resources needed to turn this returned water into potable water.

Figure 2: System boundaries for the resource, water

6. CURRENT SCARCITY SCORES (CSS)

Reporting the quantity of resources with relatively short residual lives is important in focussing the mind on the need to preserve resources. The quantities of resources include wastage, as is normal in life-cycle analysis. If the sustainability of different solutions is to be compared, it is essential to be able turn these quantities of resources into a single CSS. The CSS is a single numerical value that reflects the impact of resource use on future availability. It is the sum of the quantities of resources used times their CSS per unit volume of resource. The CSS may be calculated for a unit of product, a functional unit, or the structure over part or all of the life-cycle. As is normal with environmental indicators, a low CSS is better for the environment/society than a high CSS.

The CSS for a specific resource is:

$$S_{NRi} = aw.V_{NRi} \quad \text{[Eq. 3]}$$

and the CSS for a product is:

$$S_{Pi} = \sum(S_{NRi}) \text{ per unit of product} \quad \text{[Eq. 4]}$$

The detailed calculations use volume as there is a potential problem with using mass. For example if two materials with different densities but equal residual lives and CSSs are being compared to produce a wall of equal volume, the CSSs will be different. The heavier material will have a higher CSS than the lighter material. However in principle they should have the same score. The same CSS can be achieved if the characterization value is based on unit volume and not on a unit of mass.

The reverse situation, i.e. where equal mass is required, would also lead to unfairness if volume is used. However the University of Dundee could identify very few situations where equal mass is required. One example is to prevent uplift on a tank buried in ground with a high water table. In practice in these circumstances only heavy-weight building solutions would be considered. On balance using volume provides the fairest system.

CSSs are more easily calculated using a standard software spreadsheet. However for simplicity of application, the usual product unit is entered in the calculation (mass or volume), the spreadsheet is programmed to deal with the volume issue and the output is again in the usual unit. Annex A gives an example of the calculations.

If energy is taken from the national grid, the resources used are based on the European/national average, Table 2. Table 3 gives the resources used to generate 1kW/h of electricity and these resources are used to determine the CSS when power use is based on the European average. If a national fuel mix is not available, the European fuel mix should be used in calculations. If however, the power comes from a documented greener source, e.g. hydroelectricity, the producer may use this for determining the CSS.

As is normal in life-cycle analysis, the resources used to provide the facilities used to manufacture energy or products (the capital goods) are not taken into account on the assumption that these will be a secondary effect.

Table 2: Average European fuel mix[A)]

Energy Source	Proportion Of European Fuel Mix For Electricity Generation, %*	Efficiency, %[B)]
Hard coal	18.3	32
Brown coal	10.2	32
Crude oil	4.2	32
Natural gas	20.9	50
Biomass	1.0	50
Hydroelectricity	13.0	100
Nuclear	30.2	34
Other	2.2	-

[A)] (Commission EC, 2008)
[B)] (Boyle *et al*, 2003; Ramage, 1997)

Table 3: Current Scarcity Score (CSS) for 1 kW/h of power based on the European average

Energy Source	Quantity of resource per kW/h, m^3	Weighting	CSS
Hard coal	3.16×10^{-5}	5.56×10^{-2}	1.76×10^{-6}
Brown coal	2.32×10^{-5}	1.09×10^{-2}	2.53×10^{-7}
Crude oil	5.23×10^{-6}	5.00×10^{-2}	2.61×10^{-7}
Natural gas	2.31×10^{-5}	3.33×10^{-2}	7.71×10^{-7}
Biomass	3.86×10^{-6}	0	0
Hydroelectricity	-	0	0
Nuclear (Uranium)	9.66×10^{-13}	6.25×10^{-2}	6.04×10^{-14}
Other	-	0	0
Total CSS per kW/h			**3.04×10^{-6}**

7. CHARACTERIZATION MODEL

To differentiate between resources with different residual lives, the quantity of a resource is multiplied by the characterization per unit of resource, which is normally dependent on the residual life. A number of potential characterization models were assessed (Harrison et al, 2011). It is appropriate that the characterization per unit volume of resource should be proportionally greater for resources with the shorter residual lives, as these should be the priority for reducing their use. Given the uncertainties with predicting very long residual lives, particularly with respect to patterns of use, the ideal characterization model should have modest changes in values at residual lives over, say, 2000 years. If for construction it is accepted that the most concern should be for those resources with residual lives less than, say, 750 years, and that the residual life of all resources used in construction is likely to be proven in time as being at least 100 years, a wide range of characterization values per unit volume of resource between these residual lives is appropriate. These characterization values are the CSSs per unit volume of resource.

For these reasons, the hyperbolic curve (Figure 3) has the best properties. The values increase rapidly for residual lives of less than 850 years, i.e. discouraging the use of the scarcer resources, and change little at long residual lives, with their very large uncertainty. With such a curve the CSS per unit volume of resource will never be zero. As there may be small impacts of resource use that are not covered by the other indicators, always having a positive CSS has merit.

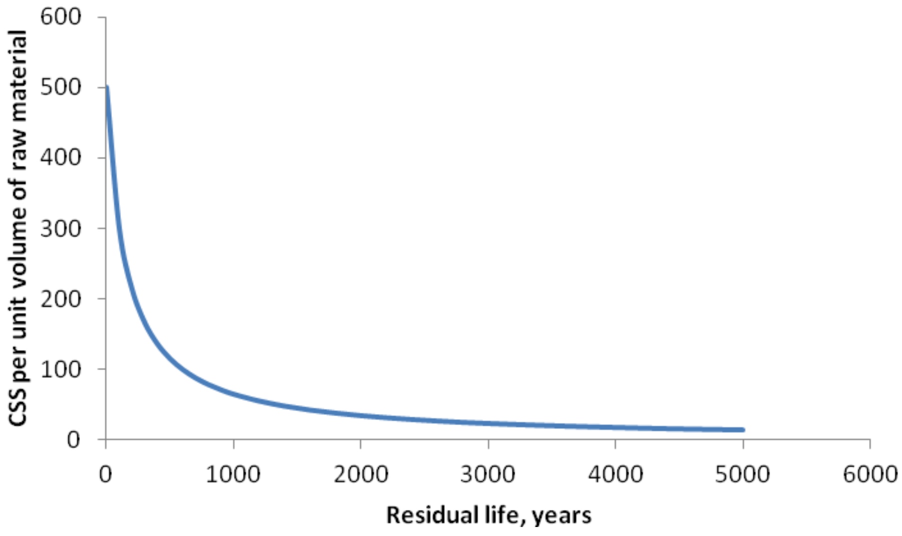


Figure 3: CSS per unit volume of resource

The CSS per unit of resource is given by the equation:

CSS per unit of resource = 75000/(150 + residual life in years) [Eq 5]

This equation gives CSSs of 300.0, 65.2, 34.9, 23.8, 18.1 and 14.6 for residual lives of 100, 1000, 2000, 3000, 4000 and 5000 years respectively. Given the uncertainties associated with such long residual lives caused mainly by uncertainty in the rate of use, there should be no significant differences in the CSSs between resources with long residual lives. This is achieved by having a maximum residual life; any resource that has a residual life longer than this value has the same CSS. As stated previously, the prime purpose of the resource indicator is a measure of availability to future generations and that other impacts of resource extraction and processing are covered by other indicators. It has also been suggested that there may be some small impacts not covered by these other indicators and so some positive CSS is appropriate. The choice of the maximum residual life will determine what CSS is allocated to impacts not covered by the other indicators as it applies regardless of the length of the residual life.

A maximum residual life of 5000 years allocates 5% of the CSS when compared with the CSS for a residual life of 100 years to impacts not covered by the other indicators and this is reasonable in a system that has a comprehensive set of indicators.

Many secondary materials have a finite residual life. For example, blastfurnace slag will only be produced when iron is made from primary ores. However the current political will in Europe is that secondary resources are preferable to primary resources and to reflect this will, the CSS per unit volume of resource is the lowest used in this system and independent of the residual life. In addition, there is also a benefit in the reduction of waste and so the CSS is reduced further from 14.6 to 5.0. However, the resources needed to process and transport secondary resources are taken fully into account in an identical way to primary resources. Consequently using recycled may not always give a lower CSS, e.g. when the energy requirements to process and transport secondary resources is significantly greater than those needed for primary resources.

A principle of the system is that the benefits in terms of a reduced CSS goes to the manufacturer that actually uses the secondary resources, For example if on average p% of a resource is recycled materials, all users of that resource cannot claim p% recycled materials: they can only claim what they use. The aims of this approach are to reward manufacturers who use secondary materials with a lower CS Score and create markets for such materials.

The CSSs applied to biotic resources where there is no residual life should be the minimum value (14.6). This CSS per unit volume of resource is to cover the impacts not covered by the other indicators.

Leaving the CSSs for water as a national issue could lead to unfair market distortion and the better solution would be for agreed European values. The simplicity of a single value has merit but it does nothing to reduce water demand in water stress areas or it creates a relatively high impact where not justified. Having a range of CSSs based on water scarcity and impact on downstream users seems the better approach. It is proposed that the minimum CSS per cubic metre of water should be 5.0, but in areas of water stress, it should be significantly more. Table 4 proposes some tentative values. This minimum CSS value is lower than for other resources, but it can be justified on the basis of fewer impacts not covered by the other indicators.

Table 4: Proposed CSSs per cubic metre for water

Region	**CSS per cubic metre**	**Equivalent residual life**[A)]
Water is always plentiful	5	14850
Irrigation water having no consequences on water availability or quality to downstream users	14.6	5000
Periods of restriction on non-essential water use, e.g. watering domestic gardens, washing cars	20	3600
Irrigation water creating shortages or water quality issues to downstream users	60	1100
Months of water shortages to industry or agriculture every year	130	425
Water availability is always a critical issue	250	150
[A)] For calculation purposes, it is easier to enter the equivalent residual life as the CSS per cubic metre is a generated value.		

8. RAW MATERIALS INITIATIVE

The method proposed for converting an RMI classification into a CSS is to use the Supply Risk and Economic Importance scores used in the RMI document to generate a single value which adequately describes the location of each resource on the plot shown in Figure 4. This is achieved by first converting the Supply Risk and Economic Importance scores to a single RMI Score using the equation:

$$RMI\ \ Score = \sqrt{(b + SR)^2 \times (c + EI)^2} \qquad \text{[Eq 6]}$$

where *b,c* = constants;
SR = supply risk score; and
EI = economic importance score.

The constants *b* and *c* were adjusted to achieve an RMI score that best reflects the demarcation of the ‘critical’ and ‘concern’ classifications given in the RMI report. Exploration of these values has found that a value of 1.5 for *b* and a value of 1.0 for *c* achieve a reasonably good reflection of the classification. This is shown in Table 5, where the resources are ranked in order of their score.

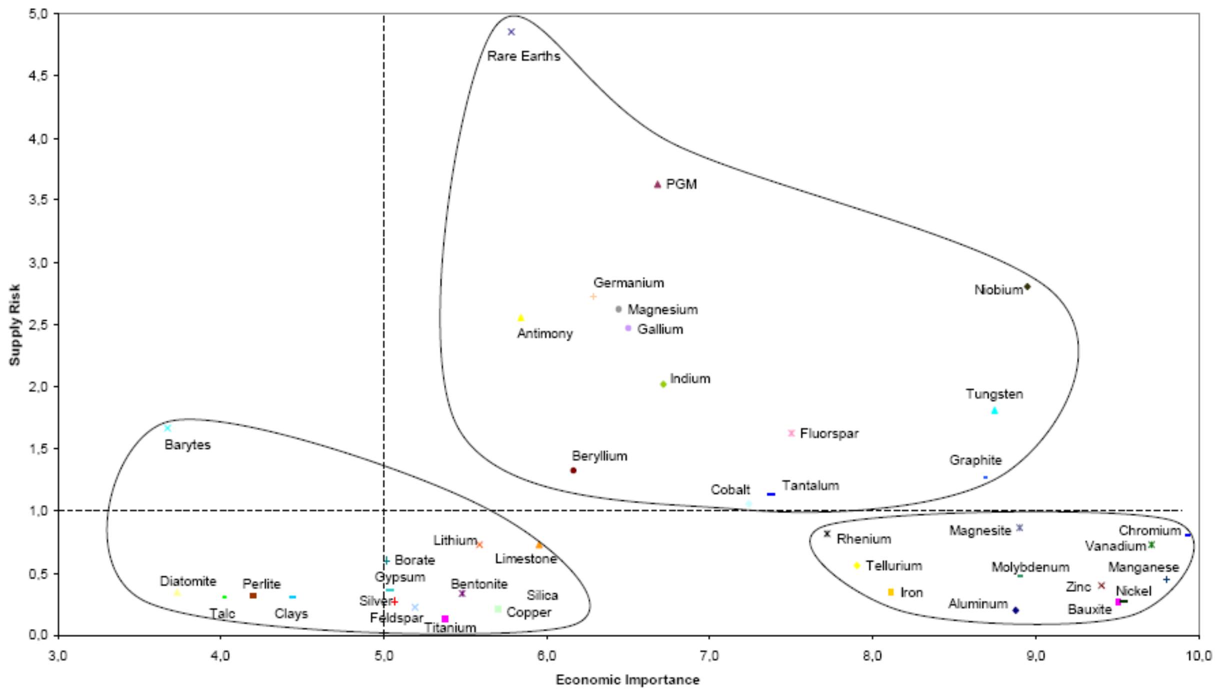


Figure 4: Supply Risk and Economic Importance Scoring

A means of converting the score obtained to an equivalent residual life has been devised. This is achieved by fitting a line to a plot of the lowest RMI score values obtained for the resources in the 'critical', 'concern' and 'normal' categories in Table 5 against threshold residual lives. Proposed threshold values are 100 years for 'critical', 200 years for 'concern' and 1000 years for 'normal'. The equivalent residual life curve is shown in Figure 5 and uses the RMI Scores for beryllium (19.88) which is the lowest scoring 'critical' resource, iron (16.38) which is the lowest scoring 'concern' resource and diatomite (8.46) – the lowest scoring 'normal' resource. This means that resources classified as 'critical' will have an equivalent residual life not exceeding 100 years and those classified as of 'concern', a residual life not exceeding 200 years. It should be stressed that this approach is subjective – there is no scientific basis for the 100, 200 and 1000 year thresholds. Taking into account the correlation shown in Figure 5 and the proposed values for *b* and *c*, Equation 6 is modified to:

$$\textit{equivalent residual life} = 5554e^{-0.2027\sqrt{(1.5+SR)^2(1+EI)^2}} \qquad \text{[Eq. 7]}$$

The equivalent residual life is only used for resources that have been classified in the RMI as being 'critical' or of 'concern' and, in principle, to fossil fuels (coal, natural gas, oil and petcoke). The residual life used in calculating the CSS is the shorter of the equivalent residual life or the residual life calculated from the available resources and rate of use. Table 6 gives the residual lives to be used in calculations of the CSS for resources classified as 'critical' or of 'concern' in the RMI.

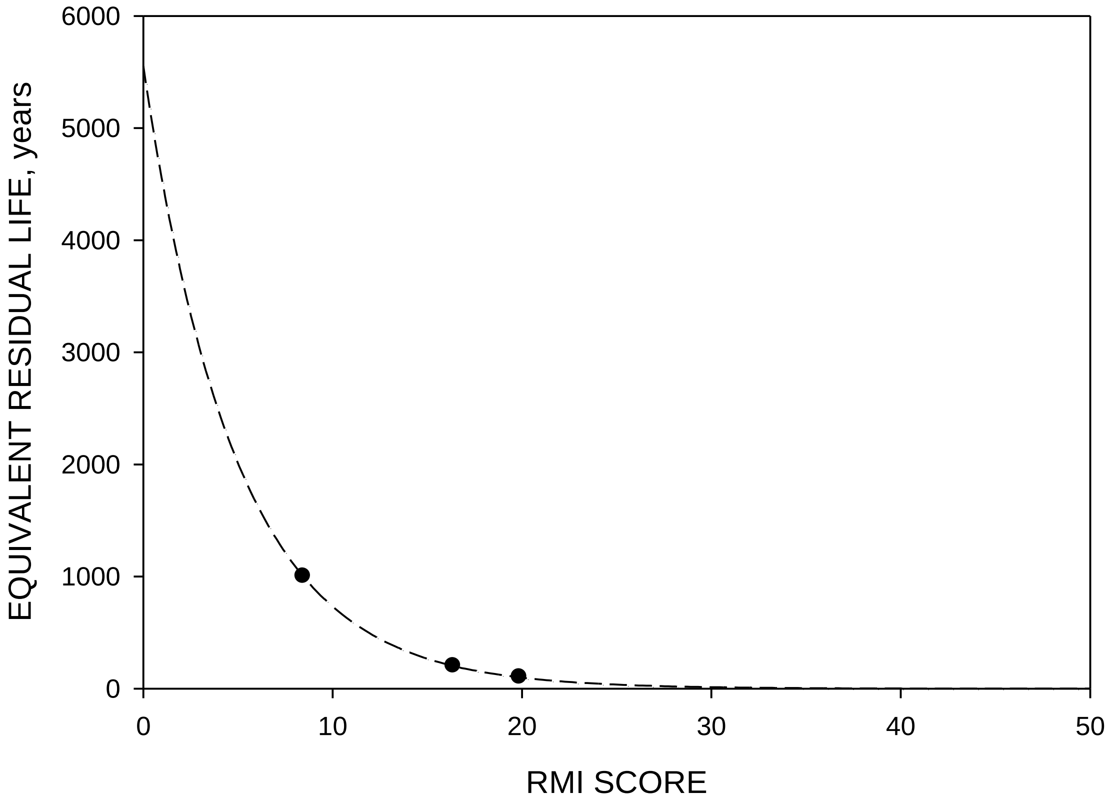


Figure 5: Results of applying the proposed characterization per unit of resource to the RMI score to obtain an equivalent residual life.

Table 5: RMI Score and equivalent residual life for resources assessed under the RMI

Resource	**EI**	**SR**	**RMI Score**	**RMI Classification**	**Equivalent residual life, years**
Rare earths	5.8	4.9	43.52	critical	1
Niobium	8.9	2.8	42.57	critical	1
PGM	6.7	3.6	39.27	critical	2
Tungsten	8.7	1.8	32.01	critical	8
Germanium	6.3	2.7	30.66	critical	11
Magnesium	6.4	2.6	30.34	critical	12
Gallium	6.5	2.5	30	critical	13
Antimony	5.8	2.6	27.88	critical	20
Graphite	8.7	1.3	27.16	critical	23
Indium	6.7	2	26.95	critical	24
Fluorspar	7.5	1.6	26.35	critical	27
Chromium	9.9	0.8	25.07	concern	34
Magnesite	8.9	0.9	23.76	concern	45
Vanadium	9.7	0.7	23.54	concern	47
Tantalum	7.4	1.1	21.84	critical	66
Cobalt	7.2	1.1	21.32	critical	74
Manganese	9.8	0.4	20.52	concern	87
Rhenium	7.7	0.8	20.01	concern	96
Beryllium	6.1	1.3	19.88	critical	99
Molybdenum	8.9	0.5	19.8	concern	100
Zinc	9.4	0.4	19.76	concern	101
Bauxite	9.5	0.3	18.9	concern	120
Nickel	9.5	0.3	18.9	concern	120
Tellurium	7.9	0.6	18.69	concern	126
Aluminium	8.9	0.2	16.83	concern	183
Iron	8.1	0.3	16.38	concern	201
Limestone	6	0.7	15.4	normal	245
Barytes	3.7	1.7	15.04	normal	263
Lithium	5.6	0.7	14.52	normal	293
Borate	5	0.6	12.6	normal	432
Bentonite	5.5	0.3	11.7	normal	518
Silica	5.8	0.2	11.56	normal	533
Gypsum	5	0.4	11.4	normal	551
Copper	5.7	0.2	11.39	normal	552
Silver	5.1	0.3	10.98	normal	600
Feldspar	5.2	0.2	10.54	normal	656
Titanium	5.4	0.1	10.24	normal	697
Clays	4.4	0.3	9.72	normal	774
Perlite	4.2	0.3	9.36	normal	833
Talc	4	0.3	9	normal	896
Diatomite	3.7	0.3	8.46	normal	1000

Table 6: Residual lives to be used when calculating a CSS per unit volume of resource

Resource	**Residual life, years**	**Equivalent residual life, years**	**Residual life for calculating the CSS, years***
Rare earths	23	1	1
Niobium	Long	1	1
Platinum group metals	B)	2	
Tungsten	B)	8	
Germanium	B)	11	
Magnesium	Long	12	12
Gallium	B)	13	
Antimony	B)	20	
Graphite	730	23	23
Indium	B)	24	
Fluorspar	B)	27	
Chromium	620	34	34
Magnesite	B)	45	
Vanadium	1180	47	47
Tantalum	B)	66	
Cobalt	B)	74	
Manganese	5500	87	87
Rhenium	B)	96	
Beryllium	B)	99	
Molybdenum	60	100	60
Zinc	170	101	101
Bauxite	280	120	120
Nickel	90	120	90
Tellurium	B)	126	
Aluminium	380	183	183
Iron	100	201	100
Fossil fuels			
Anthracite + bituminous coal	90	A)	
Oil	100	A)	
Petcoke	100	A)	
Natural gas	150	A)	
Lignite + sub-bituminous coal	460	A)	

A) Supply risk and economic importance data are not available.
B) Not examined in this phase of the project.
* Shorter life adopted.

9. EXAMPLES

The CSS calculations for a DN 300 polyethylene pipe were undertaken and the results are shown in Table 7. It should be noted that this example is for the pipe itself and not for the complete piping system. Oil, gas and hard coal make the largest contribution to the CSS along with water used in the manufacturing of the pipe. However, it should be noted that when presented in terms of score-per-length of pipe, the scores are very much sensitive to the mass per unit length value used.

Table 7: Resources used and CSSs for DN 300 polyethylene pipe*

Resource[A)]	**Quantity, m^3/ m pipe**	**Residual life, yrs**	**CSS**
Oil	$2.65x10^{-2}$	100	8.42
Gas	$2.74x10^{-2}$	150	7.68
Water[B)C)]	$2.43x10^{-1}$	3600	4.85
Hard coal	$2.62x10^{-3}$	90	1.31
Brown coal	$5.11x10^{-8}$	460	$6.64x10^{-2}$
Sulfur	$9.29x10^{-7}$	70	$3.17x10^{-4}$
Iron	$7.99x10^{-7}$	100	$2.40x10^{-4}$
NaCl	$1.62x10^{-4}$	5000	$8.71x10^{-5}$
Limestone	$1.82x10^{-6}$	5000	$2.64x10^{-5}$
Sand	$1.17x10^{-6}$	5000	$1.70x10^{-5}$
Bauxite	$5.00x10^{-8}$	280	$8.72x10^{-6}$
Zinc	$1.33x10^{-8}$	170	$3.12x10^{-6}$
Bentonite	$1.10x10^{-7}$	5000	$1.61x10^{-6}$
Gypsum	$1.43x10^{-6}$	5000	$7.68x10^{-7}$
Dolomite	$7.39x10^{-7}$	5000	$3.98x10^{-7}$
Olivine	$4.82x10^{-7}$	5000	$2.60x10^{-7}$
Shale	$1.46x10^{-8}$	5000	$2.13x10^{-7}$
Uranium	$5.55x10^{-11}$	80	$3.87x10^{-8}$
Biomass	$8.90x10^{-4}$	5000	0.00
TOTAL	**$5.75x10^{-2}$**	**-**	**22.33**

A) System boundary is the gate of the manufacturing plant.
B) The applied CSS is 20 per cubic metre.
C) Sixth Framework Programme, 2008

*Energy and raw materials information acquired from TNO (2010) and Boustead (2005).

Table 8 is the CSS for an average UK (but un-real) concrete. It is average because it contains all the main constituents used in the UK in the proportions they are used and un-real because no real concrete would contain so many constituents. However it does provide a useful benchmark and a basis for measuring resource efficiency of UK concrete over time. If over time this CSS reduces, the resource efficiency of UK concrete will have improved. With concrete the unit volume (a cubic metre) has not changed and so any change is a measure of the scarcity of the resources used. However, if applied to a product where the volume of the product/functional unit can also be changed, a changed CSS will be a combination of the change in volume of resources used and the scarcity of the resources used.

Concrete contains many resources with very long residual lives, which attract the minimum weighting, but as the quantities used are large, the impacts are therefore significant. In this calculation fresh water use has been included with a CSS of 20, which is the CSS associated with a residual life of 3600. Water use includes water in the concrete mix and water used for production of concrete and its constituents. Table 8 suggest that water has a high impact. However, a closer examination of the resource data (Table 8), shows that the combined fossil fuels and the combined coarse and fine aggregates (used as concrete constituents only) have significantly higher impacts of 10.99 and 9.87 respectively than the combined fresh and recycled water (3.08 + 0.20). In this example the aggregates masses are taken as being in the saturated surface dry condition and a CSS of 14.6 per cubic metre applies. When considering the CSS for concrete, it should be recognised that any CSS is unlikely to be lower than 14.6 and consequently a CSS of 26.75 per cubic metre is a product with low impact. In addition the total volume of resources is greater that the unit volume of 1 cubic metre. In general this will be the case as, for example, burning fossil fuels to provide energy make no contribution to the volume of the product and the calculations have to take account of wastage.

Table 8: CSS for reference concrete*

Resource[A)]	**Quantity, m^3**	**Residual life, years**	**CSS**[B)]
Hard coal	0.014	90	4.40
Crude oil	0.014	100	4.15
Crushed rock	0.240	5000	3.49
Natural gravel	0.214	5000	3.12
Potable water[C)]	0.154	3600	3.08
Natural sand	0.150	5000	2.14
Limestone	0.127	5000	1.84
Natural gas[D)]	0.009	150	1.66
Crushed rock sand	0.061	5000	0.90
Brown coal	0.006	460	0.78
Recycled aggregate	0.044	14850	0.22
Recycled water	0.040	14850	0.20
Clay	0.025	5000	0.36
GGBS[E)]	0.022	100	0.13
Flyash	0.009	14850	0.04
Gypsum	0.005	5000	0.07
Waste fuels	0.005	14850	0.02
Total	**1.139**	-	**26.75**

[A)] System boundary is the gate of the concrete plant.
[B)] Quantities per cubic metre.
[C)] The applied CSS is 20 per cubic metre.
[D)] Expressed as coal equivalent.
[E)] 2% allocation of impacts of iron production.
*Energy and water information acquired from The Concrete Society (2009)

An alternative way of viewing the data is by concrete constituents, Table 9. In Table 9 each CSS includes the resources, energy and water to manufacture and transport that constituent. The row for mix water comprises the free water (combined fresh and recycled is taken as 180 litres/m^3). The row for the production of concrete comprises the energy used to batch and mix the concrete. It is assumed that the truck mixer drum wash water is used as mix water in other batches of concrete.

Due to the large volume per cubic metre, aggregates have the greater impact in spite of the resources themselves having the minimum weighting. The second highest impact comes from the Portland cement. The quantity per cubic metre is low (206kg/m^3), but the fossil fuel use pushed up its impact.

Table 9: CSS for constituents in reference concrete*

Constituent[A)]	CSS per cubic metre
Aggregate	12.65
Portland cement	9.02
Mix water	3.28
Additions	0.72
Production	0.63
Admixtures	0.45
Total CSS	26.75

[A)] System boundary is the gate of the concrete plant.
*Energy and water information acquired from The Concrete Society (2009).

10. CONCLUSIONS

10.1 A resource use indicator should be a measure of availability to future generations.

10.2 A resource use indicator should always be assessed within a suite of other indicators that cover the three pillars of sustainability.

10.3 While the majority of the other impacts of resource use are covered by these other indicators, there may be small impacts that are not covered elsewhere and these can be accommodated by having a minimum impact.

10.4 It is practical to combine all resource use into a single indicator, the Current Scarcity Score, and this is a useful first step towards combining all the different indicators into single values for comparisons of different solutions over the life cycle.

10.5 For the materials and products examined in preparing this paper, fossil fuel use has the biggest impact and zero recyclability.

10.6 The use of this indicator will encourage the use of secondary materials by rewarding those who use them with a lower Current Scarcity Score.

10.7 The use of the Current Scarcity Score is an ideal way of providing information with respect to Basic Requirement for Construction Works 7: *Sustainable use of natural resources.*

10.8 The use of the Current Scarcity Score will help discourage the use of resources that are classified as ‘critical’ or ‘of concern’ in the Raw Materials Initiative.

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ANNEX A: EXAMPLE OF THE CALCULATIONS

The method used to calculate CSS for a polyethylene pipe is outlined below.

Stage 1

The inventory of mineral resources required to manufacture 1 tonne of polyethylene and extrude it as a pipe is compiled along with the densities of each resource and the residual life. The mass and density values are used to calculate the volume of each resource. These inputs and the calculated volumes are shown in Table 10.

Table 10. Resource masses used to manufacture and extrude 1 tonne of polyethylene pipe, resource densities, residual lives and calculated volumes.

Resource	Mass, kg	Density, kg/m^3	Residual life, years	Volume, m^3
Biomass	1.00×10^{3}	650	5000	2.41×10^{-2}
Sodium Chloride	1.56×10^{1}	2165	5000	1.62×10^{-4}
Iron Ore	3.50×10^{-1}	7874	100	2.16×10^{-5}
Limestone	1.70×10^{-1}	2650	5000	4.91×10^{-5}
Sand	1.30×10^{-1}	2660	5000	3.16×10^{-5}
Sulfur	8.40×10^{-2}	2070	70	2.51×10^{-5}
Bentonite	5.20×10^{-2}	2350	5000	2.98×10^{-6}
Zinc Ore	7.00×10^{-3}	5560	170	3.60×10^{-7}
Shale	2.00×10^{-3}	2350	5000	3.96×10^{-7}
Bauxite	9.30×10^{-4}	3700	280	1.35×10^{-6}
Gypsum	5.00×10^{-3}	2315	5000	1.43×10^{-6}
Dolomite	3.30×10^{-3}	2840	5000	7.39×10^{-7}
Olivine	2.10×10^{-3}	3320	5000	4.82×10^{-7}
Water	6560	1000	3600*	6.56
* a residual life of 3600 years was selected for water such that a CSS of 20 was obtained from the characterization equation discussed previously.				

Stage 2

The energy requirement to manufacture 1 tonne of polyethylene is 7.67×10^{4} MJ. The requirement to extrude it as a pipe is 9.38×10^{3} MJ. The fuel mix of polyethylene production and extrusion, and the gross calorific value and density of each fuel are used to calculate the volume of each energy resource. This is shown in Table 11 for the polyethylene manufacturing process.

Table 11. Calculation of the volume of each energy resource used in the manufacture of a tonne of polyethylene.

Energy resource	% of fuel mix	Energy, kJ	Gross calorific value, kJ/kg	Density, kg/m^3	Volume
Hard Coal	2.56	1.96×10^{-6}	2.10×10^4	1.32×10^3	7.08×10^{-2}
Brown Coal	3.79×10^{-5}	2.91×10^1	1.63×10^4	1.29×10^3	1.38×10^{-6}
Oil	35.99	2.76×10^7	3.85×10^4 (kJ/l)	8.26×10^2	7.17×10^{-1}
Gas	26.79	2.05×10^7	2.10×10^4*	1.32×10^3*	7.41×10^{-1}
Liquid Wastes	2.56	1.96×10^6	2.97×10^4 (kJ/l)	7.89×10^2	6.61×10^{-2}
Biomass	2.56	1.96×10^6	1.59×10^4	6.50×10^2	1.90×10^{-1}
Uranium	2.76	2.11×10^6	7.40×10^{10}	1.91×10^4	1.50×10^{-9}
* gross calorific value and density of hard coal used for natural gas to convert gas energy into equivalent volume of hard coal.					

Stage 3

The CSS for each resource is calculated using the equation:

$$\mathrm{CSS} = \frac{75000 \bullet V_a}{150 + RL_a}$$

where V_a = volume of resource *a* (m^3); and
RL_a = the residual life of resource *a* (years).

The individual scores can then be summed to give a total CSS per tonne of polyethylene. The results of the calculation for 1 tonne of polyethylene pipe are shown in Table 12.

Stage 4

Since pipe is seldom measure in terms of mass, the CSS for 1 m length of pipe is calculated by multiplying by the mass of a 1 m length of a typical DN 300 polyethylene pipe (37kg/m). This gives a CSS of 22.33.

Table 12. Calculation of the CSS for 1 tonne of polyethylene pipe.

Resource	Volume, m^3	Residual life, years	CSS
Hard Coal	0.114	90	3.55×10^{1}
Brown Coal	0.015	460	1.79
Crude Oil	0.758	100	2.27×10^{2}
Natural Gas	0.830	150	2.07×10^{2}
Liquid wastes	0.066	5000	0
Biomass	0.000	5000	0
Uranium	0.000	80	1.05×10^{-6}
Biomass	0.024	5000	0
Sodium Chloride	0.000	5000	2.35×10^{-3}
Iron Ore	0.000	100	6.48×10^{-3}
Limestone	0.000	5000	7.14×10^{-4}
Sand	0.000	5000	4.60×10^{-4}
Sulfur	0.000	70	8.56×10^{-3}
Bentonite	0.000	5000	4.34×10^{-3}
Zinc	0.000	170	8.43×10^{-5}
Shale	0.000	5000	5.76×10^{-6}
Bauxite	0.000	280	2.36×10^{-4}
Olivine	0.000	5000	2.08×10^{-5}
Water	6.560	3600	1.31×10^{2}
		TOTAL:	**338.68**