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Is gravel becoming scarce? Evaluating the local criticality of construction aggregates

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ABSTRACT

Natural aggregates are considered an immense natural resource at the global level; however some regions face a supply constraint due to the overexploitation of natural aggregates in construction. This paper presents an assessment of the local criticality of quarried aggregates by adapting the methodology for metal criticality determination to the characteristics of construction aggregates. Two approaches, strong and weak locality, are envisaged to examine different substitution scenarios in the case of local supply constraint. The adapted methodology examines three dimensions: Supply Risk, Environmental Implications and Vulnerability to Supply Restriction. The application of the methodology to the cantons of Switzerland shows that inside a country, the criticality is driven by the Supply Risk, which depends on the surface and number of quarries and their distribution in the region. A comparison of the supply risk of aggregates with the supply risk of steel shows that for most of the cantons the supply risk of natural aggregates is lower. The application of this methodology at a world scale will indicate highly critical regions and enable policymakers to define measures for ensuring a sustainable growth, either by regulating the extraction of aggregates or by demonstrating the local need to consider the use of other materials, apart from concrete.

1. Introduction

The current fast pace of technological development and the increasing demands of the economy lead to a soaring consumption of energy and resources. The modern trend of energy efficiency in the building sector is on the one hand making buildings self-sufficient with respect to energy, but on the other hand comes at a cost of huge material investments (Rovers, 2014; Horvath, 2004). Among the resources used in construction, one of the major categories in terms of volume are natural aggregates, namely crushed rock, natural gravel and sand. “Aggregates are essential and valuable resources for the economic and social development of humankind” (Blengini et al., 2012).Natural aggregates are used in the production of portland cement and as a component of portland cement concrete and asphalt concrete (Horvath, 2004).

Stone reserves are considered infinite at the global scale, however at a regional level they can face a supply constraint and potentially lead to critical situations (Habert et al., 2010). This situation is especially observed in many parts of the world, such as Dubai and Singapore, where the construction industry is booming and construction resources are overexploited (UNEP, 2014). It is, therefore, desirable to evaluate locally the criticality of construction aggregates in order to facilitate decision-making and regional planning (Agioutantis et al., 2014) and the adoption of policies to prevent critical situations in regional building sectors.

Criticality as a concept refers both to a high potential impact of shortage (when the resource is particularly important for the value chain and has few or no substitutes) and to a comparatively high probability of such a shortage (Buijs et al., 2012; National Research Council, 2008; European Commission, 2011; Jin et al., 2016). The criticality assessment of minerals integrates environmental, socio-economic and geopolitical aspects related to the availability and use of minerals (Sonnemann et al., 2015; Drielsma et al., 2016). Both the United States National Research Council (2008) and the European Commission (2010) have published studies on the criticality of various metals. One of the most widely discussed criticality methodologies

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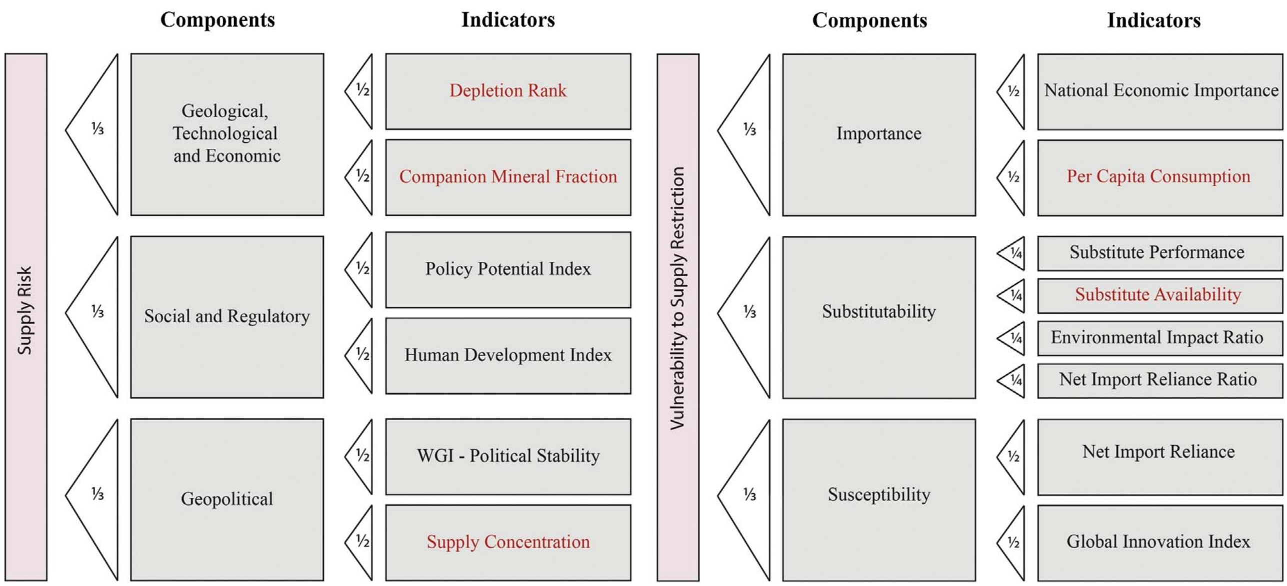

Fig. 1. Diagram of the supply risk and the vulnerability to supply restriction dimensions, their components and indicators (framework based on Graedel et al. (2012) and adapted to gravel).

integrating these three dimensions was developed at Yale University by Graedel et al. (2012). There have been numerous studies applying this criticality methodology to various metals (Harper et al., 2015a; Nassar et al., 2012; Panousi et al., 2015; Harper et al., 2015b) or other resources, such as water (Sonderegger et al., 2015).

An evaluation of the availability of aggregates can currently be performed either following the generic methods for abiotic resource depletion (Guinée et al., 2002; Goedkoop and Spriensma, 2001; Jolliet et al., 2003) or by following one of the newly developed methods which try to incorporate economic criteria in the assessment (Habert et al., 2010; Sonnemann et al., 2015). A small number of methods account for the variability in the local availability of construction aggregates (Habert et al., 2010; Ioannidou et al., 2015).

The present paper presents an adaptation of the criticality methodology for the case of quarried construction aggregates (gravel and sand). To facilitate comparability across different resources beyond metals (Sonderegger et al., 2015), the framework of the initial methodology of metal criticality was maintained; some indicators were adapted and new ones that could better capture the specific characteristics of gravel were introduced. The aim of this adaptation is to enable a regionalized assessment of the criticality of gravel through the introduction of two new concepts, strong and weak locality. The methodology is applied to the cantons of Switzerland and the results are contrasted to the criticality of steel and antimony.

2. Materials and methods

2.1. Framework and concepts

The methodology for the criticality of construction aggregates maintains the same structure adopted by Graedel et al. (2012). The main differentiation is the regional spatial focus for evaluating the criticality of aggregates, since these resources can be at a risk of depletion at a regional scale, while their global reserves can be considered immense. The term depletion refers to "the process of physically reducing the global amount" of a resource (p. 90) (Drielsma et al., 2016), which can create a supply constraint.

Two new concepts are here introduced: strong and weak locality in accordance with strong and weak sustainability (Pearce and Atkinson, 1993; Ekins et al., 2003; Daly, 2005; Frischknecht, 2010). Strong locality is based on the idea of making use of only the local resources. It is related to a more self-sufficient economy, where importation is limited. In this case, the available resources for the local economy are the natural aggregates, extracted from the regional quarries. In case of local depletion, the best locally available substitute will be used, here considered to be the recycled aggregates.

Weak locality is associated with an open and globalized economy, where it is possible to import from other areas the resources that face a supply constraint at a local level. In this perspective, natural aggregates imported from other countries are considered as a substitute. The recycled aggregates are here a component of the regional supply of aggregates and differ from aggregates sourced at regional quarries merely in the life cycle stage they are in. In other words, they are part of the quantity of aggregates that can be supplied in a region. Depending on the locality approach, the boundary conditions of the system change. In the strong locality approach, both natural and recycled aggregates are sourced from inside an administrative division and a transportation distance of 30 km is assumed for both, which is consistent with other studies (Gustavsson and Sathre, 2006; Stucki et al., 2013; Guignot et al., 2015). In the weak locality approach, where aggregates imported from other administrative regions are considered as a substitute, a mean transportation distance of 150 km is considered for these aggregates (Ioannidou et al., 2016) while for the main mineral (natural and recycled aggregates from inside the administrative division), a transportation distance of 30 km continues to apply. These transportation distances were assumed for Switzerland and can be adapted to the individual cases (e.g., US).

The criticality of quarried aggregates is evaluated at a middle level of administrative division inside a country (e.g. department or canton). It is comprised of three dimensions: Supply Risk (SR), Environmental Implications (EI) and Vulnerability to Supply Restriction (VSR). The evaluation of SR and VSR is performed based on three components and each component consists of different indicators. Fig. 1 presents the indicators considered in these two criticality dimensions for construction aggregates. With red are denoted the indicators that have been modified from the initial methodology of Graedel et al. (2012) in order to differentiate between strong and weak locality or to better represent the characteristics of aggregates. The other indicators retain the same logic as in the initial methodology.

2.2. Supply risk

The three components of Supply Risk (SR) are: (1) Geological, Technological and Economic, (2) Social and Regulatory and (3)