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Sustainable management and supply of natural and recycled aggregates in a medium-size integrated plant

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ABSTRACT

The consumption of natural aggregates in civil engineering applications can cause severe environmental impacts on a regional scale, depleting the stock of bulk resources within a territory. Several methods can improve the environmental sustainability of the whole aggregates' supply process, including natural and recycled aggregates' productive chains, for instance promoting the use of recycled aggregates (RA). However, when quarrying and recycling activities are considered as stand-alone processes, also the RA supply chain may not be as sustainable as expected, due to the high environmental loads associated to transportation, if high distances from the production to the use sites are involved. This work gives some insights on the environmental impact assessment of the aggregates' industry in the Italian context, through a comparative assessment of the environmental loads of natural and recycled aggregates' productive chains. An integrated plant for the extraction of virgin aggregates and recycling of construction and demolition waste (C&DW) was analyzed as significant case study, with the aim to identify the influence of sustainable solutions on the overall emissions of the facility. A Life Cycle Assessment (LCA) approach was used, using site-specific data and paying particular attention on transportation-related impacts, land use, avoided landfill and non-renewable resources preservation. From this work it was possible to evaluate the influence of transportation and PV energy use on the overall environmental emissions of natural and recycled aggregates' productive chains.

1. Introduction

Construction industry is one of the main consumers of raw materials, asking for huge amounts of non-renewable bulk resources, also causing great waste streams, particularly of construction and demolition waste (C&DW). This material represents one of the most voluminous streams of waste generated worldwide, accounting for about 25–30% in mass of the whole waste produced in Europe (JRC-IES, 2011). It typically comprises large quantities of inert mineral materials, with smaller amounts of other components, depending on the source and separation techniques. Despite the high potential for recycling of C&DW in the aggregate market, a large fraction ends up in C&D landfills, and barriers to materials recovery still exist (USEPA, 2009). Hence, a great amount of land is currently dedicated to the disposal of those materials, leading to increase the ecological footprint of construction industry.

Several reasons can explain the still low valorization of C&DW, especially where the competitiveness of RA industry is poorer than virgin aggregates' one (e.g. in non-densely populated areas, where recycling is less developed or natural materials are largely available). Main reasons are: buildings are not designed to be nor reused nor recycled; there is a lack of recovery facilities in some areas; and for some materials, the demand is too low due to the unwillingness to use recycled materials in place of virgin ones, principally for some regulatory or normative barriers. Additionally, the quality of RA may be lower than natural aggregates (NA) when not properly treated and processed, due to the poorer mechanical properties of the attached old mortar or the presence of some contaminants (Pepe et al., 2014; Faleschini et al., 2014a; Fathifazl et al., 2009). As an indicative data, the minimum target of recycling of non-hazardous C&DW set at 70% before the end of 2020 by the European Union in the Directive 2008/98/EC on waste, is quite far from the official Italian statistics, which states that about 80% of the inert waste was simply landfilled in 2010 (Blengini and Garbarino, 2010).

RAs are valuable resources which could be used for various applications, depending on their quality, i.e. for environmental filling and rehabilitation of depleted quarries and landfills, in road works as sub-base, base or unbound material, as granular bedding or filter material for drainage layers, and in concrete production as

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paving block, pedestrian paving slab, curbs, roads meridians, anti-crash barriers, railway platform, mass concrete applications (e.g. bridge abutments, seawall blocks, shore protection works), and high grade applications (e.g. precast elements). Concerning this latter application, one important barrier limiting further use of RAs is the common cultural mistrust of recycled products in the construction sector; in addition most of the existing codes, guidelines and regulations fix strict barriers for the maximum allowable quantities of RAs, with respect to the exposure and strength class of the structure where they will be placed (DIN 1045-2, 2008; DM 14/01/2008, 2008; EHE-08, 2011; EN 206, 2013). Besides the technical requirements which may limit their use, environmental concerns should also be taken into account, related to the release of dangerous substances to air (outdoor and indoor), soil, surface water and groundwater, particularly with respect to leaching potential (Hjelmar et al., 2013). Currently these problems are under consideration by the Technical Committee CEN/TC 351.

Some researchers have also reported the possibility that more energy is spent due to the recycling chain than to landfilling, and that transportation-related environmental loads may heavily contribute to the aggregates' impacts (Marinković et al., 2010; Blengini and Garbarino, 2010). A possible increase in RAs delivery distances can indeed occur, depending on the geographical coverage of both production facilities and market demand for some type of RAs, and on the local availability of NAs. However, recycling and processing of C&DW into added-value products such as RA, can generally lead to relevant environmental savings, i.e. landfill avoidance of inert waste, non-renewable resources preservation and partial displacement of environmental impacts of quarrying activities. The achievement of these objectives results in use of land savings (a scarce resource in countries such as Italy), which has been dedicated to C&DW landfilling during the last years, and contributes to solve scarcity problems of bulk non-renewable resources that may arise at local scale. Additionally, the NA processing and supplying activities involve a complex set of direct and indirect environmental impacts, which can be mitigated by the increase in RA use.

The effects of C&DWs valorization processes on the environmental impacts of aggregates' productive chain are analyzed in this work, paying particular emphasis on the interactions between quarrying, transportation, recycling and landfilling activities. The aim of this research is to identify whether recycling is convenient from an environmental point of view, via analyzing the influence of C&DW recycling activity on the impacts of an integrated existing facility where both NA and RA are produced. A Life Cycle Assessment (LCA) methodology (ISO 14040, 2006; ISO 14044, 2006) is used to quantify the impacts associated with a product's entire life, i.e. "from cradle-to-grave". This tool is growing to be applied to evaluate building materials' sustainability (Faleschini et al., 2014b; Josa et al., 2007). Site specific data are used to capture the realistic dimension of the problem: in fact, according to Van Zyl (2005), when no site specific data are used, misleading conclusions can be drawn because each mining activity is very different to another (as occurs also for other industrial activities), and therefore associated environmental loads may be very different. Accordingly, a medium-size integrated plant, sited in the district of Vicenza (Italy), where quarrying of NA and recycling of C&DWs in a stationary plant take place, is considered as case study.

2. Bulk natural resources consumption and disposal of inert waste in Veneto region (Italy)

The analyzed case study is sited in the district of Vicenza (Italy), located in the Veneto region (Fig. 1). This section aims to illustrate the current situation about aggregates' availability in the analyzed territory. A regional plan (PRAC, 2013) regulates quarrying activity, and authorizes a volume of extraction of about 36 millions of m^3 for natural gravel and sand during its validity (10 years). In the regional territory, there were 88 existing quarries in 2008, with an estimated volume of 106,431,675 m^3 of available aggregates, representing the potential reserve of bulk natural resources. This volume is subdivided into three main districts: 68% in Treviso, 20% in Verona and 12% in Vicenza. Fig. 2 shows mining activity from 1990 until 2008, with the imports of natural aggregates: the trend is overall decreasing, even though some fluctuations occurred in the first 90s. Additionally, the extracted volume of gravel and sand in 2011, which is the last official available data (PRAC, 2013), is about 5,850,835 m^3, highlighting a decreasing trend from 2008 to 2011, due to the economic crisis after 2009. On the contrary, imports have been increased during the last 20 years, and in particular the *I/DMC* ratio, where *I* represents the imports and *DMC* is the domestic consumption, has been raised from 0.298 in 1990 until 0.560 in 2008. According to Habert et al. (2010), the temporal evolution of this parameter should be used as the base to assess the potential stock of bulk resources available for concrete industry, since it well describes the potentially accessible stock of resources, considering all the constraints from the anthroposystem (e.g. the social constraints due to noise and dust, or the environmental ones due to new quarries opening), and not only the geological availability in one site. In the analyzed case, Fig. 3 shows the temporal evolution of *I/DMC* in Veneto: the housing demand, which was very high during the first 90s, was predominantly satisfied by local extraction activities. Nowadays the consumption has been reduced due to the economic crisis, however, as many of other commodities (Istat, 2013), the imports have been increased, reflecting a potential depletion state at local scale, highly affected by social constraints.

When dealing with RAs, a fundamental issue that should be analyzed relates to their alternative end-of-life, which is the landfill of inert waste. According to the Italian standard (DM 27/09/2010), Italian inert landfills can accept C&DW, e.g. concrete, masonry, ceramics, soils (with some restrictions) and other wastes, which should comply with the limits prescribed in the previous regulation, principally in terms of concentration of metals and other compounds in the leachate. In Veneto there are 38 authorized landfills for inert wastes (Fig. 4) according to ARPAV (2010), which are mainly located in the districts of Belluno (24%), Treviso (31.5%), Verona (13%) and Vicenza (31.5%). In 2010 about 510,000 ton of inert wastes have been disposed: 335,000 ton were marble sludge and the remaining 175,000 ton came from construction and demolition operations. The estimated available volume for disposal in the region is about 6,000,000 m^3 (official available data from 2010): accordingly, the average service life of the existing landfills is about 15 years.

3. Methodology

A LCA methodology is used in this work to draw a comprehensive overview about the environmental impacts due to the activities for aggregates production, using as significant case study the productive process of an Italian medium-size facility, sited in Rosà (Vicenza district, Italy), where both the extraction of NA and C&DW recycling take place in a stationary plant. The average production of the facility, evaluated in the last 4 years, is about 56,361 ton/y of NA, and 5993 ton/y of RA (about 10% of the whole production), although the Region has authorized the plant to increase RA production up to 18,000 ton/y. Concerning NA, about 17% of the production is currently destined to low-quality aggregates, satisfying EN 13242 (2008) standard, whereas the remaining 83% is destined to high-quality aggregates, complying with EN 12620 (2008) standard. About 32% of the produced RAs can be used