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Exploring factors influencing post-consumer gypsum recycling and landfilling in the European Union

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ABSTRACT

Post-consumer gypsum waste (GW) is increasingly generated in the European Union and not adequately managed in 20 out of the 28 European countries. Overall, it is estimated that 87% of post-consumer GW is landfilled in the EU-28. This waste stream holds unique characteristics, mainly due to its non-inert nature and its high sulphate content. Two main undesirable effects are produced when gypsum is not managed appropriately. First, gypsum contaminates concrete for recycling when treated as mixed waste. Second, the disposal of GW at landfills poses a risk of higher landfill emissions. Overall, potential secondary resources are lost. The main objective of this study is to explore factors influencing gypsum recycling and landfilling in the EU-28. The method includes a study of the literature and a structured questionnaire distributed to stakeholders. Data analysis is used to rank the critical factors (CFs) and conduct a comparison of respondents' views divided into two groups (gypsum recycling and non-gypsum recycling countries are differentiated). The results show a set of 15 CFs categorized into four domains: policy, economic, social and environmental. More than half of the CFs belong to the policy domain, which indicates the relevance of regulatory and economic instruments for promoting a circular economy for gypsum.

1. Introduction

Although certain factors can determine more favourable destinations, post-consumer construction products (also termed as construction and demolition (C&D) waste) are typically disposed of in landfills in most of the EU-28 countries (European Commission, 2011). Higher options in the priority order include reusing, recycling and recovery operations, following the waste hierarchy (European Parliament and the Council of the European Union, 2008). Nonetheless, a few European countries have already managed to divert high rates of waste from landfills. Examples include Denmark, the Netherlands, and the UK (European Commission, 2011).

Inert and non-inert C&D waste can be distinguished, each of whom possess particular recovery operations with diverse environmental implications. An example of non-inert waste is gypsum. Besides contaminating recyclable inert waste, gypsum waste (GW) has special requirements to be disposed in landfills (The Council of the European Union, 2003). What is more, GW ends up in landfills in 20 out of the 28 European countries (Jiménez Rivero et al., 2015), not always in "landfills for non-hazardous waste in cells where no biodegradable waste is accepted" (hereinafter referred to as "monocell landfill"), as established in the Council Decision 2003/33/EC, as a consequence of a range of factors that affect this fate.

Post-consumer GW represents a small percentage of the total C&D waste, but the potential impacts on the environment can be quantified as follows. A total of 1.9 million tonnes were estimated to be generated in 2013 in the EU-27, which equals to 0.23% of the total C&D waste (Jiménez Rivero et al., 2016). Two main undesirable effects are produced when gypsum is not managed appropriately. First, gypsum contaminates concrete for recycling due to its sulphate content (Barbudo et al., 2012), mainly when all waste streams are treated as mixed C&D waste. Second, diversion of GW from landfills avoids potential landfill emissions, enhances resource efficiency and contributes to meeting the European target on C&D waste recovery (European Parliament and the Council of the European Union, 2008). For example, 13.5% kg CO_2eq/m^2 were estimated to be avoided when moving from a zero to a high recycling case (0 and 93.6% of gypsum plasterboard being recycled, respectively) (Jiménez Rivero et al., 2016).

Although gypsum recycling holds the potential for avoiding gypsum landfilling, it is estimated that currently only six per cent of post-consumer gypsum close the material loop in a circular economy, being the rest downcycled or landfilled (Jiménez Rivero et al.,

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2016). Gypsum recycling (GR) countries include France, Benelux (Belgium, the Netherlands, and Luxembourg), Finland, the UK, Denmark, and Sweden (Jiménez Rivero et al., 2015). Therefore, the rest of non-gypsum recycling (NGR) countries lead the current scene. Two key conditions enable the production of quality recycled gypsum (RG) (in compliance with the RG quality criteria as detailed in GtoG project (2015a)): the implementation of building deconstruction and the existence of recycling facilities following the relevant quality criteria. For these conditions to be met, a number of factors are influential. Understanding what factors lead to achieve these conditions becomes vital to perform sustainable waste management practices and increase the use of recycled gypsum.

The term "factor" can be defined as "something that helps produce or influence a result: one of the things that cause something to happen" (Merriam-Webster, 2015). A number of authors have investigated factors and measures that influence more sustainable approaches in C&D waste management. The focus remains on construction and renovation works in Asia, Oceania and some regions of Europe. For example, Tam and Tam (2006) outlined recommendations to improve the implementation of waste management in Honk Kong. In this region also, factors that hinder the implementation of a waste management plan were explored by Tam (2008). Factors influencing attitudes, behaviours and perceptions on waste management have also been examined from district perspectives: Begum et al., 2009 focused on contractors in Malaysia, Teo and Loosemore (2001) surveyed construction workers in Australia and Kulatunga et al., 2006 focused on workers in Sri Lanka. Other authors have identified critical factors (CFs) for different processes and works (Li and Yang, 2014; Lu and Yuan, 2010; Wang et al., 2010), specifically for C&D waste management in China (Lu and Yuan, 2010), on-site sorting of construction waste in China (Wang et al., 2010) and office building retrofit projects in Australia (Li and Yang, 2014). In the form of measures, Yuan (2013) discussed management measures that contribute to effective construction waste management in China. Regarding on-site management factors, Ya'cob et al. (2013) surveyed contractors in Malaysia. More recently, Ajayi et al. (2015) explored factors, practices and strategies to achieve effective waste management in the UK context.

The specific objective of this study is to analyse the factors influencing gypsum recycling and landfilling in the European Union. Section 2 is concerned with the methodology used, including the selection of potential factors from the literature (see Section 2.1). Section 3 presents and discusses findings from the data analysis, which reveals CFs categorized into four domains: policy, economic, social, and environmental aspects. It is worth noting that some of the factors are interrelated and might influence each other. For example, the "Recycler's gate fee" (identified as CF6 in Section 3 et seq.) may vary with the "Price of the recycled gypsum (RG)" (identified as CF3 in Section 3 et seq.). These connections are explained, along with the description of each factor, in Sections 3.1 and 3.2.

The present study complements the already started analysis on gypsum recycling in the EU-28, framed in the European Life+ Gypsum to Gypsum project "From production to recycling: a circular economy for the European gypsum Industry with the demolition and recycling Industry" (GtoG project, 2013a). First, a report on current practices on gypsum recycling in Europe was drafted (GtoG project, 2013b). Then, five case studies were monitored between 2014 and 2015 (covering deconstruction of gypsum-based systems, processing of GW and reincorporation of RG). As a result, the ideal conditions to produce RG from end-of-life gypsum were formulated (Jiménez-Rivero and García-Navarro, 2016). Best practices for the management of gypsum were then proposed (GtoG project, 2015b). These practices aim to ensure quality recycled gypsum, and they are based on best techniques and technology in gypsum recycling countries, supported by the monitoring and analysis conducted in the GtoG pilot projects. Examples of best practices are "Perform on-site segregation of GW" and "Set clear RG quality criteria". The main aspect differentiating factors from practices is the level of analysis. While best practices focus at the micro-level (i.e. a particular deconstruction-recycling value chain) factors are applicable at the macro-level (e.g. EU-28 or a EU country). In contrast with practices adopted by the value chain operators, factors cannot be directly controlled by individuals. Both of them (practices and factors) determine the fate of GW and might be mutually beneficial. For instance, implementing best practices can promote mutual trust between agents

This investigation brings together, for the first time, factors influencing the emerging market for post-consumer RG. These include factors previously considered by EU institutions, public bodies, international organisations and EU research projects (Section 2.1). The identified factors are thus considered representative at EU level.

2. Method

Inspired by the critical success factor approach, the method is divided into three phases: selection of factors, stakeholders' consultation and data analysis. This approach was first used by Rockart (1979) and recently adopted to investigate critical factors and best practices in C&D waste (Lu et al., 2008; Villoria Saez et al., 2013; Wang et al., 2010).

2.1. Selected factors influencing the success of gypsum recycling

Factors for the success of gypsum recycling were identified from the literature as shown in Table 1, and adapted to the case of GW when required. The time period of study resulted from the published literature on the topic, which was found to be the 1998–2016 period. Additional factors were defined as a result of findings from the GtoG project, which framed this investigation.

2.2. Stakeholders' consultation

A questionnaire was used to investigate stakeholders' views on the factors influencing the success of gypsum recycling. The online questionnaire was designed and conducted between September and December 2015. Before being launched, the survey was pretested in an expert meeting conducted in October 2015 with a group of eight experts, participants of the GtoG project. As a result, the descriptions of the questions were fine-tuned. In this meeting, the consultation strategy was also defined (i.e. GtoG partners in charge of translating the questionnaire and timeline to collect responses and analyse data). The questionnaire was prepared in English, French, German and Spanish, with the aim to reach the maximum number of responses.

The questionnaire was distributed among 152 stakeholders. Efforts were made to ensure a high response rate. These included a personalized accompanying email, information on the confidentiality clause in the GtoG project consortium agreement and follow-ups of all non-respondents. Respondents were required to rate each practice on a 5-point Likert-type scale, in terms of importance (i.e. influence of the given practice on closing the loop of gypsum products). Space was provided to accommodate comments. The questionnaire also contained a general data part (see Supplementary Appendix A). A 38% response rate was achieved.

A total of 58 responses ($N = 58$) were gathered. These stakeholders included manufacturers, construction agents, waste collectors and gypsum recyclers as well as other stakeholders (researchers and public institutions and associations). Responses from some countries could not be gathered (e.g. Poland) or were limited (e.g.