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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 analyse the factors influencing gypsum recycling in the European Union. 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 indicate the relevance of regulatory and economic instruments for promoting a circular economy for gypsum.

Keywords: gypsum waste; plasterboard; recycling market; policy instruments; circular economy; urban mining.

Highlights

- 15 factors are identified as critical for gypsum recycling versus landfilling.
- Respondents from different contexts hold different views on the critical factors.
- The critical factors fit into policy, economic, social and environmental domains.
- Policy instruments make up the majority of critical factors.
- The critical factors can assist decision-makers towards a gypsum circular economy.

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 (DG ENV), 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 (DG ENV), 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., 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 Gypsum to Gypsum project LIFE11 ENV/BE/001039 (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 & 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, Siwar, Pereira, & Jaafar (2009) focused on contractors in Malaysia, Teo & Loosemore (2001) surveyed construction workers in Australia and Kulatunga, Amaratunga, Haigh, & Rameezdeen, (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 (2013a) discussed management measures that contribute to effective construction waste management in China. Regarding on-site management factors, Ya'cob, Zawawi, Isa, & Othman (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 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 categorised 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 European Union, 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 LIFE11 ENV/BE/001039, 2013). First, a report on current practices on gypsum recycling in Europe was drafted (Gypsum to Gypsum project LIFE11 ENV/BE/001039, 2013a). 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 (Gypsum to Gypsum project LIFE11 ENV/BE/001039, 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 (i.e. EU-28). 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, international organisations and agencies and EU research projects (Section 2.1). Having surveyed professionals and experts from countries in which post-consumer GW has started to be recycled (Belgium, France, the Netherlands, the UK and Scandinavia according to the report Gypsum to Gypsum project LIFE11 ENV/BE/001039 (2013a)), the identified critical factors (CFs) are considered to be representative at EU level (see Section 2.2. for further details on the consultation process).

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 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.

Table 1. Factors for the success of gypsum recycling

Factors	Source
Availability of natural and/or FGD gypsum	European Commission (DG ENV) (2011), Yuan, Shen, & Li (2011), Jiménez Rivero, Sathre, & García Navarro (2016)
Awareness of the impacts of gypsum landfilling and gypsum recycling	Teo & Loosemore (2001), Klang, Vikman, & Brattebø (2003), Weisheng Lu & Yuan (2010), Ya'cob, Zawawi, Isa, & Othman (2013), Yuan (2013), Ajayi et al. (2015), European Commission (2015), Lieder & Rashid (2015), Jiménez Rivero, Sathre, & García Navarro (2016)
Building rating tools	Antink et al. (2014), Oyedele et al. (2014), Ajayi et al. (2015)
Collaboration between stakeholders	Lönngren, Rosenkranz, & Kolbe (2010), Department for Environment Food and Rural Affairs - defra and the Plasterboard Sustainability Partnership - psp (2013), European Commission (2014b), Ajayi et al. (2015)
Environmental taxes (landfill tax)	Morris, Phillips, & Read (1998), Klang et al. (2003), OECD (2003), Duran, Lenihan, & O'Regan (2006), Fischer, Lehner, & Mckinnon (2012), Emma Watkins et al. (2012), Garbarino & Blengini (2013), Scharff (2014), WRAP (2014), Ajayi et al. (2015), European Commission (2015)
Green public procurement criteria	OECD (2003), Garbarino & Blengini (2013), GtoG project LIFE11 ENV/BE/001039 (2013), Antink, Garrigan, Bonetti, & Westaway (2014), European Commission (2015)
Landfill ban	OECD (2003), WRAP (2012), Finnveden et al. (2013), Scharff (2014)
Landfill operation cost	Eurogypsum (2007), European Commission (DG ENV) (2011), Environment Agency (2012), GtoG project LIFE11 ENV/BE/001039 (2013)
Legal alternative destinations that do not favour the options that are higher in the waste hierarchy	GtoG project LIFE11 ENV/BE/001039 (2013)
Legal status of GW (end-of-waste status)	Delgado et al. (2009), WRAP & Environment Agency (2013), GtoG Project (2013), Garbarino & Blengini (2013), Jiménez Rivero, De Guzmán Báez, & García Navarro (2015), GtoG project LIFE11 ENV/BE/001039 (2015)

Objectives and targets on waste management	De Minister van Volkshuisvesting et al (2008), Les Industries du Platre (2008), Department for Environment Food and Rural Affairs - defra and the Plasterboard Sustainability Partnership - psp (2013)
Other levies and fines	OECD (2003), Garbarino and Blengini (2013), Seror et al. (2014)
Price of the RG	OECD (2003), Field & Sroufe (2007), GtoG project LIFE11 ENV/BE/001039 (2013), Oyedele, Ajayi, & Kadiri (2014)
Recycler's gate fee	GtoG project LIFE11 ENV/BE/001039 (2015b)
Regulatory framework favouring building deconstruction	OECD (2003), Couto & Couto (2010), CIB International Council for Research and Innovation in Building and Construction (2014), European Commission (2014b)
Regulatory framework favouring pre-deconstruction audit	GtoG project LIFE11 ENV/BE/001039 (2013), Deloitte (2015), European Commission (2014b)
Regulatory framework favouring SWMP	Tam (2008), Couto & Couto (2010)
Regulatory framework favouring the use of recycled materials	OECD (2003), European Commission (2014), Deloitte (2015)
Strategy of the gypsum recycler (sources, brands or type of board accepted)	GtoG project LIFE11 ENV/BE/001039 (2013)
Waste management software solutions	Cheng & Ma (2013), Ajayi et al. (2015), Akinade et al. (2015), Deloitte (2015)

GW: gypsum waste; RG: recycled gypsum; SWMP: site waste management plan

2.2 Stakeholders' consultation

A questionnaire was used to investigate stakeholders' views on the factors influencing gypsum recycling. The online questionnaire was designed and conducted between September and December 2015. Before being launched, the survey was pre-tested 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 Appendix A). A 38% response rate was achieved.

A total of 58 responses (*N=58*) were gathered from stakeholders working in gypsum recycling (GR) and non-gypsum recycling (NGR) countries. These stakeholders included manufacturers, construction agents, waste collectors and gypsum recyclers as well as other stakeholders (researchers and public institutions and associations). While 62% of them (*N*=36) perform their activity in GR countries (Belgium, Denmark, France, the Netherlands, and United Kingdom), 48%

(*N*=22) work in NGR countries (Austria, Germany, Greece, Portugal and Spain). Respondents working at European level were considered in the GR countries group. Further details on the break down per country and per activity can be found in the Appendix A.

2.3. Data analysis

The analysis, performed using SPSS v23, included descriptive statistics (central tendency: mean, median and dispersion: standard deviation) and the Mann-Whitney U test, a non-parametric test that compares distributions of responses between groups (Harpe, 2015), at 95% confidence interval. In the Mann-Whitney U test the null hypothesis is rejected if the observed p-value is less than the significance level (α=0.05). Moreover, Cronbach's alpha coefficient was assessed to check the internal consistency of the scale. The alpha value was 0.903. As this value is above 0.8, the scale can be considered reliable with our sample (Carmines and Zeller, 1979).

The CFs were ranked according to their mean value (*M*), an approach commonly adopted in construction management research to evaluate Likert-type scales (Ali et al., 2013; Lu and Yuan, 2010; Poon et al., 2001; Villoria Saez et al., 2013; Wang et al., 2010). M can be expressed as follows: $M = \sum_{y=1}^{5} N_{xy} S_y / \sum_{y=1}^{5} N_{xy}$, where N_{xy} is the number of stakeholders that chose the yth score (S_y) for the xth factor and S_y is the score given by stakeholders for each factor. The cut-off mean value was set at 4.00 to be selected as a CF, as 4.00 in the 5-point Likert-type scale denotes "important", recognized by value chain operators in GR countries as current leading approaches, built on their experience.

CFs are categorized based on the analysis performed by OECD (2003), where policy instruments are labelled as regulatory, economic and information tools. Three additional domains are taken considering the triple bottom line: economic, social, and environmental aspects. As Lieder & Rashid (2015) found in the recent review on the circular economy concept, business and economic perspectives have been traditionally neglected while studying the circular economy (Lieder and Rashid, 2015).

3. Results and discussion

Table 2 summarizes the analysis on the importance given by stakeholders to the selected factors (see Section 2.3 for details on the selected statistics). CFs are ranked (from the highest to the lowest mean) according to the mean value from GR countries, due to their experience in the achievement of an improved deconstruction-recycling value chain. The higher the mean value, the higher the stakeholders valued the factor. In addition, results from the Mann-Whitney U test are shown, which are useful to determine statistical difference between how the stakeholders working in GR and NGR countries view the CFs.

Table 2. Results of the questionnaire survey on the factors influencing gypsum recycling

Domain	Factor	GR countries		NGR countries		Mann-Whitney		CF
		M	SD	M	SD	Z	p	
Policy	Landfill ban	4.53	0.61	4.24	1.00	-0.99	0.324	CF1
Policy	Environmental taxes (landfill tax)	4.51	0.89	4.30	0.98	-1.16	0.247	CF2
Economic	Price of the RG	4.45	0.72	4.57	0.68	-0.63	0.531	CF3
Environmental	Availability of natural and/or FGD gypsum	4.39	0.79	4.10	1.02	-1.00	0.319	CF4
Social	Awareness of the impacts of gypsum landfilling and gypsum recycling	4.34	0.76	3.36	1.09	-3.46	0.001	CF5
Economic	Recycler's gate fee	4.31	0.87	4.28	0.57	-0.71	0.476	CF6

Economic	Landfill operation cost	4.29	0.80	4.05	1.08	-0.66	0.509	CF7
Social	Objectives and targets on waste management	4.26	0.78	3.64	1.26	-1.85	0.065	CF8
Policy	Regulatory framework favouring the use of recycled materials	4.26	0.85	4.33	0.73	-0.17	0.861	CF9
Policy	Regulatory framework favouring building deconstruction	4.24	0.82	4.19	0.93	-0.06	0.955	CF10
Social	Collaboration between stakeholders	4.23	0.88	3.36	1.05	-3.05	0.002	CF11
Policy	Green public procurement criteria	4.16	0.81	3.86	1.01	-1.02	0.308	CF12
Policy	Legal alternative destinations that do not favour the options that are higher in the waste hierarchy	4.13	0.94	3.33	1.19	-2.37	0.018	CF13
Policy	Other levies and fines	4.00	0.94	4.25	0.79	-0.89	0.375	CF14
Policy	Regulatory framework favouring SWMP	4.00	0.98	3.55	1.43	-0.90	0.367	CF15
Policy	Legal status of GW (end-of-waste status)	3.97	1.17	3.81	1.17	-0.59	0.554	
Policy	Regulatory framework favouring pre-deconstruction audit	3.94	0.98	3.71	1.35	-0.35	0.724	
Economic	Strategy of the gypsum recycler (sources, brands or type of board accepted)	3.85	1.12	3.37	0.96	-1.67	0.095	
Environmental	Building rating tools	3.67	1.05	3.73	0.94	-0.27	0.790	
Environmental	Waste management software solutions	3.42	1.09	2.86	1.20	-1.60	0.110	

3.1. Policy domain

Fig. 1 shows complementary graphical representations of the critical policy instruments. The left part illustrates the calculated rate of respondents choosing a particular score (5=extremely important, 4=important, 3=neutral, 2=unimportant, 1=negligible). The right part displays the comparison of the mean rank between GR and NGR countries.

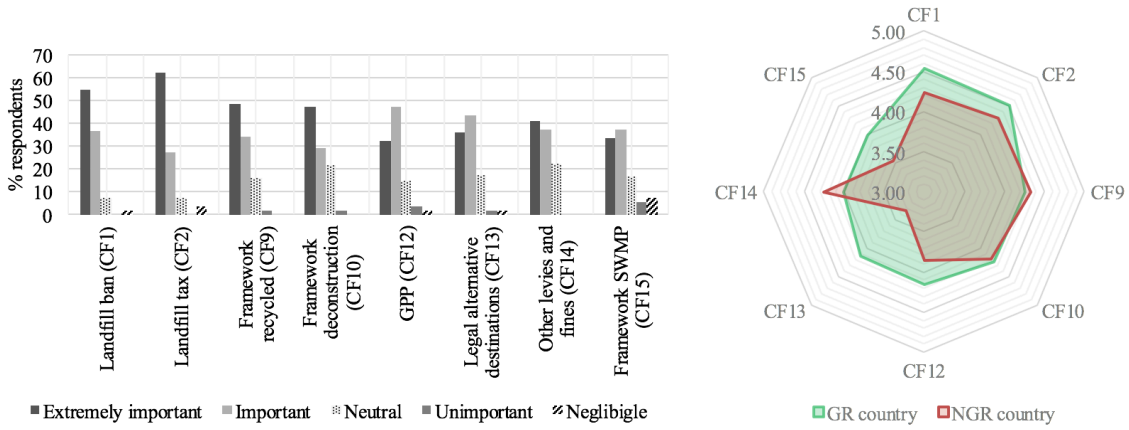

Fig. 1. Additional analysis on the factors part of the policy domain. Breakdown into respondents' rate (left) and group of countries (right). GR countries: BE, UK, FR, NL, DK. NGR countries: AU, DE, GR, SP, PT. GPP: green public procurement

3.1.1. Regulatory instruments

CFs that fall into regulatory aspects encompass "Landfill ban" (CF1), "Regulatory framework favouring the use of recycled materials" (CF9), "Regulatory framework favouring building deconstruction" (CF10), "Legal alternative destinations that do not favour the options that are higher in the waste hierarchy" (CF13), and "Framework favouring SWMP" (CF15) (see Table 2).

"Landfill ban" (CF1) ranked first regarding the contribution to building a circular economy around gypsum. In particular, 91% of stakeholders considered that CF1 is an important or extremely important factor towards that end (see Fig. 1). This might be due to the potential of landfill bans on diverting waste from landfills. As the incineration of GW typically affects emissions because of its sulphate content (Eurogypsum, 2007), a ban would be likely to move the waste from disposal to recycling, which implies two steps up in the waste hierarchy. An alternative option would be to promote "Compulsory recycling of recyclable materials" (Finnveden et al., 2013).

As WRAP recently warned, restrictions on landfill may entail fly-tipping and illegal exports (WRAP, 2012). Legal exports might also fail to contribute to a circular economy, destination included within the CF13 "Legal alternative destinations that do not favour the options that are higher in the waste hierarchy". For instance, the export of waste might be considered a recovery operation under certain conditions, being the waste disposed of in "underground storage" in other country (Scharff, 2014). As for the case of gypsum, exports for backfilling operations have been already observed (European Commission (DG ENV), 2011). In order to prevent such alternative destinations that do not favour the waste hierarchy, instruments such as mandatory reporting and demolition permissions can be put in place (see OECD, 2003 for further information). The Mann-Whitney U-test revealed significant difference in the way GR and NGR stakeholders rate this factor, being CF13 the least valued CF in NGR countries (see Table 2, $p<0.05$). This difference can be explained by the limited experience in the circular economy principles in these contexts.

A "Regulatory framework favouring the use of recycled materials" (CF9) and a "Regulatory framework favouring building deconstruction" (CF10) were similarly rated by GR and NGR countries (see Fig. 1). It should be noted that construction agents might not always perceive deconstruction as a favourable means for a circular economy, as higher associated costs are commonly reported owing to additional time and labour needed when compared to traditional demolition (Coelho and de Brito, 2011; Dantata et al., 2005; Pacheco-Torgal et al., 2013). Nevertheless, building deconstruction enables maximum recovery of resources from end-of-life products (Jiménez-Rivero and García-Navarro, 2016), being a key condition for enabling gypsum recycling (see Section 1). Moreover, deconstruction may provide economic benefits from the landfill cost avoided (see "Landfill tax" (CF2) in Section 3.1.2 and "Landfill operation cost" (CF7) in Section 3.2.1), compared to conventional demolition practices (Rodríguez-Quijano et al., 2015).

On the other hand, a regulatory framework favouring the site waste management plan (CF15) was the least valued CFs, being particularly low the mean scores of the NGR countries. A possible explanation relates to the perception of a SWMP as extra paperwork (Department for Environment Food and Rural Affairs - defra, 2013) or as difficult to implement, due to reasons such as "Low economic incentive", "Increase in overhead cost" or "Complicated subcontracting system" (Tam, 2008). Similarly, Ajayi et al. (2015) found a number of limitation to the effectiveness of a SWMP (e.g. "It requires additional man-hours/specialist"). Nevertheless, SWMPs involve multiple potential benefits, including waste prevention and management strategies before, during and after the construction works (Ajayi et al., 2015).

3.1.2. Economic and general policy instruments

The CFs falling into this category are related to economic instruments and information tools. Economic instruments involve "Landfill tax" (CF2) and "Levies and fines" (CF13). On the other hand, "Green Public Procurement criteria" (CF12) is considered to be a general policy instrument (OECD, 2003).

A “Landfill tax” (CF2) or levy was viewed as important or extremely important by 89% of respondents (see Fig. 1). Such environmental tax has also recently been identified as a crucial economic parameter for gypsum recycling (Gypsum to Gypsum project LIFE11 ENV/BE/001039, 2013a; Rodríguez-Quijano et al., 2015). Moreover, high landfill taxes produced cost savings in five case studies on the deconstruction-recycling value chain (Jiménez-Rivero and García-Navarro, 2016). Furthermore, the effectiveness of this instrument for the reduction of landfill disposal has been demonstrated through case studies in Denmark, the Netherlands and the UK (OECD, 2003), countries in which a market for RG exists (Gypsum to Gypsum project LIFE11 ENV/BE/001039, 2013). More recently, Scharff (2014) emphasized the role of the landfill tax in achieving low landfill rates in the Netherlands. Likewise, Garbarino & Blengini (2013) highlighted the effect of increased landfill cost as relevant in the development of gypsum recycling practices.

Besides the “Landfill tax” (CF2), the factor “Other levies and fines” (CF14) was perceived as important for closing the loop on gypsum, being one of the most valued CF in NGR countries (see Table 2). These instruments may raise awareness among stakeholders and thus help to manage C&D waste (Ajayi et al., 2015) In building construction, other levies relate to the use of natural or virgin materials (e.g. “Aggregate levy” in the UK) and the control of excavation or gravel extraction (OECD, 2003). For its part, fines or penalties on landfill can discourage fly-tipping when sanctions are actually applied and hence the level of awareness is raised (Seror et al., 2014).

As regards other general policy mechanisms, the voluntary instrument “green public procurement” (GPP) was already identified as a driver for gypsum recycling by EU plasterboard manufacturers, particularly in countries such as Germany and Belgium (Gypsum to Gypsum project LIFE11 ENV/BE/001039, 2013a), which is in line with the findings of Garbarino and Blengini (2013) on the main drivers that can enhance C&D waste recycling. In our study, “Green Public Procurement criteria” (CF12) was rated as important or extremely important by 79% of respondents (see Fig. 1). This validates the previous findings and agrees with the last developments on GPP criteria for gypsum boards as described below. In 2010, the gypsum industry developed with the European Commission the green public procurement criteria for wall panels (Gypsum to Gypsum project LIFE11 ENV/BE/001039, 2013a). The document includes a proposal for core and comprehensive criteria, such the “Encourage the purchase of gypsum wall panels using synthetic gypsum and recycling gypsum” (European Commission DG Environment, 2010). Moreover, the Commission has recently announced future actions on GPP as part of the EU Action plan for the circular economy (European Commission, 2015).

3.2. Economic, social and environmental domains

Fig. 2 shows complementary graphical representations of the critical economic, social and environmental aspects, both on the percentage of respondents selecting a particular rate (5=extremely important, 4=important, 3=neutral, 2=unimportant, 1=negligible) and the average mean rank obtained for GR and NGR countries.

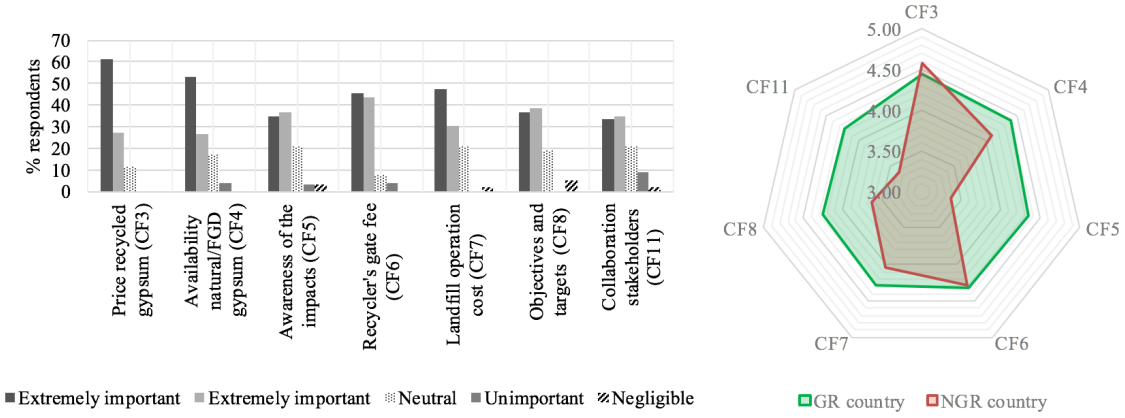

Fig. 2. Additional analysis on the factors part of the economic, social and environmental domains. Breakdown into respondents' rate (left) and group of countries (right). GR countries: BE, UK, FR, NL, DK. NGR countries: AU, DE, GR, SP, PT.

3.2.1 Economic domain

Three factors were identified as crucial by respondents: "Price of the RG" (CF3), "Recycler's gate fee" (CF6), and "Landfill operation cost" (CF7) (see Table 2). These economic factors, along with those falling into the category Policy-Economic (See section 3.1.2), influence the competitiveness of gypsum recycling compared to landfill disposal.

The "Price of the RG" (CF3) was rated as important or extremely important by 88% of respondents. In average, stakeholders in NGR countries valued CF3 slightly higher than those in GR countries (see Fig. 2). As Oyedele et al. (2014) found, one of the impediments to the use of recycled materials in the construction sector is that "Materials selection and specification are influenced by cost rather than environmental benefits". Indeed, the integration between economic, social and environmental aspects is needed (Yuan et al., 2011). At present, RG is available at a lower price than natural gypsum, and EU plasterboard manufacturers identified "cost savings" and one of the seven drivers for using RG. The average sales price calculated in the GtoG project equals to zero euro/tonne (Gypsum to Gypsum project LIFE11 ENV/BE/001039, 2013a).

"Recycler's gate fee" (CF6) is typically paid to the operator of the recycling facility by owners of the waste. This charge may vary with the sales "Price of the RG" (CF3) and the transportation distances for RG (Gypsum to Gypsum project LIFE11 ENV/BE/001039, 2013a). CF6 was rated as important or extremely important by 89% of respondents, being the mean value of both groups of countries very similar (see Fig. 2). According to gypsum recyclers within the GtoG project, the average recycler's gate fee is 50 euro/tonne (Gypsum to Gypsum project LIFE11 ENV/BE/001039, 2013a).

When economic issues take precedence over any other factor, "Recycler's gate fee" (CF6) is likely to be compared to the standard cost of landfilling (composed of CF7 and CF2 "Landfill tax", being CF2 previously discussed in Section 3.1.2). The "Landfill operation cost" (CF7) may determine the final decision of construction agents, as the operating cost increase between 30% and 230% when monocell landfills operate (Gypsum to Gypsum project LIFE11 ENV/BE/001039, 2013a). The requirement of landfilling GW in monocell landfills was introduced in the European Union in 2003 (The Council of the European Union, 2003). However, monocell landfills are observed in a limited number of countries, such as Belgium, the UK and France (Gypsum to Gypsum project LIFE11 ENV/BE/001039, 2013b). This may be the reason why GR countries value such measure above NGR countries (probably because of the inexistence of monocell

landfills in such regions). A report from Eurogypsum foresees a critical change on the economics of gypsum recycling due to the shortage of monocell landfills and higher landfill costs (Eurogypsum, 2007).

3.2.2 Social and environmental domains

The "Availability of natural/FGD gypsum" (CF4) can be considered an environmental factor that affect the uptake of RG. 79% of respondents identified this factor as important or extremely important for closed-loop gypsum recycling. Until the 1980s, most of the gypsum feedstock was natural. Then, FGD gypsum started to be produced in Western Europe, and countries such as Belgium, the Netherlands and Nordic Countries, import it. Interestingly, such countries also lead the use of RG (Gypsum to Gypsum project LIFE11 ENV/BE/001039, 2013a). The high availability of primary raw materials, along with their low prices, have been identified as a barrier towards the 70% recovery target by 2020 (European Commission (DG ENV), 2011).

With respect to social issues with environmental implications, three factors were selected as critical: "Awareness of the impacts of gypsum recycling and gypsum landfilling" (CF5), "Objectives and targets on waste management" (CF8), and "Collaboration between stakeholders" (CF11). These three social factors were the least valued in the economic-social-environmental domain by NGR countries (see Fig. 2).

"Awareness of the impacts of gypsum recycling and gypsum landfilling" (CF5) demonstrated a highly significant difference between the views of GR and NGR respondents (see Table 2, Mann-Whitney U test, $p<0.001$). GR respondents rated CF5 as critical, whereas NGR respondents rated it as one of the least valued CFs (see Table 2). Overall, 35% of respondents considered that such awareness is extremely important for a circular economy around gypsum. Our finding compares well with those reported by previous authors. For instance, in the study conducted by Weisheng Lu & Yuan (2010) on factors for C&D waste management in China, the awareness ranked third ($M=3.53$; $SD=0.45$), which is a similar value to that resulting in our European NGR contexts. In a more recent study, Yuan (2013a) identified "Improving Major Stakeholders' Awareness about Resource Savings and Environmental Protection" as a critical management measure, ranking fifth for the case of China ($M=4.188$; $SD=0.67$).

Two factors "Collaboration between stakeholders" (CF11) and the setting of "Objectives and targets on waste management" (CF8), indicate stakeholder's engagement on a particular action, and are commonly interrelated. The signature of voluntary agreements standards and schemes; mechanisms that includes targets and timeline related to gypsum recycling, typically cover both CFs. Mann-Whitney U test showed a significant different on how GR and NGR view CF11 (see Table 2, $p<0.05$). This is in line with the fact that NGR countries are unfamiliar with value chain voluntary agreements on gypsum recycling, which have been only found in three European countries: France, the Netherlands and the UK. In 2008, a voluntary agreement "La Charte sur la Gestion des déchets" (Les Industries du Platre, 2008), was signed by the French gypsum manufacturers through their industrial association "Les Industries du Plâtre", with the intention of promoting the proper management of post-consumer GW coming from C&D waste generated. In the Netherlands a covenant to close the gypsum cycle in the building sector has been drawn up, with the objective of doubling the recycling rates for gypsum from C&D waste (from 20% in 2008 to 40% in 2010) and converting this country in the European leader in the field of gypsum recycling in 2015, "Convenant voor sluiten van kringloop van gips in bouwsector" (De Minister van Volkshuisvesting et al, 2008). Several agreements related to the plasterboard sector can be found in the UK: the Ashdown Agreement, the Contractors Agreement on Reducing Waste, the

Demolition Waste Action Plan, and the End of life plasterboard waste agreement (see (Department for Environment Food and Rural Affairs - defra and the Plasterboard Sustainability Partnership - psp, 2013) for further details). For instance, the Ashdown Agreement in the UK (WRAP, 2010) covers four targets including the engagement with all stakeholders and the reduction of the waste sent to landfill.

4. Conclusions

This investigation set out to determine critical factors (CFs) for gypsum recycling in the European Union. Factors were first identified based on a review of the literature and findings from the Life+ GtoG project. These factors were further examined by conducting a questionnaire that targeted the main agents of the value chain. Data analysis revealed a set of CFs that were categorized into four domains: policy, economic, social, and environmental aspects. More than a half of the CFs relate to policy instruments, being five of them regulatory instruments. This indicates the relevant role of governments to strengthen waste legislation, regulatory frameworks and the enforceability of such instruments in line with the circular economy principles.

Particularly, the following regulatory aspects are identified as critical: "Landfill ban" (CF1), "Regulatory framework favouring the use of recycled materials" (CF9), "Regulatory framework favouring building deconstruction" (CF10), "Legal alternative destinations that do not favour the options that are higher in the waste hierarchy" (CF13), and "Regulatory framework favouring site waste management plan (CF15)". These have to be accompanied by economic incentives, control measures and other policy instruments, including "Landfill tax" (CF2), "Other levies and fines" (CF14), and "Green Public Procurement" (CF12). Such economic instruments along with other economic factors (i.e. "Price of the recycled gypsum" (CF3), "Recycler's gate fee" (CF6) and "Landfill operation cost" (CF7)), determine the competitiveness of gypsum recycling versus disposal, and become vital to create and develop markets for recycled materials. In addition, the critical social and environmental factors involve "Availability of natural and/or FGD gypsum" (CF4), "Awareness of the impacts of gypsum recycling and gypsum landfilling" (CF5), "Objectives and targets on waste management" (CF8), and "Collaboration between stakeholders" (CF11), maintaining the triple bottom line perspective of economic, social and environmental sustainability. It should be noted that respondents from gypsum recycling and non-gypsum recycling countries hold different views on the critical factors. Those performing their activity in non-gypsum recycling countries generally rated the importance of the factors lower than those working in gypsum recycling countries, except those factors related to economic aspects (e.g. "Other levies and fines", "Price of the recycled gypsum"). These findings may imply that stakeholders in non-gypsum recycling countries mostly rely on economic aspects to enhance the recovery of gypsum waste. For its part, responses from gypsum recycling countries show a higher balance between economic, social, and environmental aspects.

Although the CFs here identified are applicable to any European context, the results are subject to certain limitations. For instance, some factors are interrelated with each other and certain combinations of factors may result in more general factors (e.g. investment climate). Consequently, additional quantitative assessment could be investigated in order to set out the relationship between CFs. Notwithstanding this, the 15 CFs can assist decision-makers and stakeholders as follows. On the one hand, decision-makers count with a framework to improve the functioning of the gypsum value chain. On the other hand, stakeholders can better comprehend what factors influence their activity and therefore the factors that should be taken into consideration in order to improve a

given situation. Moreover, these CFs are considered to be valuable references for other waste streams and specific national contexts.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://www.sciencedirect.com/science/article/pii/S0921344916302476

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