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Life cycle energy and material flow implications of gypsum plasterboard recycling in the European Union

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ABSTRACT

Turning waste into a resource is a way to increase resource use efficiency and close the material loop of a circular economy. Gypsum plasterboard is well suited for this, because the raw material calcium sulphate dihydrate ($CaSO_4{\cdot}2H_2O$) can repeatedly change its properties through a reversible hydration reaction. The waste hierarchy is applied when plasterboard is recycled instead of landfilled, which contributes to the European 2020 target of 70% recovery of construction and demolition (C&D) waste, as defined in the Directive 2008/98/EC on Waste. This paper evaluates the energy and climate impacts of different levels of plasterboard recycling. First, we formulate a life cycle model of gypsum mass flows in the European Union (EU-27) in the reference year 2013. This model constitutes the basis of the quantitative scenario analysis. Secondly, we assess the material flows, energy use and greenhouse gas (GHG) emissions in different recycling scenarios. We compare the current situation ("2013 base case") to two scenarios: a worst case scenario of 0% recycled gypsum ("Zero recycling case"), and a best case scenario of zero gypsum waste sent to landfill, corresponding to 18.7% recycled gypsum in new plasterboard ("High recycling case"). We find no significant variation between scenarios in terms of life cycle energy use, as lower impacts from gypsum mining, transport of natural gypsum and final disposal in the best case scenario are balanced by the energy for the transport of plasterboard waste and recycled gypsum and for material pre-processing during manufacturing. In contrast, life cycle GHG emissions are lower as recycling increases, largely driven by the degradation of plasterboard lining paper in landfills.

1. Introduction

Working towards greater resource efficiency in the construction sector is essential for addressing global issues such as mitigating climate change and moving to a more circular economy, and is essential to achieving the resource efficiency agenda established under the Europe 2020 Strategy for smart, sustainable and inclusive growth (Antink et al., 2014; European Commission, 2014a). A circular economy system keeps the added value in products for as long as possible and reduces waste. This strategy of turning waste into a resource is an essential part of increasing resource efficiency and "closing the loop" in a circular economy (European Commission, 2014b). Closed-loop supply chain management entails the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time (Govindan et al., 2014). It implies forward and reverse supply chains operating simultaneously, and closed-loop recycling as a necessary link for its success.

Gypsum is a versatile construction material that can effectively close the material loop, being fully and eternally recyclable. Unfortunately, a large proportion of gypsum waste is currently being landfilled worldwide, including building plaster, gypsum blocks and plasterboard waste (the latter being the most common recyclable gypsum waste generated in Europe). However, the processing of gypsum waste into high quality recycled gypsum is possible, already occurring in different regions of Belgium, Finland, France, Denmark, Sweden, the Netherlands and the United Kingdom, in which recycling systems are now operating and supplying plasterboard manufacturers. Moreover, all over Europe efforts are being made to increase the recycling rate of this material, boosted by the development of the Life+ GtoG project, which from January 2013 has been working to transform the gypsum waste market, with the aim of achieving higher gypsum recycling rates in Europe (GtoG Project, 2013a). This approach contributes to mitigating primary resource depletion, contributing at the same time to

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minimizing construction and demolition (C&D) waste streams sent to landfills.

Knowledge of the quantities of waste streams generated constitutes an essential step in the development of an appropriate scheme for their management (Kourmpanis et al., 2008). Material flow analysis (MFA) is an analytical approach to quantifying the system-wide flows and stocks of materials associated with a defined product. Life-cycle assessment (LCA) is the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle (International Standard, 2006a). Together, these approaches provide the means to evaluate the environmental implications of gypsum plasterboard recycling.

Consequently, the formulation of a life cycle model associated with gypsum plasterboard material flows in the European Union, in the reference year 2013, constitutes the basis of this investigation. It enables establishing the relations between gypsum recycling, energy use and GHG emissions, in a life cycle perspective. Scenario-based modelling has been conducted for this purpose, evaluating the impact of different levels of recycled gypsum reincorporated in the manufacturing process. To our knowledge, this analysis is the first to comprehensively quantify the system-wide life cycle energy and mass flows associated with gypsum plasterboard in EU-27, and to model their changes under varying levels of plasterboard recycling.

2. The life cycle of gypsum plasterboard

The life cycle of gypsum plasterboard typically begins with the extraction and processing of raw materials, continues with the manufacture and use of the plasterboard, and then reaches end-of-life (EoL) that involves either landfilling, recycling or other forms of recovery (Fig. 1). These life cycle processes are described in the following Sections 2.1–2.4.

2.1. Supply of gypsum and other inputs

Sources of gypsum for plasterboard production include gypsum mining, flue gas desulfurization (FGD) gypsum, and recycled products. Other required plasterboard inputs include paper and additives.

Natural gypsum

Natural gypsum is a mineral composed of calcium sulphate dihydrate ($CaSO_4{\cdot}2H_2O$). Data on gypsum mine production are provided by several different sources (Eurostat, 2013b; Roskill, 2014; USGS, 2013). The authors consider the annual publication Roskill Report (Roskill, 2014) to be the most authoritative estimate, as it is based on data from the other two references (USGS, 2013) as well as company reports and trade press. According to this report, 24.91 million tonnes (Mt) of natural gypsum were mined in the EU-27 in 2013. Globally, 139.38 Mt of gypsum was mined in 2013. In addition to plasterboard production, gypsum is also used in other plaster products, in cement manufacture and for agricultural applications. Gypsum mining involves drilling and blasting the rock, after which it is loaded onto trucks using front-end loaders and mechanical shovels (Venta, 1997). Gypsum extraction processes typically use diesel fuel and electric power. World resources of natural gypsum are considered to be large, and are expected to be sufficient to meet demand well into the future (Roskill, 2014). Although there is no global shortage of natural gypsum, mining can cause impacts in terms of land occupation, energy use and potential loss in biodiversity (European Commission DG Environment, 2010).

FGD gypsum

The gypsum industry uses synthetic gypsum that is a by-product of industrial processes used to reduce sulphur emissions from coal-fired power plants. Flue-gas desulphurization (FGD) systems consist of wet scrubbers that remove sulphur dioxide (SO_2) through the reaction with an alkaline material such as lime. This process is shown in Eq. (1), where lime slurry ($Ca(OH)_2$) is used to remove the SO_2 from the flue gas, creating calcium sulphite ($CaSO_3$) and water.

$$Ca(OH)_{2(solid)} + SO_{2(gas)} \rightarrow CaSO_{3(solid)} + H_2O_{(liquid)} \qquad \text{(Eq. 1)}$$

For this by-product to be used as raw material for plasterboard production, it must be further oxidized (Eq. (2)). Additional energy is required for this forced oxidation to produce calcium sulphate dihydrate ($CaSO_4{\cdot}2H_2O$), a saleable gypsum product sourced by the plasterboard industry. This oxidation energy is estimated by (WRAP, 2008) at 1.4 MJ of coal combustion per kg of FGD gypsum produced.

$$CaSO_{3(solid)} + 1/2O_{2(gas)} + 2H_2O_{(liquid)} \rightarrow CaSO_4 \cdot 2H_2O_{(solid)} \qquad \text{(Eq. 2)}$$

FGD gypsum is produced in several EU countries, but is concentrated in Germany where 6 Mt of the estimated total EU production of 8 Mt was produced in 2013 (Roskill, 2014). Of this total production, and based on the latest published ECOBA statistics (ECOBA, 2010), 50.6% was used for plasterboard manufacturing in the EU-15 in 2010. This is an average figure; in some EU countries such as France, Spain and Italy, the use of FGD gypsum is limited or non-existent, while the use is higher in others such as Belgium, Germany and Scandinavian countries. There are currently EU and national political debates about sustainable energy, the EU commitment to reduce CO_2 emissions, secure energy supply including the need to balance the energy mix, the growing need to use renewable energy sources and the development of new efficient technologies for power generation. Together, these factors are expected to reduce coal use and thus the production of FGD gypsum within the coming decades, particularly in Germany and other western EU member states.

Other sources of synthetic gypsum, such as phosphogypsum, fluorogypsum and titanogypsum, have not been considered here as they are usually consumed by other markets (such as cement manufacture) and not used in significant amounts in plasterboard manufacturing in the EU-27 (Roskill, 2014).

Recycled gypsum

Recycled gypsum is the result of controlled processing of waste plasterboard to separate the gypsum, paper lining, and any impurities, such that it can be used in lieu of natural or synthetic gypsum. The recycled gypsum can be either pre-consumer or post-consumer. As a general rule, pre-consumer gypsum waste is cleaner than post-consumer gypsum waste. Pre-consumer recycled gypsum is material diverted from the waste stream during a manufacturing process (International Standard, 1999). Post-consumer recycled gypsum usually comes from recyclers (CRI, 2010), mainly from C&D gypsum waste. Recycled gypsum is usually in the form of a fine or sandy powder, or a small-aggregate type material (WRAP, 2008).

Plasterboard has been identified as one of the major components contributing to the total potential recycled content of a construction project, in terms of recycled value (Emery et al., 2007). Following the need to reduce the volume of C&D waste sent to landfill and to increase the efficiency of using resources, the use of recycled gypsum is expected to grow in the coming years.