GYPSUM TO GYPSUM

GtoG (from gypsum to gypsum)
The perfect loop, the path to a circular economy: a European collaborative project between the recycling industry, the demolition sector and the gypsum industry

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03 – Final version	29/07/2015	UPM Team: – Consolidation of comments from Gyproc (Tom Rommens), Siniat UK (Steve Hemmings) and KnaufKG (Anna Lang). – Improvement of the content and organization of the document.

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1. INTRODUCTION

This document aims to evaluate the carbon footprint along the life cycle of the optimized plasterboard value chain, comparing the landfill disposal versus the recycling route at the End-of-Life.

By carrying out the analysis it is sought to comprehensively quantify and interpret the implications of different levels of recycled gypsum reincorporated in the EU-27. The aim of this study is to promote recycling practices thus avoiding landfill disposal and increasing the demand for gypsum plasterboard that incorporates recycled content.

The carbon footprint study starts with an overview of the existing reference standards, then sets up a background for the product under analysis, and finally develops the analysis, focusing only on the impact category of interest: climate change.

It should be noted that the quality of the results is directly related to the quality of the available data for the study. Consequently the outcomes obtained should be illustrative but not determined. In addition, industry differences among the different national contexts, from a set of case studies part of the GtoG project, could influence the resulting emission factors.

2. ANALYSIS OF BACKGROUND DOCUMENTATION

The following reference documents have been analysed (Section 2.1 - 2.2) as background documentation for the life cycle carbon emissions of plasterboard. Figure 1 shows the relation among the relevant background documentation considered.

2.1. European standards – Lifecycle, carbon footprint and Environmental Product Declarations

ISO 14040:2006: Environmental management - Life cycle assessment - Principles and framework [1]. This core standard describes the principles and framework for the LCA.

ISO 14044:2006: Environmental management - Life cycle assessment - Requirements and guidelines [2]. It specifies requirements for the individual phases of the LCA, both standards (ISO 14040 and 14044) results allow for conclusions on diverse environmental impacts.

ISO/TS 14067:2013: Greenhouse gases-Carbon footprint of product -Requirements and guideline for quantification and communication [3]. It exclusively addresses the impact category climate change, the specific subject category under this study. ISO/TS 14067 provides guidelines for studies related to carbon footprint of a product (CFP), comprising principles, requirements and recommendations for the quantification and the communication of complete as well as partial product carbon footprints. It builds largely on the existing standards ISO 14040, ISO 14044 and ISO 14025 "Environmental labels and declarations", delivering thereby support for the development of product category rules (PCRs).

EN 15804:2012, Sustainability of construction works, Environmental product declarations, Core rules for the product category of construction products [4].

ISO 14025:2006, Environmental Labels and Declarations, Type III Environmental Declarations, Principles and Procedures [5]. An Environmental Product Declaration, EPD, is a verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact of products.

EN 15978:2011, Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method [6].

2.2. European guides

International Reference Life Cycle Data System (ILCD) Handbook: consist of a series of detailed provisions documents on life cycle methods, data and assessments to support consistency and quality assurance. It provides a detailed technical guidance on the ISO 14040 and 14044:2006 standards on Life Cycle Assessment [7].

Operational Guidance for life cycle assessment studies of the Energy-Efficient Building Initiative (EeBGuide): European Commission funded project that has developed a method, rules and operations for the preparation of LCA studies for energy-efficient buildings and building products. It brings together CEN and ISO standards in one comprehensively and harmonized guide [8]. The guidance is based on existing ISO standards on LCA (ISO 14040-44), European Standards (EN 15804 and EN 15978) as well as the ILCD Handbook.

Product Environment Footprint (PEF) Guide: aims to provide detailed and comprehensive technical guidance on how to conduct a PEF study as well as how to develop product category specific methodological requirements for Product Environmental Footprint Category Rules [9]. PEF considers: ISO standards (in particular: ISO 14044(2006), Draft ISO/DIS 14067(2012); ISO 14025(2006), ISO 14020(2000)), the ILCD Handbook; the Ecological Footprint Standards [10]; the Greenhouse Gas Protocol [11]; the general principles for an environmental communication on mass market products BPX 30-323-0 [12]; and the specification for the assessment of the life cycle greenhouse gas emissions of goods and services [13].

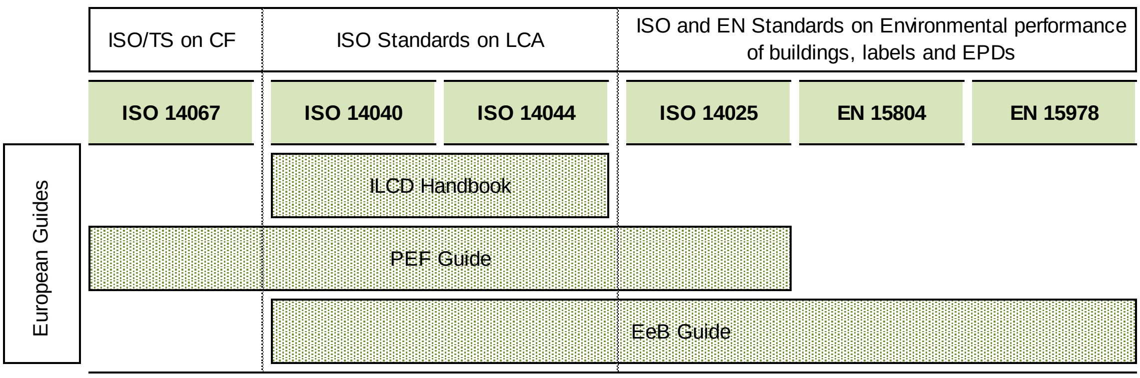

Figure 1. Relevant background documentation: relation among ISO, EN standards and guides. CF: carbon footprint. LCA: life cycled assessment; EPDs: environmental product declarations.

2.3. Existing Life Cycle Analysis on gypsum products

Previous LCA studies on gypsum products focus, generally, on gypsum plasterboard, and range from reports and life cycle inventories to Environmental Product Declarations (EPDs). These documents are listed below:

- Athena Institute. (2011). A Cradle-to-Gate Life Cycle Assessment of ½ ” Regular and 5 / 8 ” Type X Gypsum Wallboard [14].
- Bjorklund, T., & Tillman, A.-M. (1997). LCA of Building Frame Structures. Environmental Impact over the Life Cycle of Wooden and Concrete Frames. Technical Environmental Planning. Chalmers University of Technology. doi:ISSN 1400-9560 [15].
- Eurogypsum. (2010). European Life Cycle Assessment on Plasterboard : European Environmental Declaration – Explanatory Note [16].
- Fossdal, S. (1995). Energy- og miljoregnskap for bygg. Prosjektrapport 173 [17].
- Gypsum Boards Manufacturers of Australia. (n.d.). Sustainability in the Australian and New Zealand Gypsum Board Industry [18].
- Venta, G. J. (1997). Life cycle analysis of gypsum board and associated finishing products [19].
- WRAP and Environmental Resources Management Ltd (ERM). (2008). WRAP Technical Report: Life Cycle Assessment of Plasterboard [20].
- Environmental Product Declarations (EPDs) communicating transparent and comparable information about the life-cycle environmental impact of Standard 12.5 mm plasterboard, in accordance with EN 15804 and ISO 14025 and verified by an independent third party have been considered [21], [22].

2.4. Analysis of background documentation: conclusion

To quantify the gypsum recycling impact of the entire plasterboard life cycle, existing results from European LCAs of gypsum products (sub-section 2.3), in accordance with the applicable ISO and EN standards identified (sub-section 2.1), are used. Additionally, the analysis is complemented by the European reference Life Cycle database ELCD, as specified in Table S2. “Life cycle inventory data” [23]–[26].

3. BACKGROUND FOR THE CARBON FOOTPRINT STUDY

The "Product Life Cycle" is stated as "the consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to the final disposal" [27]. The present assessment compares the CO_2 equivalent emissions associated with variable recycling rates of gypsum waste focusing on plasterboard waste, which corresponds to the majority of the recyclable gypsum waste generated, both in the EU-27 and in each of the countries under study.

The life cycle of gypsum plasterboard begins with the extraction and processing of raw materials, continues with the production and use of plasterboard, until it reaches the EoL, which involves landfilling, recycling or other forms of recovery (Fig. 2).

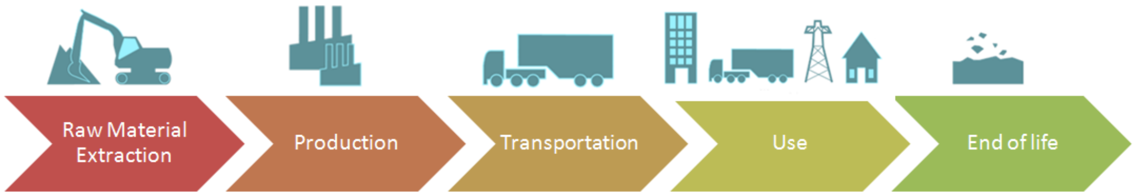

Figure 2. Life cycle stages as given in ISO 14040.

Figure 3 shows the representative stages of gypsum plasterboard life cycle and their relation to EN 15804:2012, which specifies the life cycle stages.

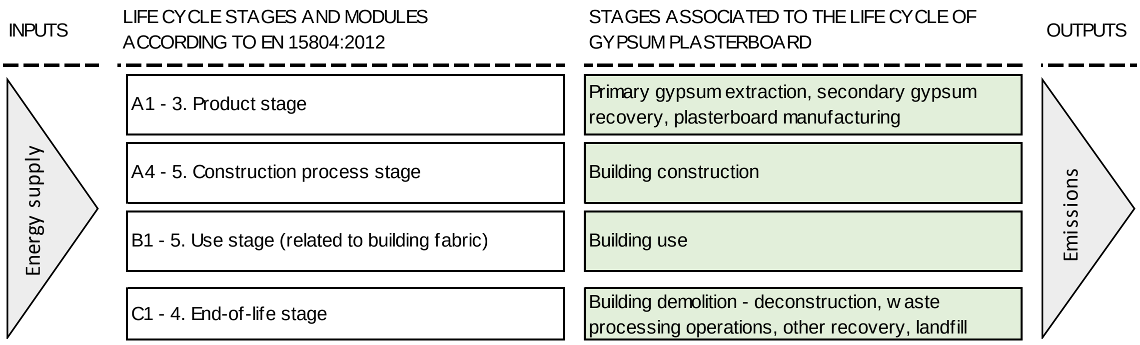

Figure 3. Representative stages of gypsum plasterboard life cycle and their relation to EN 15804:2012

2. CARBON FOOTPRINT STRUCTURE AND APPROACH

The general purpose of this study is to assess the CO_2 equivalent emissions associated to different gypsum recycling scenarios. By increasing the demand for gypsum plasterboard that incorporates recycled content, the emissions related to extraction, FGD production (energy required to further oxidized the by-product from coal-fired power plants to produce sealable gypsum), transport and pre-processing of mined gypsum, are expected to be minimised. In addition, landfill disposal is avoided, which reduces the Hydrogen Sulphide (H_2S) and methane (CH_4) emissions.

The environmental implications of gypsum recycling versus landfilling are analysed and quantified in terms of kg CO_2 eq. Such a potential impact will vary according to the specific condition of the different national contexts.

The technical guidance provided is primary aimed for researchers, companies, designers and consultants in the field of construction (technical experts, stakeholders, etc.).

2.1. Product to be studied and functional unit

Gypsum plasterboard is a common construction material mainly used as partition for walls and ceilings, so that the functional unit has been termed as m² of plasterboard. The unit provides the basis which enables to link the material flows, inputs (material and energy) with the outputs (product and waste) produced, for which the reference flow is been referred as 1 m² of plasterboard consumed.

2.2. Assumptions

Defining boundaries requires the identification of processes directly attributable to the entire life cycle of plasterboard. The assumptions for the carbon footprint are related to the materials and energy used.

The assumptions for the recycling and the landfilling route are described below and are further detailed in the annexed table S1 “Life cycle inventory data”.

Route 1: Recycling route

- **Building deconstruction**

  Data from Doka (2003) and WRAP and Environmental Resources Management Ltd (2008) have been used to estimate the on-site segregation burden of plasterboard.

- **Collection and transportation from construction or deconstruction site to the gypsum recycling facility**

  Emissions are calculated from vehicles fuel consumption, depending on distance travelled and means of transportation.

  In some instances, gypsum waste can be taken to a transfer station for a temporary storage, prior to a recycling facility. No further emission are assumed but for the total transportation distance travelled.

- **Gypsum waste processing (gypsum recycling)**

  Plasterboard waste grinding and sieving processes and transportation within the plant entails emissions in this stage. The recycled gypsum ready to be reincorporated in the manufacturing process is then obtained.

- **Transportation from the recycling facility to the manufacturing plant**

Emissions are calculated from the fuel consumption depending on distance travelled and means of transportation.

- **Reincorporation**

  Emissions from drying, crushing and sieving procedures (pre-processing stage), gypsum calcination and production, are considered in this stage.

Route 2: Landfill route

- **Building demolition**

  Data from Doka (2003) has been used to estimate the demolition burden of plasterboard.

- **Collection and transportation from construction or demolition site to landfill**

  Emissions are calculated from vehicles fuel consumption, depending on distance travelled and means of transportation.

- **Landfill**

  Operational burdens associated with the disposal of plasterboard to landfill as well as emissions from landfill are considered. Two core alternatives for the waste disposal are detailed below. Both alternatives are influenced by the relevance of the gases released from gypsum plasterboard facing paper degradation.

  - Alternative 1: Mixed waste landfill. As the facing paper on plasterboard is organic, it results in landfill methane emissions and carbon emissions. The latter CO_2 emissions are not counted as a GHG, as they are considered part of the natural carbon cycle of growth and decomposition (United States Environmental Protection Agency EPA, 2014). In addition, the combination of sulphate content of gypsum and biodegradable waste may break down, amongst other substances, into Hydrogen Sulphide (H_2S), a hazardous flammable gas with environmental and health effects when inhaled. This H_2S emission rate is variable and depends on different factors such as soil moisture, H_2S concentration and temperature (Xu & Townsend, 2014)

  - Alternative 2: Monocell. In cells where no biodegradable waste is in contact. Fugitive methane emissions are negligible and no combustion equipment is assumed to exist.

3. METHODOLOGY

Scenario-based modelling is conducted to evaluate the GHG emission implications of different levels of recycled gypsum reincorporated in the EU-27. Our analysis is based on the mass flows associated with plasterboard consumption in the reference year 2013. Figure 4 presents the schematic diagram of material flows associated with the life cycle of gypsum plasterboard building material.

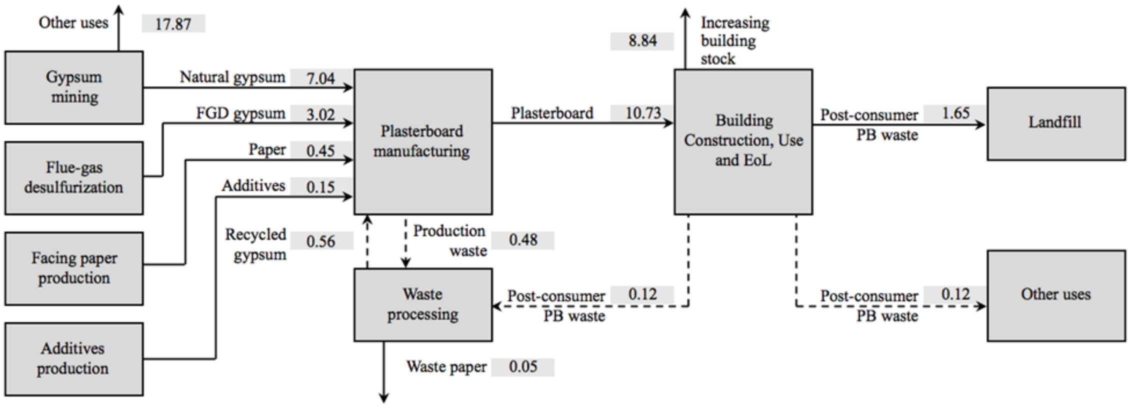

Figure 4. Schematic diagram of material flows associated with the life cycle of gypsum plasterboard building material in SC 1 (EU-27, reference year 2013). PB: plasterboard, Other uses include recovery, open loop recycling, etc. Unit: million tonnes per year (Mt/year). Reverse logistics shown with dashed line.

Quantitative scenario analysis is then followed to determine how system material flows, energy use and GHG emissions would be affected by increased or decreased levels of plasterboard C&D waste recycling. We compare the current situation [29] SC1 (5% recycled gypsum reincorporated) to two alternatives: SC0 – worst case scenario (0% recycled gypsum) and SC2 (18.5% of recycled gypsum, corresponding to nearly 0 tonnes of waste sent to landfill) studying how variations of different selected parameters would affect the environmental impact associated with gypsum plasterboard over its life cycle. Both SC1 and SC2 count with an input of 4% of pre-consumer recycled gypsum, as sources estimate that 3-5% of production is lost as waste [30].

Based on 5 European references of normal/standard plasterboard (Table 1), the statistical average of paper and additives contained in the plasterboard produced in the EU-27 is formulated. The recycled content of the plasterboard is 35.90%, which includes FGD, recycled gypsum and recovered paper [31]. It is important to note that the proportion of each type of gypsum, paper and additives varies by product and by manufacturer (Table 2).

Table 1. European LCI references. For the case of Environmental Product Declarations (EPDs), only those available, reporting complete data for standard plasterboard and verified by a third party, have been considered.

Reference	Region	Thickness (mm)	Density (kg/m^2)	Contents in final product (% by weight)				
				Natural gypsum	Synthetic gypsum	Recycled (pre+post consumer)	Paper liner	Additives
Bjorklund and Tillman, 1997	SE	13.0	9.0	47.3	47.3	-	4.9	0.5
WRAP, 2008[a]	GB	12.5	-	33.6	50.8	9.9	4.2	1.5
ELCD database 2.0, 2007	EU-27	12.5	10.0	-	35.9			-
EPD System, 2013	GB	12.5	8.4	0.0	94.5		3.0	2.5
EPD System, 2013	SE	12.5	9.0	45.8	49.7		3.8	0.7

Table 2. Composition, by weight percentage, of the considered Reference Plasterboard, based on the statistically average of total gypsum, paper and additives in plasterboard produced in EU-27 (SC1).

Raw materials in Plasterboard	Reference PB
Total gypsum	94.7%
Natural gypsum	62.8%
FGD gypsum	26.9%
Recycled gypsum	5.0%
Pre-consumer	4.0%
Post-consumer	1.0%
Facing paper	4.0%
Additives	1.3%
Total recovered content	35.9%

The Technical Report of Life Cycle Assessment of Plasterboard [20] is the only European available reference currently providing detailed data of the EoL stage (modules C1-C4 according to EN 15804). The ELCD process data set, together with an Explanatory note [16], are the main references for obtaining the GHG emissions of the plasterboard manufacturing process. Following the analysis in the WRAP Report, gypsum calcining and plasterboard production do not change with increased proportion of recycled gypsum, and only the pre-processing stage, which involves size reduction and drying of the gypsum feedstock to reduce its moisture content, varies in the different scenarios.

For estimating the distances travelled by raw materials, plasterboard, gypsum waste and recycled gypsum, assumptions detailed in Table 3 are made. For the case of natural and FGD gypsum, two alternatives are considered, using weighting factors to reflect their potential occurrence. Case A is considered to be the most common situation in Europe, in which natural gypsum is mostly locally sourced (87% weighting factor) and FGD gypsum is transported from a nearby coal power station (89%).

Table 3. Transport details. RG=recycled gypsum.

Materials, products and waste	From	To	Mode	Source	Distance (km)	Baseline	
						Mtpy	Mtkm
Natural gypsum - Case A	Mine or quarry	Manufacturing plant	Road	EPD System, 2013	2.00	7.04	14.09
Natural gypsum - Case B	Mine or quarry (imp)	Manufacturing plant	Road	WRAP, 2008	16.00	7.04	112.72
	Mine or quarry (imp)	Manufacturing plant	Ship	WRAP, 2008	2,730.00	7.04	19,232.60
FGD gypsum - Case A	Coal power station	Manufacturing plant	Road	WRAP, 2008	54.00	3.02	163.13
	Coal power station	Manufacturing plant	Rail	WRAP, 2008	54.00	3.02	163.13
FGD gypsum - Case B	Coal power station (imp)	Manufacturing plant	Road	WRAP, 2008	2.00	3.02	6.04
	Coal power station (imp)	Manufacturing plant	Ship	WRAP, 2008	1,083.00	3.02	3,271.66
Facing paper	Paper production	Manufacturing plant	Road	Average from WRAP, 2008	200.00	0.45	89.01
Additives	Additives production	Manufacturing plant	Road	Considered by authors	200.00	0.15	29.19
Plasterboard	Manufacturing plant	Building site	Road	Average LCI references	189.64	10.73	2,035.72
C&D PB waste	Building site	Waste processing	Road	Average DA1 Report, GtoG	150.00	0.12	18.09
RG (post-consumer)	Waste processing (ext)	Manufacturing plant	Road	Average DA1 Report, GtoG	12.50	0.11	1.40
RG (pre-consumer)	Waste processing (int)	Manufacturing plant	Road	DA1 Report, GtoG	0.00	0.45	0.00
Plasterboard waste	Jobsite or Manuf. plant	Landfill	Road	WRAP, 2008	40.00	1.66	66.45

GHG emission intensity factors for gypsum mining, paper and additives manufacture are based on Ecoinvent (2012). For the case of FGD gypsum, plasterboard waste processing and gypsum pre-processing, data from WRAP Report have been used. Demolition or deconstruction works and final disposal assumptions are based on [28], [32]. Further details can be found on Table S1.

Emissions intensity factors for train, truck and ship transport are based on data published by the International Energy Agency for the year 2005 and the European Environment Agency for the year 2011, which are the most recent data found [24], [33]. EU-27 average GHG emissions factor, grid electricity provided by the European Environment Agency, has been also utilized in this investigation [25]. Table 4 summarizes important data taken into account.

Table 4. Summary of relevant data considered

DATA	ASSUMPTION
Reference year	2013
Geographical boundary	European Union (EU-27)
Raw materials in plasterboard	Statistically average of natural, FGD and recycled gypsum, paper and additives in plasterboard produced (table 2) and recycled content 35.90%, which includes FGD, recycled gypsum and recovered paper
Plasterboard consumed	Statistics on the production of manufactured goods. Code 23621050 – Prodcom Database (NACE Rev.2). Calculation of "Apparent consumption" (production + import – exports). 10 kg/m^2 is considered to be the standard plasterboard density, taking as a basis the EU process data set, available in the EU ELCD database and representative of the EU-27 region.
Plasterboard waste generated	Based on the plasterboard waste generated in 8 Member States (Belgium, Denmark, Greece, Spain, France, the Netherlands, Poland the United Kingdom) assessed in the framework of the GtoG project: 1.15 Mt. In these countries the total C&D waste generated amounted to around 499 million tonnes in 2012, last update of the Eurostat database (2012). This means an estimated rate of plasterboard waste of 0.23% of the total C&D waste in the EU-27, equivalent to 1.9 tonnes.
End of Life (EoL)	0% - 5% and 18.5% recycled content Scenarios (SC1, SC2, SC3)

4. RESULTS

Gypsum plasterboard – material flows

Fig. 5 shows the composition by weight percentage, of the resulting two plasterboards in the alternative scenarios: SC0 and SC2 (composition in SC1 presented in table 2). In our model, when the recycled gypsum content varies, it impacts the natural gypsum used, whereas the FGD gypsum, paper and additives remain fixed in the 3 scenarios.

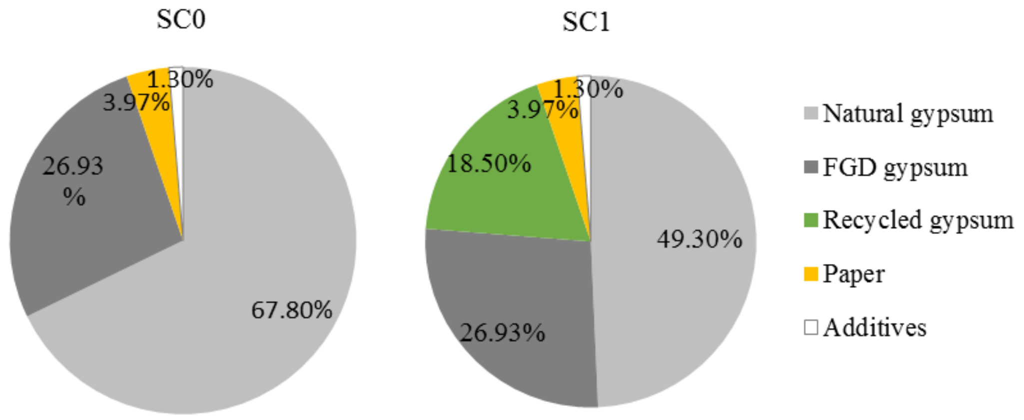

Figure 5. Composition, by weight percentage, of the two plasterboard compositions derived from the alternative scenarios.

The system mass flows in the different scenarios (table 5) allow us to determine the variation in terms of post-consumer plasterboard waste final route: 93.6% would be landfilled in the worst case scenario (SC0), while in SC1 around 87.3% is disposed. These values are drastically reduced in SC2, in which only 1.4% of the plasterboard waste would be landfilled. In SC1, around 6.4% of plasterboard waste is recycled into plasterboard; corresponding to 5% recycled gypsum content in new plasterboard production.

Table 5. Material mass balance in Mt/year.RG: recycled gypsum.

Mass flows	SC0	SC1	SC2
Gypsum mining (all uses)	25.39	24.91	23.28
Total gypsum in plasterboard	10.63	10.63	10.63
Natural gypsum	7.61	7.04	5.53
FGD gypsum	3.02	3.02	3.02
Recycled gypsum	0.00	0.56	2.08
Pre-consumer recycled gypsum	0.00	0.45	0.45
Post-consumer recycled gypsum	0.00	0.11	1.63
Paper	0.45	0.45	0.45
Additives	0.15	0.15	0.15
Production waste	0.48	0.48	0.48
Production waste derived RG	0.00	0.45	0.45
Waste paper	0.00	0.05	0.17
Plasterboard	10.73	10.73	10.73
Post-consumer plasterboard waste (tc	1.90	1.90	1.90
To recycling	0.00	0.12	1.75
To landfill	1.77	1.65	0.03
To other uses	0.12	0.12	0.12
Plasterboard waste to landfill	2.26	1.65	0.03

Gypsum plasterboard – GHG flows

Fig. 6 and 7 show the potential contribution of the plasterboard life cycle scenarios to the global warming impact category, expressed as CO_2 equivalents, estimated by quantifying all significant GHG emissions and removals over the product's life cycle [34][3]in the three scenarios.

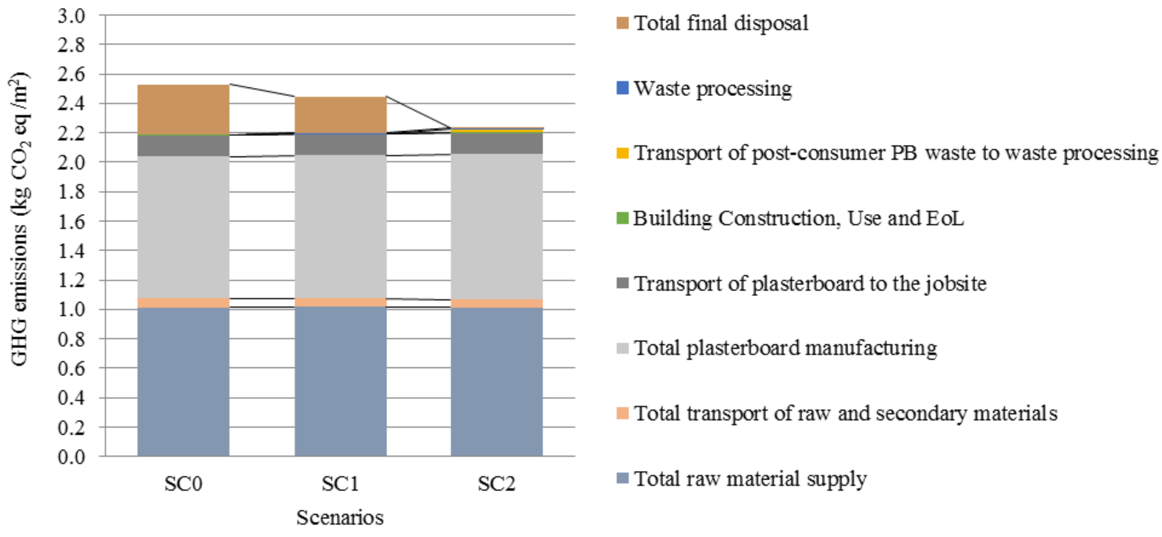

Figure 6. GHG emissions per square meter of plasterboard consumed

GHG emitted from extraction to plasterboard production (commonly known as cradle-to-gate or embodied carbon), equals to 2.05 kg CO_2 eq in the reference scenario (SC1) and to 2.06 kg CO_2 eq in the SC2, per square meter of plasterboard. This minor difference means that decreased emissions derived from gypsum mining and transport of natural gypsum in SC2 are almost balanced by the increased emissions from the pre-processing stage. By analysing the entire life cycle, the variations of the impacts are higher: 2.45 kg CO_2 eq in SC1 and 2.24 kg CO_2 eq in SC2. The emissions from landfill have a decisive contribution to the final result, due to the methane released from degradation of facing paper. This biogenic emission constitutes 94% of the emissions in the final disposal stage and 10% of the total life cycle emissions.

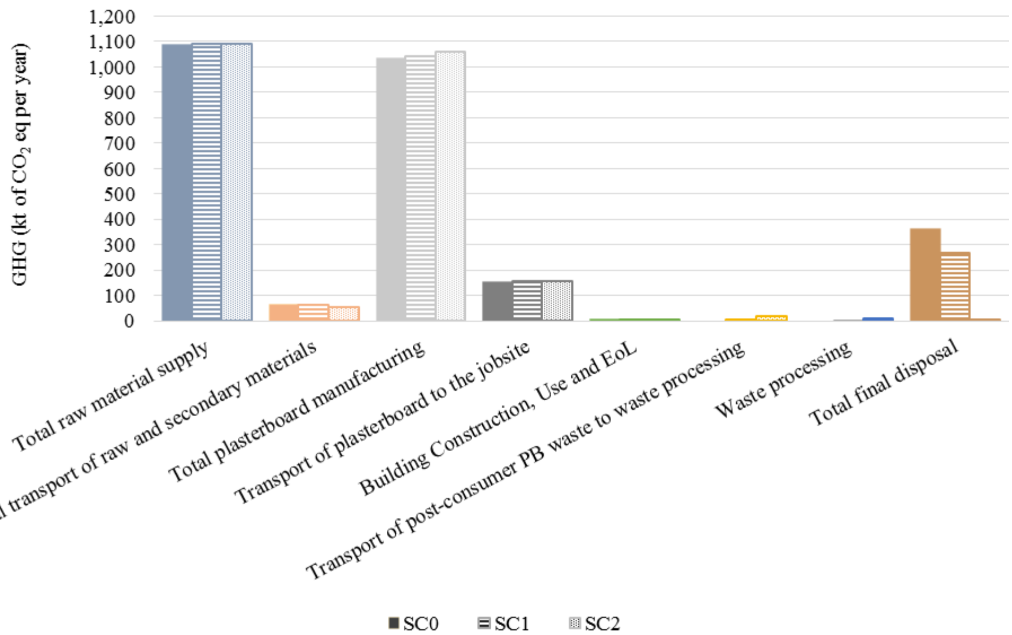

Figure 7. GHG emissions, in kt of CO2 eq per year, of the EU-27 plasterboard life cycle.

5. CONCLUSIONS

A life cycle model is the basis of the assessment, from which the known mass flows are quantified using principles of mass balance. GHG intensity factors are applied to each process to estimate GHG emissions. Three scenarios are defined (SC0, SC1, SC2) and different assumptions based on LCI references are considered, with the aim of evaluating the impact of different levels of recycled gypsum reincorporated in the manufacturing process (0%, 5%, 18.5%, respectively).

- A total of 1.63 Mt/year of plasterboard waste landfilling is avoided when moving from SC1 to SC2, contributing to mitigating primary resource depletion and preventing H_2S and CH_4 emissions from landfills.

- The potential contribution of different plasterboard scenarios to global warming, expressed as CO_2 equivalents, results in greater differences: 2.53 kg CO_2 eq/m^2 in SCO, 2.45 kg CO_2 eq/m^2 in SC1 and 2.24 kg CO_2 eq/m^2 in SC2. Biogenic emissions from paper degradation in the End-of-Life stage, which are dependent on landfill type and infrastructure, are primary drivers of the difference between total GHG emissions in the different scenarios.

- When moving from SC1 towards SC2, greater impacts occur in the processes of transport of recycled gypsum, pre-processing stage, transport of plasterboard waste to recycling and waste processing, while lower impacts are observed in gypsum mining, transport of natural gypsum and final disposal.

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ANNEX 1

Table S1. Life cycle inventory data

Process	Material	Derived from Source	Energy input	Value	Unit	MJ/tonne (total)	kg CO_2 eq/tonne (total)
Gypsum mining	Natural gypsum	Ecoinvent v2.2 (2012)	Various	0.35	MJ/kg	353.85	2.03
FGD gypsum (burdens to get a saleable product)	FGD gypsum	WRAP and ERC (2008)	Coal	1.40	MJ/kg	1,400.00	1.52E-04
Paper	Paper	Ecoinvent v2.2 (2012)	Various	16.45	MJ/kg	16,445.27	986.58
Additives	Additives[b]	Ecoinvent v2.2 (2012)	Various	34.20	MJ/kg	34,200.00	1,208.00
Transport	All materials	EEA (2011) and IEA (2008)[a]	Various - Road	2.73	MJ/tkm	n.a.	n.a.
				76.00	g CO_2 eq/tkm	n.a.	n.a.
			Various - Rail	0.63	MJ/tkm	n.a.	n.a.
				21.00	g CO_2 eq/tkm	n.a.	n.a.
			Various - Ship	0.47	MJ/tkm	n.a.	n.a.
				13.00	g CO_2 eq/tkm	n.a.	n.a.
Plasterboard manufacturing (pre-processing)	Natural gypsum	WRAP and ERC (2008) from Ecoinvent	Grid electricity	4.80	kWh/tonne	80.56	3.76
			Natural gas	28.72	MJ/tonne		
	FGD gypsum	WRAP and ERC (2008) from Ecoinvent	Grid electricity	3.80	kWh/tonne	450.30	29.19
			Natural gas	409.26	MJ/tonne		
	Recycled gypsum (pre and post-consumer)	WRAP and ERC (2008) from Ecoinvent	Grid electricity	10.00	kWh/tonne	226.47	11.80
			Natural gas	118.47	MJ/tonne		
From gypsum mining to total plasterboard manufacturing	Plasterboard	ELCD database 2.0 (2007-2014) (Cradle-to-gate process data set)	Various	35.90	MJ/m^2	3,590.00	195.79
Bulding contruction, Use and EoL: Demolition	Plasterboard	Doka (2003)	Diesel	35.90	MJ/tonne	35.90	3.37
Bulding contruction, Use and EoL: Waste segregation	Plasterboard	WRAP and ERC (2008)	Diesel	30.30	MJ/tonne	30.30	2.84
Waste processing	Pre-consumer plasterboard waste	WRAP and ERC (2008) from Ecoinvent	Grid electricity	9.60	kWh/tonne	150.35	7.99
			Diesel	46.67	MJ/tonne		
	Post-consumer plasterboard waste	WRAP and ERC (2008) from Ecoinvent	Grid electricity	9.90	kWh/tonne	139.23	6.76
			Diesel	32.31	MJ/tonne		
Operation of landfill site	Plasterboard waste	Plimmer, Davies, & Carter (2007)	Diesel	63.51	MJ/tonne	63.83	5.99
			Diesel	0.32	MJ/tonne		
Biogenic emissions from landfill	Plasterboard waste	Plimmer, Davies, & Carter (2007) and EPA (2014)	-	4.48	kg CH_4/tonne	-	152.32
			-	0.00	kg CO_2/tonne	-	

[a]For energy demand (MJ): Figure 6.11, IEA (2008), Freight Transport Use, by Mode (Average Germany, France and the UK as representative EU-27, according to Eurogypsum (2010). For GWP (g CO_2): EEA (2011). (for ship, maritime value has been taken) http://www.eea.europa.eu/data-and-maps/figures/specific-co2-emissions-per-tonne-2
[b]Although a variety of additives are used in plasterboard manufacturing, maize starch is considered to be the most used in Standard/Normal plasterboard, according to WRAP and Environmental Resources Management Ltd (ERM) (2008)

Table S2. GHG emissions per square meter of plasterboard consumed.

Stage	Process	SC0	SC1	SC2
Raw material supply, including processing of secondary material input	Gypsum mining	0.01	0.01	0.01
	FGD gypsum	0.43	0.43	0.43
	Paper	0.41	0.41	0.41
	Additives	0.16	0.16	0.16
	Waste processing (Production waste)	0.00	0.00	0.00
	Total raw material supply	1.02	1.02	1.01
Transport of raw material and secondary material to the manufacturer	Transport natural gypsum	0.03	0.03	0.02
	Transport FGD	0.02	0.02	0.02
	Transport recycled gypsum	0.00E+00	9.93E-05	1.44E-03
	Transport paper	0.01	0.01	0.01
	Transport additives	0.00	0.00	0.00
	Total transport of raw and secondary materials	0.06	0.06	0.05
Manufacture of plasterboard an all upstream processes	Plasterboard manufacturing (Pre-processing)	0.11	0.11	0.12
	Plasterboard manufacturing (Calcination, production)	0.86	0.86	0.86
	Total plasterboard manufacturing	0.96	0.97	0.99
Transport of plasterboard to the building site	Transport of plasterboard to the jobsite	0.14	0.14	0.14
Plasterboard installation and/or deconstruction	Building Construction, Use and EoL	0.01	0.01	0.00
Transport of the post-consumer plasterboard waste to waste pro	Transport of post-consumer PB waste to waste proces	0.00	0.00	0.02
Waste processing of post-consumer plasterboard waste	Waste processing	0.00	0.00	0.01
Final disposal of plasterboard	Transport of post-consumer PB waste to landfill	0.01	0.00	0.00
	Operation of landfill site	0.01	0.01	0.00
	Biogenic emissions from landfill	0.32	0.23	0.00
	Total final disposal	0.34	0.25	0.00
		2.53	2.45	2.24

Table S6. GHG emissions, in kt of CO_2 eq per year, of the EU-27 plasterboard life cycle.

Stage	Process	SC0	SC1	SC2
Raw material supply, including processing of secondary material input	Gypsum mining	15.44	14.30	11.23
	FGD gypsum	458.86	458.86	458.86
	Paper	439.07	439.07	439.07
	Additives	176.29	176.29	176.29
	Waste processing (Production waste)	0.00	3.86	3.86
	Total raw material supply	1,089.67	1,092.39	1,089.31
Transport of raw material and secondary material to the manufacturer	Transport natural gypsum	36.37	33.69	26.45
	Transport FGD	18.84	18.84	18.84
	Transport recycled gypsum	0.00	0.11	1.55
	Transport paper	6.76	6.76	6.76
	Transport additives	2.22	2.22	2.22
	Total transport of raw and secondary materials	64.20	61.62	55.82
Manufacture of plasterboard an all upstream processes	Plasterboard manufacturing (Pre-processing)	116.77	121.28	133.47
	Plasterboard manufacturing (Calcination, production)	918.32	921.00	928.24
	Total plasterboard manufacturing	1,035.08	1,042.28	1,061.71
Transport of plasterboard to the building site	Transport of plasterboard to the jobsite	154.71	154.71	154.71
Plasterboard installation and/or deconstruction	Building Construction, Use and EoL	5.98	5.91	5.06
Transport of the post-consumer plasterboard waste to waste pro	Transport of post-consumer PB waste to waste proces	0.00	1.37	19.93
Waste processing of post-consumer plasterboard waste	Waste processing	0.00	0.82	11.82
Final disposal of plasterboard	Transport of post-consumer PB waste to landfill	6.86	5.03	0.08
	Operation of landfill site	13.52	9.90	0.16
	Biogenic emissions from landfill	343.95	252.00	4.03
	Total final disposal	364.33	266.93	4.26
		2,713.96	2,626.04	2,402.63