GTOG: From production to recycling: a circular economy for the European gypsum Industry with the demolition and recycling Industry

INVENTORY OF BEST PRACTICES

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GYPSUM TO GYPSUM

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GYPSUM TO GYPSUM

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INTRODUCTION

Background

Across Europe, there are large amounts of potential secondary raw materials in the existing building stock. However, while the reasons to recycle instead of landfill gypsum waste are laid down [1], in the EU-28 a market for recycled gypsum only exists in France, Benelux, Finland, the UK, Denmark and Sweden. The European Life+ GtoG Project ENV/BE/001039: "From Production to Recycling, a Circular Economy for the European Gypsum Industry with the Demolition and Recycling Industry" aims to transform the gypsum demolition waste market to achieve higher recycling rates of gypsum waste, thereby helping to achieve a resource efficient economy.

The present report refers to the results of GtoG project's Action A1 – "Value chain analysis in terms of deconstruction methodologies, economics of logistics and recycling" which focuses on deconstruction, recycling and plasterboard manufacturing practices. This Action built the Inventory of current practices [2] in 2013, which constitutes the preliminary work within the GtoG project.

Action A1 is divided in three complementary sub-actions which ran during the first and third annuality of the GtoG project (i.e. 2013 and 2015). While sub-action A1.1 addressed deconstruction current practices, sub-action A1.2 focused on gypsum recycling and plasterboard manufacturing practices, in eight EU national contexts: Belgium (BE), France (FR), Germany (DE), Greece (GR), Poland (PL), Spain (SP), the Netherlands (NL) and the United Kingdom (UK). In addition, technical-economic-legislative and environmental parameters based on literature data and output of A1.1 and A1.2 were outlined in the first stage of the project. Moreover, Action A1 has been enriched with results from the implementation (Action B) and monitoring actions (Action B and C), as shown in Figure 1, from which the following deliverables have been produced:

- European handbook on best practices in deconstruction techniques [3]. It aims to promote the implementation of best practices for a controlled deconstruction process of gypsum-based systems, which might ease recovery. Recyclable and non-recyclable gypsum-based systems are also described.
- European handbook for best practices in audit prior to deconstruction of buildings [4], which aims at standardizing waste audits and ensuring that they cover all elements.
- Report on best practice indicators for deconstruction, recycling and reincorporation practices [5]. It sets out an approach for developing key performance indicators for the gypsum value chain and select best practice indicators that aim to increase the recovery ratios of recyclable gypsum waste, as well as maximize its quality and the percentage of recycled gypsum that can be reincorporated in the manufacturing process.
- Protocol of action B2.2: Quality criteria for recycled gypsum, technical and toxicological parameters [6], which provides agreed guidelines for a quality recycled gypsum.

- Guidance document with criteria for acceptance of secondary gypsum for recycling [7], which describes the waste acceptance criteria (WAC) agreed by the three recyclers of the project.
- Report on production process parameters [8]. It presents important parameters of the plasterboard manufacturing process affected by the use of recycled gypsum as feedstock and to assess and quantify the resulting impact on product quality and on the process' energy consumption and variable production costs.

To achieve the main objective of the study, i.e. to identify the most appropriate best practices for the gypsum value chain, key performance indicators (KPIs) were firstly developed and applied in 5 EU pilot projects located in Belgium, France, Germany and the United Kingdom. Only KPIs specifically aiming to recognize and encourage best practices were selected as best practice indicators (BPIs). On this basis, practices addressing BPI's compliance are/were drafted.

In this report, the concept of good practice is applied to actions leading to optimize closed-loop recycling. Among them, best practices are identified from an EU consultation mainly targeting construction companies, waste collectors, gypsum recyclers and gypsum products manufacturers.

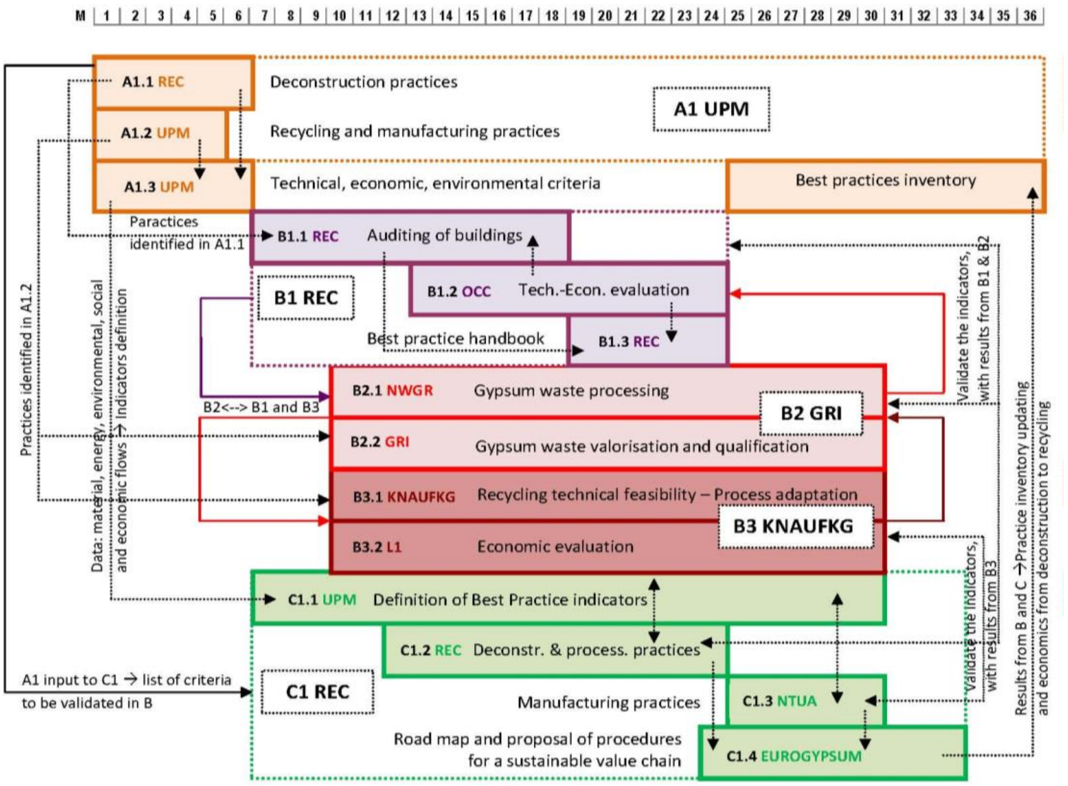

Figure 1. Structure of the GtoG project actions

Aim and scope of the study

The purpose of this report is to provide the most appropriate best practices for the value chain of gypsum products, with the objective of promoting closed-loop gypsum recycling, therefore minimising landfilling of gypsum waste and the related methane and carbon dioxide emissions as well as avoiding primary mineral resource depletion.

If best practices are applied in the gypsum value chain, recyclable gypsum waste is optimized, the potential environmental impacts are minimized and quality recycled gypsum is ensured.

This document is organized as follows: (description under development)

- Section 1 provides an overview of (monitoring indicators)
- Section 2 describes

Moreover, four annexes

1. MONITORING INDICATORS

Key Performance Indicators (KPIs) are used to assess the performance of gypsum waste management in construction works through the whole End-of-Life (EoL), setting the foundation for the Best Practice Indicators (BPIs) development. From the analysis of these developments, the objective is to formulate good practices for the gypsum plasterboard value chain, which gives rise to the selection of the most appropriate best practices for the entire value chain

For the formulation and feasibility of the initial KPIs, a preliminary study compiling current practices along the value chain was completed in 2013, showing existing differences between countries under technical, economic, legislative and environmental factors. Some recommendations were already outlined in that report [1]. Following to that study, in 2014, a number of demonstration activities, applying good practices in deconstruction, processing and reincorporation of recycled gypsum (RG), were monitored and assessed in five pilot projects, by the stakeholders involved in the GtoG gypsum value chain: contractors, gypsum recyclers and plasterboard manufacturers.

The so-called pilot covered:

- 5 deconstruction projects: where five selected public buildings, with gypsum products and systems were audited and deconstructed, using various techniques and practices in Belgium, France, Germany and the United Kingdom.
- 5 recycling plants: the gypsum waste supplied by the deconstruction projects have been processed and then transferred as recycled gypsum to the five manufacturer's plants.
- 5 reincorporation plants: the recycled gypsum supplied by the recyclers has been re-incorporated into the production process.

The methodological approach for the KPIs consisted of seven steps as summarized below[1] .

1. Identify key areas of influence to be measured:
Based on literature research and consultation addressing the current gypsum recycling practices among EU construction agents from Spain, Greece, Poland, Germany, UK, France, Denmark and Belgium, the most relevant areas to be measured according to their potential influence through the EoL of gypsum products were firstly identified, and set as an initial group of indicators (e.g. RG quality).

2. Group areas in categories:

[1] Further explanation can be found in the report: Gypsum to Gypsum project LIFE11 ENV/BE/001039, "DC1. Report on best practice indicators for deconstruction, recycling and reincorporation," 2015. Available: http://ec.europa.eu/environment/life/news/newsarchive2015/documents/20150715_gtog.pdf. [Accessed: 09-Nov-2015]

Then the identified areas are grouped in accordance with their relevant impacts in four categories: economic (ECO), social (SOC), environmental (ENV) and technical (TECH).

3. Identify precise parameters:
Monitoring parameters related to the areas of influence are classified according with the four categories identified. (e.g. gypsum waste generated and tracked).

4. Define preliminary KPIs:
KPIs are set by combining parameters into equations, (e.g. effectiveness of the traceability).

5. Apply KPIs: data collection:
The preliminary set of KPIs is applied in the aforementioned pilot projects

6. Validate KPIs
Monitor and measure performance of the management activities.

The comparative analysis between pilot projects data revealed overlaps and improvements.

1.1. CRUCIAL PARAMETERS

Once influencing areas are determined, the first approach of indicators is outlined with their relevant parameters, being parameters the variables that combined in an equation compose the indicator and enable the data collection, according to the indicator they are addressing.

The section presents the selected parameters per stage of the value chain and influencing area, in an Excel spreadsheets classification breakdown that facilitates the data collection to the stakeholders and subsequent individual evaluation for a more effective analysis.

1.1.1. Deconstruction parameters

PARAMETERS FOR THE TECHNICAL INDICATORS				
Pre-deconstruction audit for gypsum systems	Existence (Y/N)			
GYPSUM WASTE(GW) GENERATED		VALUE	UNIT	kg/m2
Gypsum Waste (GW) foreseen (within the audit)	Plasterboard waste		t	0.00
	Plaster blocks waste		t	0.00
	Total GW foreseen	0.00	t	0.00
GW generated	Plasterboard waste		t	0.00
	Plaster blocks waste		t	0.00
	Total GW generated	0.00	t	0.00
Recyclable GW foreseen	Plasterboard waste		t	0.00
	Plaster blocks waste		t	0.00
	Total recyclable GW foreseen	0.00	t	0.00
Recyclable GW generated	Plasterboard waste		t	0.00
	Plaster blocks waste		t	0.00
	Total recyclable GW generated	0.00	t	0.00
IMPURITIES	**TYPE**			
Presence of impurities in the GW load (please specify type)				
TRACEABILITY				
GW refused due to non compliance with the specifications			t	0.00
Certified end route of GW tracked			t	0.00
Tracked GW sent to landfill			t	0.00

PARAMETERS FOR THE ENVIRONMENTAL INDICATORS		VALUE	UNIT
TRANSPORT			
Gypsum Waste (GW) sent from jobsite to	Transfer station		t
	Recycling facility		t
	Landfill		t
GW per roundtrip to recycling			t/load
GW per roundtrip to landfill		0	t/load
Recycling route roundtrips			No.
Landfill route roundtrips		0	No.
Distance to recycling			km
Distance to landfilling			km
Freight transportation factor. Data source= European Environmental Agency, 2011		76.00	g CO_2 equiv /tkm

PARAMETERS FOR THE SOCIAL INDICATORS		VALUE	UNIT
LABOUR			
Labour time by man needed for the dismantling and loading of the Gypsum Waste (GW) (min/m²)	Plasterboard waste		min/m²
	Plaster block waste		min/m²
Labour time by man estimated to demolish and loading the GW			min/m²
Hours of training received per year			hours/year
Labour time by man devoted to follow-up the waste management including the tracking records (hours for the jobsite considered)			hours
Existence and number of workers trained for the jobsite			workers
Existence of worker(s) appointed to follow-up the waste management (includ.tracking records) (Y or N)			
As there is a lack of common methodology for a coherent comparability in data regarding the labour time estimations, please explain below in detail the characteristic of the dismantling process followed and calculation considerations, so as to establish a sensible benchmarking criteria.			

PARAMETERS FOR THE ECONOMIC INDICATORS		VALUE	UNIT
JOBSITE			
Deconstruction site floor area			m^2
Cost of the audit (for the whole deconstruction process)			€
Duration of the deconstruction works			days
GYPSUM PRODUCTS DISMANTLING			
Surface area of gypsum waste dismantled	Plasterboard waste		m^2
	Gypsum blocks waste		m^2
	Total	0.00	
Cost of dismantling and loading	Plasterboard waste		€
	Gypsum blocks waste		€
	Total	0.00	€

TRACEABILITY		VALUE	UNIT	€/t
Transport cost of GW, including gate fee and tax.	From the jobsite to the the transfer station or recycling facility		€	0.00
	From the jobsite to the landfill		€	0.00
Cost of recycling per ton (including all taxes) (either direct / via a transfer station)			€	
Cost of landfilling per ton (including all taxes) (direct/via a transfer station))			€	

1.1.2. Recycling parameters

PARAMETERS FOR THE TECHNICAL INDICATORS		VALUE	UNIT
QUALITY CHECK DATA			
Gypsum waste received			t
Gypsum waste rejected			t
Wet Gypsum Waste received - GW_w (t)			t
Slightly wet gypsum waste received (e.g. rain during transport)			t
Wet gypsum waste received (completely soaked)			t
Presence of…	Plastics and foils		-
	Insulation materials		-
	Steel rails and bars		-
	Wood		-
	Other impurities		-
Impurities manually separated			t
Reference gypsum waste density			t/m^3
GYPSUM WASTE PROCESSING			
Gypsum waste processed			t
Output of:	Recycled gypsum		t
	Paper fraction		t
	Metal		t
Number of stops of the recycling equipment to solve technical problems due to the presence of contaminants:	Plastics and foils		No.
	Insulation materials		No.
	Steels rails and bars		No.
	Wood		No.
	Other impurities		No.

PARAMETERS FOR THE SOCIAL INDICATORS	VALUE	UNIT
SOCIAL DATA		
Total number of employees		No.
Distance from recycling plant to residential areas		km

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PARAMETERS FOR THE ENVIRONMENTAL INDICATORS	VALUE	UNIT
RECYCLING PROCESS ENERGY CONSUMPTION DATA		
Electricity consumption		kWh
Conversion factor, EU-27 average electricity emissions factor. Data source EEA, 2008.	0.38	$kgC0_2$/ kWh
Fuel consumption		l
Calculated conversion factor. Data source: IPCC and Fuel cycle emissions NETL.	3.63	kg CO_2 equiv per l
TRANSPORT FROM RECYCLING TO THE MANUFACTURING PLANT		
Freight transportation factor. Data source EEA 2011, road transportation	76.00	g CO_2 eq/tkm

PARAMETERS FOR THE ECONOMIC INDICATORS		VALUE	UNIT	VALUE	UNIT
RECYCLING FACILITY DATA					
Total processing electricity cost	Average electricity consumption		kWh	0	€
	Electricity cost		€/kWh		
Total processing fuel cost	Average fuel consumption		l	0	€
	Fuel cost		€/l		
TRANSPORT DATA					
Lorry energy consumption					l/km
Distance to the plasterboard manufacturing plant* * Note: A maximum of 5 km will be considered					km
Roundtrips to reincorporation					No.

1.1.3. Reincorporation

PARAMETERS FOR THE TECHNICAL INDICATORS			VALUE	UNIT
RECYCLED GYPSUM RECEIVED				
Average recycled gypsum received per load				t
Total recycled gypsum received				t
Total recycled gypsum rejected				t
Quality criteria		**GtoG guidelines**	**VALUE**	**UNIT**
Technical parameters	Particle size (mm)	0-15		mm
	Free moisture	<10		%w/w
	Purity - Content of calcium sulphate dihydrate	>80		%w/w
	Total organic carbon (TOC) - Content of residual paper / fibres	<1.5		%w/w
	Magnesium salts, water soluble, MgO	<0.1		%w/w
	Sodium salts, water soluble, Na_2O	<0.06		%w/w
	Potassium salts, water soluble K_2O	<0.05		%w/w
	Soluble Chloride Cl	<0.02		%w/w
	pH	6-9		

Toxicological parameters	DIN EN ISO 11885 Determination of selected elements ICP-OES (acc to DepV)	As	< 4		mg/kg
		Be	< 0,7		mg/kg
		Pb	< 22		mg/kg
		Cd	< 0,5		mg/kg
		Cr	< 25		mg/kg
		Co	< 4		mg/kg
		Cu	< 14		mg/kg
		Mn	< 200		mg/kg
		Ni	< 13		mg/kg
		Se	< 16		mg/kg
		Te	< 0,3		mg/kg
		Tl	< 0,4		mg/kg
		V	< 26		mg/kg
		Zn	< 50		mg/kg
	DINEN 1483 AAS-DINEN 12338-Merury process after enrichment by amalgation. DIN ISO 1785 atomic fluorescnce spectrometry (acc to MatelV O)	Hg	< 1,3		mg/kg
	Radioactivity index	-	< 0,5		
	Asbestos	-	0.00		

RECYCLED GYPSUM STORAGE			
Total recycled gypsum stored			t
PREPROCESSING			
Recycled gypsum crushed and sieved in the manufacturing plant			t
BUSINESS-AS-USUAL FEEDSTOCK			
Conventional feedstock	Natural gypsum		t
	FGD gypsum		t
	Other (please specify)		t
	Total	0.00	t
Recycled gypsum	Pre-consumer recycled gypsum		t
	Post-consumer recycled gypsum		t
	Total	0.00	t
Total business-as-usual feedstock		0.00	t

FEEDSTOCK WITH MAXIMIZED RECYCLED CONTENT			
Conventional feedstock	Natural gypsum		t
	FGD gypsum		t
	Other (please specify)		t
	Total	0.00	t
Recycled gypsum	Pre-consumer recycled gypsum		t
	Post-consumer recycled gypsum		t
	Total	0.00	t
Total feedstock with maximized recycled content		0.00	t
PRODUCTION			
Total plasterboard produced			m^2
			t
Total non-conforming plasterboard generated			m^2
			t
BUSINESS-AS-USUAL REINCORPORATION RATE			
Usual recycled gypsum reincorporation rate			%

PARAMETERS FOR THE ENVIRONMENTAL AND ECONOMIC INDICATORS		VALUE		UNIT
QUALITY CHECKS				
Recycled gypsum feedstock quality checks	Number of quality checks			No.
	Cost per quality check			€
	Total	0.00		€
Conventional feedstock quality checks	Number of quality checks			No.
	Cost per quality check			€
	Total	0.00		€
FEEDSTOCK				
Cost of natural gypsum per tonne, including transportation				€/t
Cost of FGD gypsum per tonne, including transportation				€/t
Cost of recycled gypsum per tonne, including transportation				€/t
ELECTRICITY - PREPROCESSING				
Electricity consumption		Business-as-usual	Upgraded	Unit
				kWh/m^2 board
				kWh/t board

FUEL -PREPROCESSING			
Natural gas	Business-as-usual	Upgraded	Unit
			kWh/m^2 board
			kWh/t board
Waste fuel	Business-as-usual	Upgraded	Unit
			kWh/m^2 board
			kWh/t board
ELECTRICITY - TOTAL MANUFACTURING PROCESS			
Electricity consumption	Business-as-usual	Upgraded	Unit
			kWh/m^2 board
			kWh/t board
FUEL - TOTAL MANUFACTURING PROCESS			
Natural gas	Business-as-usual	Upgraded	Unit
			kWh/m^2 board
			kWh/t board
Waste fuel	Business-as-usual	Upgraded	Unit
			kWh/m^2 board
			kWh/t board
ELECTRICITY AND FUEL COST			
Cost of electricity			€/kWh
Cost of natural gas			€/KWh Lower Heating Value
Cost of waste fuel			€/KWh Lower Heating Value
Electricity emissions factor* *EU-27 average. Data from European Environment Agency, 2008. http://www.eea.europa.eu/data-and-maps/figures/trends-in-energy-ghg-emission#tab-documents			
Electricity	3.77E-01		kg CO_2 eq per kWh
Emissions intensity of fossil fuels* *Reference: Combustion emissions: IPCC (Intergovernmental Panel on Climate Change). 2006. Guidelines for national greenhouse gas inventories. <http://www.ipcc.ch>. Fuel cycle emissions: NETL (National Energy Technology Laboratory). 2010.			
Natural gas	2.37E-08		kg CO_2 eq/kWh
Waste fuel	1.00E-03		kg CO_2 eq/kWh

PARAMETERS FOR THE SOCIAL INDICATORS	VALUE	UNIT
LABOUR		
Total plasterboard produced	0.00	t
Plasterboard sold		t
Manufacturer's satisfaction		-

1.2. SUMMARY OF KEY PERFORMANCE INDICATORS (KPIs)

The resulted performance indicators for the measurement and monitoring of the deconstruction works are summarized in the following tables 1-3, by category, formula and evaluation criteria. Such quantitative or qualitative evaluation criteria are based on the outcome from the pilot project data, in order to monitor the degree of compliance with a minimum level of performance established.

Table 1. KPIs Deconstruction

INDICATOR	FORMULA	EVALUATION CRITERIA
TECH1. Existence and deviation of the audit for gypsum-based systems	TECH1.1 *Pre-deconstruction audit -(YES/NO)* $\text{TECH1.2}=\frac{GW_f - GW_g}{GW_g}$ $\text{TECH1.3}=\frac{RGW_f - RGW_g}{RGW_g}$	TECH1.1 = yes; TEC1.2 <10%; TECH1.3<20%
TECH2. Effectiveness of the deconstruction process	TECH 2.1 *(YES/NO)* $\text{TECH 2.2} = \frac{RGW_g - RGW_r}{RGW_g}$	TECH2.1 = NO; TECH2.2 =100%
TECH3. Effectiveness of the traceability	$\text{TECH3} = \frac{GW_t - RGW_t}{GW_t}$	100%
ENV1. Gypsum waste sent to landfill	$\text{ENV1} = \frac{\text{GW}_\text{l}}{\text{GW}_\text{g}}$	0%
ENV2. Transport emissions comparison between recyclnig and landfilling	$\text{ENV2} = \frac{F_{CO2} \text{ x GW x } D \text{ x } RT}{1000}$ ENV2.1 *Recycling* - ENV2.2 *landfilling*	ENV2.1 - ENV2.2 < 0 kg CO_2 equiv
SOC1. Labour time difference between dismantling and demolishing plasterboard	$\text{SOC1} = (\text{LPB}_{\text{di}} - \text{LPB}_{\text{de}})$	(n/a) min/m²
SOC2. Productivity	$\text{SOC2}=\frac{(A_A + A_{gb})}{N_W * D}$	(n/a) m²/(workers day)
SOC3. Training of the deconstruction team	SOC3 *Existence of trained worker(s) in gypsum waste deconstruction(YES/NO)*	Yes
SOC4. Follow-up of the waste management	SOC4 *Existence of worker(s) appointed to follow-up the waste management (includ.tracking records)* (YES/NO)	Yes
ECO1. Audit cost	$\text{ECO1} = \frac{\text{AU}}{\text{D}_\text{A}}$	(n/a) €/m²
ECO2. Plasterboard dismantling and loading cost	$\text{ECO2} = \frac{\text{DL}_\text{p}}{\text{A}_\text{p}}$	(n/a) €/m²
ECO3. Gypsum block dismantling and loading cost	$\text{ECO3} = \frac{\text{DL}_\text{p}}{\text{A}_\text{gb}}$	(n/a) €/m²
ECO4. Cost difference between recycling GW and landfilling route	ECO4.1 = R+RT ECO4.2 = L+LT	ECO4.1 - ECO4.2 < 0 €/t

Gypsum Waste foreseen - GW_f (t)	Gypsum Waste sent to landfill - GW_l (t)	Duration of the deconstruction - D (day)
Gypsum Waste generated - GW_g (t)	Freight transportation factor - F_{CO2} (g CO_2 eq/tkm)	Cost of the audit - AU (€)
Recyclable Gypsum Waste foreseen - RGW_f (t)	GW per rountrip to recycling - GW_r (t)	Deconstruction site floor area - D_A (m²)
Recyclable Gypsum Waste generated - RGW_g (t)	Distance to recycling -D_r (km)	Cost of the dimantling and loading - DL_p (€)
Presence of impurities in the GW load (YES/NO)	Roundtrips to the recycling facility - RT_r (No.)	Cost of recycling - R (€/t)
Recyclable GW refused by the waste outlet- RGW_r (t)	Total area of plasterboard - A_p (m^2)	Recycling transport cost - RT (€/t)
Recyclable GW generated- RGW_g (t)	Total area of gypsum block - A_{gb} (m^2)	Cost of landfilling - L (€/t)
GW generated and tracked - GW_t (t)	Number of workers trained for the jobsite - N_w (No.)	Landfilling transport cost - LT (€/t)
GW generated - GW_g (t)		(n/a) not applicable
Labour time by man needed for the dismantling and loading of the GW - LPB_{di}(min/m²)		
Labour time by man estimated to demolish and loading the GW - LPB_{de}(min/m²)		

Considering that deconstruction enable the quantity and quality optimization of valuable materials, increasing the potential for their future recycling, resulting in different waste fractions

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with minimal damage, due to the time and care taken for separating the waste, technical KPIs focus on:

- -Implementation of an audit. Such waste prediction will set the basis for the development of a sound Site Waste Management Plan, which in turn, will result in maximising the reduction, reuse, recycling and recovery options of materials, and the potential cost savings associated.
- -Implementation of relevant deconstruction practices to guarantee an efficient source separation.
- -Existence of a traceability system which guarantees transparency and quality assurance.

Social KPIs cover issues related to productivity, employment and training.

Environmental KPIs refer to diverting gypsum waste from landfill and the emissions caused by the transportation from the jobsite to the recycling facility compared with the landfilling route. The frequency for containers' collection should be planned in advance, ensuring that, whenever possible, only full container load is transported.

Economic KPIs involve the cost evaluation of all the key processes part of this stage, comparing potential benefits from deconstruction instead of common demolition works.

Table 2. KPIs Recycling

INDICATOR	FORMULA	EVALUATION CRITERIA
TECH1. Quality of the gypsum waste received	$\mathrm{TECH1.1} = \frac{I}{GW}$ $\mathrm{TECH1.2} = \frac{GW_w}{GW}$	TECH2.1 ≤ 2%; TECH2.2≤ 10%
TECH2. Gypsum waste rejected	$\mathrm{TECH2} = \frac{\mathrm{GW_r}}{\mathrm{GW}}$	0%
TECH3. Required space for storage the gypsum waste	$\mathrm{TECH3} = \frac{\mathrm{GW}}{0.40}$	TECH1 ≥ 0.40/GW m^3
TECH 4. Output materials of the recycling process	$TECH4.1 = \frac{RG}{GW_p}$ $TECH4.2 = \frac{P}{GW_p}$ $TEC54.3 = \frac{M}{GW_p}$	Paper output > 0%:
ENV1. CO_2 emissions from the recycling process	$\mathrm{ENV1.1} = \frac{(\mathrm{EExEe})+(\mathrm{EFxEf})}{\mathrm{GW_p}}$ $\mathrm{ENV1.2} = \frac{F_{CO2} \text{ x RG x } D_r \text{ x } RT_r}{1000}$	ENV1.1+ENV1.2 < 2.033 kg CO_2 eq/t
ENV2. Natural gypsum saved	RG (t)	ENV2 > 0 t
SOC1. Recycler's satisfaction	TECH2 = COMPLIANCE ; TECH3 = NO RECYCLED GYPSUM REJECTED	High
ECO1. Energy cost of the gypsum waste processing	$\mathrm{ECO1} = \frac{C_{TE}+CTF}{GW_p}$	(n/a) €/t
ECO2. Transport cost of the recycled gypsum	$\mathrm{ECO2} = \frac{C_F\, x\, ELF\, x\, Dm\, x\, RTm}{RG}$	(n/a) €/t
Gypsum waste received - GW (t)	Electricity consumption - E_e (kWh)	Total processing electricity cost - C_{TE} (€)
Reference density - 0.40 (t/m^3)	Fuel consumption - E_f (l)	Total processing fuel cost - C_{TF} (€)
Impurities manually separated - I (t)	Electricity emission factor - EE (kg CO_2 eq/kWh)	GW processed by the recycling equipment - GW_p (t)
Wet Gypsum Waste received - GW_w (t)	Emission intensity of Fuel -EF (kg CO2 equiv/l)	Fuel cost - C_F (€/l)
Gypsum waste rejected - GW_r (t)	RG per roundtrip to reincorporation- RG_{rd} (t)	Lorry consumption - E_{LF} (l)
Recycled gypsum obtained - RG (t)	Distance to reincorporation - D_r (km)	Distance manufacturing plant - D_m (km)
Paper fraction - P (t)	Roundtrips to reincorporation - RT_r (No.)	Number of roundtrips - RT_m (No.)
Metal fraction - M (t)	C. Freight transportation factor - F_{CO2} (g CO2 eq/tkm)	(n/a) not applicable
Gypsum waste processed - GW_p (t)		

Once gypsum waste from construction and demolition waste is separated on site, it shall be collected by a third party and transported to a recycling plant for its processing.

Identified technical KPIs at this stage, mainly involve issues related to the compliance with the recyclers' acceptance criteria, in accordance with the report "Guidance document with criteria for acceptance of recycled gypsum for recycling" developed in the GtoG project [9], as a rejection rate may occur if high moisture content or presence of contaminants is found in the load. After processing gypsum waste, ratio of the output material is considered due to the fact that if paper value is low, it can be attributed to not a properly removal, affecting therefore the quality of the final recycled gypsum. Besides, the required space for storage is assessed, as a covered warehouse keeps gypsum waste clean and dry.

Environmental KPIs measure the emissions resulting from the waste recycling process and the transport of the recycled gypsum to the manufacturing plant for its reincorporation. The results shall be compared with the extraction of natural gypsum, which has been obtained from reference data [10]

Social KPIs assess satisfaction reported by the recycler in relation to the quality of the gypsum waste received.

Economic KPIs involve the cost evaluation of all the key processes part of this stage (i.e. recycling process and transportation).

Table 3. KPIs Reincorporation

INDICATOR	FORMULA	EVALUATION CRITERIA
TECH1. Recycled gypsum rejected by the manufacturer	$\mathrm{TECH1} = \frac{RG_R}{RG}$	0%
TECH2. Recycled gypsum quality criteria	*Technical parameters are within the limit value* *Toxicological parameters are within the limit value*	Compliance with the agreed criteria*
TECH3. Warehouse storage capacity for recycled gypsum	$\mathrm{TECH3} = \frac{RG_S}{0.70}$	TECH3 ≥ 0.70/RG_S m^3
TECH4. Recycled gypsum content	$TECH4.1 = \frac{RG_{PRE}}{PB}$ $TECH4.2 = \frac{RG_{POST}}{PB}$	TECH4.1+TECH4.2 ≥ 22.3%
TECH5. Recycled content increase	$\mathrm{TECH5.1} = \frac{\mathrm{RG_{PRE}+RGPOST}}{\mathrm{PB}}$ TECH5.2 *RG reincorporation rate***	TECH5.1-TECH5.2 > 10%
TECH6. Production waste	$TECH6 = \frac{PB_{NC}}{PB}$	TECH6 ≤ 4%
ENV1. CO_2 emissions: business-as-usual compared to maximized recycled content (RC)in the pre-processing	$\mathrm{ENV1} = (E_{PRE}\ x\ EE) + (NG_{PRE}\ x\ EF_{NG}) + (WF_{PRE}\ x\ EF_{WF})$ ENV1.1Bussines as usual -ENV1.2 Maximized RC	ENV1.1 - ENV1.2 ≥ 0 kg CO_2 eq
ENV2. CO_2 emissions: business-as-usual compared to maximized recycled content in the production process	$\mathrm{ENV2.1} = (E\ x\ EE) + (NGx\ EF_{NG}) + (WFx\ EF_{WF})$ ENV2.1Bussines as usual -ENV2.2 Maximized RC	ENV2.1 - ENV2.2 ≥ 0 kg CO_2 eq
SOC1. Manufacturer's satisfaction	*Plasterboard fulfillment with EN 520 Standard (YES/NO)*	YES= High
ECO1. Cost difference between business-as-usual and maximized recycled content quality check	$\mathrm{ECO1} = \frac{CF_{QCC}}{CF} - \frac{RG_{QCC}}{RG}$	ECO1 > 0 €/t
ECO2. Cost difference between natural gypsum and recycled gypsum	$\mathrm{ECO2} = \mathrm{NG_c} - \mathrm{RG_c}$	ECO2 > 0 €/t
ECO3. Cost difference between FGD gypsum and recycled gypsum	$\mathrm{ECO3} = \mathrm{FGD_c} - \mathrm{RG_c}$	ECO3 > 0 €/t
ECO4. Energy cost difference between business-as-usual and maximized recycled content in the pre-processing	$\mathrm{ECO4} = (E_{PRE}\ x\ E_c) + (NG_{PRE}\ x\ NG_c) + (WF_{PRE}\ x\ WF_c)$ ECO4.1.1Bussines as usual -ECO4.2 Maximized RC	ECO4.1 - ECO4.2 > 0 €/t
ECO5. Energy cost difference between business-as-usual and maximized recycled content in the production process	$\mathrm{ECO5} = (E\ x\ E_c) + (NG\ x\ NG_c) + (WF\ x\ WF_c)$ ECO5.1Bussines as usual -ECO5.2 Maximized RC	ECO5.1 - ECO5.2 > 0 €/t

*The considered limit values are taken from the GtoG report "Protocol of action B2.2: Quality criteria for recycled gypsum, technical and toxicological parameters "

**30% is the reincorporation target rate of the GtoG project

Total recicled gypsum received - RG (t)	Total non-conforming plasterboard generated - PB_{NC} (t)	Total conventional feedstock - CF (t)
Total RG rejected - RG_R (t)	Electricity consumption - E_{PRE}(kWh/m^2 board)	Total RG feedstock - RG (t)
Total RG stored - RG_S (t)	Natural gas - NG_{PRE} (kWh/m^2 board)	Cost of natural gypsum per tonne NG_C (€/t)
Reference density - 0.70 (t/m^3)	Waste fuel - WF_{PRE} (kWh/m^2 board)	Cost of RGper tonne RG_C (€/t)
Pre-consumer recycled gypsum -RG_{PRE} (t)	Electricity emission factor - EE (kg CO_2 eq/kWh)	Cost of FGD gypsum per tonne FGD_C (€/t)
Total plasterboard produced - PB (t)	Emission intensity of NG -EF_{NG} (kg CO_2 eq/kWh)	Cost of electricity - E_C (€/kWh)
Post-consumer recycled gypsum - RG_{POST} (t)	Emission intensity of WF -EF_{WF} (kg CO_2 eq/kWh)	Cost of natural gas - NG_C (€/KWh)
Total plasterboard produced - PB (t)	Conventional feedstock quality check total cost - CF_{QCC} (€)	Cost of waste fuel - WF_C
	RG feedstock quality check - RG_{QCC} (€)	

Once the plasterboard waste has been processed, the gypsum recycler provides the manufacturer with the recycled gypsum that will be reincorporated in the production process. Technical KPIs in the reincorporation stage address recycled gypsum compliance with the quality criteria (agreed between manufacturers and recyclers), in relation to technical and toxicological specifications.

A properly dimensioned storage place should be set up in order to guarantee a constant recycled gypsum feedstock.

Recycled gypsum rate used in feedstock, considering both pre-consumer and post-consumer[2] recycled gypsum reincorporated and the increase in the reincorporation rate, by comparing the business-as-usual rate with the result obtained in indicator are also calculated. Total amount of plasterboard produced is compared with the production waste (nonconforming plasterboard generated during the process), according to a reference value. The lower is the waste generated during the manufacturing process, the more efficient is.

Environmental KPIs measure the emissions resulting from maximizing the recycled feedstock in the reincorporation process versus business as usual.

Social KPIs assess satisfaction reported by the plasterboard manufacturer in relation to the acceptance of the plasterboard manufactured with increased recycled content, in line with the quality requirements in BS EN 520:2004+A1:2009 – Gypsum Plasterboards – Definitions, Requirements and Test Methods.

Economic KPIs calculate deviation between the business-as-usual quality check, input material and steps for reincorporation with the cost of the feedstock with maximized recycled content.

[2] Pre-consumer refers to waste generated from the manufacturing process after quality inspections as out-of- specification boards, failing to meet the set quality standards. Post-consumer refers to gypsum waste from construction (off-cuts, damaged plasterboards etc.) and demolition/deconstruction sites.

1.3. SUMMARY OF BPIs

From the previous analysis and reassessment 29 KPIs specifically aiming to recognize and encourage best practices through the entire value chain are selected as BPIs due to their impact and added value for close loop gypsum recycling.

BPIs seek to increase the amount of gypsum waste capable of being recycled, as well as to maximize the quality and percentage of recycled gypsum that can be reincorporated in the manufacturing process.

Table 4 summarize BPIs classified by category: technical (TEC), environmental (ENV).social (SOC) and economic (ECO).

Table 4 Final BPIs at a glance

Deconstruction - Best practice indicators (BPIs)		
Criteria	**Stage**	**Indicator**
TECH	Audit Deconstruction Traceability	TECH1. Existence and deviation of the audit for gypsum-based systems TECH2. Effectiveness of the deconstruction process TECH3. Effectiveness of the traceability
ENV	End route	ENV1. Gypsum waste sent to landfill ENV2. Transport emissions comparison between recycling and landfilling
SOC	Deconstruction	SOC3. Training of the deconstruction team SOC4. Follow-up of the waste management
ECO	Traceability	ECO4. Cost difference between recycling GW and landfilling route

Recycling - Best practice indicators		
Criteria	**Stage**	**Indicator**
TECH	Reception Storage Processing	TECH1. Quality of the gypsum waste received TECH2. Gypsum waste rejected TECH3. Warehouse storage capacity for gypsum waste TECH4. Output materials of the recycling process
ENV	Processing and transport	ENV1. CO_2 emissions from the recycling process ENV2. Natural gypsum saved
SOC	Reception	SOC1. Recycler's satisfaction

Reincorporation - Performance indicators		
Criteria	**Stage**	**Indicator**
TECH	Reception	TECH1. Recycled gypsum rejected by the manufacturer TECH2. Recycled gypsum quality criteria
	Storage	TECH3. Warehouse storage capacity for recycled gypsum
	Reincorporation	TECH4. Recycled gypsum content TECH5. Recycled content increase
	Manufacturing	TECH6. Production waste
ENV	Preprocessing	ENV 1. CO_2 emissions: business-as-usual compared to maximized recycled content in the preprocessing
	Manufacturing	ENV 2. CO_2 emissions: business-as-usual compared to maximized recycled content in the production process
SOC	Manufacturing	SOC1. Manufacturer's satisfaction
ECO	Reception	ECO1. Cost difference between business-as-usual and maximized recycled content quality check ECO2. Cost difference between natural gypsum and recycled gypsum ECO3. Cost difference between FGD gypsum and recycled gypsum
	Preprocessing	ECO4. Energy cost difference between business-as-usual and maximized recycled content in the preprocessing
	Manufacturing	ECO5. Energy cost difference between business-as-usual and maximized recycled content in the production process

Whilst for deconstruction and recycling there are several socio-economic indicators that have been discarded, mainly due to their variability depending on the country under study, for the case of reincorporation all of them are considered crucial (Table 5).

Table 6. Non-Selected KPIs as BPIs

DECONSTRUCTION KPIs	NON - SELECTED KPIs CRITERIA
SOC1. Labour time difference between dismantling and demolishing plasterboard	It doesn't impact on the implementation of best practices
SOC2. Productivity	Variable depending on skills of the workers and peculiarities of the country under study
ECO1. Audit cost	Variable depending on the country under study
ECO2. Plasterboard dismantling and loading cost	Variable depending on the country under study
ECO3. Gypsum block dismantling and loading cost	Variable depending on the country under study
RECYCLING KPIs	**NON - SELECTED KPIs CRITERIA**
ECO1. Energy cost of the gypsum waste processing	Variable depending on the country under study and the equipment performance
ECO2. Transport cost of the recycled gypsum	Variable depending on the country under study

1.4. PILOT PROJECTS OVERVIEW

Description, criteria taken into consideration for the study and BPIs results for each of the pilot projects, are shown in the following fact sheets.

GtoG Pilot project 1: Belgium

Deconstruction Site
Recycler

GENERAL DATA

Duration: **08/ 2014 – 12/2014**
Deconstruction location: **Brussels – BE** Demolisher: **RECASS**
Description of the building: **two-storey building, office, from 1990**
Square meters of gypsum system (m^2): **2,800**
Type of gypsum system: **Double-sided plasterboard partition with a metallic frame, infilled with mineral wool insulation**
Amount of recyclable gypsum waste (t): **42.94**
Amount of non-recyclable gypsum waste (t): **0.00**
Recycling location: **Källo – BE** Recycler: **NWGR**
Manufacturing location: **Källo – BE** Manufacturer: **GYPROC**

DECONSTRUCTION
Dismantling: Mechanically
Sorting: Mechanically
Loading: Mechanically (Bobcat)

TRANSPORT
3 skips of 20 m^3
3 roundtrips
2 skips per roundtrip
64.6 km

RECYCLING
Usual average output after processing:
Gypsum 94%
Paper 6%
Metal 1%

TRANSPORT
No transport needed, manufacturing plant adjacent to the recycling facility.

REINCORPORATION
Usual recycled gypsum reincorporation source: production and C&D waste.
Usual reincorporation rate: 10 %
Project's reincorporation rate: 26,32 %

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Audit	TECH1	
	Deconstruction	TECH2	
	Traceability	TECH3	
ENV	End route	ENV1	
		ENV2	
SOC	Deconstruction	SOC4	
		SOC5	
ECO	Traceability	ECO4	

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Storage	TECH1	
	Reception	TECH2	
		TECH3	
	Processing	TECH4	
ENV	Processing and transport	ENV1	-
		ENV2	
SOC	Processing	SOC1	

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Reception	TECH1	
		TECH2	
	Logistic	TECH3	
	Reincorporation	TECH4	
		TECH5	
	Production	TECH6	
ENV	Preprocessing	ENV1	-
	Manufacturing	ENV2	
SOC	Manufacturing	SOC1	
ECO	Reception	ECO1	
		ECO2	n/a
		ECO3	
	Preprocessing	ECO4	-
	Manufacturing	ECO5	

DECONSTRUCTION

The total amount of gypsum waste generated was tracked as well as accepted by the recycler. Deviation between the recyclable gypsum waste generated and foreseen is 28%, and therefore above the agreed criteria [a].

Environmental and economic benefits are shown for the recycling route compared with the landfilling route as both emissions were less and the total amount of recyclable gypsum was sent to the recycling facility.

[a] Deviation <20%: Acceptable

RECYCLING

No impurities neither any significant amount of wet gypsum was found in the load, which was been totally accepted and appropriately stored in the recycling facility. There is a lack of data regarding processing and transport for ENV1.

REINCORPORATION

Although all recycled gypsum was accepted, not all technical and toxicological parameters fulfill the GtoG guidelines (TECH2)[b].

The recycled content incorporated is in line with the project target (up to 30%), experiencing a significant increase with respect to the usual rate (TECH5).

In addition, the percentage of production waste generated is below the European average (TECH6).

There is a lack of data regarding energy consumption in the pre-processing stage (ENV1 and ECO4).

[b] Deliverable DB4: Report of Production Process Parameters

GtoG Pilot project 2: France

GENERAL DATA

Duration: **08/ 2014 – 01/2015**
Deconstruction location: **Paris – FR** Demolisher: **PIN**
Description of the building: **three-storey building, commercial, from 1998.**
Square meters of gypsum system (m²): **340**
Type of gypsum system: **Gypsum block partition, Double-sided plasterboard partition with a metallic frame, infilled with expanded polystyrene, plasterboard ceiling with a metallic frame.**
Amount of recyclable gypsum waste (t): **9.38**
Amount of non-recyclable gypsum waste (t): **7.80**
Recycling location: **Vaujours - FR** Recycler: **NWGR**
Manufacturing location: **Vaujours - FR** Manufacturer: **PLACOPLATRE**

DECONSTRUCTION
Dismantling: Manually (automatic screwdriver and pickaxe)
Sorting: Manually (wheelbarrow and shovel)
Loading: Mechanically (telescopic)

TRANSPORT
2 skip of 20 m³
1 roundtrip
2 skips per roundtrip
39.5 km

RECYCLING
Usual average output after processing:
Gypsum 94%
Paper 6%
Metal 1%

TRANSPORT
No transport needed, manufacturing plant adjacent to the recycling facility.

REINCORPORATION
Usual recycled gypsum reincorporation source: production and C&D waste.
Usual reincorporation rate: 15 %
Project's reincorporation rate: 27.77 %

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Audit	TECH1	
	Deconstruction	TECH2	
	Traceability	TECH3	
ENV	End route	ENV1	
		ENV2	
SOC	Deconstruction	SOC4	
		SOC5	
ECO	Traceability	ECO4	

DECONSTRUCTION

The total amount of gypsum waste generated was tracked as well as accepted by the recycler. This is the only case where the deviation of the audit for gypsum-based systems complies (TECH1).

Environmental and economic benefits are shown for the recycling route compared with the landfilling route as both emissions were less and the total amount of recyclable gypsum was sent to the recycling facility.

Regarding the non-recyclable gypsum waste, plaster blocks and plasterboards appeared glued to ceramics and sound / thermal insulation respectively.

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Storage	TECH1	
	Reception	TECH2	
		TECH3	
	Processing	TECH4	
ENV	Processing and transport	ENV1	-
		ENV2	
SOC	Processing	SOC1	

RECYCLING

No impurities neither any significant amount of wet gypsum was found in the load, which was been totally accepted and appropriately stored in the recycling facility. There is a lack of data regarding processing and transport for ENV1.

REINCORPORATION

All recycled gypsum was accepted, complying with the quality criteria according to the GtoG guidelines (TECH2)[a]. The recycled content incorporated is in line with the project target (up to 30%), experiencing an increase with respect to the usual rate (TECH5).

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Reception	TECH1	
		TECH2	
	Logistic	TECH3	
	Reincorporation	TECH4	
		TECH5	
	Production	TECH6	
ENV	Preprocessing	ENV1	-
	Manufacturing	ENV2	
SOC	Manufacturing	SOC1	
ECO	Reception	ECO1	-
		ECO2	-
		ECO3	-
	Preprocessing	ECO4	-
	Manufacturing	ECO5	-

The percentage of production waste generated is lightly higher than the European average (TECH6).

[a] Deliverable DB4: Report of Production Process Parameters

GtoG Pilot project 3: The United Kingdom

GENERAL DATA

Duration: **07/2014 – 02/2015**
Deconstruction location**: London – UK** Demolisher: **CANTILLON**
Description of the building: **twelve-storey building, offices, from 1980's**
Square meters of gypsum system (m²): **8,640**
Type of gypsum system**: Plasterboard partition, metal frame, glass/rock wool insulation.**
Amount of recyclable gypsum waste (t): **50.00**
Amount of non-recyclable gypsum waste (t): **0.00**
Recycling location: **Avonmouth – UK** Recycler: **NWGR**
Manufacturing location: **Bristol – UK** Manufacturer: **SINIAT**

DECONSTRUCTION

Dismantling: Manually (crowbar, pickaxe or sledgehammer)
Sorting: Manually (hopper)
Loading: Mechanically (bobcat)

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Audit	TECH1	
	Deconstruction	TECH2	
	Traceability	TECH3	
ENV	End route	ENV1	
		ENV2	
SOC	Deconstruction	SOC4	
		SOC5	
ECO	Traceability	ECO4	

TRANSPORT

199.00 km

RECYCLING

Usual average output after processing:
Gypsum: 94%
Paper: 6%
Metal: <1%

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Storage	TECH1	
	Reception	TECH2	
		TECH3	
	Processing	TECH4	
ENV	Processing and transport	ENV1	-
		ENV2	
SOC	Processing	SOC1	

TRANSPORT

6.60 km

REINCORPORATION

Usual recycled gypsum reincorporation source: production and C&D waste.
Usual reincorporation rate: around 15%
Project's reincorporation rate: 22.5%

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Reception	TECH1	
		TECH2	
	Logistic	TECH3	
	Reincorporation	TECH4	
		TECH5	
	Production	TECH6	
ENV	Preprocessing	ENV1	-
	Manufacturing	ENV2	
SOC	Manufacturing	SOC1	
ECO	Reception	ECO1	-
		ECO2	
		ECO3	n/a
	Preprocessing	ECO4	-
	Manufacturing	ECO5	

DECONSTRUCTION

A pre-deconstruction audit is not mandatory in this country (TECH1). All the gypsum waste generated was recyclable plasterboard waste, which was 100% tracked and accepted by the recycler. Environmental benefits are shown. However, a higher recycling fee than landfill is observed (ECO4).

RECYCLING

No impurities neither any significant amount of wet gypsum was found in the load, which was appropriate stored in the recycling facility.
There is a lack of data regarding processing and transport (ENV1).

REINCORPORATION

All recycled gypsum was accepted (TECH1). However, not all technical and toxicological parameters fulfill the GtoG guidelines (TECH2)[b]. The recycled content increase is 7.5%, which is considered medium achievement[a].

There is a lack of data regarding energy consumption in the pre-processing stage (ENV1 and ECO4) and the specific amount of quality checks carried out were not available (ECO1).

[a] Deliverable DC1: above10% increase: high achievement

GtoG Pilot project 4: France

Deconstruction Site
Recycler

GENERAL DATA

Duration: **01/2014- unknown**
Deconstruction location: **Levallois Perret – FR** Demolisher: **OCC**
Description of the building: **nine-storey building, offices, from 1968.**
Square meters of gypsum system (m^2): **6,740**
Type of gypsum system: **Gypsum block partition, Double-sided plasterboard partition with a metallic frame, infilled with expanded polystyrene, plasterboard ceiling with a metallic frame.**
Amount of recyclable gypsum waste (t): **67.52**
Amount of non-recyclable gypsum waste (t): **0.00**
Recycling location: **Auneuil– FR** Recycler: **Siniat**
Manufacturing location: **Auneuil– FR** Manufacturer: **Siniat**

Dismantling: Manually (automatic screwdriver and pickaxe)
Sorting: Manually (hopper)
Loading: Mechanically (Bobcat)

13 skip of 10 m^3
7 roundtrips
2 skips per roundtrip
86 km

Usual average output after processing: Confidential

No transport needed, manufacturing plant adjacent to the recycling facility.

Usual recycled gypsum reincorporation source: production and C&D waste.
Usual reincorporation rate: 10-15 %
Project's reincorporation rate: 18.05 %

DECONSTRUCTION — **TRANSPORT** — **RECYCLING** — **TRANSPORT** — **REINCORPORATION**

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Audit	TECH1	
	Deconstruction	TECH2	
	Traceability	TECH3	
ENV	End route	ENV1	
		ENV2	
SOC	Deconstruction	SOC4	
		SOC5	
ECO	Traceability	ECO4	

DECONSTRUCTION

The total amount of gypsum waste generated was tracked as well as accepted by the recycler. However, the deviation of the pre-deconstruction audit in relation to the real amount of gypsum waste generated is above the established criteria. Environmental and economic benefits are shown.

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Storage	TECH1	
	Reception	TECH2	
		TECH3	
	Processing	TECH4	
ENV	Processing and transport	ENV1	-
		ENV2	
SOC	Processing	SOC1	

RECYCLING

No impurities neither any significant amount of wet gypsum was found in the load, which was appropriate stored in the recycling facility.
There is a lack of data regarding processing and transport.

REINCORPORATION

All recycled gypsum was accepted, complying with the quality criteria according to the GtoG guidelines [a] (TECH 1 and TECH2). The recycled gypsum content is below the pilot's project average – 22.3% (TECH4). Similarly, the recycled content increase (TECH5) does not meet the threshold established (>10%).

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Reception	TECH1	
		TECH2	
	Logistic	TECH3	
	Reincorporation	TECH4	
		TECH5	
	Production	TECH6	
ENV	Preprocessing	ENV1	-
	Manufacturing	ENV2	
SOC	Manufacturing	SOC1	
ECO	Reception	ECO1	
		ECO2	
		ECO3	n/a
	Preprocessing	ECO4	-
	Manufacturing	ECO5	

There is a lack of data regarding energy consumption in the pre-processing stage (ENV1 and ECO4).

[a] Deliverable DB4: Report of Production Process Parameters

GtoG Pilot project 5: Germany

Deconstruction Site

GENERAL DATA

Duration: **02/2014 – 01/2015**
Deconstruction location: **Graben – DE** Demolisher: **KSE**
Description of the building: **five single-storey buildings, offices, from 1965**
Square meters of gypsum system (m^2): **3,450**
Type of gypsum system: **plasterboard ceiling, wooden frame, mineral wood insulation; Plasterboard laminate, metallic frame; Plasterboard partition, wooden frame, wood wool insu.**
Amount of recyclable gypsum waste (t): **23.64**
Amount of non-recyclable gypsum waste (t): **13.00**
Recycling location: **Werkendam – NL** Recycler: **GRI**
Manufacturing location: **Iphofen – DE** Manufacturer: **KNAUFKG**

DECONSTRUCTION

Dismantling: Manually (crowbar, pickaxe or sledgehammer)
Sorting: Manually (wheelbarrow and shovel)
Loading: Manually and mechanically

TRANSPORT

4 skips of 36 m^3
4 roundtrips
2 skips per roundtrip
80 km

RECYCLING

Usual average output after processing:
Gypsum: 90%
Paper: 10%
Metal: <1%

TRANSPORT

Assumption: 5 km*

*There is no gypsum recycler in Germany

REINCORPORATION

Usual recycled gypsum reincorporation source: production waste.
Usual reincorporation rate: up to 5%
Project's reincorporation rate: 17%

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Audit	TECH1	
	Deconstruction	TECH2	
	Traceability	TECH3	
ENV	End route	ENV1	
		ENV2	-
SOC	Deconstruction	SOC4	
		SOC5	
ECO	Traceability	ECO4	-

DECONSTRUCTION

Around 55% of the plasterboard waste generated was laminates, which are currently considered as non-recyclable gypsum waste (GW). This is why the deviation of the pre-deconstruction audit in relation to the real amount of recyclable GW generated is above the established criteria[a]. The rest of GW generated was tracked as well as accepted by the recycler. Environmental and economic benefits are shown. ECO4 couldn´t be calculated due to confidential issues.

[a] Deviation <20%: Acceptable

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Storage	TECH1	
	Reception	TECH2	
		TECH3	
	Processing	TECH4	
ENV	Processing and	ENV1	-
	transport	ENV2	
SOC	Processing	SOC1	

RECYCLING

No impurities neither any significant amount of wet gypsum was found in the load, which was appropriate stored in the recycling facility.

There is a lack of data regarding processing and transport (ENV1).

REINCORPORATION

The manufacturer reports 20% of not usable material (TECH1) and technical and toxicological parameters do not fulfill the GtoG guidelines (TECH2)[b]. Therefore, the manufactured plasterboard did not reach the manufacturer's requirements, so it was considered production waste (TECH6).

CATEGORY	STAGE	BPIs	COMPLIANCE
TECH	Reception	TECH1	
		TECH2	
	Logistic	TECH3	
	Reincorporation	TECH4	
		TECH5	
	Production	TECH6	
ENV	Preprocessing	ENV1	-
	Manufacturing	ENV2	
SOC	Manufacturing	SOC1	
ECO	Reception	ECO1	
		ECO2	n/a
		ECO3	n/a
	Preprocessing	ECO4	-
	Manufacturing	ECO5	

While the recycled gypsum content is below the pilot project's average - 22.3% (TECH4), the recycled content increase is above 10%, which is considered high achievement (TECH5).

[b] Deliverable DB4: Report of Production Process Parameters

2. GOOD PRACTICES FOR AN IMPROVED VALUE CHAIN

In the framework of this study, which focuses on optimal gypsum waste management, practices promoting closed-loop recycling and quality recycled gypsum, referred to as “good practices”, are outlined along with an overview emphasizing the key characteristics of each measure that seek to guide stakeholders when applying them, as factsheets. Moreover, each factsheet presents EU agents’ evaluation in terms of importance on closing the loop of gypsum products, implementation and feasibility. The most valued practices, named as “best practices”, have been recognized by value chain operators in recycling countries as current leading approaches, built on their experience. All the identified practices address BPIs’ compliance and aim to achieve the ultimate goal of achieving a circular economy for the gypsum products.

On the basis of previous BPIs developments (Section 1), the process of identifying good practices involved data gained from desk research, field visits and expert meetings. In this regard, the desk research focused on compiling previous studies on good measures concerning waste management, recycling and secondary materials quality criteria. The site visits and expert meetings helped to verify the current practices as well as the interests and concerns of the operators of the value chain.

Once the full set of measures required for achieving a circular economy for gypsum products is produced -a total of 23 good practices-, 16 best practices are identified. In addition, the relevance of each practice per level of importance, implementation and feasibility (see Annex 1) of each practice based on whether they have a market for recycled gypsum exist or countries in which a market for recycled has not exist yet, is shown. To that end, an online survey questionnaire was conducted at European scale, mainly targeting construction, deconstruction and demolition companies, gypsum recyclers, gypsum products manufacturers as well as researchers.

After the evaluation process, a total of 23 good practices, 11 practices concerning construction/deconstruction, 11 related to recycling and manufacturing issues and 1 common to both processes, were ranked as listed hereunder, in order of importance on closing the loop of gypsum products and per stage (tables 7 and 8). Among them, the 17 most valued practices recognised by agents in recycling countries are considered as best practices, which are the most leading approaches for the achievement of an improved value (index value above 4 (out of 5, see Annex 1).

Table 7. Good (DE1-DE11 and GE2) and best practices (in green) for deconstruction

No.	Best practice	Rank
DE7	Perform an on-site segregation of recyclable (e.g. plasterboard, blocks) gypsum waste	1
DE2	Appointment of a responsible for the follow-up of the waste management	2
DE3	Implement an effective pre-deconstruction audit for gypsum-based systems	3
DE5	Train workers concerning gypsum products dismantling, as well as sorting and storing of GW	4
DE1	Plan coordination and review meetings about C&D waste	5
DE11	Perform gypsum waste traceability, from source to final destination	6
DE4	Draft and implement a precise Site waste management plan (SWMP)	7
DE9	Plan number and size of containers needed	8
DE10	Minimize number of roundtrips (from building site to transfer station/recycling)	9
DE8	Effective planning of gypsum waste capture systems (from source to on-site storage)	10
GE2	Availability of suitable closed-top skips	11
DE6	Appointment of trained workers in gypsum products dismantling, sorting and storing of GW	12

Table 8. Good (RE1-RE7, MA1-MA3 and GE1-GE2) and best practices (in green) for recycling and manufacturing

No.	Best practice	Rank
RE4	Set clear Waste Acceptance Criteria (WAC)	1
RE5	Perform effective sorting operations prior to gypsum recycling	2
RE2	Have an adequate warehouse for gypsum waste and recycled gypsum storage	3
MA1	Agree clear recycled gypsum quality criteria	4
RE1	Recycling plant or warehouse strategically located	5
RE3	Operate a Quality Management System (QMS)	6
RE7	Agree suitable supply contracts between recyclers and manufacturers	7
MA3	Set a recycled gypsum reincorporation target	8
RE6	Prepare a schedule of sampling and test frequencies for each quality criteria parameter	9
MA2	Promote plasterboard take-back schemes	10
GE1	Address the End-of-Waste (EoW) status	11
GE2	Availability of suitable closed-top skips	12

The information concerning each practice is presented in datasheets, organised as follows: (blank datasheet showing each part will be placed here)

2.1. CONSTRUCTION AND DECONSTRUCTION

Associted with both deconstruction and construction activities.

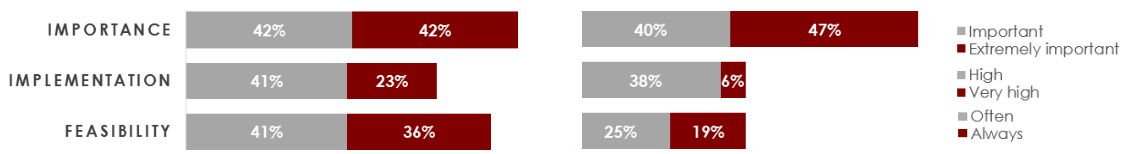
DE1. Plan coordination and review meetings

Related BPIs		
DE	RE	MA
T1	T1	
T2	T2	
T3	E2	
E1	S1	
E2		

Regular meetings to review coordination measures in order to identify problems and discuss procedures, schedules, coordination and specific requirements for waste materials recycling and disposal, in compliance with the requirements of the C&D Waste Management Plan (SWMP).

EU Agents consultation

Recycling countries | **Non-recycling countries**



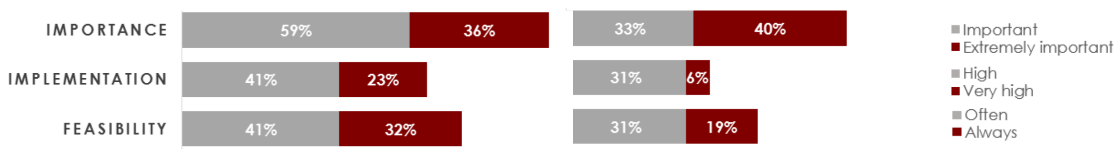
DE2. Appointment of a worker responsible for the follow-up of the waste management

BPIs RELATED		
DE	RE	MA
T1	T1	
T2	T2	
T3	E2	
E1	S1	

The only way to ensure that and effective waste management system is being followed is by having always at least one person in charge of supervising waste management operations and inspectioning storage areas regularly. Periodic checks on the use of GW skips should be carried out, which involves: covering the waste skips at the end of the day in order to reduce the potential of moisture, removal of impurities if any, and tracking records among others.

EU Agents consultation

Recycling countries | **Non-recycling countries**



DE3. Implement an effective pre-deconstruction audit for gypsum-based systems

Related BPIs		
DE	RE	MA
T1	T1	
T2	T2	
E1	E2	
	S1	

An audit of gypsum based waste materials prior to deconstruction reduces the uncertainty on what systems will be found when dismantling, identifying the range and quantities of materials expected to be procured from the dismantling of the existing buildings and structures, as well as their potential for recycling.

Due to its importance in the design and cost estimation of the early project planning, audits should be mandatory for any type of demolition work and refurbishment operations above a certain surface or a certain budget, threshold to be determined according the type of the building, residential or non-residential.

The audit shall be referenced in the SWMP and cover:

A. Identification of the key refurbishment/demolition materials (source,type, amount)

B. Potential applications and any related issues for the re-use and recycling of the key refurbishment and demolition materials.

C. Potential cost savings associated

Existing regulatory audits in the GtoG targeted projects

FRANCE
Audit of the materials prior to demolition, for buildings with a surface higher than 1000 m² and buildings where there used to be an agricultural, industrial or commercial activity and where one or several hazardous substances have been used, stocked, manufactured or distributed.

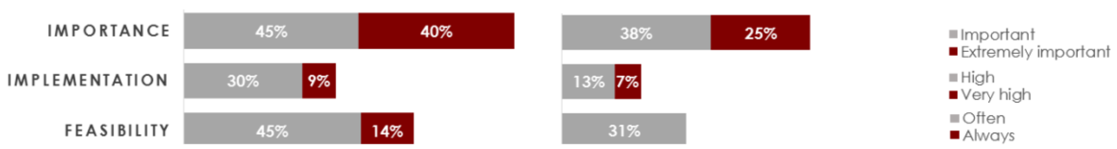
GERMANY
Audit of the materials prior to demolition, especially in suspicious cases. For mineral substances, after demolishing, an analysis of bulk materials is carried out.

Example of existing EU tools

SMARTWaste (UK): Site Methodology to Audit, developed by the Building Research Establishement (BRE).
It helps to dentify ways to maximise reuse and recycling during the demolition and refurbishment phases of a project thus saving valuable resources and reducing project costs.

EU Agents consultation

Recycling countries | **Non-recycling countries**



DE4. Draft and implement a precise site waste management plan (SWMP)

Related BPIs		
DE	RE	MA
T1	T1	
T2	T2	
T3		
E1	E2	
E2		
S4	S1	
Ec4		

Apart from a pre-deconstruction audit (DE.3), a SWMP is also crucial, to the extent that in many countries it is already a legislative requirement prior to the implementation of construction works, in line with good practices and relevant legislation objectives.
A SWMP must be started before any activity begins, consisting in a detailed description of the waste management strategies adopted and waste control applied for each type of waste fraction at all stages during the project, in order to maximise the recovery rates of material by establishing targets. It should provide an assessment of the quantity and waste flows arising, identifying cost and best options on how targest may be achieved. The SWMP must be updated during the course of the project as a live document recording any deviations on how waste is actually managed.

Existing regulatory audits in the GtoG targeted countries

SPAIN
The Spanish Government issued the Royal Decree 105/2008 (Ministry of the Presidency, 2008) which establishes as a mandatory requirement the development of waste management systems for each construction project, based on the drawing up of:
- A Waste Management Report (WMR) developed during the design phase of the project.
- A Waste Management Plan (WMP) developed during the planning of the construction work.

UK
Regulations introduced in April 2008, place the obligation to produce a SWMP before the project starts for all Construction and Demolition works over a value of £300,000.

EU Agents consultation

Recycling countries | Non-recycling countries

DE5. Train workers concerning gypsum products dismantling, as well as sorting and storing of gypsum waste (GW)

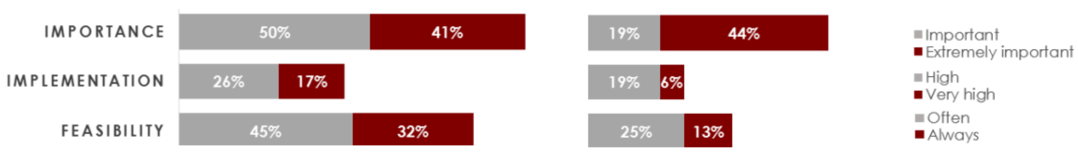
Related BPIs

DE	RE	MA
T1	T1	
T2	T2	
E1	E2	
S3	S1	

Deconstruction methods are more labor-intensive compared with demolition. However, deconstruction's basic skills are easily learned. Periodic training programmes provide unskilled and low-skilled workers the needed waste management knowledge to carry out effective handling, segregation and storage of C&D waste.

EU Agents consultation

Recycling countries | Non-recycling countries



DE6. Appointment of trained workers in gypsum products dismantling, as well as sorting and storing of gypsum waste (GW)

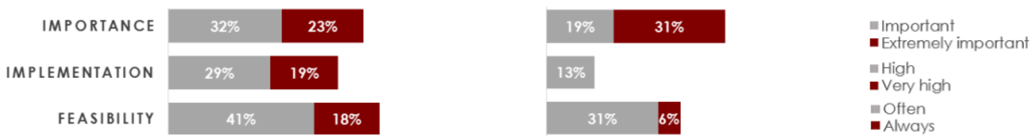
Related BPIs

DE	RE	MA
T1	T1	
T2	T2	
E1	E2	
DS3	S1	

In order to ensure an efficient source separation and subsequent storage, trained workers (DE.5) should be appointed to conduct gypsum products deconstruction. By way of example, something as simple as placing GW straight into the bins or skips, rather than stockpiling it first and collect it later on, represents noticeable time savings.

EU Agents consultation

Recycling countries | Non-recycling countries



GYPSUM TO GYPSUM

DE7. Perform an on-site segregation of gypsum waste (GW)

Related BPIs		
DE	RE	MA
T1	T1	
T2	T2	
E1	E2	
E2	S1	

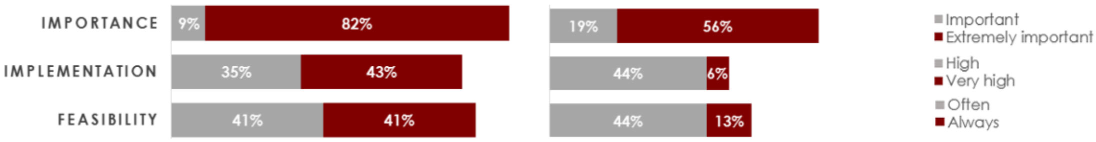
On-site segregations refers to the process of sorting gypsum waste suitable for recycling from the residual waste stream at source, or in a separate facility. However a high-quality recovery is more likely to happen when an improved segregation has been perform at source, whereas in a transfer stations the possibility of receiving a gypsum waste that fulfills the waste acceptace specifications for recycling is limited, as it might be contaminated once it has been already mixed with other waste streams. In the GtoG countries doing essentially deconstruction (the UK, the Netherlands, Belgium, France and Germany), after the strip out/dismantling phase, gypsum waste is generally segregated from the other waste.
In this regard, an improved segregation closely depends on the effectiveness of the dismantling, sorting and loading operations, determined by the type of gypsum-based system and the potential constrains associated to the pecualiarities of each work site.

Case studies segregation methods

STAGE	ADVISABLE PROCEDURES ACCORDING TO IMPLEMENTED OPERATIONS IN THE GTOG PILOT PROJECTS	
DISMANTLING	Techniques preferably must allow collection of building components in the reverse order as how they were originally constructed, which saves time on the jobsite to sorte at source and load. Tools must be choosen accordingly with the type of gypsum system.	When plasterboard: If glued, spade or shovel are than crowbar. If attached to a fixed framework, unscrew. If nailed, remove with a crowbar. If arranged to a chanel, any tool that enables the removal of the chanel. If cutting-is needed, saber saw.
		When blocks: Pickaxe allows the cutting of the blocks which facilitate their segregation and loading.
		When plasterboard hanging ceilings: Remove by hand tiles, unscrew hangers and fixed frames.
	Note: More rarely, small machines (hydraulic machines, compact excavators or other) can also be used when there is enough space on the site.	
REMOVAL AND STORAGE TO THE GROUND FLOOR	Movement of waste from the source floor to the ground floor for the off site removal, minimizing manual handling as much as possible.	Loading of a wheeled trolley by hand, then dropp down a chute/hopper by hand to ground level or bobcat machines. Loading with the help of a bobcat machines of skips lifted by a lift
	This has relation with the capture system method. (See factsheet DE8. Effective planning of gypsum waste capture systems)	
LOADING	Load in to a roll-on-roll-off skip or directly in to the back of a tipper, in specific loading locations	Loading of the skip mechanically (e.g telescopic rotating forklift, bobcat)

EU Agents consultation

Recycling countries | **Non-recycling countries**



DE8. Effective planning of gypsum waste (GW) capture systems

Related BPIs		
DE	RE	MA
T1	T1	
T2	T2	
E1	E2	
	S1	

It is essential to plan the adoption of adequate capture systems, adapted to construction site characteristics at an early project planning stage, in order to operate the most efficient means and ease its implementation on-site. Capture systems are mainly used when waste final loading involves all the steps needed to transfer gypsum waste from source to the receptacle.
The most efficient capture systems limit manual handling as far as possible, reducing the total number of collections and increasing the quantity of material recovered.

Recommendations from the implementation actions in the GtoG pilot projects

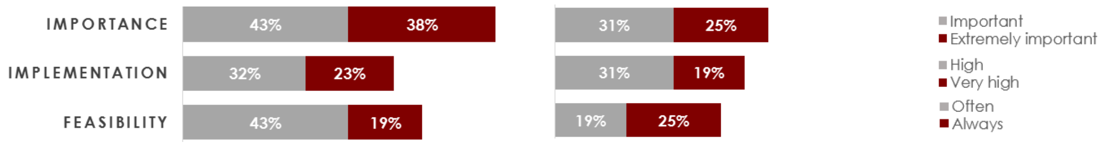
The **smaller number of steps** in the capture process proved very effective.

Encourage labourers to reduce **double-handling,** minimize potential contamination.

Skips place adjancent to the footprint of the buidling **feeding the waste directly into the skip** rather than being stockpiled before tipping into the skip.

EU Agents consultation

Recycling countries | Non-recycling countries



DE9. Plan number and size of containers needed

Related BPIs		
DE	RE	MA
T1	T1	
T2	T2	
E1	E2	
E2	S1	

The number and size of containers needed, considering the amount of storage space available depending on the construction site peculiarities, can be planned for an efficient collection frequency with the estimated volume of gypsum waste calculated in the pre-deconstruction audit (see DE3) and SWMP (see DE4), prior to the commencement of the deconstruction works.

When planning, it should be also noted that often collectors supply their own containers for the recycling of gypsum waste of various sizes. Such role can be performed by either transport, waste mangement companies and recyclers.

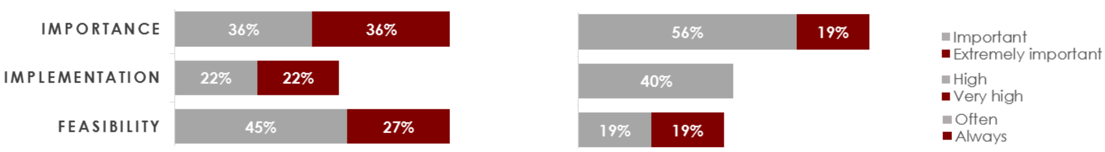
This practice entails economic and time saving as GW storage and roundtrips to its final destination are optimized.

Useful figures for planning

Plasterboard waste in the container usually has a density of 0.25 t/m^3.
By way of example, a GtoG recycler has developed specific gypsum waste steel containers with 30 m^3 and 40 m^3 of capacity.

EU Agents consultation

Recycling countries | **Non-recycling countries**



GE2. Availability of suitable close-top skips

Related BPIs		
DE	RE	MA
E1	T1	
T2	T2	
T1	E2	
	S1	

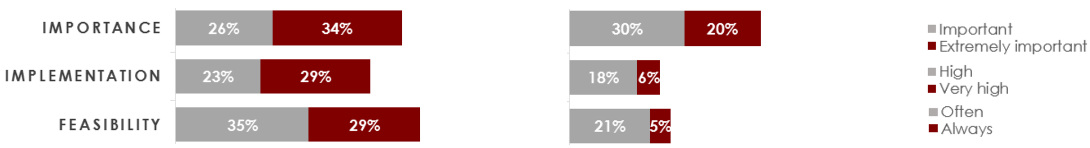
Closed-top skips are preferentially recommended for GW storage in order to protect waste safed from wet weather and minimize free moisture.

Covered C&D waste steel container

Specific gypsum waste steel containers

EU Agents consultation

Recycling countries | **Non-recycling countries**



DE10. Minimize number of roundtrips to recycling

Related BPIs		
DE	RE	MA
E2		

The frequency of waste collection should be planned in advance, ensuring that, whenever possible, only full container load is transported whilst preventing containers from overfilling.
In order to improve such logistics, it is advisable not to exchange full containers with empty ones but to collect the content from several containers, depending on the size of the grab truck. This way the number of trips to the warehouse is reduced.
When roundtrips to GW final destination are optimized by reducing vehicle movements and distances, significant cost savings and environmental benefits can be achieved.

Useful figures for planning

The coefficient of expansion is an important parameter to be determined as precisely as possible. There is no existing theoretical table. By experience demolition companies participating in the GtoG project reported:
Density of waste inside the grab truck increases to 0.35 t/m^3.

EU Agents consultation

Recycling countries | **Non-recycling countries**

DE11. Perform gypsum waste (GW) traceability, from source to final destination

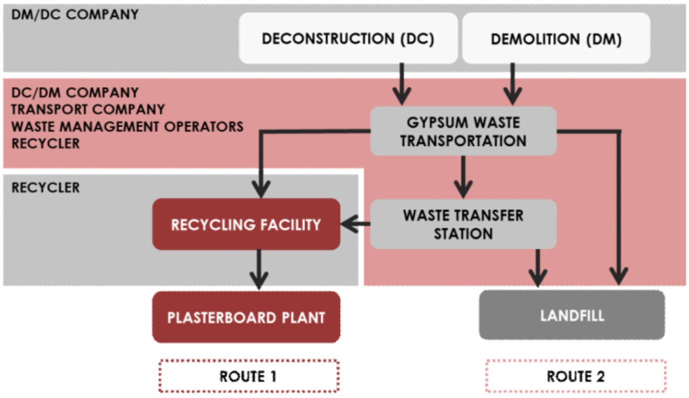
Related BPIs		
DE	RE	MA
T3	E2	
E1	S1	
S4		

Traceability involves following waste flows not only from the jobsite to the transfer station, but also and above all, from the transfer station to the final outlets.
However nowadays, it does not appear as common practice for construction or demolition companies to confirm the final outlets of the waste by keeping tracking records, with a few exceptions due to the company policy. Thus it is recommended that legislation requires traceability documents, as the countries have to monitor qualitatively and quantitatively the rates of construction and demolition wastes in order to reach European objectives at the same time that ensuring transparency, quality assurance and compliance with SWMP.

In Germany, the UK, France, Belgium, Spain and the Netherlands, the demolition companies sometimes directly carry out waste collection going in the outlets (transport) and sometimes require a third party (waste transport company). This choice is often specific to the project – its size, its geographical location – and to the costs generated. Companies which do not directly carry out waste collection and require a third party (waste transport company) rarely require other tracking records than the regulatory ones.

Agents involved in the traceability system per stage at the end-of-life (EoL)

The figure below shows the different flows of gypsum-based waste from the jobsite to the different outlets in most of the GtoG countries by agent involved and stage of the value chain.



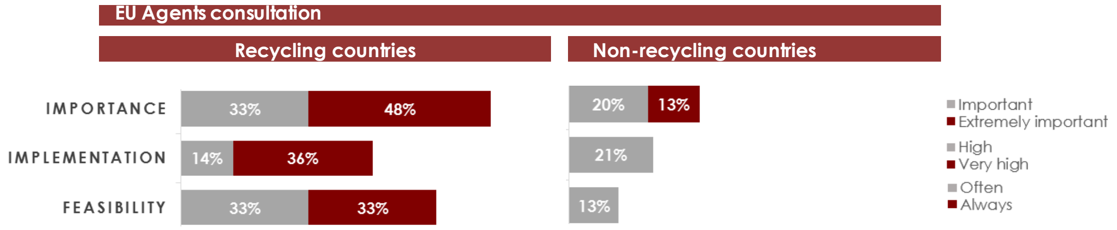
Current practices in the GtoG countries under study

In **Germany**, the demolition companies commonly use a consignment note and a weight note for non hazardous waste but it is not regulatory. For hazardous wastes, the companies use an "accompanying document". The disposal of more than 20 tonnes per construction project requires the use of an electronic register ("eANV – electronic waste

Greece legislation requires that the establishments or undertakings that transport non hazardous waste keep the records mentioned in the Waste Framework directive for at least two years.

In **France**, tracking records are only regulatory for hazardous waste but since the 29 February 2012, any operator of transfer station or waste treatment plant has to draw up and update a chronological register of outgoing wastes, whatever the waste category is.
Moreover, some companies require the weighing voucher of the transfer station, the haulage contractor approval or also the collecting company approval but this is really

In the **UK**, a transfer note is produced for the transfer of "controlled waste".


EU Agents consultation
Recycling countries
Non-recycling countries
IMPORTANCE
IMPLEMENTATION
FEASIBILITY
33%
48%
14%
36%
33%
33%
20%
13%
21%
13%
Important
Extremely important
High
Very high
Often
Always

2.2. RECYCLING AND MANUFACTURING

RE1. Recycling plant or warehouse strategically located

Related BPIs		
DE	RE	MA
E1	E1	
E2	E2	
Ec4		

The warehouse main purpose is to store waste for the recycling process. Warehouses should be placed in regions of high amount of waste produced or purchased or in a geographical proximity to the recycling plant, in order to significantly save in transportation costs not only from the waste source but also to the ultimate buyer. Besides, a suitable route should take into consideration to minimize impacts from a social and environmental perspective as well (e.g. local ecosystem disturbance, land value degradation, traffic burden, etc).

Type of recyclings plants

RECYCLING UNIT MOBILE

Sometimes there is not enought plasterboard waste in a single warehouse to use a recycling unit close to its full capacity. By using a mobile unit, the machine can operate more efficiently and a new warehouse and a new collection point ca be set up relatively fast and with reduced fixed cost.

GRI Mobile plasterboard recycling unit

RECYCLING UNIT FIXED

Fixed unit are advisable in areas with a

NWGR fixed plasterboard recycling unit

Recycling distances from GtoG Recycling operators

Responses from surveyed Gypsum recyclers operating in France, Denmark and Belgium, stated that: *(further information DA1: Inventory of current practices)*

What is the distance you travel by truck from the construction/demolition site to your facilities and from your facilities to the gypsum factories?
From site to recycling facilities the average distance travel by truck, 100-200 km
From recycling facilities to gypsum factories, 5-20 km
0 km when the recycling facilities are located in the gypsum factories' terrain

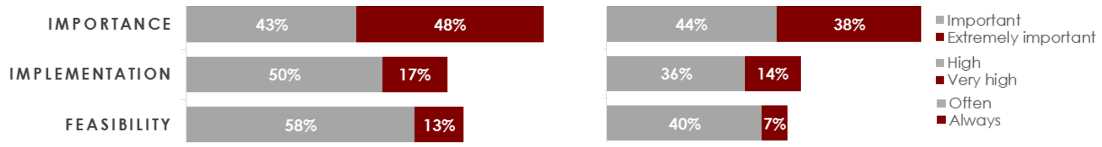
What is the distance you travel by truck from the construction/demolition site to your facilities and from your facilities to the gypsum factories?

GtoG target recycling	Transport from recycling warehouse to the plasterboard plants	Suppliers of recycled gypsum identified by PB manufacturers
Belgium	NWRG Recycling warehouse is co-located in the SG manufacturing plant in Källo (Flemish region)	NWGR
France	NWGR Recycling warehouse is co-located in the SG manufacturing plant (Vaujours, París) Siniat Plasterboard manufacturer has its own recycling warehouse Nantet Locabennes supply recycled gypsum to SG Placoplatre in Chambéry Ritleng Revalorisations supplies recycled gypsum to Siniat FR in Alsace	NWGR Nantet Locabennes Ritleng Revalorisations
The Netherlands	GRI's mobile truck collects plasterboard waste on the construction Also two GRI's fix recycling warehouse, located in Werkendam and	GRI
The UK	A plasterboard manufacturer (British Gypsum) is also collector and recycler, reincorporating the recycled gypsum in its process NWGR's recycling warehouse in Avonmouth	NWGR, Roy Hatfields, Arrow and Countrystyle

GYPSUM TO GYPSUM

EU Agents consultation

Recycling countries	Non-recycling countries



RE2. Have an adequate warehouse for gypsum waste (GW) and recycled gypsum (RG) storage

Related BPIs

DE	RE	MA
	T3	T1
	E2	T2

GW storage areas shall ensure that damage, external contamination and deterioration (e.g.moisture content) is prevented. Such areas should be maintained in accordance with the QMS requirements, taking into account the agreed recycled gypsum quality criteria (see MA1).

Requirements for the warehouse depend on the nature of the reycling unit, i.e. if the recycling unit is fixed or mobile.

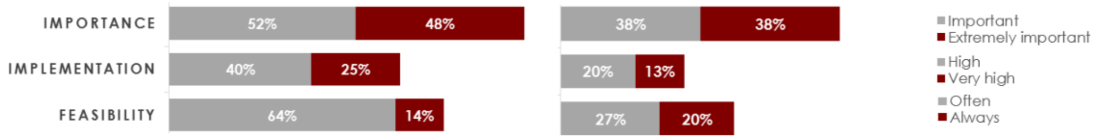
Useful figures for planning

Mobile recycling plant
The specific requirements of warehouses designed for a mobile recycling unit are the following:
Minimum size: 30x60m
Minimum height: 10m

Coefficient of expansion
By experience demolition gypsum recyclers participating in the GtoG project reported: GW increases up to 0.4 t/m^3 at the pile in the warehouse.

EU Agents consultation

Recycling countries	Non-recycling countries



RE3. Operate a quality management system (QMS)

Related BPIs		
DE	RE	MA
	T1	T1
	T2	T2
	T3	
	T4	
	E1	
	E2	

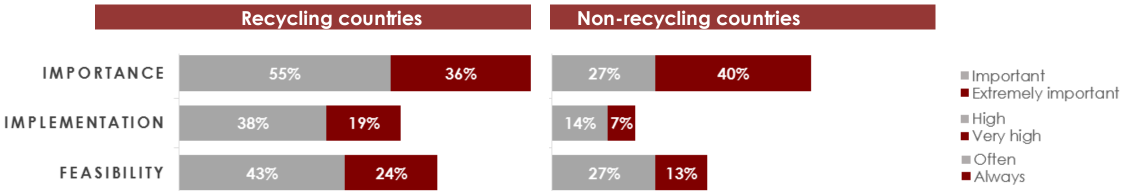
A quality assurance system is an important tool to demonstrate compliance with the RG quality criteria defined by the company, as well as to create reliability on the end-of-waste criteria, if existing. For this purpose, an internationally recognized and externally verified QMS may be operated, such as ISO 9001 or similar.
Using the example of the criteria laid down in other industries, a suitable QMS for GW shall include:
- Acceptance control of GW: The procedure for recognizing impurities (i.e. non-GW, hazardous materials, etc. -see datasheet RE4) shall be documented under the QMS.
- Monitoring quality of the RG resulting from the processing operation and record keeping of the results from monitoring.
- Monitoring the treatment processes, techniques and record keeping of the results from monitoring.
- Feedback from costumers concerning compliance with RG quality.
- Review and improvement of the management system.
- Training of staff.
- Measurable quality objectives

Moreover, the QMS should be documented, implemented, communicated, updated and audited periodically to ensure effectiviness.

Examples of existing EU QMS

British Standard PAS main aim is to provide a specification that can be adopted by recyclers for producing defined grades of recycled gypsum from waste plasterboard, such that potential customers will be assured that they are procuring a material of consistent and verifiable quality.
The standard came into effect in 2013.

EU Agents consultation



RE4. Set clear waste acceptance criteria (WAC)

Related BPIs		
DE	RE	MA
	T1	
	T2	
	E2	
	S1	

Upon reception waste is examined to ensure there is no impurities and compliance with requirements against a set of agreed value limits for the acceptance to be recycled. These requirements are the so-called Waste Acceptance Criteria (WAC) and mainly consists in visual inspection.
Once accepted, the material undergoes a second inspection in case any inappropriate substance (wood, plastic, metal etc.) was overlooked to be removed before the material reaches the main body of the plans prepared and fed into the recycling plant.

If rejected, the load shall be sent to a transfer station where sorting is applied and then it is forwarded to the recycler again.

WAC should be communicated to customers or agreed between recyclers and manufacturers thus they could develop their system in line with the WAC, so as to facilitate the acceptance control of GW.

List of accepted and non-accepted gypsum waste by the three GtoG recyclers

The three recyclers of the project agreed on the below WAC further to the detailed testing and analysis of the recycled gypsum by Loemco.

	Accepted by GRI, NWGR, SINIAT SA	After approval by specific recycler	Not accepted by GRI, NWGR, SINIAT SA
Gypsum Blocks	■		
Gypsum ceilings, floors, walls, stucco..	■		
Gypsum waste with nails and screws, wallpaper, glass tissue and other wall coverings	■		
Plaster in bags	■		
Cove	■		
Glass reinforced gypsum products (GRG)	■		
Boards with tinfoil and polystyrene		■	
Gypsum Fibre boards		■	
Moulds		■	
Plasterboard with glass fiber netting		■	
Gypsum based ceiling tiles		■	
Plasterboard with insulations (EPS-PS)		■	
Hazardous materials, e.g. asbestos			■
Autoclaved aerated concrete (AAC)			■
Cement bound boards			■

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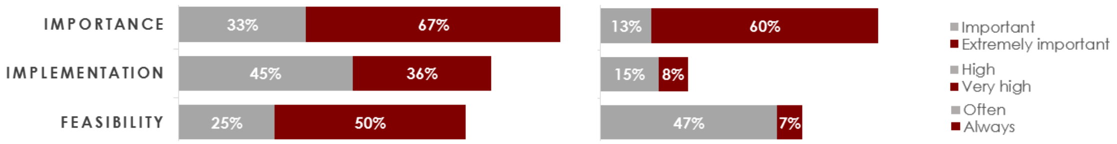
Recycling countries | **Non-recycling countries**



RE5. Perform effective sorting operations prior to gypsum waste (GW) processing

Related BPIs		
DE	RE	MA
	T4	

The source where the waste is produced usually determines the level of impurities; this is the case of pre-consumer GW (generated during the manufacturing process) or post-consumer GW (derived from construction, renovation and deconstruction works).
GW from construction works requires less sorting prior to waste storage than waste from renovation and deconstruction works, as it might be mixed with other waste fractions that contaminate the gypsum recovery.

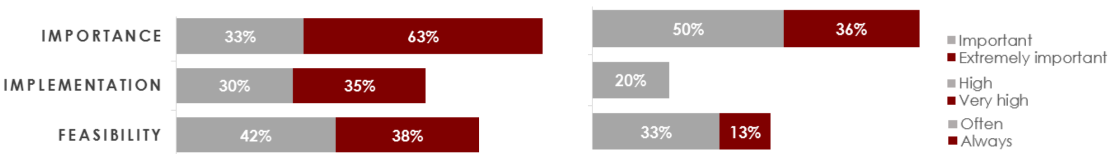
In any case, presence of impurities in the accepted waste load is typically limited to 2%*, for this reason and in order to ensure suitability for the manufacturer's feedstock as well as high quality recycled gypsum, the material undergoes a second hand-cleaned inspection(pre-sorted) of metal, plastic and other debris before

On the other hand, moisture content is also a common issue to take into consideration when accepting gypsum waste, as it hinders the separation of the paper liner from the gypsum core, increasing the use of fuel for processing the waste or even obstructing the machine mechanisms.
In order to avoid it, if a gypsum-based waste fraction presents a particular high level of moisture, it can be stored with a dryer fraction until it gets dry enough to be processed.

*This admissible content may be particularly defined by each recycler in their respective WAC

EU Agents consultation

Recycling countries | **Non-recycling countries**



RE6. Prepare a schedule of sampling and test frequencies for each quality criteria parameter

Related BPIs		
DE	RE	MA
		T1
		T2

The process of determining monitoring frequencies in accordance with RG quality criteria should be documented as part of the QMS and should be available for auditing. In addition, sampling results should be recorded, kept for the competent authorities and made available on their request. The sampling procedures and calibration methods shall be also made available to auditing.

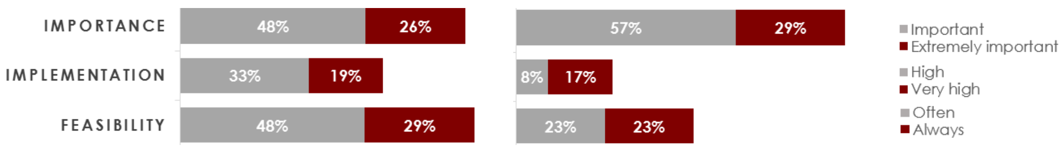
Quality parameters agreed in the GtoG project

The new testing protocol according to VGB-M 701 Instruction considers the tests of the following table: (futher information can be found in the report:
Gypsum to Gypsum project LIFE11 ENV/BE/001039, "DC2: Protocol of action B2.2: Quality criteria for recycled gypsum, technical and toxicological parameters."

Parameter	Test method	Test type
Particle size (granulometry)	UNE-EN 933-1	Physical
Humidity	VGB serial number 1	Chemical
Purity (Calcium Sulphate $CaSO_4$ $2H_2O$)	VGB serial number 2.3	Chemical
Total Organic Carbon (TOC)	UNE EN 13137	Chemical
Magnesium salts, walter soluble	VGB serial number 8.1.2	Chemical
Sodium salts, walter soluble	VGB serial number 8.2.2	Chemical
Potassium salts, water soluble	VGB serial number 8.3.2	Chemical
Soluble Chloride	VGB serial number 8.8.3	Chemical
pH	VGB serial number 4	Chemical
Trace elements (As, Be, Pb, Cd, Cr, Co, Cu, Mn, Ni, Hg, Se, Te, Tl, V, Zn)	DIN EN ISO 11885 (ICP-OES)	Analytical
Radioactivity (^{40}K; ^{137}Cs; ^{226}Ra; ^{232}Th)	Internal procedure	Analytical

EU Agents consultation

Recycling countries | **Non-recycling countries**



RE7. Agree suitable supply contracts between recyclers and manufacturers

Related BPIs		
DE	RE	MA
		T1
		T2

Supply contracts should be agreed in a collaborative manner. The required information should be obtained, supplied and retained in order to demonstrate, when requested, that RG supplied is destined for appropriate use.

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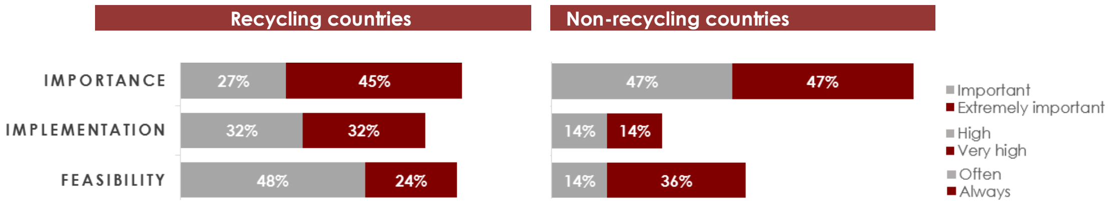


MA1. Set clear recycled gypsum (RG) quality criteria

Related BPIs		
DE	RE	MA
		T1
		T2

Criteria against which the recycler will assess the gypsum waste load to ascertain if they will accept it for processing or reject it.
the GtoG project recyclers and producers have a collaborative approach for the establishment of quality criteria for the recycled gypsum, testing
20 recycled gypsum samples by a third party laboratory, partner in the project.
According to results, it was agreed guidelines for quality criteria covering technical and toxicological parameters.

Some examples of different quality criteria currently found in the European context

In Germany: The RG initial test for recycling plants, quality management, quality requirements and analysis methods from the German Gypsum Association (BV Gips).

In the UK: PAS 109:2013 Specification For The Production Of Reprocessed Gypsum From Waste Plasterboard.

GtoG RG Quality Criteria

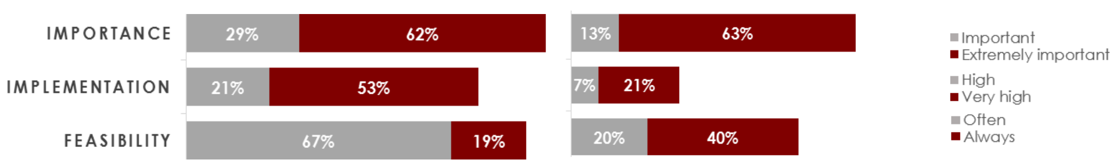
Technical parameters	Test method	GtoG guidelines
Particle size (mm)	UNE-EN 933-1	0-15
Free moisture (% w/w)	VGB serial number 1	<10
Purity - calcium sulphate dihydrate (% w/w)	VGB serial number 2.3	>80
Total organic carbon TOC (% w/w)	Gigt 3.1.3.2 DepV DIN EN 13137	<1.5
Magnesium salts, water soluble, MgO (% w/w)	VGB serial number 8.1.2	<0.1
Sodium salts, water soluble, Na_2O (% w/w)	VGB serial number 8.2.2	<0.06
Potassium salts, water soluble, K_2O (% w/w)	VGB serial number 8.3.2	<0.05
Soluble Chloride, Cl (% w/w)	VGB serial number 8.8.3	<0.02
Ph	VGB serial number 4	6-9

Toxicological parameters	Test method	GtoG guidelines
As (mg/kg)	DIN EN ISO 11885 Determination of selected elements ICP-OES (acc to DepV)	<4
Be (mg/kg)		<0.7
Pb (mg/kg)		<22
Cd (mg/kg)		<0.5
Cr (mg/kg)		<25
Co (mg/kg)		<4
Cu (mg/kg)		<14
Mn (mg/kg)		<200
Ni (mg/kg)		<13
Se (mg/kg)		<16
Te (mg/kg)		<0.3
Tl (mg/kg)		<0.4
V (mg/kg)		<26
Zn (mg/kg)		<50
Hg (mg/kg)	DINEN 1483 AAS-DINEN 12338 DIN ISO 1785[a]	
Radioactivity index	RP 112 Document (EC) 52	<0.5
Asbestos	atomic absorbance and PLM[b]	0

[a] DINEN 1483 AAS-DINEN 12338-Mercury process after enrichment by amalgamation, DIN ISO 1785 atomic fluorescence spectrometry (acc to MatelVO)

[b] see guidelines in GtoG deliverable DC2: Quality criteria for recycled gypsum, technical and toxicological parameters

Recycling countries | **Non-recycling countries**



MA2. Promote plasterboard take-back schemes

Related BPIs		
DE	RE	MA
T3	T1	
E1	T2	
	E2	
	S1	

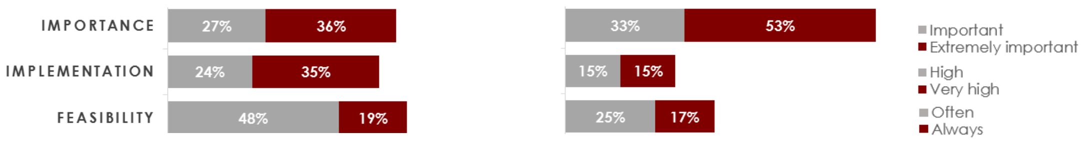
Efficient take-back and recycling or re-use programs refer to the design and organization of the collection and logistics processes from the building site to the recycling warehouses or facilities. They extend the responsibilities of the manufacturer of the product, which is known as Extended Producer Responsibilities (EPR) schemes.
Worldwide, countries are increasingly putting in place voluntary schemes and take-back laws, in which the material is taken back by the manufacturer at its End-of-Life (EoL), in order to guarantee recovery and recycling.
Currently, take-back schemes are not mandatory within the construction industry, and thus only voluntary ones exist. These initiatives respond to the construction industry's need to find easy to implement alternatives to C&D waste landfilling.

Examples of existing EU take-back schemes

Further information on already developed and tested take-back schemes for gypsum plasterboard can be found in the following document:
WRAP: Plasterboard Case Study British Gypsum take-back scheme. (2006).

EU Agents consultation

Recycling countries | **Non-recycling countries**



MA3. Set a RG reincorporation target

Related BPIs		
DE	RE	MA
E1	E2	

Once the gypsum waste has been processed, the recycler provides the manufacturer with the recycled gypsum that will be reincorporated in the production process. The establishment of corporate objectives on environmental sustainability, as a manufacturer's corporate social responsibility, particularly addressing RG content, promotes closed-loop gypsum recycling.

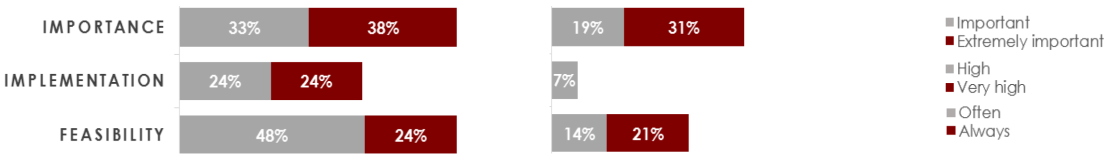
Production with gradually increasing amounts of recycled gypsum

Within the GtoG project, it has been proved technically feasible to reincorporate up to 30% of recycled gypsum, defined either by product quality and/or process efficiency in accordance with the process-specific technical features.

	BE	FR	UK	FR	DE
RG from Production source					
RG from C&D waste source					
Usual reincorporation rate	10%	15%	15%	10-15 %	5%
Project's reincorporation rate	26%	28%	23%	18%	17%

The recycled gypsum powder used during the reincorporation phase has been tested by the laboratory LOEMCO.

Recycling countries | **Non-recycling countries**



GE1. Address the End-of-Waste (EoW) status

Related BPIs		
DE	RE	MA
E1		T1
		T2

EoW was adopted by the European Parliament and the Council in the revised Waste Framework Directive (WFD) 2008/98/EC, where a provision was included by which certain specified waste shall cease to be waste when it has undergone a recovery operation and complies with specific criteria in accordance with a number of conditions, this is the

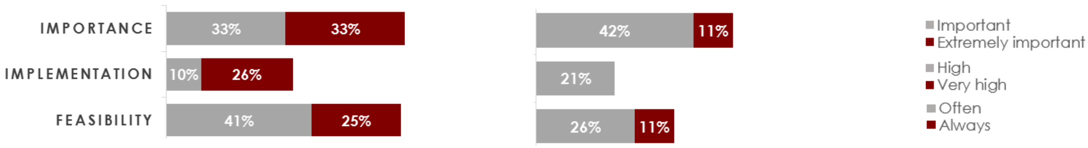
EU examples and GtoG agreement concerning the gypsum EoW status

EoW criteria for the production and use of RG from plasterboard waste are only a reality in the UK, governed by the Quality Protocol (WRAP and Environment Agency 2013).

In the GtoG Grant agreement, it was foreseen to establish the quality properties of the recycled gypsum and in parallel to assess the opportunity to establish the end-of-waste criteria for the recycled gypsum at EU level.Further information on the advances achieved so far concerning quality criteria can be found in the report:
Gypsum to Gypsum project LIFE11 ENV/BE/001039: DC2: Protocol of action B2.2: Quality criteria for recycled gypsum, technical and toxicological parameters.

EU Agents consultation

Recycling countries | **Non-recycling countries**



3. CONCLUSIONS AND RECOMMENDATIONS

Currently, in the EU-28, a market for recycled gypsum only exists in France, Benelux, Finland, the UK, Denmark and Sweden. The European Life+ GtoG Project ENV/BE/001039: "From Production to Recycling, a Circular Economy for the European Gypsum Industry with the Demolition and Recycling Industry" has laid the foundations to transform markets for recycled gypsum in order to achieve higher recycling rates, thereby helping to contribute to an effective resource efficient economy. Large amounts of recyclable gypsum waste (i.e. mainly plasterboard and gypsum blocks) can be recovered from the existing building stock and follow the recycling route. By choosing better practices that promote gypsum recycling instead of landfilling, natural resource depletion is minimized, H_2S, CO_2 and CH_4 emissions from landfill disposal are avoided and landscape preservation is promoted.

The present report presents 23 good practices focused on optimal gypsum waste management and the use of recycled gypsum in new gypsum products, assessed by their importance on closing the loop of gypsum products, implementation and feasibility. Among them, the 17 most valued practices recognised by agents in recycling countries are considered as best practices, which are the most leading approaches for the achievement of an improved value chain.

The identified best practices address the entire gypsum value chain (i.e. deconstruction, recycling and reincorporation), being focused on the end-of-life (EoL) of gypsum products (i.e. deconstruction, transport to recycling, recycling), due to the importance of the EoL stage on closing the materials cycles. Recommended best practices are listed below by influence order per stage of the value chain.

During the deconstruction process:

- Perform an on-site segregation of recyclable (e.g. plasterboard, blocks) gypsum waste
- Appointment of a responsible for the follow-up of the waste management
- Implement an effective pre-deconstruction audit for gypsum-based systems
- Train workers concerning gypsum products dismantling, as well as sorting and storing of gypsum waste
- Plan coordination and review meetings about C&D waste
- Perform gypsum waste traceability, from source to final destination
- Draft a precise Site waste management plan (SWMP) and implement it
- Plan number and size of containers needed
- Minimize number of roundtrips (from building site to transfer station/recycling)

During the recycling and manufacturing processes:

- Set clear Waste Acceptance Criteria (WAC)
- Perform effective sorting operations prior to gypsum recycling
- Have an adequate warehouse for gypsum waste and recycled gypsum storage
- Agree clear recycled gypsum quality criteria
- Recycling plant or warehouse strategically located
- Operate a Quality Management System (QMS)
- Agree suitable supply contracts between recyclers and manufacturers
- Set a recycled gypsum reincorporation target

ANNEXES

ANNEX 1. CONSULTATION TO STAKEHOLDERS

Good practices regarding their contribution to an efficient closed-loop supply chain
Each section was evaluated in relation to three main aspects with a grading of a 5-point scale where:

For the level of importance: Influence of the given practice on closing the loop of gypsum products.
1 - Negligible;
2 - Unimportant;
3 - Neutral;
4 - Important;
5 - Extremely important;
DK/NA - Don't know/Not applicable

The level of implementation: Current probability of occurrence of the given practice, in your national context.
1 - Never;
2 - Seldom;
3 - Occasionally;
4 - Often;
5 - Always;
DK/NA - Don't know/Not applicable

The feasibility: The extent to which they can be applied or put in practice.
1 - Very low;
2 - Low;
3 - Moderate;
4 - High;
5 - Very high;
DK/NA - Don't know/Not applicable

(further explanation with detailed description of the survey still to be added)

The composition of the survey respondents were agents from table 9.

Table 9. Respondents of the final GtoG consultation

Agent	Responses
Gypsum products manufacturer	9
Building project manager	1
Deconstruction/demolition company	13
Construction company	5
Waste collector	3
Gypsum recycler	8
Researcher	9
Public institution	3
Environmental consultant	1
Other	6
Total	58

From the total number of responses the distribution per country participation is shown in the following graph.

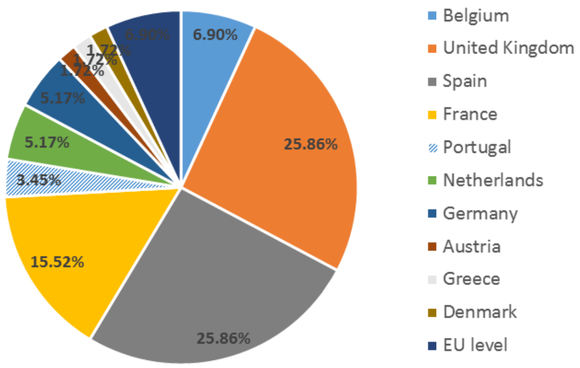


Figure 2. Respondents per country

ANNEX 2. FACTORS IMPACTING GYPSUM RECYCLING

Drivers towards deconstruction, gypsum recycling and reincorporation of recycled gypsum were outlined in a report on current practices [2]. Economic, legislative and environmental issues were the most highly rated drivers encouraging closed-loop gypsum recycling. On this basis, six factors were formulated to analyse markets for recycled gypsum:

- Coverage of the gypsum recycling route
- Segregation of gypsum waste from other C&D waste
- Environmental focus of the waste owner and/or gypsum manufacturer
- Competitiveness of the recycling route compared to local landfills
- Compliance with the existing regulation impacting gypsum waste
- Legal alternative destinations that do not favour the options that are higher in the waste hierarchy

Such factors, along with their related sub-factors extracted from the body of literature covering C&D waste management and previous GtoG reports, have been subject to public consultation in November 2015, with the aim of assessing the validity of such framework amongst experienced value chain operators in Europe, from both countries with and without a market for recycled gypsum.The success factors for gypsum recycling in Europe will serve as reference to help stakeholders and decision-makers on the path towards a circular economy around gypsum.

Results from the recycling countries point out three factors among the top three, with roughly the same percentage of importance – from 94 to 97%- regarding their contribution to build a circular economy around gypsum in terms of importance: “Compliance with the existing regulation”, “Segregation of GW from other C&D waste” and “Competitiveness of the recycling route”. Notwithstanding, in the overall assessment, all factors are rated as highly valued (Figure 3).

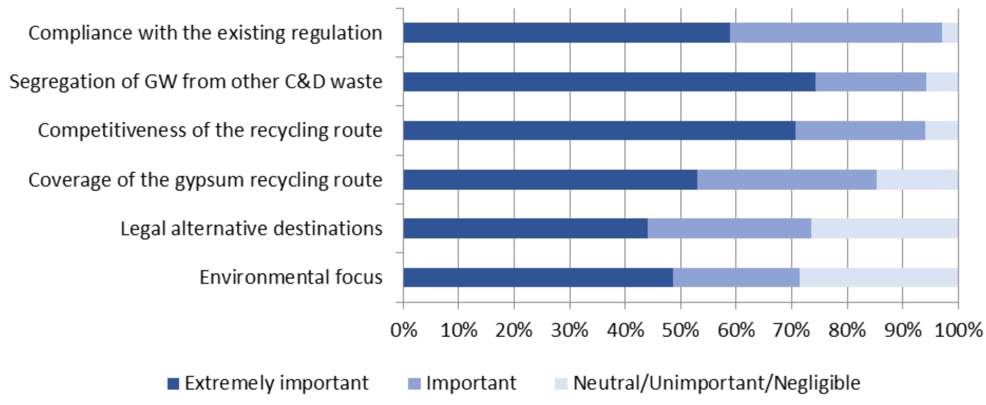


Figure 3. Success factors for gypsum recycling

As regards the related sub-factors, results have been grouped and evaluated into three categories, comparing the importance given by agents carrying their activity out in countries recycling post-consumer gypsum waste with countries not yet systematically recycling this fraction as presented in the following headings.

Factors related to the segregation of gypsum waste from other C&D waste and the environmental focus of the waste owner and/or gypsum manufacturer

These variables are usually capable of being controlled by the value chain operators (i.e. waste owners, gypsum recyclers, plasterboard manufacturers), and highly influence the amount of recyclable gypsum waste, for either recycling or landfilling route.

Agent’s priorities in countries currently recycling post-consumer gypsum waste and countries not yet recycling this fraction are shown below.

While in non-recycling countries priorities seem to focus on regulation sub-factors, i.e. green public procurement (GPP) criteria or a regulatory framework favouring deconstruction, in recycling regions with usually more compliance and enforcement of regulations, awareness of the impacts of gypsum landfilling is the most rated. In both cases, GPP results to be crucial.

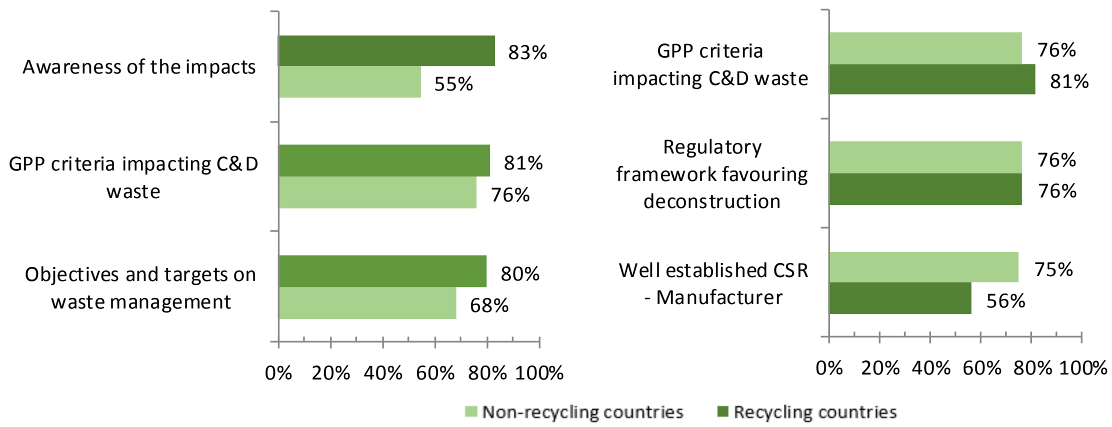


Figure 4. Top three related sub-factors rated as extremely important and important by agents in recycling countries

Factors related to the competitiveness of the recycling route compared to local landfills, compliance with the existing regulation impacting gypsum waste and the coverage of the gypsum recycling route

Most of these variables are related to legislative issues. As already explained before, legislative measures have an effect on gypsum recycling. Figure 5 compares the importance given by agents in each group of countries.

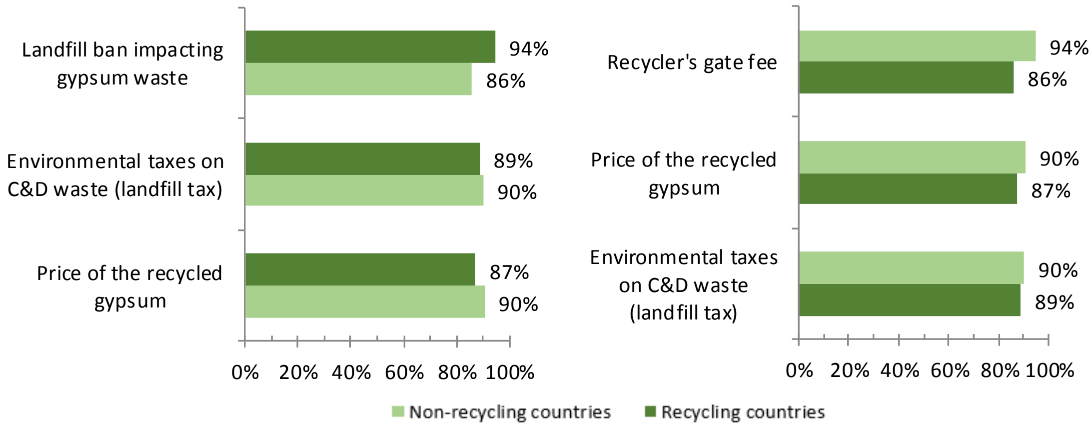


Figure 5 Top three related sub-factors rated as extremely important and important by agents in recycling countries (left) and non-recycling countries (right)

As shown in this figure, most agents in recycling countries rate the implementation of a landfill ban as extremely important to build a circular economy around gypsum. The efficiency of a landfill ban for recyclable fraction of C&D waste was already stressed by most agents in a previous report [11]. Both recycling and non-recycling countries report high degree of influence of two sub-factors: landfill tax and the price of the secondary material.

Factors related to legal alternative destinations that do not favour the options that are higher in the waste hierarchy

Alternative destinations include gypsum open-loop recycling purposes (e.g. for use in agriculture, cement manufacture and open cast mines backfilling operations) and waste exports. To limit the latter is a recognized priority for agents in recycling countries (75% of respondents), while a lower percentage of non-recycling ones rate this sub-factor as influential (56%).
The existence of legal alternative destinations not favouring the waste hierarchy highly limits or even disables closed-loop gypsum recycling, even more when presenting lower costs compared to recycling.

ANNEX 4. CARBON FOOTPRINT ASSESSMENT

Final version produced in July 2015 - 201507. C1.1_Life cycle gypsum - GHG emissions_final -, entitled Carbon footprint of gypsum: landfilling versus recycling route, to be inserted here.

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(Still under development)

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