GYPSUM TO GYPSUM

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

Start date of the project: 2013/01/01 Duration: 36 months

LIFE PROGRAMME
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Title:	**Report best practice indicators for deconstruction, decontamination, characterization and recycling practices**

DOCUMENTS HISTORY

Version	Date	Author(s)
00	02/06/2015	UPM Team

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AIM AND SCOPE

The best practice indicators aims to increase the recovery of gypsum waste capable of being recycled, as well as maximize its quality and the percentage of recycled gypsum that can be reincorporated in the manufacturing process, covering the whole End-of-Life (EoL) of gypsum plasterboard. From the dismantling of the gypsum system during building deconstruction, through the processing of gypsum waste, to the reincorporation of the resulting recycled gypsum into the manufacturing process.

The study therefore is based on three pillars: the crucial factors for the effectiveness of the recycling route, relevant results from the monitoring of a set of European pilot projects, and conclusions regarding the close loop recycling effects.

The present document explains the methodology followed and definition of the set of best practice indicators for the monitoring of the deconstruction, recycling and reincorporation practices, as well as results obtained from the monitoring of five pilot projects, from four different European countries (Belgium, France, Germany and the United Kingdom). Differences arising in each country have also been underlined.

These indicators enable not only to monitor and compare progress, but also to set the basis for future formulation of mitigation measures to avoid and minimize the negative effects derived from potential weaknesses detected.

1. INTRODUCTION

The establishment of a system of indicators has been set in recent years as a simple method of evaluation in decision-making processes (Srinivasan, Ingwersen, Trucco, Ries, & Campbell, 2014). The indicators give quantitative, qualitative or descriptive information about an item and / or process, in a relatively simple way to use and understand (García Navarro, Maestro Martínez, Huete Fuertes, & García Martínez, 2009). In this sense, the information given must be relevant and useful to ease the decisions that will be taken on the basis of their results, in order to optimize the processes that are being measured and identify changes and improvements (Picado, 1997).

2. METHODOLOGY

The first part of the methodology consists on selecting the parameters that will constitute the indicators according to the impact to be measured. Such impacts were determined and obtained from a previous preparatory actions, where a thorough review on existing literature (regulation, construction systems and technologies, sustainability assessment tools and other common practices), and the gypsum business model were analysed. Such literature review, along with questionnaires distributed among European stakeholders, were essential in this preliminary stage. Consequently, a framework for assessing the success of closed-loop gypsum recycling based on six influencing indicators that encompass economic, legislative, environmental and social issues were formulated as an output of these preparatory actions of the project. Results highlighted a number of drivers influencing the market share for gypsum recycling. According to that, a first approach of crucial factors to be measured was formulated and their related parameters defined. Key parameters were combined in resulting monitoring indicators that enable the data collection and assessment of different aspects related to demolition, recycling and reincorporation practices, such as the effectiveness of the processes, waste traceability, labour time, costs or recycled gypsum quality amongst others.

Subsequently, resulting monitoring/performed indicators were evaluated, validated and refined by their application in five pilot projects, from distinct national context. The related parameters were provided to the relevant stakeholders in n the form of an Excel spreadsheet, the according to the schedule below:

- Deconstruction. Spreadsheet delivered in October 2013. Different improvements were incorporated while tested on-site. Finally, an improved version was ready in February 2015.
- Recycling. Spreadsheet first delivered in January 2014. After minor fine-tuning, an improved version was ready in February 2015.
- Reincorporation. Spreadsheet delivered in February 2014. An in-depth reformulation was carried out, due to lack of data available and the output of the implementation actions of the project. The improved indicators were ready in May 2015.

From consolidation and analysis of the data obtained, only a number of best practice indicators, specifically aiming to recognize and encourage best practice throughout the whole end-of-life stage (EoL), were selected.

Figure 1 and 2 show the summary of the developments and planned timeline.

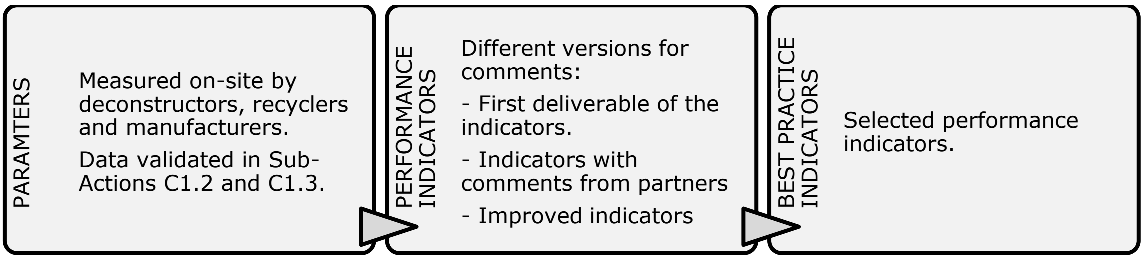

Figure 1. Parameters, performance indicators and best practice indicators

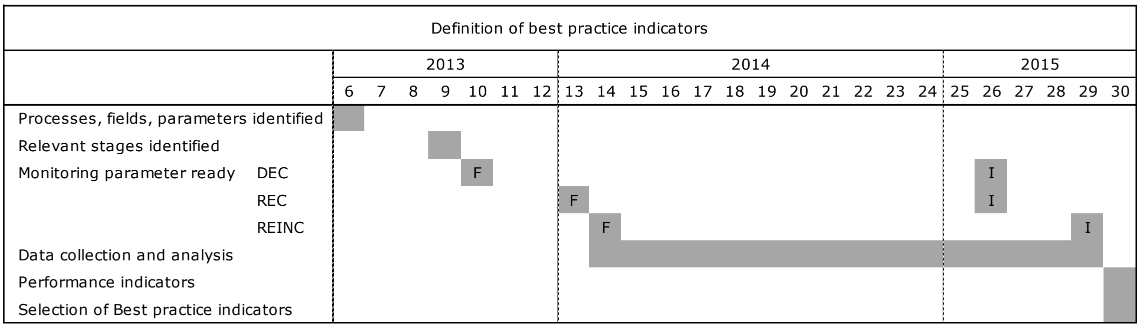

Figure 2. Work Plan summary.
DEC=deconstruction; REC=recycling; REINC=reincorporation; F=first deliverable; I=improved version

2.1. CASE STUDIES DESCRIPTION

As already mentioned, the different practices implemented have been monitored and analysed through five pilot projects located in Belgium, France (2), United Kingdom and Germany. Table 1 shows the operators involved in the different recycling routes followed, by the gypsum waste, from its source to its processing and final reincorporation as recycled gypsum in the manufacturing process.

Route	*Country*	*Demolisher*	*Recycler*	*Manufacturer*
R1	Belgium	RECASS	NWGR	GYPROC
R2	France	PIN	NWGR	PLACOPLATRE
R3	United Kingdom	CANTILLON	NWGR	SINIAT UK
R4	France	OCC	SINIAT FR	SINIAT FR
R5	Germany	KSE	GRI	KNAUFKG

Table 1. Recycling routes followed

The deconstruction, recycling and reincorporation techniques were monitored in order to compared and quantify the out from the developed performance indicators. In all cases gypsum waste was dismantled manually or mechanically, segregated at source and transported to different recycling facilities according to the respective project's locations, for a posteriori processing into recycled gypsum. The pilot projects were all tertiary buildings located in countries where deconstruction is a usual practice.

Tables 2-4 presents the pilot project main characteristic and the deconstruction, recycling and reincorporation techniques implemented.

General data - Deconstruction	*R1*	*R2*	*R3*	*R4*	*R5*
Description of the building	2 floors object of the study, offices	3 floor building, commercial	12 floor building, offices	9 floor building, offices	5 single-floor buildings, offices
Gypsum system (m^2)	2,800	340	8,640	6,750	3,450
Duration (months)	5	2	5	6	4
Type of gypsum system found	Plasterboard partition, metallic frame, mineral wool insulation.	Gypsum block partition; Plasterboard partition, metallic frame; Insulation system: plasterboard, expanded polystyrene; Plasterboard ceiling, metallic frame.	Plasterboard partition, metal frame, glass/rock wool insulation.	Double plasterboard partition, metallic frame, glass wool insulation.	Plasterboard ceiling, wooden frame, mineral wool insulation; Plasterboard laminate, metallic frame; Plasterboard partition, wooden frame, wood wool insulation.
Recyclable GW (t)	28.00	9.38	50.00	67.52	23.64
Non-recyclable GW (t)	-	7.80	-	-	13.00
Dismantling	Mechanically	Manually (automatic screwdriver and pickaxe) Removal by hand	Manually (crowbar, pickaxe or sledgehammer) Removal by hand	Manually (automatic screwdriver and pickaxe) Removal by hand	Manually (crowbar, pickaxe or sledgehammer) Removal by hand
Sorting	Mechanically	Manually (wheelbarrow and shovel)	Manually (hopper)	Manually (hopper)	Manually (wheelbarrow and shovel)
Loading	Mechanically (bobcat)	Mechanically (telescopic rotating forklift)	Mechanically (bobcat)	Mechanically (bobcat)	Manually and mechanically
Waste management option	Recycling facility	Recycling facility	Recycling facility via transfer station	Recycling facility	Recycling facility via transfer station

Table 2. General data deconstruction

Recycling description	*R1*	*R2*	*R3*	*R4*	*R5*
Deconstruction-recycling distance (km)	64.6	39.5	199	86	150*
Usual average output from recycling equipment	Gypsum (94%) Paper (6%) Metal (<1%)	Gypsum (94%) Paper (6%) Metal (<1%)	Gypsum (94%) Paper (6%) Metal (<1%)	unknown	Gypsum (90%) Paper (10%) Metal (<1%)

Table 3. Recycling description
*Assumption for Germany, where there is no gypsum recycler. Average distance travelled from DA1 report, GtoG project

Manufacturing description	*R1*	*R2*	*R3*	*R4*	*R5*
Recycling-reincorporation distance (km)	0.00	0.00	6.60	0.00	5.00*
Usual RG reincorporated source	production and C&D waste	production and C&D waste	production and C&D waste	production and C&D waste	production waste
Usual RG reincorporation rate	around 10%	around 15%	around 15%	between 10 - 15%	up to 5%

Table 4. Manufacturing description
*Assumption for Germany, where there is no gypsum recycler. Average distance travelled from DA1 report, GtoG project

2.2. *PERFORMANCE INDICATORS AND ASSOCIATED PARAMETERS*

2.2.1. Performance indicators index

Deconstruction - Performance Indicators

Criteria	Stage	Indicator
TEC	Audit Deconstruction Traceability	TECH1. Existence and deviation of the audit for gypsum 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 VS demolition Deconstruction	SOC1. Labour time difference between dismantling and demolishing SOC2. Labour time difference between dismantling and demolishing SOC3. Productivity SOC4. Training of the deconstruction team SOC5. Follow-up of the waste management
ECO	Audit Deconstruction Traceability	ECO1. Audit cost ECO2. Plasterboard dismantling and loading cost ECO3. Gypsum block dismantling and loading cost ECO4. Cost difference between recycling GW and landfilling route

Recycling - Performance Indicators

Criteria	Stage	Indicator
TEC	Storage Reception Processing	TECH1. Required space for storage the gypsum waste TECH2. Quality of the gypsum waste received TECH3. Gypsum waste rejected TECH4. Output materials of the recycling process
ENV	Processing and transport	ENV1. CO_2 emissions from the recycling process ENV2. Natural gypsum saved
SOC	Processing	SOC1. Recycler's satisfaction
ECO	Processing Transport	ECO1. Energy cost of the gypsum waste processing ECO2. Transport cost of the recycled gypsum

Reincorporation - Performance indicators

Criteria	Stage	Indicator
TECH	Reception Logistics Reincorporation Production	TECH1. Recycled gypsum rejected by the manufacturer TECH2. Recycled gypsum quality criteria TECH3. Recycled gypsum required space for storage TECH4. Recycled gypsum content TECH5. Recycled content increase TECH6. Production waste
ENV	Preprocessing Manufacturing	ENV1. CO_2 emissions: business-as-usual compared to maximized recycled content in the preprocessing ENV2. CO_2 emissions: business-as-usual compared to maximized recycled content in the production process
SOC	Manufacturing	SOC1. Manufacturer's satisfaction
ECO	Reception Preprocessing Manufacturing	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 ECO4. Energy cost difference between business-as-usual and maximized recycled content in the preprocessing ECO5. Energy cost difference between business-as-usual and maximized recycled content in the production process

2.2.2. Deconstruction

Deconstruction - Technical - TECH1

Audit

TECH1. Existence and deviation of the audit for gypsum systems

Description

Existence of a pre-deconstruction audit for gypsum systems and its deviation compared with the real amount and type of Gypsum Waste (GW) generated as well as its potencial recyclability.*

The present indicator is divided into:

TECH1.1 Existence of the audit.

TECH1.2 Deviation 1: This sub-indicator aims at assessing the deviation between the GW

TEC 1.3 Deviation 2: This sub-indicator aims at assessing the deviation between the recyclable GW foreseen and the amount of recyclable GW generated.

Evaluation method

If the result of TECH1.1 is "Yes", TECH1.2 and TECH.1.3 can be applied:

TECH1.2 <10% Acceptable

TECH1.3 < 20% Acceptable

The quality of the audit will be considered "Effective" if sub-indicators TECH1.2 and TECH1.3 comply.

TECH1.1 Pre-deconstruction audit existence

Parameters	Existence of a pre-deconstruction audit for gypsum systems - (YES/NO)

	TECH1.2 Deviation 1 (%)	TECH1.3 Deviation 2 (%)
Parameters	Gypsum Waste foreseen - GW_f (t)	Recyclable Gypsum Waste foreseen - RGW_f (t)
	Gypsum Waste generated - GW_g (t)	Recyclable Gypsum Waste generated - RGW_g (t)
Equation	$TECH1.2 = \frac{GW_f - GW_g}{GW_g}$	$TECH1.3 = \frac{RGW_f - RGW_g}{RGW_g}$
	0%	0%
	EFFECTIVE/NON EFFECTIVE	

*Deliverable DB1 defines the acceptance criteria specified by the recyclers in the GtoG project.

Deconstruction

TECH2. Effectiveness of the deconstruction process

Description

This indicator aims at assessing to what extent the deconstruction operations of dismantling, segregation and storage have been well managed.

The present indicator is divided into:

TECH2.1 Impurities: a qualitative sub-indicator that assesses the presence of visual contaminants in the Gypsum Waste (GW) stored (wood, insulation, metal frame), before being loaded.

TECH2.2 Gypsum Waste (GW) accepted: a quantitative sub-indicator that assesses the deviation between recyclable GW refused by the waste receptor because of non compliance with the specifications and the recyclable GW transfered.

Evaluation method

If the result of the qualitative sub-indicator TECH2.1 is NO, and the quantitative sub-indicator TECH2.2 is 100% it is consired "effective". On the contrary, "non effective" will be either when TECH2.1 is YES or TECH2.2 is below 100%.

	TECH2.1 Impurities	TECH2.2 Gypsum Waste accepted (%)
Parameters	Presence of impurities in the GW load (YES/NO)	Recyclable Gypsum Waste refused by the waste outlet- RGW_r (t)
		Recyclable GW generated- RGW_g (t)
Equation	0	$\text{TECH 2.2} = \frac{RGW_g - RGW_r}{RGW_g}$
		0.00%
	NON EFFECTIVE / EFFECTIVE	

Deconstruction - Technical - TECH3

Traceability

TECH3. Effectiveness of the traceability

Description

Deviation between the Gypsum Waste (GW) generated and the GW tracked.

Evaluation method

Regardless the final route, to be considered "effective" the result must be 100%, if not it is "non-effective".

Traceability (%)

Parameters

- GW generated and tracked - GW_t (t)
- GW generated - GW_g (t)

Equation

$$TECH3 = \frac{GW_t - RGW_t}{GW_t}$$

0%

EFFECTIVE / NO EFFECTIVE

End route

ENV1. Gypsum waste sent to landfill

Description

Percentage of Gypsum Waste(GW) sent to landfill.

Evaluation method

The result is an indicative value as it depends on the type of GW generated, due to the fact that there are non-recyclable gypsum systems. However, recyclable GW may be inadequatly sent to landfill. In any case 0% demonstrates the implementation of efficient deconstruction practices.

Gypsum waste sent to landfill (%)

Parameters

- Gypsum Waste sent to landfill - GW_l (t)
- Gypsum Waste generated - GW_g (t)

Equation

$$ENV1 = \frac{GW_l}{GW_g}$$

%

End route

ENV2. Transport emissions comparison between recycling and landfilling

Description

Difference between transport CO_2 equiv emissions from the jobsite to the recycling facility compared with the emissions from the jobsite to the landfill.

Evaluation method

The result is an indicative value as the parameters related to the number of roundtrips, depend on the deconstruction technique applied which influences on the GW size and shape, type of skips and the way the waste is placed inside of the skips.
If the substraction of "ENV2.1 Recycling" and "ENV2.2 Landfilling" is a negative value means emission savings by recycling.

	ENV2.1 Recycling (kg CO_2 equiv)	ENV2.2 Landfilling (kg CO_2 equiv)
Parameters	Freight transportation factor - F_{CO2} (g CO_2 eq/tkm)	Freight transportation factor - F_{CO2} (g CO_2
	GW per rountrip to recycling - GW_r (t)	GW per rountrip to landfill - GW_l (t)
	Distance to recycling -D_r (km)	Distance to landfilling - D_l (km)
	Roundtrips to the recycling facility - RT_r (No.)	Roundtrips to landfill - RT_l (No.)
Equation	$\text{ENV2.1} = \frac{F_{CO2}\text{ x }GW_r\text{ x }D_r\text{ x }RT_r}{1000}$	$\text{ENV2.2} = \frac{F_{CO2}\text{ x }GW_l\text{ x }D_l\text{ x }RT_l}{1000}$

SAVINGS / NO SAVINGS

Deconstruction VS demolition

SOC1. Labour time difference between dismantling and demolishing plasterboard

Description

Difference between the labour time needed to dismantle-load and demolish-load a square meter of plasterboard in minutes.
Demolition refers to C&D mixed waste on-site collection.

Evaluation method

The result is an indicative value as it depends on the type of plasterboard system to be dismantled or demolished, the type of deconstruction or demolition process (manual or mechanical), the skills of the workers and any other peculiarity of the jobsite.
A negative value means time saving when dismantling.

Labour time difference (min/m²)

Parameters

- 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)

Equation

$$SOC1 = (LPB_{di} - LPB_{de})$$

-

SAVINGS / NO SAVINGS

*In the GtoG pilot projects, labour time for demolition has been estimated based on the deconstruction companies experience.

Deconstruction VS demolition

SOC2. Labour time difference between dismantling and demolishing gypsum blocks

Description

Difference between the labour time needed to dismantle-load and demolish-load a square meter of gypsum blocks in minutes.
Demolition refers to C&D mixed waste on-site collection.

Evaluation method

The result is an indicative value as it depends on the type on the type of deconstruction or demolition process (manual or mechanical), the skills of the workers and any other peculiarity of the jobsite.
A negative value means time saving when dismantling.

Labour time difference (min/m²)

Parameters	Labour time by man needed for the dismantling and loading of the GW - LGB_{di} (min/m²)
	Labour time by man estimated to demolish and loading the GW - LGB_{de} (min/m²)
Equation	$SOC2 = (LGB_{di} - LGB_{de})$
	-
	SAVINGS / NO SAVINGS

*In the GtoG pilot projects, labour time for demolition has been estimated based on the deconstruction companies experience.

Deconstruction

SOC3. Productivity

Description

Square meter of gypsum waste dismantled, sorted and loaded per day and per worker.

Evaluation method

The result is an indicative value as it depends on the type of gypsum system to be dismantled, the type of deconstruction or demolition process (e.g. manual or mechanical), the skills of the workers and any other peculiarity of the jobsite.

Productivity (m^2/(workers*day))

Parameters	Total area of plasterboard - A_p (t)
	Total area of gypsum block - A_{gb} (t)
	Number of workers trained for the jobsite - N_w
	Duration of the deconstruction works - D (day)
Equation	$SOC3 = \frac{(A_A + A_{gb})}{N_W * D}$

Deconstruction

SOC4. Training of the deconstruction team

Description

Number of hours of training in waste dismantling, sorting and storing, per number of trained workers.

Evaluation method

Minimum of 10 hours per year/worker.

Training (hours per year/worker)

Parameter	Hours of training received per year - H_t (hours/year)
	Workers trained for the jobsite - W_t (No.)
Equation	$SOC4=\frac{H_t}{W_t}$
	COMPLIANCE / NO COMPLIANCE

Deconstruction

SOC5. Follow-up of the waste management

Description

Existence of a person appointed to follow-up the waste management including the tracking records

Evaluation method

There should be always a person in charge of the tracking.
Compliance if yes.

Follow-up (YES/NO)

Parameters	Existence of worker(s) appointed to follow-up the waste management (includ.tracking records)
	YES/NO
	COMPLIANCE / NO COMPLIANCE

Deconstruction - Economic - ECO1

Audit

ECO1. Audit cost

Description

Cost of the pre-deconstruction audit for gypsum systems, per floor area of jobsite.

Evaluation method

The result is an indicative value as it depends on the country under study.

Audit Cost (€/m²)

Parameters

- Cost of the audit - AU (€)
- Deconstruction site floor area - D_A (m²)

Equation

$$ECO1 = \frac{AU}{D_A}$$

Deconstruction

ECO2. Plasterboard dismantling and loading cost

Description

Cost of dismantling and loading per square meter of plasterboard

Evaluation method

The result is an indicative value as it depends on the peculiarities of the country under study.

Dismantling and loading cost (€/m²)

Parameters

Cost of the dimantling and loading - DL_p (€)

Total area of platerboard - A_p (t)

Equation

$$ECO2 = \frac{DL_p}{A_p}$$

Deconstruction

ECO3. Gypsum block dismantling and loading cost

Description

Cost of dismantling and loading per square meter of gypsum blocks.

Evaluation method

The result is an indicative value as it depends on the peculiarities of the country under study.

Dismantling and loading cost (€/m^2)

Parameters

- Cost of the dimantling and loading - DL_p (€)
- Total area of gypsum block - A_{gb} (t)

Equation

$$ECO3 = \frac{DL_p}{A_{gb}}$$

Traceability

ECO4. Cost difference between recycling GW and landfilling route

Description

Cost difference per tonne between recycling and landfilling routes, either direct or via transfer station, including gate fee and tax

Evaluation method

If the substraction of "ECO4.1 Cost of recycling" and "ECO4.2 Cost of landfilling" is a negative value means recycling cost savings.

	ECO4.1 Cost of recycling (€/t)	ECO4.2 Cost of landfilling (€/t)
Parameters	Cost of recycling - R (€/t)	Cost of landfilling - L (€/t)
	Recycling transport cost - RT (€/t)	Landfilling transport cost - LT (€/t)
Equation	ECO4.1 = R+RT	ECO4.2 = L+LT

SAVINSG/ NO SAVINGS

2.2.3. Recycling

Recycling - Technical -TECH1

Storage

TECH1. Required space for storage the gypsum waste

Description

Required space for storage the gypsum waste at the recycling plant.

Evaluation method

A properly dimensioned storage place should be set up in order to guarantee a constant gypsum waste feedstock. Based on this, this indicator gives a rough estimation of the required space for storage. The reference density obtained from the GtoG pilot projects is 0.40 t/m^3.

Volume (m^3)

Parameters

- Gypsum waste received - GW (t)
- Reference density - 0.40 (t/m^3)

Equation

$$TECH1 = \frac{GW}{0.40}$$

0.00

Reception

TECH2. Quality of the gypsum waste received

Description

Gypsum waste compliance with the recyclers' acceptance criteria in relation to the presence of impurities and the percentage of wet gypsum waste received.

Evaluation method

"TECH2.1 Presence of impurities ":
- Qualitative assessment criteria for each parameter:
High = >3%*: non-accepted;
Low = ≤ 3% accepted.
None = 0% accepted.
- Quantitative global assessment criteria
>3%*: non-accepted;
≤ 3% accepted.
0% accepted.
"TECH2.2 Wet gypsum waste received " criteria:
> 25%*: non-accepted;
≤ 25% accepted.
0% accepted.

Both sub-indicators and their related parameters must be "Accepted" to comply with the overall required quality.

	TECH2.1 Impurities	TECH2.2 Wet gypsum waste received (%)
Parameters	Presence of plastics and foils	Wet Gypsum Waste received - GW_w (t)
	Presence of insulation materials	Slightly Wet Gypsum Waste received - GW_{sw} (t)
	Presence of steels rails and bars	Gypsum Waste received - GW (t)
	Presence of wood	
	Presence of other impurities	
	Impurities manually separated - I (t)	
	Gypsum waste received - GW (t)	
Equation	Plastics and foils = High / Low / None	
	Insulation materials = High / Low / None	
	Steels rails and bars = High / Low / None	
	Wood = High / Low / None	
	Other = High / Low / None	
	$\text{TECH2.1} = \frac{I}{GW}$	$\text{TECH2.2} = \frac{GW_W + GWSW}{GW}$
	COMPLIANCE / NO COMPLIANCE	

*The considered limit value is taken from the developed "Acceptance criteria per country", in B1 Action.

Reception

TECH3. Gypsum waste rejected

Description

Rate of gypsum waste rejected by the recycler due to non conformity with the relevant acceptance criteria*, mainly if high moisture content or presence of contaminants are found in the load.

Evaluation method

If best practices are applied during deconstruction, the result is tipically 0%. Corrective actions in the value chain are needed when TECH3 ≠ 0%.

Gypsum waste rejected (%)

Parameters

Gypsum waste received - GW (t)

Gypsum waste rejected - GW_r (t)

Equation

$$TECH3 = \frac{GW_r}{GW}$$

–

No recycled gypsum rejected / Need of corrective actions

*"Acceptance criteria per country", in B1 Action.

Processing

TECH4. Output materials of the recycling process

Description

Ratio of the materials output after processing the gypsum waste.

Evaluation method

The result is an indicative value as it depends on the functioning characteristics of the recycling equipment.
Recycling process typical output streams are:
Recycled gypsum: 90 – 94% by weight.
Paper fraction; 6 – 10% by weight.
Metal: < 1% by weight.

Paper output > 0%: compliance.
If paper ratio is significantly low, it can be attributed to the fact that paper hasn't been properly removed, therefore affecting the quality of the recycled gypsum output.

Output (%)

Parameters

Recycled gypsum obtained - RG (t)
Paper fraction - P(t)
Metal fraction - M (t)
Gypsum waste processed GW_p(t)

Equation

$TECH4.1 = \frac{RG}{GW_p}$	Recycled gypsum	-
$TECH4.2 = \frac{P}{GW_p}$	Paper fraction	-
$TEC54.3 = \frac{M}{GW_p}$	Metal	-

COMPLIANCE / NO COMPLIANCE

Processing and transport

ENV1. CO2 emissions from the recycling process

Description

Emissions resulting from the waste recycling process and transport of the recycled gypsum.

Evaluation method

The result can be compared with the extraction of gypsum (natural or FGD gypsum) from reference data*.

Savings < 2.033 kg CO_2 eq/t**

Non savings ≥ 2.033 kg CO_2 eq/t.

	ENV1.1 Processing CO_2 emissions (kg CO_2 equiv/t)	ENV1.2 Transport CO_2 emissions (kg CO_2 equiv/t)
Parameters	Gypsum waste processed - GW_p(t)	RG per rountrip to reincorporation- RG (t)
	Electricity - E_e (kg CO2 equiv)	Distance to reincorporation - D_r (km)
	Fuel consumption - E_f (kg CO2 equiv)	Roundtrips to reincorporation - RT_r (No.)
	A. Electricity emission factor - EE (kg CO_2 eq/kWh)	C. Freight transportation factor - F_{CO2} (g CO2 eq/tkm)
	B. Emission intensity of Fuel -EF (kg CO2 equiv per kJ LHV)	
Equation	$\mathrm{ENV1.1} = \frac{(\mathrm{EExEe})+(\mathrm{EFxEf})}{\mathrm{GW_p}}$	$\mathrm{ENV1.2} = \frac{F_{CO2} \text{ x RG x } D_r \text{ x } RT_r}{1000}$
	-	-

SAVINGS / NON SAVINGS

*It should be noted that this data doesn't include either transport or further preprocessing of the raw materials.

**Calculated from Ecoinvent. 2012. Ecoinvent v2.2 Life Cycle Inventory (LCI) database, Gypsum, mineral, at mine/CH S. Rigips Saint-Gobain, "Environmental Product Declaration Gypsum plasterboard RIGIPS PRO and RIGIPS 4PRO." 2014.

Recycling - Environmental - ENV2

Processing and transport

ENV2. Natural gypsum saved

Description

The amount of recycled gypsum, avoiding natural resource depletion, landscape preservation and H_2S emissions from landfill disposal.

Evaluation method

Natural gypsum equals recycled gypsum obtained.
Savings > 0

Natural gypsum saved (t)

Parameters

Recycled gypsum obtained - RG (t)

0

SAVINGS / NON SAVINGS

Processing

SOC1. Recycler's satisfaction

Description

Satisfaction reported by the recycler in relation with the gypsum waste received.

Evaluation method

Under discussion

HIGH:

MEDIUM:

LOW:

Satisfaction (qualitative)

Parameters

Equation

HIGH/MEDIUM/LOW

Processing

ECO1. Energy cost of the gypsum waste processing

Description

Energy cost of the recycling process.

Evaluation method

The result is an indicative value as it depends on the electricity, fuel cost as well as on the performance of the equipment, in the country under study.

Processing cost (€/t)*

Parameters

- Total processing electricity cost - C_{TE} (€)
- Total processing fuel cost - C_{TF} (€)
- Gypsum waste processed by the recycling equipment - GW_p (t)

Equation

$$ECO1 = \frac{C_{TE} + CTF}{GW_p}$$

-

Transport

ECO2. Transport cost of the recycled gypsum

Description

Transport cost from the recycling facility to the manufacturer.

Evaluation method

The result is an indicative value as it depends on the peculiarities of each country. The nearest the manufacturing plant is to the recycling facility, the more profitable is for the company and the easier to achieve a closed-loop gypsum recycling.

Processing cost (€/t)*

Parameters
Fuel cost - C_F (€)
Lorry energy consumption - E_{LF} (€/l)
Distance to the plasterboard manufacturing plant - D_m (km)
Number of roundtrips - RT_m (No.)
Recycled gypsum obtained - RG (t)

Equation

$$ECO2 = \frac{C_F \; x \; ELF \; x \; Dm \; x \; RTm}{RG}$$

2.2.4. Reincorporation

Reincorporation - Technical - TECH1

Reception

TECH1. Recycled gypsum rejected by the manufacturer

Description

Rate of recycled gypsum rejected by the manufacturer due to non compliance with the agreed quality specifications.

Evaluation method

If best practices are applied during deconstruction and recycling of the gypsum waste, the result is typically 0%. Corrective actions in the value chain are needed when TECH1 ≠ 0%.

Recycled gypsum rejected (%)

Parameters

- Total recycled gypsum received - RG (t)
- Total recycled gypsum rejected - RG_R (t)

Equation

$$TECH1 = \frac{RG_R}{RG}$$

-

No recycled gypsum rejected / Need of corrective actions

Reception

TECH2. Recycled gypsum quality criteria

Description

Recycled gypsum compliance with the quality criteria (agreed between manufacturers and recyclers), in relation to technical and toxicological specifications.

Evaluation method

When the value of all parameters is within the agreed criteria*, the result is "Compliance", if not it is "Non Compliance".

Quality criteria assessment

Parameters

- Technical parameters
- Toxicological parameters

Equation

Technical parameters are within the limit value
Toxicological parameters are within the limit value

COMPLIANCE / NON COMPLIANCE

*The considered limit value is taken from the "GtoG first approach guideline", develop in B2 Action.

Logistics

TECH3. Recycled gypsum required space for storage

Description

Recycled gypsum required space for storage at the manufacturing plant.

Evaluation method

A properly dimensioned storage place should be set up in order to guarantee a constant recycled gypsum feedstock. Based on this, this indicator gives a rough estimation of the required space for storage. The reference density obtained from the GtoG pilot projects is 0.70 t/m^3.

Volume (m^3)

Parameters

- Total recycled gypsum stored - RG_S (t)
- Reference density - 0.70 (t/m^3)

Equation

$$\text{TECH3} = \frac{RG_S}{0.70}$$

0.00

Reincorporation

TECH4. Recycled gypsum content

Description

Recycled gypsum rate used in feedstock, considering both pre-consumer and post-consumer recycled gypsum reincorporated.

Evaluation method

When the sum of "TECH4.1 Pre-consumer recycled gypsum content" and "TECH4.2. Post-consumer recycled gypsum content" is:

≥ 22.3%*: high achievement;

22.3% - 5.0%: medium achievement;

≤ 5.0%**: low achievement

	TECH4.1. Pre-consumer content (%)	TECH4.2. Post-consumer content (%)
Parameters	Pre-consumer recycled gypsum -RG_{PRE} (t)	Post-consumer recycled gypsum - RG_{POST}
	Total plasterboard produced - PB (t)	Total plasterboard produced - PB (t)
Equation	$TECH4.1 = \frac{RG_{PRE}}{PB}$	$TECH4.2 = \frac{RG_{POST}}{PB}$
	0%	0%
	0%	
	LOW / MEDIUM / HIGH ACHIEVEMENT	

*Reference value calculated from the GtoG pilot projects.

** European current recycled gypsum reincorporation rate.

Reincorporation

TECH5. Recycled content increase

Description

The increase in the reincorporation rate, by comparing the business-as-usual rate with the result obtained in indicator TECH4.

Evaluation method

The higher the increase, the greater the effort made by the plasterboard manufacturer towards achieving a reincorporation target rate*:

0-5% increase: low achievement;

5-10% increase: medium achievement;

>10% increase: high achievement

	TECH5.1 Recycled gypsum content (%)	TECH5.2 Business-as-usual reincorporation rate (%)
Parameters	Pre-consumer recycled gypsum - RG_{PRE} (t)	Recycled gypsum reincorporation rate (%)
	Post-consumer recycled gypsum-RG_{POST}	
	Total plasterboard produced - PB (t)	
Equation	$\mathrm{TECH5.1} = \frac{RG_{PRE} + RGPO_{ST}}{PB}$	%
	0%	0%
	0%	
	LOW / MEDIUM / HIGH ACHIEVEMENT	

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

Production

TECH6. Production waste

Description

Percentage of nonconforming plasterboard during the production process.

Evaluation method

Total amount of plasterboard produced is compared with the production waste (nonconforming plasterboard generated during the process), according to a reference value*. The lower the production waste, the more efficient the manufacturing process.
≤4%: within the European average;
>4%: need corrective actions;

Production waste (%)

Parameters

Total plasterboard produced - PB (t)
Total non-conforming plasterboard generated - PB_{NC} (t)

Equation

$$TECH6 = \frac{PB_{NC}}{PB}$$

0%
on average / corrective actions

*4% is the European average production waste generated. Data collected during the GtoG project.

Preprocessing

ENV1. CO2 emissions: business-as-usual compared to maximized recycled content in the preprocessing *

Description

Emissions difference per m^2 of board, resulting from maximizing the recycled feedstock, derived from the preprocessing stage (drying of gypsum feedstock to reduce its moisture content).

Evaluation method

If the subtraction of "ENV1.1 kg CO2 eq emissions generated during business-as-usual" and "ENV1.2 kg CO2 eq emissions generated during preprocessing when maximum recycled content (RC)" is a positive value, CO_2 equivalent emissions are saved.

	ENV1.1. kg CO_2 eq emissions business-as-usual	ENV1.2. kg CO_2 eq emissions maximixed RC
Parameters	Electricity consumption - E_{PRE1} (kWh/m^2 board)	Electricity consumption - E_{PRE2} (kWh/m^2 board)
	Natural gas - NG_{PRE1} (kWh/m^2 board)	Natural gas - NG_{PRE2} (kWh/m^2 board)
	Waste fuel - WF_{PRE1} (kWh/m^2 board)	Waste fuel - WF_{PRE2} (kWh/m^2 board)
	A. Electricity emission factor - EE (kg CO_2 eq/kWh)	A. Electricity emission factor - EE (kg CO_2 eq/kWh)
	B. Emission intensity of NG -EF_{NG} (kg CO_2 eq/kWh)	B. Emission intensity of NG -EF_{NG} (kg CO_2 eq/kWh)
	C. Emission intensity of WF -EF_{WF} (kg CO_2 eq/kWh)	C. Emission intensity of WF -EF_{WF} (kg CO_2 eq/kWh)
Equation	$ENV1.1 = (E_{PRE1}\, x\, EE) + (\,NG_{PRE1}\, x\, EF_{NG}) + (WF_{PRE1}\, x\, EF_{WF})$	$ENV1.2 = (E_{PRE2}\, x\, EE) + (\,NG_{PRE2}\, x\, EF_{NG}) + (WF_{PRE2}\, x\, EF_{WF})$
	0.00E+00	0.00E+00
	0.00	
	SAVINGS / NON SAVINGS	

*According to the available bibliography, ENV2 and ENV1 are expected to be the same value.

Manufacturing

ENV2. CO2 emissions: business-as-usual compared to maximized recycled content in the production process *

Description

ENV1 presents the difference in the potential emissions, per m^2 of board, resulting from miaximizing the recycled feedstock, derived from the manufacturing process (including gypsum preprocessing and calcination and plasterboard production).

Evaluation method

If the subtraction of "ENV2.1 kg CO_2 eq emissions generated during business-as-usual" and "ENV2.2 kg CO2 eq emissions generated duringthe manufacturing process when maximum recycled content (RC)" is a positive value, CO_2 equivalent emissions are saved.

	ENV2.1. kg CO_2 eq emissions business-as-usual	ENV2.2. kg CO_2 eq emissions maximixed RC
Parameters	Electricity consumption - E_1 (kWh/m^2 board)	Electricity consumption - E_2 (kWh/m^2 board)
	Natural gas - NG_1 (kWh/m^2 board)	Natural gas - NG_2 (kWh/m^2 board)
	Waste fuel - WF_1 (kWh/m2 board)	Waste fuel - WF_2 (kWh/m2 board)
	A. Electricity emission factor - EE (kg CO2 eq/kWh)	A. Electricity emission factor - EE (kg CO2 eq/kWh)
	B. Emission intensity of NG -EF_{NG} (kg CO2 eq/kWh)	B. Emission intensity of NG -EF_{NG} (kg CO2 eq/kWh)
	C. Emission intensity of WF -EF_{WF} (kg CO2 eq/kWh)	C. Emission intensity of WF -EF_{WF} (kg CO2 eq/kWh)
Equation	$ENV2.1 = (E_1 x\ EE) + (NG_1 x\ EF_{NG}) + (WF_1 x\ EF_{WF})$	$ENV2.2 = (E_2 x\ EE) + (NG_2 x\ EF_{NG}) + (WF_2 x\ EF_{WF})$
	0.00E+00	0.00E+00
	0.00	
	SAVINGS / NON SAVINGS	

*According to the available bibliography, ENV2 and ENV1 are expected to be the same value.

Reincorporation - Social - SOC1

Manufacturing

SOC1. Manufacturer's satisfaction

Description

Satisfaction reported by the plasterboard manufacturer in relation with the acceptance of plasterboard with high content of recycled gypsum.

Evaluation method

Under discussion

HIGH:

MEDIUM:

LOW:

Satisfaction (qualitative)
Parameters

Equation

HIGH/MEDIUM/LOW

Reception

ECO1. Cost difference between business-as-usual and maximized recycled content quality check

Description

Deviation between the quality check cost of the business-as-usual feedstock and the quality check cost of the feedstock with maximized recycled content.

Evaluation method

A positive value means savings.

Cost difference (€/t)

Parameters

Conventional feedstock quality check total cost - CF_{QCC} (€)
Total conventional feedstock - CF (t)
Recycled gypsum feedstock quality check total cost - RG_{QCC} (€)
Total recycled gypsum feedstock - RG (t)

Equation

$$ECO1 = \frac{CF_{QCC}}{CF} - \frac{RG_{QCC}}{RG}$$

0.00

SAVINGS / NO SAVINGS

Reception

ECO2. Cost difference between natural gypsum and recycled gypsum

Description

Comparison between the cost of natural gypsum and the cost of recycled gypsum.

Evaluation method

A positive value means savings.

Cost difference (€/t)

Parameters

Cost of natural gypsum per tonne, including transportation- NG_C (€/t)

Cost of recycled gypsum per tonne, including transportation - RG_C (€/t)

Equation

$$ECO2 = NG_c - RG_c$$

0.00

SAVINGS / NO SAVINGS

Reception

ECO3. Cost difference between FGD gypsum and recycled gypsum

Description

Comparison between the cost of FGD gypsum and the cost of recycled gypsum.

Evaluation method

A positive value means savings.

Cost difference (€/t)

Parameters

Cost of FGD gypsum per tonne, including transportation- FGD_C (€/t)
Cost of recycled gypsum per tonne, including transportation - RG_C (€/t)

Equation

$$ECO3 = FGD_c - RG_c$$

0.00

SAVINGS / NO SAVINGS

Preprocessing

ECO4. Energy cost difference between business-as-usual and maximized recycled content in the preprocessing

Description

Cost difference in the preprocessing stage (drying of gypsum feedstock to reduce its moisture content), using business-as-usual feedstock against increasing the recycled gypsum content on it.

Evaluation method

If the substraction of "ECO4.1 Business-as-usual energy cost - preprocessing" and "ECO4.2.Maximum RC energy cost - preprocessing" is a positive value, savings are achieved.

	ECO4.1. Business-as-usual energy cost - preprocessing (€/m^2 and €/t)		ECO4.2. Maximum RC energy cost - preprocessing (€/m^2 and €/t)	
Parameters	Electricity consumption - E_{PRE1} (kWh/m^2 board and kWh/t		Electricity consumption - E_{PRE2} (kWh/m^2 board and kWh/t	
	Natural gas - NG_{PRE1} (kWh/m2 board and kWh/t board)		Natural gas - NG_{PRE2} (kWh/m2 board and kWh/t board)	
	Waste fuel - WF_{PRE1} (kWh/m2 board and kWh/t board)		Waste fuel - WF_{PRE2} (kWh/m2 board and kWh/t board)	
	A. Cost of electricity - E_C (€/kWh)		A. Cost of electricity - E_C (€/kWh)	
	B. Cost of natural gas - NG_C (€/KWh Lower Heating Value)		B. Cost of natural gas - NG_C (€/KWh Lower Heating Value)	
	C. Cost of waste fuel - WF_C		C. Cost of waste fuel - WF_C	
Equation	$ECO4.1 = (E_{PRE1} \times E_c) + (NG_{PRE1} \times NG_c) + (WF_{PRE1} \times WF_c)$		$ECO4.2 = (E_{PRE2} \times E_c) + (NG_{PRE2} \times NG_c) + (WF_{PRE2} \times WF_c)$	
	0.00	In €/t:	0.00	In €/t:
	0.00			In €/t:
	SAVINGS / NO SAVINGS			

Manufacturing

ECO5. Energy cost difference between business-as-usual and maximized recycled content in the production process

Description

Cost difference in the whole production process (including gypsum preprocessing and calcination and plasterboard production), comparing business-as-usual feedstock with an increase in the recycled gypsum content.

Evaluation method

If the substraction of "ECO5.1 Business-as-usual energy cost - production" and "ECO5.2.Maximum RC energy cost - production" is a positive value, savings are achieved.

	ECO5.1. Business-as-usual energy cost - production (€/m^2 and €/t)		ECO5.2. Maximum RC energy cost - production (€/m^2 and €/t)	
Parameters	Electricity consumption - E_1 (kWh/m^2 board and kWh/t		Electricity consumption - E_2 (kWh/m^2 board and kWh/t	
	Natural gas - NG_1 (kWh/m^2 board and kWh/t board)		Natural gas - NG_2 (kWh/m^2 board and kWh/t board)	
	Waste fuel - WF_1 (kWh/m2 board and kWh/t board)		Waste fuel - WF_2 (kWh/m2 board and kWh/t board)	
	A. Cost of electricity - E_C (€/kWh)		A. Cost of electricity - E_C (€/kWh)	
	B. Cost of natural gas - NG_C (€/KWh Lower Heating Value)		B. Cost of natural gas - NG_C (€/KWh Lower Heating Value)	
	C. Cost of waste fuel - WF_C		C. Cost of waste fuel - WF_C	
Equation	$ECO5.1 = (E_1 \times E_c) + (NG_1 \times NG_c) + (WF_1 \times WF_c)$		$ECO5.2 = (E_2 \times E_c) + (NG_2 \times NG_c) + (WF_2 \times WF_c)$	
	0.00	In €/t:	0.00	In €/t:
	0.00			In €/t:
	SAVINGS / NO SAVINGS			

3. ANALYSIS AND CASE STUDIES COMPARISON

3.1. BEST PRACTICE INDICATORS

Best Practice Indicators can be defined as those impacting and encouraging gypsum closed-loop gypsum recycling practices throughout the different stages of the plasterboard value chain. Best Practice Indicators have been selected from the developed performance indicators.

Tables 5-7 show, for the three stages of the plasterboard value chain, the defined criteria for selecting them or not as Best Practice Indicators.

For the case of reincorporation, all the performance indicators have been selected as Best Practice Indicators, whilst for deconstruction and recycling there are several socio-economic indicators that have been left out mainly due to their variability depending on the country under study.

DECONSTRUCTION INDICATORS	BP INDICATOR	BP CRITERIA	NON SELECTED INDICATORS CRITERIA
TECH1. Existence and deviation of the audit for gypsum systems	✓	TECH1.1 = yes; TEC1.2 <10%; TECH1.3<20%	-
TECH2. Effectiveness of the deconstruction process	✓	TECH2.1 = NO; TECH2.2 =100%	-
TECH3. Effectiveness of the traceability	✓	100%	-
ENV1. Gypsum waste sent to landfill	✓	0%	-
ENV2. Transport emissions comparison between recyclnig and landfilling	✓	ENV2.1 - ENV2.2 < 0 kg CO_2 equiv	-
SOC1. Labour time difference between dismantling and demolishing plasterboard	X	-	SOC1 doesn't impact on the implementation of best practices
SOC2. Labour time difference between dismantling and demolishing gypsum blocks	X	-	SOC2 doesn't impact on the implementation of best practices
SOC3. Productivity	X	-	Variable depending on skills of the workers and peculiarities of the country under study.
SOC4. Training of the deconstruction team	✓	≥10 h per year/worker	-
SOC5. Follow-up of the waste management	✓	Yes	-
ECO1. Audit cost	X	-	Variable depending on the country under study.
ECO2. Plasterboard dismantling and loading cost	X	-	Variable depending on the country under study.
ECO3. Gypsum block dismantling and loading cost	X	-	Variable depending on the country under study.
ECO4. Cost difference between recycling GW and landfilling route	✓	ECO4.1 - ECO4.2 < 0 €/t	-

Table 5. Deconstruction best practice indicators

RECYCLING INDICATORS	BP INDICATOR	BP CRITERIA	NON SELECTED INDICATORS CRITERIA
TECH1. Required space for storage the gypsum waste	✓	TECH1 ≥ 0.40/GW m^3	-
TECH2. Quality of the gypsum waste received	✓	Compliance with the agreed criteria*	-
TECH3. Gypsum waste rejected	✓	0%	-
TECH 4. Output materials of the recycling process	✓	Paper output > 0%:	-
ENV1. CO_2 emissions from the recycling process	✓	ENV1.1+ENV1.2 < 2.033 kg CO_2 eq/t	-
ENV2. Natural gypsum saved	✓	ENV2 > 0	-
SOC1. Recycler's satisfaction	✓	High	-
ECO1. Energy cost of the gypsum waste processing	X	-	Variable depending on the country under study and the equipment performance.
ECO2. Transport cost of the recycled gypsum	X	-	Variable depending on the country under study.

*The considered limit value is taken from the developed "Acceptance criteria per country", in B1 Action.

Table 6. Recycling best practice indicators

REINCORPORATION INDICATORS	BP INDICATOR	BP CRITERIA	NON SELECTED INDICATORS CRITERIA
TECH1. Recycled gypsum rejected by the manufacturer	✓	0%	-
TECH2. Recycled gypsum quality criteria	✓	Compliance with the agreed criteria*	-
TECH3. Recycled gypsum required space for storage	✓	TECH3 ≥ 0.70/RG_S m^3	-
TECH4. Recycled gypsum content	✓	TECH4.1+TECH4.2 ≥ 22.3%	-
TECH5. Recycled content increase	✓	TECH5.1-TECH5.2 > 10%	-
TECH6. Production waste	✓	TECH6 ≤ 4%	-
ENV1. CO2 emissions: business-as-usual compared to maximized recycled content in the pre-processing	✓	ENV1.1 - ENV1.2 ≥ 0 kg CO_2 eq	-
ENV2. CO2 emissions: business-as-usual compared to maximized recycled content in the production process	✓	ENV2.1 - ENV2.2 ≥ 0 kg CO_2 eq	-
SOC1. Manufacturer's satisfaction	✓	High	-
ECO1. Cost difference between business-as-usual and maximized recycled content quality check	✓	ECO1 > 0 €/t	-
ECO2. Cost difference between natural gypsum and recycled gypsum	✓	ECO2 > 0 €/t	-
ECO3. Cost difference between FGD gypsum and recycled gypsum	✓	ECO3 > 0 €/t	-
ECO4. Energy cost difference between business-as-usual and maximized recycled content in the pre-processing	✓	ECO4.1 - ECO4.2 > 0 €/t	-
ECO5. Energy cost difference between business-as-usual and maximized recycled content in the production process	✓	ECO5.1 - ECO5.2 > 0 €/t	-

*The considered limit value is taken from the "GtoG first approach guideline", develop in B2 Action.

Table 7. Reincorporation best practice indicators

3.2. TECHNICAL - ENVIRONMENTAL – SOCIAL – ECONOMIC IMPACT

3.2.1. Deconstruction

The following table 8 shows the results obtained after testing the best practice indicators in the deconstruction pilot projects.

Deconst indicator	Route					Unit
	R1	R2	R3	R4	R5	
TECH1	Non effective	Effective	Non effective	Non effective	Non effective	-
TECH2	Effective	Effective	Effective	Effective	Effective	-
TECH3	Effective	Effective	Effective	Effective	Effective	-
ENV1	0.00	45.40	0.00	0.00	54.99	%
ENV2	Savings	Savings	Savings	No savings	Savings	-
SOC4	No compliance	No compliance	No compliance	No compliance	Compliance	-
SOC5	Yes	Yes	Yes	Yes	Yes	Yes/No
ECO4	Savings	Savings	No savings	Savings	-	-

Table 8. Deconstruction results

Existence and deviation of the audit for gypsum systems (TECH1):
Only one pilot project complied with the criteria established (R2). For the case of R3, a pre-deconstruction audit didn't exist as it is not mandatory in this country. In the other three cases, the deviation of the audit in relation to the real amount of recyclable gypsum waste generated is above the criteria, 20%. The main reason is that the construction systems that appeared during the deconstruction weren't those expected. For the case of R4, presenting the highest deviation, wooden systems were taken by gypsum systems during the audit.

Effectiveness of the deconstruction process (TECH2):
The results show that during dismantling, segregation and storage operations, best practices were implemented, as all gypsum waste was accepted by the recyclers, with no presence of impurities in the loads.

Effectiveness of the traceability (TECH3):
All the gypsum waste generated was effectively tracked in the five pilot projects (from the jobsite to the recycling facility).

Gypsum waste sent to landfill (ENV1):
In R2, plaster blocks and plasterboards appeared glued to ceramics and sound / thermal insulation respectively.
In R5, around 55% of the plasterboard waste was laminates, which are not recyclable[1].

Transport emissions comparison between recycling and landfilling (ENV2):
In all cases, recycling facility is closer than landfill, but for R4, where the recycling route doubles the landfilling distance.

Training of the deconstruction team (SOC4):

[1] Gypsum waste acceptance criteria agreed by the GtoG participating recyclers.

R5 is the only one that complies with the criteria established, 10 hours per year/worker.

Follow-up of the waste management (SOC5):
All case studies reported the existence of a person appointed to follow-up the waste management.

Cost difference between recycling GW and landfilling route (ECO4):
R3 has a higher recycling fee than landfill. This is the reason why it is the only one not providing savings.
R5 couldn´t be calculated due to confidential issues.

3.2.2. Recycling

The following table 9 shows the results obtained after testing the best practice indicators in the recycling pilot projects.

Recycling Indicators	Route					Unit
	R1	R2	R3	R4	R5	
TECH1	550.00	510.55	121.50	169.05	92.50	m^3
TECH2	Compliance	Compliance	Compliance	Compliance	Compliance	-
TECH3	0.00	0.00	0.00	0.00	0.00	%
TECH4	Compliance	Compliance	Compliance	Compliance	Compliance	-
ENV1	-	-	-	-	-	-
ENV2	Savings	Savings	Savings	Savings	Savings	-
SOC1	-	-	-	-	-	-

Table 9. Recycling results

Required space for storage the gypsum waste (TECH1):
The figures obtained are indicative as they highly vary according to the amount of gypsum waste received. The compliance of this indicator mainly relies on having the adequate space for storage.

Quality of the gypsum waste received (TECH2):
There is not a relevant presence of impurities neither a significant amount of wet gypsum waste received in any of the case studies.

Gypsum waste rejected (TECH3):
All gypsum waste has been accepted.

Output materials of the recycling process (TECH4):
There is paper output in all cases.

CO_2 emissions from the recycling process (ENV1):
There is a lack of data regarding transport and roundtrips.

Natural gypsum saved (ENV2):
As all the recyclable gypsum waste has been processed into recycled gypsum, a total of 547.02 tonnes of natural gypsum has been saved.

Recycler's satisfaction (SOC1):
Under discussion.

3.2.3. Manufacturing

Under development. Waiting for the comments from the manufacturers to the improved indicators.

CONCLUSIONS

Under development.