CINDERELA

End of Waste criteria protocol for waste used as aggregates

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Executive summary

The deliverable D5.5 "End of Waste (EoW) criteria protocol for waste used as aggregates" aims to define a proposal of harmonized approach for End of Waste protocol (including lab and field tests, parameters to be assessed, limit values, etc.) for the use of Secondary Raw Materials (SRM) obtained from the valorisation of Construction and Demolition Wastes (CDW) and industrial waste or by-products. The protocol will be based on a previous analysis of already existing normative/regulation related with End of Waste criteria around Europe, a review of product regulations, involved stakeholders' requirements, and main outputs from the different related tasks of the project.

A first review and analysis of the existing regulations related with general waste management plans, EoW criteria and technical/environmental regulations was performed in order to extract the general rules and main requirements around the different European countries and regions for the use of SRM (from CDW and industrial waste or by-products) in the civil and construction works' applications.

The most relevant information and the applicability of the product regulatory framework at European level for SRM-based products was extracted: Construction Product Regulation (CPR), Harmonized European Standards (hEN), CE marking, European Technical Assessment (ETA) and Environmental Product Declaration (EPD).

The CINDERELA project has designed and developed three large scale demonstration cases in different locations: in Slovenia at the NIGRAD premises in Maribor; in North Macedonia at the premises of Makstil Steelwork Company in Skopje; and in Spain at the CTC facilities in Madrid. In these demos, different SRM-based products have been manufactured and installed in the real civil and construction works' applications. The main outcomes (difficulties encountered, recommendations, good practices, etc.) were extracted from the DEMO cases and from the prior stages related with the assessment of different wastes suitability for the preparation of SRM and the optimization of the different SRM-based products.

Finally, the proposal of harmonized approach for EoW criteria protocol is presented considering the outcomes from the previous analysis. The proposed protocol intends to visualize the current state of the art in terms of regulations to achieve the EoW status of CDW and industrial waste or by-products for the use of SRM with the highest environmental and technical guarantees. It presents a methodology based on a stepwise procedure for the development of new or updated EoW criteria and proposes recommendation and boundaries criteria for the achievement of EoW status and the correct use in final applications.

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Keywords:
End-of-Waste (EoW) criteria, Secondary Raw Materials (SRM), SRM-based construction products, recycling, potential applications, restrictions of use, technical and environmental requirements, quality control, SRM manufacturing and use recommendations.

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Explanation of acronyms & abbreviations

Acronym	Full name
AA	Artificial aggregates
ADR	Advanced Dry Recovery
AVCP	Assessment and Verification of the Constancy of Performance
BIM	Building Information Modeling
BOF	Basic Oxygen Furnace
BRCW	Basic Requirements for Construction Works
CDW	Construction and Demolition Wastes
CEN	European Committee for Standardization
CinderOSS	CINDERELA One-Stop-Shop
CPD	Construction Products Directive (89/106/EEC)
CPR	Construction Products Regulation (305/2011/EC)
CRA	Combined Recycled Aggregates
DoP	Declaration of Performance
EAD	European Assessment Document
EAF	Electric Arc Furnace
EC	European Commission
EDP	Environmental Product Declaration
EEA	European Economic Area
EN	Technical European Standards
EOTA	European Organisation for Technical Assessment
EoW	End of Waste
ER	Essential Requirements
ETA	European Technical Assessment
EU	European Union
EWC	European Waste Code
GBF	Granulated Blast Furnace
HAS	Heating Air System
hEN	harmonized European Standard
LCA	Life Cycle Assessment
L/S	Liquid/Solid ratio
LWRA	Light Weight Recycled Aggregates
MS	Member State
NWRA	Normal Weight Recycled Aggregates
OPC	Ordinary Portland Cement
PET	Polyethylene Terephthalate
PSD	Particle Size Distribution
RAA	Recycled Asphalt Aggregates
RBA	Recycled Ceramic Aggregates
RCA	Recycled Concrete Aggregates
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RG	Recycled Glass
RMA	Recycled Mixed Aggregates
RP	Recycled Plaster
SPI	Sustainable Products Initiative
SRM	Secondary Raw Materials
TAB	Technical Assessment Body
WFD	Waste Framework Directive
WP	Work Package

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1. Context, Objective and Purpose of the document

The main objective of this document is to analyse the different End of Waste (EoW) criteria existing around the European Union (EU) and the results obtained from the CINDERELAs project in order to propose a harmonized End of Waste (EoW) criteria protocol for the correct use of Secondary Raw Materials (SRM) from Construction and Demolition Wastes (CDW) and industrial waste or by-products in the construction sector.

This EoW criteria protocol is aimed at facilitating recycling and guiding those countries or regions that are going to implement new EoW criteria or update existing ones and thus, in a harmonized way at European level, establish the different criteria and considerations to correctly use the SRM obtained from CDW and industrial waste or by-products in different construction applications, thus guaranteeing the product status, the technical quality and the environmental and human health safety.

What is EoW criteria?

End-of-Waste criteria specify when certain waste ceases to be waste and obtains a status of a product[1].

According to Article 6 of the Waste Framework Directive (WFD) 2008/98/EC and 2018/851/EC, certain specified waste shall cease to be waste when it has undergone a recovery (including recycling) operation and complies with specific criteria to be developed in line with certain legal conditions, in particular:

- The substance or object is to be used for specific purposes;
- There is an existing market or demand for the substance or object;
- The use is lawful (substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products);
- The use will not lead to overall adverse environmental or human health impacts.

Such criteria should be set for specific materials by the Commission using the procedure described in Article 39(2) of the Waste Framework Directive (so called "comitology"). A mandate to set EoW criteria was introduced to provide a high level of environmental protection and an environmental and economic perspective. The aim of the EC is to further encourage recycling in the EU by creating legal certainty and a level playing field as well as removing unnecessary administrative burden.

Different protocols for EoW criteria can be found in the EU depending on the member countries and local regulations on waste. Therefore, although the EU regulates the generalities of the EoW criteria in the WFD, no clearly and harmonized protocol can be found for defining the parameters that should be complied by the different wastes in order to be employed respecting the technical, human health and environmental requirements.

What is the objective of the CINDERELA EoW criteria protocol?

Based on the analysis of the different EoW protocols around the EU and the outcomes of the project, the main objective of the CINDERELA project is **to define a proposal of harmonized approach of EoW criteria protocol for the use of SRM from CDW and industrial waste or by-products.** The EoW criteria protocol is intended for those countries in the EU that want to implement or update their EoW Criteria with the latest advances in EoW criteria.

[1] Waste Framework Directive (WFD) 2008/98/EC

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The proposal of the CINDERELA EoW Criteria Protocol is based on already existing EoW protocols (e.g., in the Basque Country, France, Belgium, Slovenia, the Netherlands and Nordic region), analysing the content of each of them and extracting the most relevant and common aspects.

This protocol will be also proposed according to the outcomes obtained from the CINDERELA tasks 3.2 (Valorisation of waste potential for the purpose of production of the SRM-based construction products) and 5.1 (Development and testing of the SRM-based products on the laboratory scale) with respect to the technical, environmental, and human health aspects.

Such a protocol would be considered as an appropriate demand side measure, which would be introduced through the CINDERELA One-Stop-Shop (CinderOSS) service management and legislation module to the relevant stakeholders (e.g., the national and regional decision makers for environmental and spatial planning).

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2. EXISTING EOW CRITERIA IN THE EU

The hierarchy of Member States (MS) regarding waste management and the use of SRM is as follows:

- General waste framework that regulates the management of all types of waste in a given region;
- Protocols and decrees that regulates the valorisation, management and use of SRM in different applications. They generally describe the general administrative and waste management requirements, referring to other specific standards for the technical and environmental aspects;
- Specific local technical and environmental regulation for the use of SRM in different sectors - in this document we focus on the construction sector as targeted market;
- Specific technical European Standards (EN) drafted and updated by the CEN (European Committee for Standardization (EN standards are a key component of the Single European Market which provide common rules, guidelines or characteristics for certain activities and uses).

The existing protocols and legislation at the level of the different EU countries usually focus on two major categories of SRM:

- SRM obtained from CDW;
- SRM obtained from industrial wastes or by-products (steel and iron industry; incinerators, paper industry, etc.).

The analysis performed in this work will be focused on the following European countries and regions:

- European Union (common legislation);
- Countries of the CINDERELA´s partners:
    - Spain (including the Basque Country region and Madrid region),
    - Italy,
    - Slovenia,
    - The Netherlands,
    - Poland,
    - North Macedonia,
- Other MS or regions adopting EoW criteria protocols:
    - France,
    - Germany,
    - Belgium,
    - Nordic region (including Denmark, Finland, Iceland, Norway, Sweden, the Faroe Islands, Greenland, and Åland).

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2.1. General waste frameworks and waste plans

The general waste frameworks and waste plans established in each country and region include the legislative frameworks for the correct management of all kind of wastes generated at all levels and all activity sectors.

They normally include strategic plans, actions to be carried out, objectives and financial and administrative instruments to improve the waste management at the national, regional or local level.

For each country, the different legislative waste framework and waste plans have been listed in Table 1. Some countries (e.g., Spain, France, Poland, the Netherlands) adopt National Waste Plans aimed at prevention, reutilization, recycling, and recovery of waste. On the contrary, other countries (e.g. Italy, Belgium, Germany) do not apply National Waste Plan in force but only Regional Waste Plan.

Table 1: List of legislative waste frameworks and waste plans in different European countries/regions

Countries and regions	Protocol or legislation	Content
EU	Waste Framework Directive 2008/98/EC	Sets the basic concepts and definitions related to waste management, such as the definition of waste, recycling and recovery. It explains when waste ceases to be waste and becomes a SRM (so called EoW criteria), and how to distinguish between waste and by-product.
SPAIN	Law 22/2011: Waste and Contaminated Soils. Royal Decree 105/2008: CDW Production and Management.	Establish the legal framework for the production and management of waste, as well as the provision of measures to prevent its generation and to avoid or reduce the adverse impacts on human health and the environment associated with its generation and management.
	The 2016-2022 State Waste Framework Plan (Plan Estatal Marco de Residuos - PEMAR)	The current plan on CDW management in Spain, which outlines the status of CDW management in between the years of 2008-2015, provides projections for the years 2014-2020. It aims to establish objectives on: prevention, reutilization, recycling, and forms of recovery and elimination of CDW.
SPAIN - BASQUE COUNTRY	Law 3/1998 General law on the environmental protection in the Basque country	General framework for the protection of the environment of the Basque Country. In the process of updating.
SPAIN - MADRID	Law 5/2003 on waste management	Specific regularization of the production and management of waste, according to the peculiarities that characterize the region.
ITALY	General criteria for the implementation of regional plans are defined in article 199 of legislative decree 152/2006 (Code on the environment)	Regional legislation is very broad and refers to several types of waste. Almost all regions have also set specific provisions for CDW.
SLOVENIA	Decree on Waste (Official Gazette of RS, Nos. 37/15, 69/15, 129/20)	This Decree of the Government of the Republic of Slovenia, with a view to protect the environment and human health, lays down requirements for preventing or reducing the adverse impacts of the generation and management of waste by reducing the overall impacts of the use of natural resources and improving the efficiency of such use. These requirements relate to recycling, control of hazardous waste, ban on the mixing of hazardous waste and rules on labelling of waste.
	The National Waste Management and Waste Prevention Plan	Part of the national Environment Protection Law aiming at prevention and decreasing waste in Slovenia. CDW management is part of numerous activities in the plan.

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Countries and regions	Protocol or legislation	Content
NETHERLANDS	The National Waste Plan (Landelijk Afval Plan; LAP).	This is the policy framework derived from the Environmental Protection Act regarding waste. The LAP is explicitly intended to include implementation of the Waste Framework Directive. The first LAP was introduced in 2003, LAP2 is the current document which was introduced in 2009 and is valid till 2015 with a proposed view towards 2021. The main goal is getting as much quality reused wasted as possible (instead of landfilling and incineration).
POLAND	The National Waste Management Plan 2014 was adopted by the resolution 217 of the Council of Ministers on 24 December 2010	Construction and demolition waste from buildings and road infrastructure are analysed in the National Waste Management Plan 2014. Hazardous waste such as waste containing asbestos are also addressed in this Plan.
NORTH MACEDONIA	National Environmental Program 1996/2006	Includes basic stipulations on environmental permitting, Environmental Impact Assessment procedure and greenhouse gas emissions.
	Law on Waste Management (2004) National Waste Management Strategy 2008-2020	The Waste Management Strategy reflects the national policy in waste management and represents the basis for preparation and implementation of an integrated and cost-effective waste management system. With this strategic document, the Republic of North Macedonia defines the fundamental directions in waste management for the twelve year period (2008-2020) and it determines the fundamental directions of the gradual waste management system set-up based on the hierarchy of the main principles of waste management and on the main principles of sustainable use of natural resources.
FRANCE	Ordonnance n° 2020-920 on waste prevention and waste management	Order relative to the waste prevention and management.
	National Waste prevention program for 2014-2020.	Prevention program identifies CDW as a priority stream and sets as a target to at least stabilize CDW production by 2020. To reach this target, this program plans several key actions.
GERMANY	Regional Waste Management Plans (WMPs).	The Circular Economy Act, which transposes Directive 2008/98/EC into German law, stipulates that the Federal States have to issue waste management plans for their area of responsibility. The Federation shall draw up a waste prevention programme (Section 33 of the Circular Economy Act). The Federal States may take part in the preparation of the waste prevention programme.
BELGIUM	N.A.	Waste Frameworks Plans are developed at regional level.
NORDIC REGION	Action plan for Vision 2030 Norden.	The action plan describes how the Nordic Council of Ministers will work to achieve the objectives of the vision through a series of initiatives linked to the vision's three strategic priorities: a green Nordic Region, a competitive Nordic Region, and a socially sustainable Nordic Region.

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2.2. EoW criteria and decrees that regulates the valorisation, management and use of SRM

Table 2 briefly presents the status of EoW criteria and EoW legislation as well as the current policy on EoW in each of the analysed countries and regions.

Table 2: List of EoW criteria and decrees in the different European countries/regions

Countries and regions	Protocol or legislation	Content
SPAIN	Article 5 of the 22/2011 Law on Waste and Contaminated Soil transposes the Waste Framework Directive's (WFD) into Spanish legislation including the definition of the EoW principle.	At the national level, Spain has not yet developed an EoW status for any waste flow. Discussions on how to integrate a set of EoW statuses for various waste flows for aggregates have recently started.
	ROYAL DECREE 105/2008 on CDW Production and Management.	Regulation of production and management of CDW.
SPAIN - BASQUE COUNTRY	Decree 112/2012, of 26 June, regulating the production and management of construction and demolition waste.	Decree for the regulation of the production and management of CDW in the Basque Country.
	Decree 64/2019, of 9 April on the legal framework applicable to recovery of black slag produced from the manufacture of steel in electric arc furnaces.	Legal framework applicable to the valorisation activities of Electric Arc Furnaces (EAF) and the use of EAF manufactured aggregates. The Decree establishes the conditions for the use of EAF aggregates in bound and unbound applications.
ITALY	In Italy the EU Directive 2008/98/EC was implemented by the Decree N. 205/2010, which in turn has amended Part IV of Legislative Decree No. 52/06. In particular, art. 184 contains the technical criteria for the determination of EoW material flows that need to be disciplined and priority modes of procedure to be followed for the adoption of the implementing regulations.	To date, there is only one material within CDW for which EoW criteria are being developed: aggregates made from CDW for paving roads ("granulato da conglomerato bituminoso").
	D.M. 5/2/98 (amended by Decreto 5/4/06 n. 186)	It contains also EoW criteria for construction and demolition waste, e.g. the conditions for construction waste to be considered as "Materie prime secondarie".
SLOVENIA	Decree on Waste (Official Gazette of RS, Nos. 37/15, 69/15, 129/20) and Decree on environmental interventions (Official Gazette of the Republic of Slovenia No. 51/14, 57/15, 26/17, 105/20)	EoW criteria, compliant with the European Waste Directive (EU) 2018/851 and national legislative demands from the Decree on Waste (Official Gazette of RS, Nos. 37/15, 69/15, 129/20). These criteria for example shall be met to achieve EoW status of a so-called heavy fraction (remaining of solid municipal waste treatment) in geotechnical composite, developed in Task 5.1 of the CINDERELA project as well as other SRM.
NETHERLANDS	The Netherlands uses the EU defined EoW criteria. In addition, EoW regulations for inert CDW are in place.	Any waste that fulfils the criteria for the EoW has no longer the status waste. That is the case if the waste has undergone a recovery operation and complies with specific criteria. A Dutch regulation applies for the recycling aggregates from stony waste, Regulation No IENM/BSK-2015/18222 of February 5, 2015.
POLAND	Chapter 5 of the Act on Waste defines EoW status and criteria.	Poland does not establish its own technical rules that determine the criteria of losing the status of waste in relation to any types

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		of waste, neither for the CDW.
NORTH MACEDONIA	N.A.	-
FRANCE	EoW status is defined by Order no. 2010-1579 of 17 December 2010 based on the WFD definition and supplemented by Decree no. 2012-602 of 30 April 2012.	Decree specifies the terms according to which the EoW criteria are adopted as well as the procedure applicable to the EoW. The Order of 19 June 2015 defines the quality management system applicable to EoW procedures.
GERMANY	The EoW status is defined in the German Circular Economy Act (Kreislaufwirtschaftsgesetz, § 5 KrWG Ende der Abfalleigenschaft, 2012).	According to Article 5, a substance no longer qualifies as waste when specific criteria are met. In its judgement of 5 December 2012 (7 B 17/12), the Federal Administrative Court decided that the EoW status also applies for construction and demolition waste.
BELGIUM	Flemish region: The concept of secondary resources was introduced in 1997 in Flanders and further evolved to EoW criteria in 2012 (in the new implementing decision of the Materials Decree of 2012).	Some criteria correspond to the ones set in Regulation 333/2011 at the European level and others are specific to the case of Flanders. For example, also a management system to guarantee quality and traceability of recycled granulates is in place ("eenheidsreglement voor gerecycleerde granulaten"). CDW that fulfils EoW criteria are included in the data collected in Flanders under a category called "new resources".
	Brussels Capital Region: The EoW criteria are the same as the WFD and are established in the article 9 of "Ordonnance relative aux déchets du 14 juin 2012".	If there are no defined criteria, the regional Government can decide that waste cease to be waste if some conditions are respected. Up to now, no CDW ceased to be waste.
	Walloon region: The criteria are the same as the WFD.	If no specific criteria are defined by the EU, the Walloon government can decide in specific cases if waste can take the EoW status. Up to now, there is no EoW status attributed in Walloon region. New legislation is under development. When this legislation will be in place, Federations will try to create an EoW for recycled aggregates and for excavated soils.
NORDIC REGION	EoW criteria for Construction & Demolition Waste. Promoted by NORDEN.	Common EoW criteria for the Nordic region involving Denmark, Finland, Iceland, Norway, Sweden, and the Faroe Islands, Greenland, and Åland. Nordic cooperation has firm traditions in politics, the economy, and culture. It plays an important role in European and international collaboration, and aims at creating a strong Nordic community in a strong Europe.

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2.3. Technical and environmental regulation for the use of SRM

Table 3 briefly presents the status of technical and environmental regulation for the use of SRM in each of the analysed countries and regions, which is normally addressed in functional specifications for SRM from CDW and industrial waste or by-products.

Table 3: List of technical and environmental regulation for the use of SRM in the different European countries/regions

Countries and regions	Protocol or legislation	Content
SPAIN	Code on Structural Concrete (EHE - 08)	The Code on Structural Concrete EHE - 08 specifies the general rules in Spain for the application of recycled aggregates in structural concrete.
	General technical specifications for road and bridge works (so called PG-3) (Art. 550.2.4.1 and 551.2.4.1)"	Establishes the technical parameters for the use of recycled CDW aggregates in concrete and unbound materials for roads.
	Order APM/1007/2017 of 10 October	General rules for the valorisation of excavated natural materials for their use in filling operations and works other than those in which they were generated.
SPAIN - BASQUE COUNTRY	Standard for the dimensioning of pavements of the Basque Country Road Network	Establishes the technical parameters for the use of recycled CDW aggregates in unbound materials for roads in the Basque Country.
	ORDER of 12 January 2015	Technical and environmental requirements for the use of recycled aggregates from the recovery of construction and demolition waste. This Order is in the process of updating by TECNALIA (expected for the end of 2021).
SPAIN - MADRID	Order 2726/2009, of 16 July	Decree for the regulation of the production and management of CDW in the Madrid region.
ITALY	Circolare 15/7/05 n. 5205 Green Publc Procurement	Sets green public procurement rules for construction activities (including roads works).
	DM 161/2012 Regolamento materiali da scavo	Sets the rules for re-use of excavated materials.
SLOVENIA	Slovenian Technical Specification 06.100:2003	Establishing the technical and environmental limit values for the use of SRM in geotechnical applications.
	Slovenian Technical Specification 06.800:2001	Establishing conditions and types of waste materials to be used in different road construction applications. Currently, ZAG and other national stakeholders are revising specifications under Slovenian Road Agency order.
THE NETHERLANDS	VROM 1995 Building materials Decree	The Decree defines quality requirements for the application and re-use of stony materials as building materials without differentiating primary materials, secondary materials and waste materials.
	VROM – Soil Quality Decree. Decree of 22 November 2007	Containing rules with respect to the quality of soil (Soil Quality Decree). Bulletin of Acts, Orders and Decrees of the State of the Netherlands, 2007.
POLAND	N.A.	-
NORTH MACEDONIA	N.A.	-

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FRANCE	Acceptability of alternative materials in road construction. Environmental assessment SRM obtained from CDW. SRM obtained from steel slags. SRM obtained from non-hazardous incineration wastes SRM obtained from Foundry Sands.	France has EoW regulation for aggregates produced from construction and public works to be used in road building. Wastes that are accepted for the production of aggregates are from the construction and demolition wastes category and include, among others, concrete, bricks, glass, tiles and ceramics. Those guides provides an approach to assess the environmental acceptability of alternative materials produced from CDW and industrial waste or by-products for road construction usage specifying that they must be capable of being implemented under the conditions and with the same equipment as the natural materials they replace.
GERMANY	Technische Lieferbedingungen für Gesteinskörnungen im Straßenbau, Ausgabe 2004	Technical conditions for aggregates in road construction.
	Zweiter Arbeitsentwurf der Bundesregierung 2011	Requirements for the introduction and discharge of substances into the groundwater, for the installation of substitute building materials and for the use of soil and soil-like material.
BELGIUM	PTV 406 (9.0) - Prescriptions techniques pour granulats recyclés	Determine the requirements for recycled aggregates employed for non-treated and treated materials used for civil engineering works, for the construction of roads and for the utilization in concrete applications.
NORDIC REGION	EoW Criteria for Construction & Demolition Waste. Promoted by NORDEN	Stablish the environmental criteria for the use of SRM obtained from CDW.

2.4. European Technical Standards (EN)

The following European Standards specify, for different uses, the properties of aggregates obtained by processing natural, manufactured or recycled materials. They also specify the establishment of a quality control system for the factory production control and the evaluation of conformity of products:

- EN 12620:2002+A1:2008. Aggregates for concrete;
- EN 13139:2002/AC:2004. Aggregates for mortar;
- EN 13055-1:2002/AC:2004. Lightweight aggregates - Part 1: Lightweight aggregates for concrete, mortar and grout;
- EN 13055-2:2004. Lightweight aggregates - Part 2: Lightweight aggregates for bituminous mixtures and surface treatments and for unbound and bound applications;
- EN 13043:2002/AC:2004. Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas;
- EN 13242:2003+A1:2008. Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction.
- EN 13286: Unbound and hydraulically bound mixtures – Test methods.
- EN 13285: Unbound mixtures – Specifications.
- EN 12457-4:2004. Characterisation of waste - Leaching - Compliance test for leaching of granular waste materials and sludges - Part 4: One stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 10 mm (without or with size reduction).

2.5. New perspectives at European level

The European Commission has recently published (on 17th March 2021) a consultation on its Sustainable Products Initiative (SPI). The SPI is one of several initiatives designed to help the EU reach

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the Green Deal objectives of lower resource consumption and reduced environmental impact and responds directly to the EU Circular Economy Action Plan. Feedback on the SPI closes on 9th June 2021.

The SPI proposes to revise the Ecodesign for Energy-Related Products Directive 2009 ("Ecodesign Directive"), adding legislative measures to increase the sustainability of products placed on the EU market. By expanding the scope of the Ecodesign Directive beyond energy-related products (and also including services where appropriate) the SPI is designed to encourage production of products that are more durable, reusable, repairable, recyclable and energy efficient - to the benefit of consumers, the environment and the climate. This initiative comprises just one part of a larger legislative puzzle being pieced together by the EU in a push towards its carbon and emissions targets.

The SPI is expected to move beyond the narrow scope of the Ecodesign Directive – exclusively aimed at products, such as household appliances, information and communication technologies or engineering – and set sustainability criteria based on harmonized indicators and life-cycle assessments such as environmental footprints, to the broadest range of products such as:

- Electronics & ICT equipment,
- Textiles,
- Furniture,
- Steel, cement & chemicals.

Several additional measures are also proposed under the SPI, including (among others) the establishment of:

- Overarching product sustainability principles,
- EU rules to require provision of repair and spare parts,
- Setting mandatory sustainability labelling and/ or introduction of digital product passports,
- Setting mandatory minimum sustainability requirements on public procurement of products.

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3. Analysis of the different EoW Criteria

3.1. Definitions

Each country adopts a different terminology and a way of defining the terms used in the EoW criteria protocols and the regulatory frameworks regarding SRM from CDW and industrial waste or by-products.

Without going into details about each country and specific definitions (harmonized definitions are provided in the Section 6), the following definitions that can be found in the different countries are listed below:

- Wastes and SRM definitions, e.g., waste, inert waste, hazardous waste, non-hazardous waste, industrial by-product, CDW, SRM;
- Type and composition of SRM, e.g., aggregate, natural aggregate, recycled aggregate, manufactured aggregate, artificial aggregate;
- Aggregates size: e.g., sieve size, particle size distribution, coarse recycled aggregate, fine recycled aggregate, all-in aggregate, fine, filler aggregate, ballast;
- Production and treatment: e.g., waste collection, prevention, segregation, treatment, recycling, preparing for reuse, best available techniques, extended producer responsibility;
- Applications: e.g., backfilling, disposal, bound application, unbound application, waterproofing layer, permeability, draining application;
- Others: e.g., leachate, quality control, durability.

3.2. Types and composition of SRM obtained from CDW

According to Article 6 of the WFD, "waste which has undergone a recycling or other recovery operation is considered to have ceased to be waste if it complies with the following conditions:

- The substance or object is to be used for specific purposes;
- A market or demand exists for such a material;
- The substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and
- The use of the substance or object will not lead to overall adverse environmental or human health impacts."

An alternative route for a material to cease being a waste is described in Article 5 of the WFD which states:

"1. Member States shall take appropriate measures to ensure that a substance or object resulting from a production process the primary aim of which is not the production of that substance or object is considered not to be waste, but to be a by-product if the following conditions are met:

(a) Further use of the substance or object is certain;
(b) The substance or object can be used directly without any further processing other than normal industrial practice;
(c) The substance or object is produced as an integral part of a production process; and
(d) further use is lawful, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental and/or health impacts.

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2. The Commission may adopt implementing acts in order to establish detailed criteria on the uniform application of the conditions laid down in paragraph 1 to specific substances or objects.

Those detailed criteria shall ensure a high level of protection of the environment and human health and facilitate the prudent and rational utilisation of natural resources.

Those implementing acts shall be adopted in accordance with the examination procedure referred to in Article 39(2). When adopting those implementing acts, the Commission shall take as a starting point the most stringent and environmentally protective of any criteria adopted by Member States in accordance with paragraph 3 of this Article and shall prioritise replicable practices of industrial symbiosis in the development of the detailed criteria.

3. Where criteria have not been set at Union level under paragraph 2, Member States may establish detailed criteria on the application of the conditions laid down in paragraph 1 to specific substances or objects.

Member States shall notify the Commission of those detailed criteria in accordance with Directive (EU) 2015/1535 of the European Parliament and of the Council (*) where so required by that Directive."

Depending on the country and the local regulations, the recycled aggregates are classified according to different parameters:

a) According to the weight:

Recycled aggregates can be classified based on their particle density:

- Normal weight aggregates: aggregate with a particle density not less than 2,000 kg/m^3 (in some case 1,700 or even 1,500 kg/m^3) and not more than 3,000 kg/m^3;
- Light weight aggregates: aggregate with a particle density less than 2,000 kg/m^3 (in some cases 1,700 or 1,500 kg/m^3).

b) According to the size:

The Particle Size Distribution (PSD) is expressed as mass percentages passing through a specified set of sieves. The recycled aggregates can be classified as a function of the sizes of the lower (*d*) and upper (*D*) sieves, expressed as *d*/*D* (size range depending on the country):

- Coarse recycled aggregates: designation given to the aggregate sizes with *d* equal to or greater than 2 mm and D equal to or greater than 4 mm;
- Fine recycled aggregates: designation given to the aggregate sizes with *D* equal to or less than 4 mm;
- All-in aggregate: aggregates composed of a mixture of fine and coarse aggregates with a continuous PSD;
- Fines: particle size fraction of an aggregate which passes the 0.063 mm sieve;
- Ballast (in some countries): designation given to the coarser aggregate sizes with *d* equal to or greater than 40 mm and *D* equal to or greater than 150 mm.

c) According to the composition:

Recycled aggregates are classified according to their physical composition based on the weight percentage of each of the components that make it up, in accordance with the EN 933-11 (2009) standard as presented in Table 4.

Table 4: Components of coarse recycled aggregates according to EN 933-11 (2009)

Component	Description
Rc	Concrete, concrete products, mortar Concrete masonry units
Ru	Unprocessed aggregates, natural stone Hydraulically bound aggregate
Rb	Clay masonry units (i.e., bricks and shingles) Calcium silicate masonry units Non-floating aerated concrete
Ra	Bituminous materials
Rg	Glass
X	Others: cohesive (i.e., clay and sand) Various: metals (ferrous and non-ferrous), non-floating wood, plastic and rubber Gypsum plaster
FL	Floating Particles

Table 5 summarizes the types of recycled aggregates from CDW in each area and the common term used for each SRM according to this list:

- Recycled Concrete Aggregates (RCA): recycled aggregates composed mostly of concrete from CDW;
- Recycled Mixed Aggregates (RMA): recycled aggregates composed of concrete and ceramic from CDW;
- Recycled Ceramic Aggregates (RBA): recycled aggregates obtained by processing predominantly ceramic material from CDW;
- Recycled Asphalt Aggregates (RAA): aggregates obtained from the milling operations of old bituminous pavement;
- Recycled plaster (RP): SRM from CDW composed of recycled gypsum with purities greater than 99% and X≤1% of improper content;
- Recycled glass (RG): SRM from the valuation of glass from CDW with purities greater than 99% and X≤1% of improper content; and
- Combined Recycled Aggregates (CRA): mixture of natural aggregates and recycled or artificial aggregates.

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Table 5: Types of recycled aggregates from CDW and composition according to EN 933-11 for the different countries/regions

Specification	Country	Types	Alternative name	Composition (%)							
				Rc	Ru	Rb	Ra	Rg	Organic material	X Other contaminants	FL
EN 206	EU	Type A	RCA	> 95	< 10	< 1	< 1	< 2			-
		Type B	RMA	> 70	< 30	< 5	< 2	< 2			-
EHE-08	Spain	Recycled aggregate	RCA	-	-	-	< 5	< 1			< 1
Orden 12/2015	Spain-Basque Country	Recycled Concrete Aggregates	RCA	> 90		< 10	< 10	< 2	< 1		< 1
		Recycled Mixed Aggregates	RMA	> 60		< 10	< 10	< 2	< 1		< 1
		Recycled Ceramic Aggregates	RBA	< 30		< 10	< 10	< 2	< 1		< 1
BRL 2506-1	The Netherlands	Type A1	RCA	> 95		< 10	< 1	< 1			< 2
		Type A2	RCA	> 95		< 10	< 1	< 1			< 2
		Type B	RMA	> 70		< 30	< 5	< 2			< 2
		Type C	RMA	-	-	> 85	< 5	< 2			< 2
NF-P-18-545	France	Type 1	RCA	> 95		< 10	< 1	< 0.5			< 0.2
		Type 2	RCA	> 90		< 10	< 10	< 1			< 2
		Type 3	RMA	> 70		< 30	< 10	< 2			< 2
DIN-4226-101	Germany	Type 1	RCA	> 90		< 10	< 1	< 1			< 2
		Type 2	RMA	> 70		< 30	< 1	< 2			< 2
		Type 3	RMA	< 20		> 80	< 1	< 2			< 2
		Type 4	CRA	> 80			< 20	< 2			< 5
PTV-406	Belgium	Concrete aggregate	RCA	> 90		< 10	< 5	< 2	< 1		< 5
		Mixed aggregate	RMA	> 50		< 50	< 5	< 2	< 1		< 5
		Asphalt gravel	RA	< 30		< 10	> 70	< 2	< 1		< 5
		Masonry aggregate	RMA	< 40		> 60	< 5	< 2	< 1		< 5
		High quality concrete aggregate	RCA	> 95		-	< 1	< 0.5			< 2
		Mixed and asphalt gravel	CRA	> 30		< 50	<50	< 2	< 1		<2
		Concrete and asphalt gravel	CRA	> 70		< 10	< 30	< 2	< 1		< 5
		High quality mixed aggregate	RMA	> 70		< 30	< 5	< 2	< 1		< 2
DRI (2002)	Denmark	Quality A	RCA	> 98		< 2	< 2	< 2	< 0.5		-
		Quality B	RCA	> 95		< 5	< 2	< 5	< 1		-
		Quality C	RCA	> 80		< 20	< 2	< 20	< 2		-

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An example of how to regulate the content of each component for different recycled aggregates (Belgium-PTV406) is shown in Figure 1.

Composition NBN EN 933-11	Gravillon de béton		Gravillon asphaltique		Gravillon mixte		Gravillon de maçonnerie		Gravillon mixte et asphaltique		Gravillon de béton et asphaltique		Gravillon de béton de haute qualité		Gravillon mixte de haute qualité	
	Teneur	Catégorie	Teneur	Catégorie	Teneur	Catégorie	Teneur	Catégorie	Teneur	Catégorie	Teneur	Catégorie	Teneur	Catégorie	Teneur	Catégorie
Rc	≥ 70	Rc_{70}	Non requis	Rc_{NR}	Non requis	Rc_{NR}	Non requis	Rc_{NR}	Non requis	Rc_{NR}	Non requis	Rc_{NR}	≥ 90	Rc_{90}	≥ 50	Rc_{50}
Rcug	≥ 90	$Rcug_{90}$	≤ 30	$Rcug_{30-}$	≥ 50	$Rcug_{50}$	≤ 40 ≤ 30*	$Rcug_{40-}$ $Rcug_{30-}$*	≥ 30	$Rcug_{30}$	≥ 70	$Rcug_{70}$	≥ 95	Rcu_{95}	≥ 70	Rcu_{70}
Rb	≤ 10	Rb_{10-}	≤ 10	Rb_{10-}	≤ 50	Rb_{50-}	≥ 60 ≥ 50*	Rb_{60} Rb_{50}*	≤ 50	Rb_{50-}	≤ 10	Rb_{10-}	non requis	Rb_{NR}	≤ 30	Rb_{30-}
Ra	≤ 5	Ra_{5-}	≥ 70	Ra_{70}	≤ 5	Ra_{5-}	≤ 5	Ra_{5-}	≤ 30	Ra_{30-}	≤ 30	Ra_{30-}	≤ 1	Ra_{1-}	≤ 5	Ra_{5-}
Rg	≤ 2,0	Rg_{2-}	≤ 2,0	Rg_{2-}	≤ 2,0	Rg_{2-}	≤ 2,0	Rg_{2-}	≤ 2,0	Rg_{2-}	≤ 2,0	Rg_{2-}	≤ 0.5	$XRg_{0.5-}$	≤ 2,0	Rg_{2-} / XRg2-
X	≤ 1,0	X_{1-}	≤ 1,0	X_{1-}	≤ 1,0	X_{1-}	≤ 1,0	X_{1-}	≤ 1,0	X_{1-}	≤ 1,0	X_{1-}			≤ 1,0	X_{1-}
FL	≤ 5,0 ≤ 2,0*	FL_{5-} FL_{2-}*	≤ 5,0 ≤ 2,0*	FL_{5-} FL_{2-}*	≤ 5,0	FL_{5-}	≤ 5,0 ≤ 2,0*	FL_{5-} FL_{2-}*	≤ 5,0 ≤ 2,0*	FL_{5-} FL_{2-}*	≤ 5,0 ≤ 2,0*	FL_{5-} FL_{2-}*	≤ 2,0	FL_{2-}	≤ 2,0	FL_{2-}

Figure 1: Categorization of different types of recycled aggregate according to the Belgium PTV 406

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3.3. Permitted uses

Spain-Basque Country

The SRM from CDW and steel slag may be used, under the technical, environmental and productive conditions and controls to the different intended uses. The uses are classified in different scenarios according to the degree of environmental protection to which they are subjected, starting from bound applications without any type of environmental risk to unbound applications with different degrees of waterproofing requirements to minimize leaching.

Scenario 1 – Bound applications

Use of granular materials mixed with any type of binder that confers cohesion to the whole by encapsulating the aggregates within an inorganic matrix, where their exposure to the environment and the release of components are considered null or negligible. These bound applications are the following:

1) Structural concrete:
   - ready-mix concrete;
   - precast concrete elements: blocks, pavements, barriers, pipes, etc;
   - concrete caissons for docks.
2) Non-structural concrete:
   - levelling concrete;
   - infill concrete.
3) Concrete for roads and flooring:
   - concrete for pavements;
   - vibrated concrete.
4) Cement treated material for foundation courses: gravel-cement (slag-cement).
5) Bituminous mixtures (hot, warm and cold) for the execution of roads surface courses, bicycle's paths and pedestrians' paths - Figure 2.

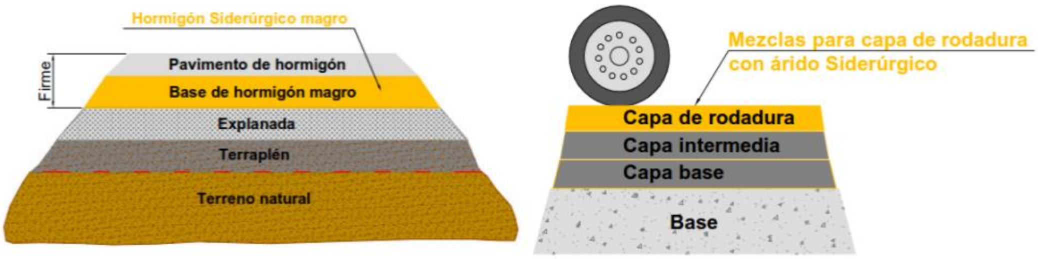

Figure 2: Example of usages foreseen in the Basque Country for scenario 1 (Type 3 and 5) (Source: Gobierno Vasco[2])

Scenario 2 – Unbound applications under a coverage that is not fully impervious

Use of compacted granular materials in layers for the execution of various civil works units, without adding any binder, under coverings of not fully impervious materials. These applications are the following:

[2] Gobierno Vasco. 2019. "Guía de aplicación del Decreto de actividades de valorización de escorias negras de fabricación de acero en hornos de arco eléctrico y su utilización como árido siderúrgico."

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1) Engineering embankments - exposed areas are excluded except when they have a waterproofing treatment (Figure 3);
2) Engineering embankments under coverings of not fully impervious;
3) Phonic protections for infrastructures.

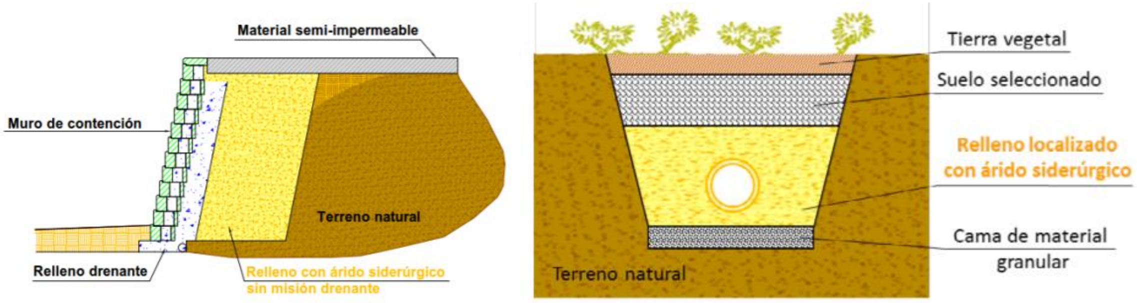

Figure 3: Example of usages foreseen in the Basque Country for scenario 2 (Type 1) (Source: Gobierno Vasco[3])

Scenario 3 – Unbound applications under fully impervious coverage

Use of compacted granular materials in layers for the execution of various civil works units, without adding any binder, under coverings of fully impervious materials. These foreseen applications are the following:

1) All-in materials;
2) Foundation courses (base course and sub-base course) for pedestrian, cycle and sport´s paths;
3) Subgrade courses;
4) Engineering embankments - exposed areas are excluded except when they have a waterproofing treatment (Figure 4);
5) Engineering capped embankments;
6) Urbanization projects.

Figure 4: Example of usages foreseen in the Basque Country for scenario 3 (Type 2 and 4) (Source: Gobierno Vasco)

[3] Gobierno Vasco. 2019. "Guía de aplicación del Decreto de actividades de valorización de escorias negras de fabricación de acero en hornos de arco eléctrico y su utilización como árido siderúrgico."

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France

Different road construction usages are foreseen as described below.

Type 1: usage for underlying courses of capped pavement or shoulder sublayers (Figure 5):

- Subgrade fill,
- Capping layer,
- Sub-base course,
- Base course,
- Sub-grade,
- Binder course.

Surfaced with a surfacing layer are considered impervious (asphalt, bituminous mixes, wearing surface dressings, cement concrete, binder jointed paving blocks) at a 1% minimum gradient.

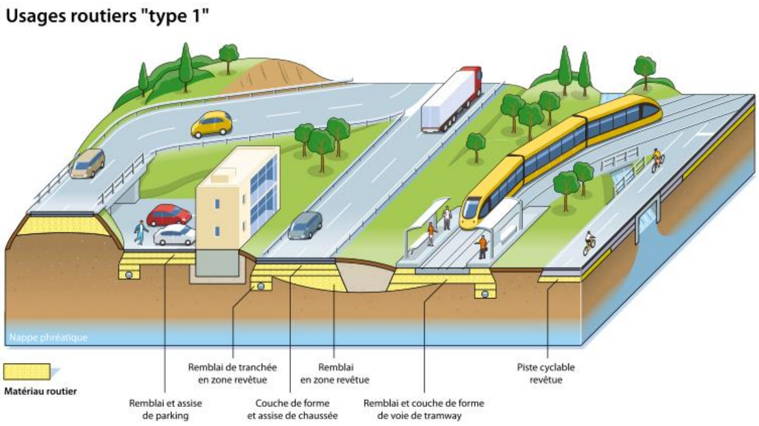

Figure 5: Usage foreseen in France for underlying courses (Type 1) (Source: SETRA)

Type 2: usage for covered engineering embankments associated with road infrastructure (e.g. phonic protection) or for capped shoulders (Figure 6)

Covered by at least 30 cm of natural materials (including topsoil) with a 5% minimum gradient on the top of this cover to limit water infiltration.

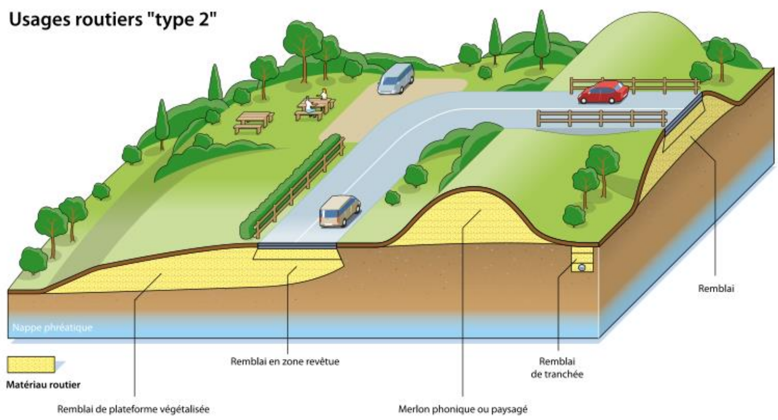

Figure 6: Usages foreseen in France for covered engineering embankments (Type 2) (Source: SETRA)

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Type 3: use of road materials, which satisfy the conditions concerning level 1 environmental characterisation[4], in unpaved or uncapped road construction usages (Figure 7):

- Usage for wearing courses,
- Usage for uncapped pavement or shoulder sublayers,
- Usage for engineering embankments associated with road infrastructure or for uncovered shoulders,
- Usage for preloading fills required road infrastructure construction, and
- Usage for drainage systems (e.g. trench or counterfort drain, reservoir pavement).

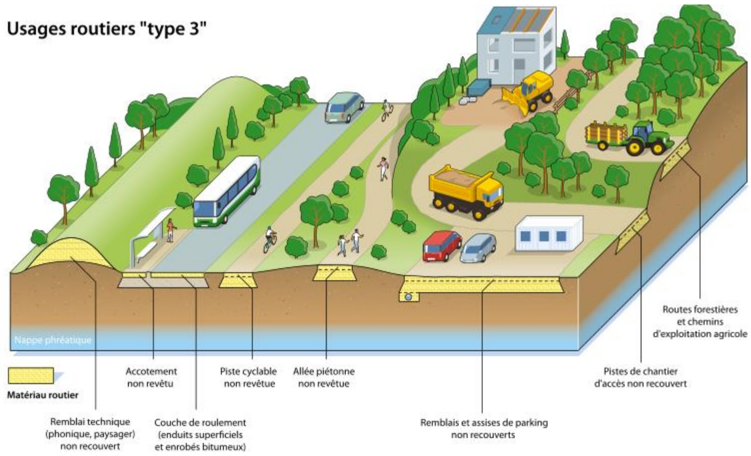

Figure 7: Usages foreseen in France for unpaved or uncapped road construction applications (Type 3) (Source: SETRA)

Nordic region

In the Nordic countries typical uses of virgin and waste-derived aggregates which are also relevant for CDW, particularly crushed concrete, with EoW status, are[5]:

- Unbound use in base and sub-base layers under roads and parking lots,
- Unbound use as sub-base in highway ramps and embankments,
- Unbound use as filling material in noise reduction barriers,
- Unbound use as filling material under buildings, and
- As aggregates in hydraulically bound applications (concrete).

3.4. Restrictions and prohibitions of use

Spain-Basque Country

The use of recycled aggregates and steel slag manufactured aggregates in any of the unbound applications contemplated in the decree that regulates the use of recycled aggregates are subjected, in general, to the following restrictions:

a) Protected areas as defined in the regulation of natural spaces to be preserved;

[4] SETRA. Acceptability of Alternative Materials in Road Construction. Environmental Assessment. March 2011.
[5] "End-of-Waste Criteria for Construction & Demolition Waste" Ole Hjelmar, Jette Bjerre Hansen, Margareta Wahlström and Ola Wik. 2016 www.norden.org/nordpub

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b) Application in direct contact with soil for those uses declared as 'other uses' as described in the Law 4/2015, for the prevention and remediation of soil contamination in the Basque Country;

c) Uses in direct contact with water;

d) Uses as draining material or places where water flows temporarily;

e) Uses without covering layers, such as forest tracks, non-paved rural roads, or railway ballast;

f) CDW for the production of recycled aggregates originated in locations where potentially contaminating activities were conducted, unless a particular authorization is issued;

g) In the production of recycled aggregates, CDW from industrial ruins that have suffered potentially soil-polluting activities may not be used, unless the corresponding environmental body certifies the correct performance of the cleaning of the industrial ruin;

h) Those aggregates that have not reached the EoW condition may not be used by not complying with the technical and environmental parameters.

In addition, recycled aggregates fulfil with CE marking and requirements in those uses where it is necessary based on applicable regulation. New uses could be included, only if the environmental authorities approve them based on evidences for acceptability presented by the interested parties.

France

Unless otherwise advised by an expert hydrogeologist, the use of alternative materials is not allowed in the following scenarios:

- In areas liable to flooding and less than 50 cm from the highest fiftieth waters or, alternatively, the highest known waters;
- Less than 30 m from any surface water, including lakes and ponds. This distance is increased to 60 m if the altitude of the watercourse bed is more than 20 m lower than that of the base of the structure and in the areas designated as a protection zone for habitats, species, wild fauna and flora in application of article L.414-1 of the environment code;
- In the close protection perimeters of drinking water supply sourcing; and
- In karsts units that can modify the flow of water present continuously or temporarily in the structure or its immediate environment.

Nordic region

Some of the conditions that could be imposed on the use of a given SRM with EoW status are listed in Table 6 which also indicates which parts of the source-pathway-receptor chain will be affected by the measures taken.

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Table 6: Overview of conditions that may be imposed on the use of waste-derived aggregates as part of EoW criteria[6]

No	Imposed condition	Source	Pathway	Receptor
1	The material can only be used for specified purpose	Can be influenced	Can be influenced	May determine which receptors are relevant
2	Take back the material after service life	Reduction in the time span to be considered	Not affected	Not affected
3	Minimum distance to groundwater level	Not affected	Attenuation in the unsaturated zone may be taken into account	Depends on point of compliance
4	Minimum distance to surface water	Not affected	Attenuation in the unsaturated zone and the aquifer may be taken into account	Depends on point of compliance
5	Restrictions on height of application	May reduce source term	Not affected	Not affected
6	Restrictions on the length and width of the application	May reduce the source term	Not affected	Not affected
7	Restrictions on allowed rate of infiltration	Reduction of the flux (the load per time unit)	Not affected	Not affected

Another restriction that is not mentioned in the table could be a minimum distance to drinking water extraction wells.

3.5. Technical requirements

The different technical standards of products and specifications of each country establish criteria for the application of SRM. In most countries the following tests apply:

1) Geometric requirements:
   - Determination of particle size distribution - Sieving method according to the EN 933-1:2012;
   - Determination of particle shape - Flakiness index according to the EN 933-3:2012.

2) Physical requirements:
   - Classification test for the constituents of coarse recycled aggregates according to the EN 933-11:2009;
   - Determination of resistance to fragmentation of coarse aggregates according to the EN 1097-2:2010;
   - Assessment of fines - Sand equivalent test according to the EN 933-8:2012+A1:2015;
   - Determination of particle density and water absorption according to the EN 1097-6:2014;
   - Determination of liquid and plastic limits according to the ISO 17892-12:2018;
   - Test for free swelling.

3) Chemical requirements:
   - Determination of the total sulphur content according to the EN 1744-1:2010+A1:2013;
   - Determination of the water and acid soluble sulphates according to the EN 1744-1:2010+A1:2013;
   - Determination of the chlorides content according to the EN 1744-1:2010+A1:2013;

[6] "End-of-Waste Criteria for Construction & Demolition Waste" Ole Hjelmar, Jette Bjerre Hansen, Margareta Wahlström and Ola Wik. 2016 www.norden.org/nordpub

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- Determination of the gypsum content;
- Determination of the soluble salts content.
- Determination of the organic matter content.
- Determination of the volume stability of steel slag aggregates according to the EN 1744-1:2010+A1:2013.

4) Durability requirements:
   - Determination of the resistance to freezing and thawing according to the EN 1367-1:2008;
   - Determination of the stability of aggregates and rock fragments against collapse in water action according to the NLT 255:1999;
   - Determination of the magnesium sulphate test according to the EN 1367-2:2009.

As an example, a classification of recycled aggregates is shown Table 7 based on the most characteristic technical properties.

Table 7: Classification of aggregates according to the characteristic technical properties of recycled aggregates for the different countries/regions

Specification	Country	Types	Min. oven dried particle density (kg/m^3)	Max. water absorption (%)	Max. sulphate content (%)	Resistance to fragmentation[b]	Flakiness index (%)
EN 206	EU	Type A	2,100	-	0.2[a]	<50%	50
		Type B	1,700	-	0.2[a]	<50%	50
EHE-08	Spain	Recycled aggregates for concretes	2,000	7	1	<40%	35
PG-3	Spain	Recycled aggregate for unbound uses	2,000	-	1 / 0,7[a]	<40%	35
BRL 2506-1	The Netherlands	Type A1	2,200	-	0.7	<40%	-
		Type A2	2,000	-	0.7	<40%	-
		Type B	2,000	-	0.7	<50%	-
		Type C	2,000	-	0.7	<50%	-
NF-P-18-545	France	Type 1	2,000	2.5	1	<40%	40
		Type 2	2,000	2.5	1	<40%	40
		Type 3	1,700	2.5	1	<50%	40
DIN-4226-101	Germany	Type 1	2,000	10	1	-	50
		Type 2	2,000	15	1	-	50
PTV-406	Belgium	Concrete aggregate	1,500	10	0.2[a]	-	-
		Mixed aggregate	1,500	10	-	-	-
		Masonry aggregate	1,500	10	-	-	-
		High quality concrete aggregate	2,200	10	1	<35%[c]	20

[a] water-soluble
[b] LA abrasion

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3.6. Environmental requirements (unbound applications)

The environmental requirements associated with the local product legislation must be fulfilled by the SRM and recycled / manufactured aggregates.

As a result of the non-existence of environmental requirements for aggregates as a product on the European level and due to the fact that for a material to cease to be waste the principle of 'no overall adverse environmental or human health impacts has to be met', definition of the environmental requirements for SRM is of the urgent necessity.

In some cases, a clear identification of the waste stream originating the input material, its composition and management practices until the processing stage (e.g., CDW from selective demolition, source segregation) can be considered a sufficient guarantee of the environmental risks linked to the use of the material. Adequate quality control measures should be established to ensure that the recycler applies the required procedures.

However, even if the traceability and quality control are correctly applied, the environmental requirements cannot be ensured since hazardous substances may exist during the release of substances from the material to the environment. In order to guarantee that the SRM can be considered safe from the environmental point of view, leaching references should be used as environmental requirements.

EoW leaching references, calculated on a risk assessment approach, have to consider the long-term behaviour of the materials, linked to the expected exposure conditions of the recycled and manufactured aggregate in the use phase of the material. Moreover, attenuation factors such as background pollution and soil interactions which influence the bioavailability of the leached substances should be part of the method to be used. The references should define quantitatively a maximum allowable impact to the environment for general use of the material.

Some MS have developed legislation or regulations establishing environmental conditions for secondary building materials from the point of view of soil and groundwater protection. An analysis of the different leaching limits is presented in Table 8.

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Table 8: Limiting values of leaching criteria for the use of SRM in unbound applications

Country	Application scenario	Leaching criteria - Limit value. (mg/kg of dry waste. L/S 10)																	
		Sb	As	Ba	Cd	Cr/Cr(VI)	Cu	Hg	Pb	Mo	Ni	Se	Sn	V	Zn	Br	Cl	F	SO4
Spain-Basque Country	Unbound application – CDW (EN12457-4)	0.06	0.5	20	0.04	0.5/-	2	0.01	0.5	0.5	0.4	0.1	-		10	-	800	10	6,000
	Unbound semi-waterproofing application – steel slags (EN12457-4)	0.06	0.5	20	0.04	0.5/0.1	2	0.01	0.5	0.5	0.4	0.1	-	1.5	4	-	800	18	1,000
	Unbound waterproofing application – steel slags (EN12457-4)	0.08	0.6	25	0.05	2/0.4	3	0.01	0.6	2.8	0.5	0.4	-	4	5	-	5,000	30	5,000
Italy	Unbound application (EN12457-2)	-	0.5	10	0.05	0.5/-	0.5	0.01	0.5		0.1	0.1	-	2.5	30	-	1,000	15	2,500
EU	EU Inert landfill	0.06	0.5	20	0.04	0.5/-	2	0.01	0.5	0.5	0.4	0.1	-	-	4	-	800	10	1000
Slovenia	Composite water permeability for use in the areas that are no subjected to the water protection regime	0.3	0.1	5	0.025	0.5/-	0.5	0.005	0.5	0.5	0.4	0.6	-	-	2	-	800	10	1,000
The Netherlands	Unbound materials - most stringent values (percolation test, NEN7373)	0.32	0.9	22	0.04	0.63/-	0.9	0.02	2.3	1	0.44	0.15	0.4	1.8	4.5	20	616	55	1,730
North Macedonia	Inertness criteria	0.06	0.5	20	0.04	0.5/-	2	0.01	0.5	0.5	0.4	0.1	-	-	4	-	800	10	1,000
France	Unbound materials - most stringent values (NEN12457-2 or 4)	0.06	0.5	20	0.04	0.5/-	2	0.01	0.5	0.5	0.4	0.1	-	-	4	-	800	10	1,000
Germany	Z0/Z1.1 LAGA – Soil - Most stringent values EN 12457-2 in µg/l*	-	14	-	1.5	12.5/-	20	0.5	40	-	-	-	-	-	150	-	30,000	-	20,000
Belgium-Flanders	Unbound materials	-	0.8	-	0.03	0.5/-	0.5	0.02	1.3	-	0.75	-	-	-	2.8	-	-	-	-
Finland	Unbound materials under covered structure	0.06	0.5	20	0.02	0.5/-	2	0.01	0.5	0.5	0.4	-	-	2	4	-	800	10	1,000
	Unbound materials under paved structure	0.06	0.5	20	0.02	0.5/-	2	0.01	0.5	0.5	0.4	-	-	2	4	-	800	50	6,000

* In accordance with soil protection regulation. Limit values will be related to the different categories of soil use (industrial, residential, etc.). Table includes most stringent use (‘other uses’, as defined in the Basque Country law).

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Organic compounds limits and total content of Inorganic compounds are presents in only few MS (e.g., Spain-Basque Country, France, Belgium-Flanders). In Table 9 and Table 10 the limits established for the organic compounds and the total content of inorganic compounds, respectively, are presented.

Table 9: Limiting values of organic compounds for the use of SRM in unbound applications

Country	Application scenario	Organic compounds Total content criteria - Limit value. (mg/kg of dry waste)									
		Asbestos	Tar-containing asphalt (PAHs)	PCB	BTEX	Mineral Oils	EOX	Hexane	Heptane	Octane	TOC
Spain-Basque Country	Unbound waterproofing application – CDW	-	-	-	6	50 (limit for chemical fractions)	-	-	-	-	-
France	-	-	50	1	6	500	-	-	-	-	30,000
Belgium-Flanders	Unbound materials	100	Individual limits for 16 PAHs	0,5	Individual limits	1,000	10	10	1	90	-
Finland	Unbound materials	-	20	1	-	500	-	-	-	-	-

Table 10: Limiting values of inorganic compounds for the use of SRM in unbound applications.

Country	Application scenario	Inorganic compounds Total content criteria - Limit value. (mg/kg of dry waste)									
		As	Cd	Cr/Cr(VI)	Cu	Hg	Mo	Pb	Ni	V	Zn
Spain-Basque Country	Unbound application – CDW*	30	5	200/8	10,000	4	75	120	110	-	10,000
	Unbound applications in direct contact with soil – steel slags	30	5	10,000/8	10,000	4	75	120	110	1,000	10,000
Belgium-Flanders	-	250	10	1250/--	375	5	-	1,250	250	-	1,250
Finland	Unbound materials	50	10	400/-	400	-	-	300	-	-	700
Sweden	Swedish Road Administration, (2007b). Criteria for use in “non sensitive areas”	-	12	-	200	-	-	250	-	-	700
	Swedish EPA (2010c). Criteria for free use	10	0,2	-	40	-	-	20	-	-	120
	Swedish EPA (2010c). Criteria for use on top of landfills.	10	1,5	-	80	-	-	200	-	-	250

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4. Review of Product Regulations

4.1. Construction Product Regulation (CPR)

The Construction Products Regulation n. 305/2011[7] (CPR) is an EU regulation harmonising performance information on construction products across the EU. It is made most visible by the mandatory CE marking of regulated products. CPR provides a common technical language to evaluate the performance of building products. It ensures that professionals, public institutions and consumers have access to reliable information so that they can compare the performance of products from different manufacturers in different countries/regions.

CPR involves any construction product or kit that is produced and put on the market and is permanently incorporated into the construction project (or part of it), and its performance affects the performance of the construction project, with respect to the 7 Basic Requirements for Construction Works (BRCW). These are:

1. Mechanical resistance and stability: The design and construction method of the construction project must ensure that the loads that may act on it during its construction and use will not cause collapse, unallowable deformation or damage.

2. Safety in case of fire: In the event of a fire, the load-bearing capacity must be maintained for a period of time, the generation and spread of fire and smoke must be restricted, and the safety of rescuers must be considered.

3. Hygiene, health and the environment: The design and construction works must not pose a threat to the hygiene or health of residents or neighbours, especially the consequences of any of the following:

- The giving-off of toxic gas,
- The presence of dangerous particles or gases in the air,
- The emission of dangerous radiation,
- Pollution or poisoning of the water or soil,
- Faulty elimination of waste water, smoke, solid or liquid wastes,
- The presence of damp in parts of the works or on surfaces within the works.

4. Safety in use: The works may not present unacceptable risks of accidents in service such as slipping, falling, collision, burns, electrocution, injury from explosion.

5. Protection against noise: Noise perceived by the occupants or people nearby has to be kept down to a level that will not threaten their health and will allow them to sleep, rest and work in satisfactory conditions.

6. Energy economy and heat retention: With consideration to the climatic conditions of the location and the occupants, the construction works and their heating, cooling, and ventilation facilities must be designed and erected in such a way that the quantity of energy required in use is as low as possible.

7. Sustainable use of natural resources: The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and ensure the:

- Reuse or recyclability of the construction works, their materials and parts after

[7] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011R0305&from=EN

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demolition;
- Durability of the construction works;
- Use of environmentally compatible raw and secondary materials in the construction works.

The CPR has introduced simplified procedures for CE marking by replacing the Declaration of Conformity (see Construction Product Directive – CPD 89/106/EEC – replaced in 2011 by CPR) with the Declaration of Performance (DoP). These simplifications were designed to reduce above all the costs incurred by small and medium-sized enterprises. In addition, the CPR has also updated the regime that governs innovative construction products (European Assessment Document/European Technical Assessment – EAD/ETA) to facilitate their route to market within Europe. Further information is given in the next sections.

As regards the BRCW, the CPR considers new aspects on life-cycle about the 3rd Basic Requirement on hygiene, health and the environment: "The construction works must be designed and built in such a way that they will, throughout their life cycle, not be a threat to the hygiene or health and safety of workers, occupants or neighbours, nor have an exceedingly high impact, over their entire life cycle, on the environmental quality or on the climate during their construction, use and demolition".

Moreover, one of the main innovations of the CPR is the introduction of the 7th BRCW on "Sustainable use of natural resources", according to which the construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable .

This is an important contribution for the market uptake of innovative products from CDW and other waste in line with the EU action plan for the Circular Economy, even if there are still uncertainties about the interpretation of this Basic Requirement.

4.2. Harmonized European Standards (hEN)

It is important to note that CE marking can only be applied to a construction product which is placed on the market either in conformity with the requirements of a harmonized European Standard (hEN) or when the product has a European Technical Assessment (ETA) document. A hEN contains an Annex ZA which defines the Essential Requirements (ER) for the particular products covered by the standard and the conditions applicable to CE marking the product. An ETA is an alternative and voluntary method of CE marking which can be applied when a product is not covered by a hEN. The details for an ETA are set out in the European Assessment Document (EAD). However, in this article reference will be made to aggregates supplied in conformity with both hENs and 'non-harmonized' European Standards for the reason which is made clear later in the article.

Technical Committees develop hENs for construction items based on the CPR's core requirements. CEN's Technical Committee is in charge of creating the necessary set of harmonised European standards and test standards, as well as upgrading the ones that already exist.

hENs in the construction sector have several advantages, the most important being a common assessment method for construction products and a single European scheme for the DoP of the product. hENs define the methods and criteria for the evaluation of the performance of construction products by referring to the intended use of the products to which they relate and including the technical details necessary to apply the system of Assessment and Verification of the Constancy of Performance (AVCP).

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Annex ZA lists the regulated mandatory requirements according to the mandate issued to CEN by the European Commission and the clauses in the standard in which they are addressed. Some of these clauses may also refer to separate supporting documents, for example test methods standards. Appendix ZA establishes the conditions for CE marking of a product according to:

- The identification of the clauses of the standard required to meet the mandate given under the CPR (point ZA.1);
- The procedure(s) for the AVCP (point ZA.2);
- The information required to accompany the CE marking and the framework of the labelling (point ZA.3).

In this way, Annex ZA becomes a sort of guide for CE marking. Compliance with Appendix ZA allows the affixing of the CE marking.

4.3. CE Marking

CE marking is necessary for the marketing of a product within Europe as it states that the product complies with the applicable legislation. On a construction product, it indicates that the product conforms to a hEN or an ETA.

The letters ‘CE’ appear on many products traded on the extended Single Market in the European Economic Area (EEA). They signify that products sold in the EEA have been assessed to meet high safety, health, and environmental protection requirements. CE marking also supports fair competition by holding all companies accountable to the same rules.

By affixing the CE marking to a product, a manufacturer declares that the product meets all the legal requirements for CE marking and can be sold throughout the EEA. This also applies to products made in other countries that are sold in the EEA.

There are two main benefits CE marking brings to businesses and consumers within the EEA:

- Businesses know that products bearing the CE marking can be traded in the EEA without restrictions;
- Consumers enjoy the same level of health, safety, and environmental protection throughout the entire EEA.

CE marking (Figure 8) is a part of the EU’s harmonisation legislation, which is mainly managed by Directorate-General for internal market, industry, entrepreneurship and small and medium enterprises.

Figure 8: CE Marking logo (Source: EC)

The CE mark denotes the publication of information on:

- Safety,
- Testing criteria,
- Fire resistance,
- Mechanical resistance and stability,
- User instructions, including hygiene and environmental instructions,
- Protection against noise,
- Energy, economy and heat retention,
- Sustainable use of natural resources,
- Handling instructions,
- Storage recommendations,
- Maintenance,
- Warranties,
- Dealerships.

Manufacturers who plan to CE-mark their products or who are looking for a 'to-do list' can consult the CE marking step-by-step[8] (Figure 9). The guide is available in all EU languages. The guide also explains what to do if the product changes (its processes, raw materials, testing, etc.) which makes it necessary to revise the documents required.

Figure 9: CE Marking step by step (Source: EC)

4.4. European Technical Assessment (ETA)

The ETA is a method of applying CE marking to construction products that do not meet all of the requirements of a harmonised standard. It provides information on evaluating product performance. The assessment procedure is laid down in the CPR: when a manufacturer realizes his product is not covered by a hEN, a Technical Assessment Body (TAB) designated by EU countries according to national procedures should be contacted. First, the TAB shall check and inform the manufacturer whether the product is fully or partly covered by a hEN (if the product is covered by a hEN, it is not possible to issue an ETA). If the product is not covered by hEN, the TAB shall assess the product on the basis of EADs, which are harmonised technical specification for construction products developed by the European Organisation for Technical Assessment – EOTA (Figure 10).

[8] https://ec.europa.eu/docsroom/documents?tags=ce-guide

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Figure 10: EOTA logo (Source: EOTA)

EADs are the basis for issuing ETAs as they contain:

- A general description of the construction product;
- The list of ER agreed between the manufacturer and EOTA;
- The methods and criteria for assessing the performance of the product in relation to these essential characteristics;
- Principles for factory production control to be applied.

TAB prepares the ETA if an EAD suitable to the product already exists; otherwise, a new EAD must be drafted, submitted to TAB for adoption, and the ETA must be prepared. This procedure may take some time, particularly for new items that are not covered by existing EADs. As soon as the manufacturer receives the ETA, he has the basis for being able to draw up the DoP and then affixes the CE marking.

Diagram in Figure 11 summarizes the process leading to the issues of ETAs.

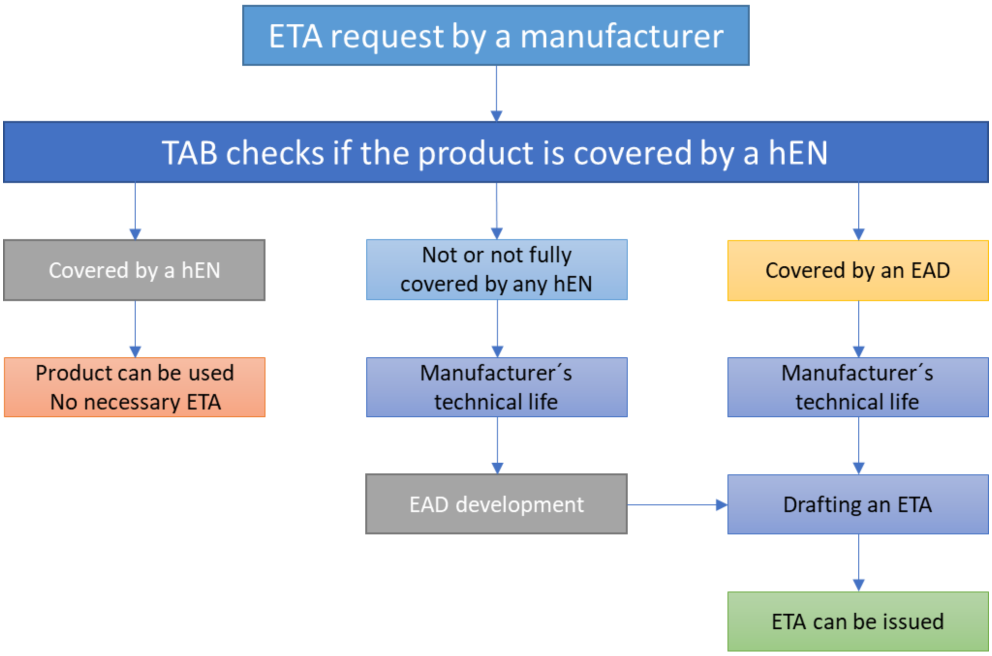

Figure 11: Process leading to the issues of ETAs

4.5. Environmental Product Declaration (EPD)

An Environmental Product Declaration (EPD)[9] is an independently verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact of products in a credible way.

A life cycle assessment (LCA) is the cornerstone of any EPD, where the EPD is the final report. This LCA allows assessing the environmental performance of a product across its entire life cycle. It usually considers entire value chain, from raw materials to finished products, as well as their stages of use and end of life.

EPD is a type III environmental declaration that complies with the ISO 14025 standard. In the context of a program, such as the International EPD® System (Figure 12), a type III environmental declaration is generated and registered. The EPD Library makes EPDs registered in the International EPD System publicly available and free to download.

The series of ISO 14020 standards introduces three main different types labelling schemes:

- Type I is a multi-attribute label developed by a third party;
- Type II is a single-attribute label developed by the producer;
- Type III is an eco-label whose awarding is based on a full life-cycle assessment.

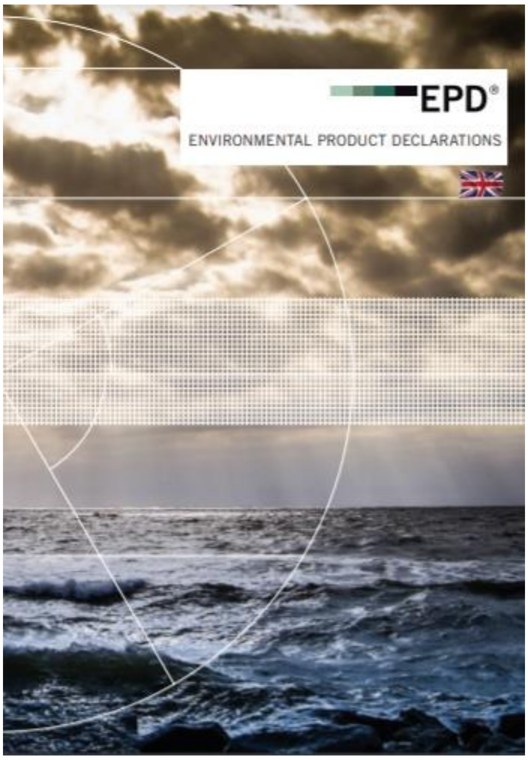

Figure 12: The "Environmental Product Declaration" guide (Source: Environdec)

In physical terms, an EPD consists of two key documents:

- EPD background project report, a systematic and comprehensive summary of the LCA project to support the third-party verifier when verifying the EPD -the report is not part of the public communication;

[9] https://www.environdec.com/all-about-epds0/all-about-epds

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- Public EPD document that provides the results.

As a voluntary declaration of the life-cycle environmental impact, having an EPD for a product does however not imply that the declared product is environmentally superior to alternatives.

4.6. Application of the harmonised product regulations to the SRM-based products

For all products produced and supplied in conformity with a hEN, the producer/supplier making an aggregate available on the market has a legal responsibility to draft and provide DoP and to affix or provide CE marking information for these products as from 1st July 2013. If a product is supplied in conformity with a hEN but has no DoP and, therefore, is not CE marked, it cannot be legally placed on the market.

This applies to eight categories of aggregate products including:

- Aggregates for bituminous mixtures and surface treatments;
- Lightweight aggregates;
- Aggregates for concrete, mortar;
- Unbound and hydraulically bound materials;
- Armourstone;
- Railway ballast.

What is then required to demonstrate EoW status so that a SRM may be sold as a product in the same way as a natural aggregate?

To demonstrate that products are no longer waste the producer must have in place procedures that meet the following EoW requirements:

1. The waste has been converted into a distinct and marketable product;

2. The processed substance can be used in exactly the same way as a non-waste; and

3. The processed substance can be stored and used with no worse environmental effects when compared to the material it is intended to replace.

These criteria may be applied to recycled and manufactured aggregates as follows:

1. Suitable wastes processed into recycled aggregates in conformity to an aggregates' product standard become a distinct and marketable product;

2. Recycled aggregates produced in conformity to an aggregates product standard to show compliance with construction application specifications can be used in exactly the same way as natural aggregates; and

3. Recycled and manufactured aggregates produced from suitable wastes and in conformity to an aggregates' product standard can be stored and used with no worse environmental effects when compared to natural aggregates.

In order for recycled and manufactured aggregate producers to market their products as non-waste they must have in place and operate to procedures and documentation that demonstrate:

- The aggregates are produced in conformity to an aggregates' product standard;

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- The aggregate products are compliant with application specifications;
- The aggregates are processed from suitable wastes.

Where such procedures and documentation are not in place, or operational, the recycled and manufactured aggregates will remain waste.

5. Outcomes of CINDERELA´s WP3, WP5 and WP6

Several demo cases have been designed in the Work Package (WP) 6 and built on three main locations: in Slovenia at the NIGRAD premises in Maribor; in North Macedonia at the facility of Makstil Steelwork Company in Skopje; and in Spain at the CTC facilities in Madrid.

In order to perform the demo cases, different wastes were collected and characterized during the WP3 for their characterization and analysis of potential uses, technical and environmental viability. The main objectives of the WP3 were:

- To develop a holistic protocol for material flow analysis in urban and peri-urban areas for the purpose of predicting the most optimal waste-to-product solution based on waste availability, quantity, and location;
- To analyse waste potential in the studied cases for the production of the SRM-based products and CinderCEBM;
- To assess existing and potential value and supply chains and main actors along the value and supply chains, including policy and decision makers, legislative bodies and the general public; and
- To set up a framework for SRM-based urban and peri-urban construction.

The selected wastes were specifically processed to optimize their use in new SRM-based construction products at laboratory scale during the WP5. The main objectives of WP5 are:

- To design, develop and test sustainable and durable SRM-based construction products, which will be used in individual pilot demonstrations in WP6;
- To **develop a technical specification of the EoW criteria** according to the final intended use of the SRM-based products;
- To elaborate plans for pilot production, which will be demonstrated in WP6; and
- To develop detailed designs (including Building Information Modelling – BIM - designs) for the pilot activities in WP6.

Finally, during the WP6, the SRM-based products were employed in different real demonstration cases. The main objectives of this WP6 are the following:

- To demonstrate the systemic, technological and economic value of the pilot production of the SRM-based materials;
- To demonstrate the systemic, technological and economic value of use of the SRM-based construction products in different construction works supported with BIM modelling (e.g. revitalization of degraded areas, construction of small building facilities and roads construction).

While construction legislation such as the CPR already enable and encourage using of the SRM-based products, one of the outcomes of Task 5.1 is the optimization of testing methods, which will be proposed to CEN TC 154 on Aggregates and the optimization of the use of SRM in new construction products.

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5.1. Outcomes of WP3 and Task 3.2

The main objective of this task was to propose criteria for the valorisation of different wastes such as (i) quantity, (ii) quality, (iii) availability, and (iv) recyclability of wastes according to intended use taking into account available legal and administration paths. Technical (mechanical, chemical and mineralogical properties) and environmental (leaching properties) characterization of waste was carried out on a laboratory level in order to be able to evaluate applicability for SRM-based products made from different types of valorised wastes. This initial characterization was employed as a basis for the selection of the most promising wastes from the targeted waste groups and further development of SRM-based construction products in WP5 (e.g., recycled and manufactured aggregates for geotechnical works, concrete, asphalt, recycled soil for earthworks, and construction composites for geotechnical purposes). The final output of the task was knowledge on promising waste resources in the demonstration areas (i.e., Maribor and Madrid-Henares), and their utilization for the SRM-based construction products which was used in WP6.

Slovenia (Maribor)

Table 11 illustrates main characteristics of waste considered for the SRM production in the case of Maribor demo.

Table 11: Outcomes from task 3.2 - Valorisation of waste potential for the purpose of production of SRM-based construction products – for the Slovenian case

Waste	Waste code	Picture	Outcomes from Task 3.2: Suitability for SRM preparation.
Soil and stones other than those mentioned in 17 05 03	17 05 04		The waste material is composed of virgin material with low portion of secondary (anthropogenic) materials (around 4% of brick particles in fine aggregate). Based on the results of the sieving analysis the sample as such is not applicable for unbound layers in geotechnical works due to large quantity of fine fraction. In order to gain suitable material, the coarse grain material needs to be added.
Dredging spoil other than those mentioned 17 05 05	17 05 06		Based on the results of the chemical analysis, the waste material doesn't pose any threats to environment since concentration of parameters in eluate is under limiting values of SETRA[10] recommendations for alternative materials in road construction. Waste material would be applicable in geotechnical fills or potentially in geotechnical composites, where clay fraction is needed.

[10] Limiting values are summarized according to "Acceptability of Alternative Materials in Road Construction, Environmental Assessment, Appendicle 3 – Limit Values associated with Level 1 Environmental Characterisation, Table 1, Column 1, SETRA, France, February 2012

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Concrete	17 01 01		The waste material, after a crushing and sieving process, is applicable as recycled aggregate for green concrete, geotechnical fill and embankments, and unbound layers for road construction.
Bituminous mixtures containing other than those mentioned in 17 03 01	17 03 02		Based on the results of the sieving analysis this waste material as such is not applicable for unbound layers in geotechnical works due to surplus of coarse grains. In order to gain suitable material for easier installation, fine material needs to be added. The same is with use in asphalt layers and other applications where appropriate grain size distribution of aggregate needs to be achieved.
Mixed CDW other than those mentioned in 17 09 01, 17 09 02 and 17 09 03	17 09 04		This waste material is applicable for geotechnical fill. Other applications (e.g., unbound layers, use in concrete) would be possible with additional treatment of the sample (crushing) in order to get suitable granulation and if increased quantity of sulphates is immobilized. An excess of sulphates was also detected. It is also mandatory to reduce the gypsum content for its suitable use in bound and unbound applications.
Sludges from treatment of urban waste water	19 08 05		Waste material would be potentially applicable for use in geotechnical composites if it would be pre-treated according to the standard procedures in wastewater treatment plants (e.g., stabilization with lime). As such material is too risky to pose threat to workers in production of the SRM-based construction materials.
Waste from desanding	19 08 02		Waste material is applicable in geotechnical fills and embankments. It is also applicable for unbound layers in road construction under condition that its granulation is adapted.
Street-cleaning residues	20 03 03		This waste material is potentially applicable for unbound layers in road construction if grain size distribution is corrected by adding coarse fraction. Namely, based on sieving analyses, methylene blue and sand equivalent test currently there is too much fine fraction. Waste material could also be applicable as recycled aggregate used in green concrete.

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Other wastes (including mixtures of materials) from mechanical treatment of wastes other than those mentioned in 19 12 11	19 12 12		An excess of Nickel, Antimony, Zinc and Sulphates was detected, making it not possible to use it in unbound applications due to potential environmental contamination. Based on chemical analysis this waste material is applicable only for geotechnical composites with addition of other waste-based material (e.g., clay, dredging spoil, ashes) or other natural materials for immobilisation of potential toxic substances in material.
Waste from the mechanical treatment of waste (glass)	19 12 05		Waste material is potentially applicable in concrete if appropriate grain size is achieved with pre-treatment of waste. Grain size might also impact Alkali Silica Reaction therefore this needs to be tested.
Waste from the mechanical treatment of waste (plastic and rubber)	19 12 04		Waste material is potentially applicable in concrete. Different grain size distribution and grain shapes, achieved with different pre-treatments, need to be tested.

Spain (Madrid-Henares)

Table 12 illustrates main characteristics of waste considered for the SRM production in the case of Madrid-Henares demo.

Table 12: Outcomes from task 3.2 - Valorisation of waste potential for the purpose of production of the SRM-based construction products – for the Spanish case

Waste	Waste code	Picture	Outcomes from Task 3.2: Suitability for SRM preparation.
Waste sand and clays	01 04 09		Based on water absorption values of the sample, this waste cannot be used as aggregate in application subjected to freeze thaw cycles, although it is possible to use it as additions to aggregate of different origin where fine fraction is missing. Waste material is not applicable as filler for structural concrete because exceeds the limits of sand equivalent and methylene blue values. The As content slightly exceeds the limits of the local legislation for all the uses therefore the waste cannot be used in unbound applications.

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Bituminous mixtures containing other than those mentioned in 17 03 01	17 03 02		This waste material is not applicable for structural concrete due to its high sand equivalent value. Other applications (especially as aggregate for asphalt layers) would be possible with additional treatment of the sample (crushing) or mixed to other aggregate where coarse fraction is needed to get suitable particle size distribution.
Concrete	17 01 01		This waste material is applicable for different intended uses as aggregate. As unbound material it is only applicable to be used in urban and industrial applications. Other cases are not applicable due to exceeding value of Sb and Cr total. It must be mixed with other materials to avoid environmental risk.
Mixed CDW other than those mentioned in 17 09 01, 17 09 02 and 17 09 03	17 09 04		A high sulphate value (1,59 mass%) is observed in this sample, which is probably due to the presence of gypsum, nevertheless there is no limit value defined for sulphur to be used as aggregates in asphalt, base, mortar or concrete. The As and Cr total content slightly exceeds the limits of the local legislation for all uses of soil. Therefore, waste material cannot be used as it is in unbound applications.
Unprocessed slag	10 02 02		Waste material cannot be used in structural concrete due to high value of chlorides (the upper limit of chlorides in aggregate (filler) used in structural concrete is 0,3%). The Cu, Cr total and Mo content exceed the limits of the local legislation for the uses in urban and other applications as soil. Therefore, waste material cannot be used as it is in unbound applications.
Soil and stones other than those mentioned in 170503	17 05 04		Waste material cannot be used as it is in unbound applications in urban and other areas due to exceeding limits of Cr total.
Ceramics	17 01 03		Based on technical specification for structural concrete (where the limit value is 35 for shape index) this material is not appropriate for use in structural concrete without additional treatment. Arsenic exceeds the limits of the local legislation for all uses in soil. Therefore, waste material cannot be used as it is in unbound applications.

The principal conclusions draw from the analysis of different wastes is that the wastes cannot be

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applied in bound or unbound application without carrying out a prior treatment and conditioning process to improve the characteristics of the materials. The most critical parameters are related to the physical properties of the waste (for example, PSD, absorption and resistance to fragmentation) and to the environmental properties of the waste (for example, content of heavy metals, hydrocarbons and sulphates).

5.2. Outcomes of WP5 and Task 5.1

Based on the outputs of Task 3.2, Task 5.1 was focused on the design, development and testing of SRM-based construction products at the laboratory scale, i.e.: (i) recycled and manufactured aggregates, (ii) recycled soils, and (iii) building composites.

Recycled aggregates (i.e., aggregates from recycled CDW) and manufactured aggregates (i.e., aggregates from industrial processes) were tested according to their intended final use in WP6 as specified in the relevant harmonised (hEN) and national technical specifications. The final products, e.g., unbound and hydraulically bound layers, concrete and asphalt, using recycled and manufactured aggregate, were also tested according to the relevant technical specifications.

5.2.1. Outcomes of the SRM characterization

At this stage, different SRM were processed and characterized at the laboratory scale to prepare them properly and optimize their use in new products.

Slovenia (Maribor)

Table 13 illustrates main characteristics of the SRM and the SRM-based products for production in the case of Maribor demo.

Table 13: Outcomes from task 5.1.a - SRM characterization – for the Slovenia case

SRM	Picture	Outcomes from Task 5.1: Preparation requirements and critical parameters to lose the waste condition.
MAR-SRM-1: Heavy Fraction. **Final residue of mechanical treatment of municipal solid waste.**		<u>**Preparation requirements:**</u> - Heavy fractions must be collected and temporarily stored in a dry place – ventilated depot, protected from the precipitation (rain, snow, fog), so that no additional water or moisture is infiltrated into the material. - Heavy fractions must be used in the recycling process as fresh as possible to avoid biological decay of organic part of the material, which can change its initial chemical and mechanical properties. - A depot needs to have impermeable plastic liner at the bottom. The stock pile of heavy fraction has to be covered with impermeable plastic foil or cover so that infiltration of rain (or other precipitation) is prevented and that it is protected from different weather conditions, or from pests (rodents, birds, and flies). - Pieces and grains of metals, glass, CDW, which are larger than 32 mm, must be separated from the heavy fraction by sieving (if possible, in a rotating drum sieving device), manual or mechanical sorting. - The entire batch of heavy fraction, which is designated to be used in a recycling process, must be thoroughly mixed and homogenized before it is used as a feed material. - Leaching tests in accordance with EN 12457-4:2004 shall be

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		performed regularly on representative samples of the heavy fraction from each batch (after 5,000 tonnes of processed material). - Water content in heavy fraction must be regularly checked, since optimal addition of water to the composite during its preparation must be adjusted by taking into account the amount of water, which is already present in the feed material (heavy fraction). **Critical parameters:** An excess of Molybdenum, Nickel, Zinc, Chloride and Sulphates was detected, making it not possible to use as it is in unbound applications due to potential environmental contamination.
MAR-SRM-2: Coal fly ash. Coal fly ash is a by-product in the Electricity and Heat Production Plant.		**Preparation requirements:** - Coal fly ash, which is used in the recycling process, shall be collected directly from a silo, which presents a temporary stock of ash at the production site. It should not come in contact with water or moisture before its use for production of the composite. - Coal fly ash shall be transported from the source to a location of recycling plant in a cistern or in closed containers. - At the location of the processing plant, the coal fly ash shall be transported into a silo or to a temporary depot, which shall be similar as the one described for temporary storage of heavy fraction. The coal fly ash shall be used for production of the geotechnical composite as soon as possible, after it is delivered to the production site, in a matter of a few days. - Measures for prevention of dust emissions shall be taken (for example in a form of water aerosol), when handling coal ash. - If the recycling procedures are carried out in an open area, the weather conditions shall be monitored. The procedure shall be stopped in the case of excessively high winds, heavy precipitation or freezing temperatures. - Dosing of the coal fly ash into the mixing device for production of a geotechnical composite shall be done according to predetermined dry mass ratio - composition with the use of excavator shovel, which has integrated balance, or via automated dosing system with the use of pumps. **Critical parameters:** An excess of Barium and Fluoride was detected, making it not possible to use as it is in unbound applications due to potential environmental contamination.
MAR-SRM-3: Shredded plastic from memory lights. Consists of crushed plastic from separate collection of waste grave candles.		**Preparation requirements:** According to best practices the memory lights waste is treated on a process line where in the first stage, magnets are used to separate metal particles mainly metal caps. The automated stage is followed by manual sorting, where impurities such as flowers remains, polyethylene terephthalate (PET) plastics and electronic particles from the battery powered candles are removed. The remaining material is then directed to the second stage of automatic treatment. First it is crushed, then it is washed and lastly it is treated in centrifuge to separate the paraffin from the plastic. **Critical parameters:** The critical parameters for this SRM are the physic-mechanical properties that can affect the mechanical behaviour of the final product.

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MAR-SRM-4: Biomass ash. Biomass ashes from incineration.		**<u>Critical parameters:</u>** The critical aspect of this SRM is the leachates, which present excesses in practically all the parameters analysed.
MAR-SRM-5: Foundry sand. Foundry sand from a foundry for automotive pieces.		**<u>Preparation requirements:</u>** The preparation of this SRM depends of the nature of the foundry sand and the processing company. It usually comprises a two-cycle process including a conventional processing system for foundry sand and a second locally independent regeneration system for the recovery of the usable components of the sand such as carbon dust and bentonite. **<u>Critical parameters:</u>** The critical parameter of this SRM is the organic content which is a handicap for its use in bound added value applications.
MAR-SRM-6: Reclaimed asphalt pavement.		**<u>Preparation requirements:</u>** It is highly important to perform the milling operations properly to avoid contamination between layers and with material from the lower layers of pavement. **<u>Critical parameters:</u>** This SRM is compliant with the environmental and technical requirements. The critical parameters of this SRM that should be taken into account are the organic content due to the bituminous content and the intrinsic hydrocarbon content of the material that can invalidate its use in unbound applications depending on the geographical region.
MAR-SRM-7: Recycled Mixed Aggregates (mixed CDW). Produced in a processing and recovery process by the use of a mobile crushing device.		**<u>Preparation requirements:</u>** It is mandatory to perform a selective demolition in order to obtain quality aggregates and to avoid gypsum components and other impurities. The Coarse Recycled Concrete Aggregates must be treated appropriately in order to be used in recycled concretes. Some key aspects are following: - The material must be processed by metal extraction, crushing and sieving in order to recover the wanted fraction; - Avoid the generation of fines during the processing; this can be achieved by using jaw crushers instead of impact crushers; - Pre-sieving (20 mm), to avoid the feeding with unnecessary material and thus reduce the production of more fines; - The coarse recycled concrete aggregates shall be stocked separately in order to avoid pollution. **<u>Critical parameters:</u>** The critical parameters are related to the water absorption, resistance to fragmentation, particle size distribution and Sulphate content.

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North Macedonia (Skopje)

Table 14 illustrates main characteristics of the SRM and the SRM-based products for production in the case of Skopje demo.

Table 14: Outcomes from task 5.1.a - SRM characterization – for the North Macedonia case

SRM	Picture	Outcomes from Task 5.1: Preparation requirements and critical parameters to lose the waste condition.
SKO-SRM1: Recycled steel slag aggregate (black slag). Product of the steel-making process in EAF.		**<u>Preparation requirements:</u>** Black steel slag aggregates shall be processed and treated in such a way that high quality aggregate will be produced. Some key aspects are: o Cooling and stabilization of compounds; o Crushing below 63 mm, o Deferrization using appropriate magnet separation; o Proper screening, storing and characterization of the product. **<u>Critical parameters:</u>** The critical parameter of this SRM is the expansiveness due to the free calcium oxide content, CaO in some slags and their subsequent expansiveness making them unsuitable for bound applications. The content in heavy metals is also an aspect to be taken into account, which will prevent its use in unbound applications without any waterproof protection.
SKO-SRM2: Recycled White (Ladle) Slag. Ladle furnace basic slag, also called the secondary refining slag (or the white slag) is produced in the final stages of steelmaking.		**<u>Preparation requirements:</u>** White slag aggregate shall be processed and treated in such a way that high quality aggregate will be produced. Some key aspects are: o Cooling and stabilization of compounds; o Crushing; o Deferrization using appropriate magnet separation; o Milling, screening, storing and characterization of the product. **<u>Critical parameters:</u>** This SRM is commonly employed as a supplementary cementitious material in cement and concrete production due to the hydraulicity of the material. Since the final application is a bound product, the possible leachates are no relevant, attention should be paid to ensuring that the physical and chemical properties meet the requirements of the cement, mortar and concrete standards

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Spain (Madrid-Henares)

Table 15 illustrates main characteristics of the SRM and the SRM-based products for production in the case of Skopje demo.

Table 15: Outcomes from task 5.1a - SRM characterization – for the Spain case

SRM	Aspect	Outcomes from Task 5.1: Preparation requirements and critical parameters to lose the waste condition.
MAD-SRM1: Recycled mixed aggregates. Fraction obtained from construction and demolition waste treatment, composed of a mix mainly of concrete, stones and ceramic products.		**Preparation requirements:** The components X (see table page 17) should be removed as much as possible before the demolition and during the processing in order to obtain fractions with less of 1% of gypsum, plastics, wood, insulations, metals, etc. - The ceramic components should not exceed 30% of the final recycled aggregates. - The clean concrete should be demolished and stocked separately i.e., the concrete from the structure, pavement, slabs, foundations, etc. - Avoid the generation of fines during the processing (both crushing and sieving); this can be achieved by using jaw crushers instead of impact crushers and by limiting the sieving steps. - If possible, use pre-sieves (32 mm) to avoid the feeding with unnecessary material and thus reduce the production of more fines. - Employ crushers equipped with electromagnetic systems to remove metals **Critical parameters:** The critical parameters related with this kind of aggregates are the soluble sulphate content and the total sulphur content. Both parameters are related with the presence of gypsum. Therefore, it is necessary to perform a selective demolition in order to avoid gypsum components and other waste streams in the aggregate. Other critical parameters are related to the water absorption, resistance to fragmentation, magnesium sulphate resistance and fine contents.
MAD-SRM2: Recovered Sand and Clay. Composed of sand particles and cohesive clay from an old stockpile for the production of bricks.		**Preparation requirements:** Instead of a crushing treatment which will produce high quantities of fines, it is recommended to perform a previous sieving treatment and crush the particles that remain above the sieve. **Critical parameters:** The critical value is the magnesium sulphate test due to the high amount of clay recommending limiting the use of this SRM to low proportions.
MAD-SRM3A: Coarse recycled concrete aggregates. Fraction obtained from construction and demolition waste treatment and contain at least 50 % of cementitious		**Preparation requirements:** It is mandatory to perform a selective demolition in order to obtain quality aggregates and to avoid gypsum components and other impurities. The Coarse Recycled Concrete Aggregates must be treated appropriately in order to be used in recycled concretes. Some key aspects are detailed below: - The material must be processed by metal extraction, crushing and sieving in order to recover the wanted fraction.

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products.		- Avoid the generation of fines during the processing; this can be achieved by using jaw crushers instead of impact crushers. - Pre-sieving (20 mm), to avoid the feeding with unnecessary material and thus reduce the production of more fines. - The coarse recycled concrete aggregates shall be stocked separately in order to avoid pollution. **<u>Critical parameters:</u>** The critical parameters related with this kind of materials are primarily the water absorption and the total sulphur content. Due to the high amount of attached mortar paste to the original aggregates, the water absorption is drastically increased compared to natural aggregates. This higher water absorption will determine the amount of water to be included during the mixing process in order to have a good balance between the fresh consistency and the hardened mechanical properties. The second parameter is related with the gypsum presence.
MAD-SRM3B: Fine Recycled Concrete Aggregates. Fraction of recycled concrete aggregates with a particle size distribution between 0 and 4 mm.		**<u>Preparation requirements:</u>** It is mandatory to perform a selective demolition in order to obtain quality aggregates and to avoid gypsum components and other impurities. Fine Recycled Concrete Aggregates must be treated appropriately in order to be used in recycled mortars and concretes. Some key aspects are detailed below: - The material must be obtained from the crushing process of the clean concrete waste by sieving below 4 mm in order to recover the 0-4 mm fraction. - Employ crushers equipped with electromagnetic systems to remove metals. - The fine recycled concrete aggregates must be stocked separately in big bags in dry places avoiding direct rain. **<u>Critical parameters:</u>** The critical parameters related with this kind of SRM are the water absorption, the organic matter the total sulphur content.
MAD-SRM3C: Ultrafine Recycled Concrete Particles. Fraction of recycled concrete aggregates with a particle size distribution below 0,063 mm.		**<u>Preparation requirements:</u>** There is a new trend in using the ultrafine particles obtained from the processing of recycled aggregates as Supplementary Cementitious Material for the production of eco-cements. Two ways can be explored, in both cases processing the SRM3B: - <u>Ultrafine particles production</u>: Production of ultrafine material through a ball mill and cyclone classifier. A previous thermal treatment can be necessary both to remove the moisture and organic impurities and to activate the particles. - <u>Eco-cement production</u>: The second way consists in producing the eco-cement directly in a cement factory by milling the clinker together with the SRM during the cement production. The material obtained will be a binary eco-cement with recycled CDW fines. In both cases the SRM must be pre-processed in order to obtain an optimized particle size distribution for this application and remove organic impurities and moisture. **<u>Critical parameters:</u>** The critical parameters for the use of SRM from CDW as supplementary cementitious material are the moisture and the

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		organic impurities.
MAD-SRM4A: Fine Recycled Ceramic Aggregates. Fraction from CDW treatment in which the components, determined according to UNE-EN 933-11 standard, exceed 30% by weight of bricks, tiles and ceramics products. It has a grain size between 0 and 4 mm.		**Preparation requirements:** It is mandatory to perform a selective demolition in order to avoid unwanted wastes (e.g., gypsum, wood, plastics, hazardous materials, etc. The Fine Recycled Ceramic Aggregates must be treated appropriately in order to be used in recycled mortars and concretes. Some key aspects are detailed below: - The material must be obtained through a crushing process of the clean ceramic waste and avoid the production of fine powder during the process. - The fine recycled ceramic aggregates must be stocked separately in big bags in dry places to avoid direct rain. **Critical parameters:** The critical parameters related with this kind of materials are water absorption, organic matter, and total sulphur content.
MAD-SRM4B: Ultrafine Recycled Ceramic Particles. Defined as particles below 0,063 mm obtained by processing the sample SRM4A (0-4 mm fraction).		**Preparation requirements:** **See the indications for the sample MAD-SRM3C**. **Critical parameters:** **See the indications for the sample MAD-SRM3C**.
MAD-SRM5A: Recovered soil and stones. Composed of coarse and fine aggregates (particle size between 0 and 40 mm) which is obtained from old road sub-bases.		**Preparation requirements:** The treatment for this kind of material is a crushing process with a pre-sieving. **Critical parameters:** Material suitable for all kind of application with a proper preparation.
MAD-SRM5B: Reclaimed asphalt pavement. Obtained from the milling operations of road pavements that have reached their end of life and need to be renewed.		**Preparation requirements:** It is highly important to perform the milling operations properly to avoid contamination between layers and with soil from lower layers. The material should be processed accordingly in order to obtain a proper PSD and optimize the granular skeleton. The lack of fine fractions be can be also solved by including other fine fractions from other streams of SRM. **Critical parameters:** This SRM is compliant with the environmental and technical requirements. The critical parameters of this SRM that should be considered are the organic content due to the intrinsic bituminous content and the hydrocarbon content of the material that can invalidate its use in unbound applications depending on the geographical region. It is very common for these SRM to have a fine fraction deficit between 0 and 4 mm, which reduces the compacity of the material.

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MAD-SRM6A: Fine Recycled Glass. Material collected from the processing and recovery of transparent and mixed glass from the selective collection of municipal solid waste.		**<u>Preparation requirements:</u>** Depending on the origin, the preparation process will be totally different. For example, in the case of recycled glass obtained from municipal solid waste, an advanced process of cleaning, sorting and crushing must be carried out. In the case of recycled glass from CDW, the process must remove all stony and organic impurities and reduce the particles to the desired size. **<u>Critical parameters:</u>** The critical parameter is the presence of organic impurities, mainly in those recycled waste from municipal solid wastes and industrial activities.
MAD-SRM6B: Ultrafine Recycled Glass Particles. Particles below 0,063 mm obtained by processing (milling and classification) of the MAD-SRM6A.		**<u>Preparation requirements:</u>** **See the indications for the sample MAD-SRM3C**. **<u>Critical parameters:</u>** **See the indications for the sample MAD-SRM3C**.

5.2.2. Outcomes of the the SRM-based products' optimization

Slovenia (Maribor demo case)

Table 16 lists the main outcomes from the Task 5.1 - Requirements and consideration for the use of SRM in new product – for the products to be used in the Maribor case.

Table 16: Outcomes from task 5.1 - Development and testing of the SRM-based products on the laboratory scale – the Maribor demo case, Slovenia

SRM-based Product	Picture	Outcomes from Task 5.1
MAR - P1: Geotechnical material for the embankment. Heavy fraction (MAR-SRM-1: Recycled Heavy Fraction) mixed with the coal ash (MAR-SRM-2: Coal ash)		**SRM from CDW are suitable for their use in unbound application warranting the physical and mechanical.** - The SRM-based products for sub-bases and bases fulfil all criteria according to the Slovenian Technical Specification TSC 06.100:2003. - Sub-base layers have to be installed in the thickness of 30 cm and then compacted to the prescribed density. - Field tests have to be performed on the construction site and samples have to be taken from the compacted layers for laboratory tests. - The employed SRM-based products must be controlled according to the physical requirements listed below: ○ Water content, ○ Density, ○ Particle Size Distribution, ○ Quality of fine particles (sand equivalent), ○ Resistance to fragmentation, Los Angeles test, ○ Resistance to freezing and thawing, ○ Dynamic modulus, ○ Static modulus, ○ Proctor compaction, ○ CBR at 4 days, ○ Organic matter. - From the sub-base and base layers, samples have to be taken for
MAR – P3: Recycled road base layer (01) Sub-base layer from reclaimed asphalt and recycled mixed aggregate (Ra/Ru).		
MAR – P4: Recycled road base layer (02) Recycled hydraulically bound base layer with mixture of Ra/Ru and		

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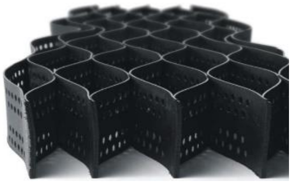
PSA.		the leaching analyses. - The concentration of the sulphate in the leachate of the P5 is too high; more attention should be paid on the incoming CDW stream to eliminate gypsum material. **In order to warranty the environmental requirements, a waterproofing layer covering the products is recommended in order to prevent leachates.**
MAR – P5: Recycled road base course (03) Base course with recycled mixed aggregate.		
MAR – P6: Recycled road base layer (04). Base layer Ra/Ru with recycled mixed aggregate.		
MAR – P7: Recycled road base course (05) Reclaimed asphalt and recycled granular base material reinforced with geocells.		
MAR – P2: Green concrete with different combinations of Reclaimed asphalt, Foundry sand, Biomass Fly Ash and Shredded plastic.		- Regarding tests results, the application of the SRM-based materials in concrete with specification C 20/25 XC1 Cl 0,2 Dmax32 S3 is possible. - Although the use of waste materials reduces the compressive strength, it is not affected to the extent that would prevent the use of such concrete. - During the production, the factory production control according to the same standards shall be implemented, which means that water to cement ratio, slump and concrete compressive strength shall be controlled. - This control shall be performed every three or five production days if the concrete has production control certification or even each production day if the concrete does not have production control certification. - Physical and mechanical parameters affected when employing SRM: ○ The density decreases with SRM content, ○ Mechanical properties may be affected depending on the amount and quality of SRM. - Depending on the water absorption of SRM, the workability of the green concretes can be affected. A strict control of the water dosage must be carried out in such a way that the mechanical properties are not affected. In this case, when employing shredded plastic, the slump increased while the water dosage decreased due to the null absorption of the shredded plastic.

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North Macedonia (Skopje)

Table 17 lists the main outcomes from the Task 5.1 - Requirements and consideration for the use of SRM in new product – for the products to be used in the Skopje case.

Table 17: Outcomes from task 5.1 - Development and testing of the SRM-based products on the laboratory scale – for the North Macedonia case

SRM-based Product	Pictures	Outcomes from Task 5.1: Requirements and consideration for the use of SRM in new product.
SKO - P1: Geotechnical material for lower bearing layer (sub-base course). 100% Aggregates from black slags of gradation 0/63 mm.		**SRM from steel slag aggregates are suitable for their use in unbound application warranting the physical and mechanical.** - Regarding the production there are mandatory procedures: ○ Before SKO P1 processing, the slag material should be produced and aged in order to ensure homogeneity. ○ The product should be mixed before being used in order to avoid segregations. - The control tests during installation are one test per 500 m^2 of layer, or a total of 5 tests per layer for the road. - It is necessary to analyse and control the leachates of this kind of products in order to avoid environmental pollution due to the black slags' aggregates. - Determination of the expansiveness of steel slag. **In order to warranty the environmental requirements, a waterproofing layer covering the products is necessary in order to prevent leachates.**
SKO – P3: Geotechnical material for lower bearing layer (sub-base). 100% Black slag aggregate of gradation 0/63 mm		
SKO – P2: Prefabricated modular concrete blocks. With coarse black slag aggregates.		**Recycled concretes with SRM from steel slag aggregates are suitable for their use in precast element applications.** - No significant effect was observed in the density and porosity. - The consistency was slightly affected du e to the higher water absorption of the SRM employed. - Mechanical properties are slightly affected when employing black slag aggregates. - Durability improved in concretes with up to 20 % of coarse black slag aggregates.
SKO – P4: asphalt layers. Aggregates from black slag with grain size 0/16 mm.		**Asphalts with SRM from reclaimed asphalt pavements with properties that meet the road standards.** - Regarding the production there are some rules to be followed: ○ Before the manufacturing of the SKO P4, material should be sorted into different gradings and stored in well separated stock piles. ○ The product should be mixed before use to avoid segregations. - For the use of black slags aggregates, it is necessary to carry out two tests in accordance with the standards MKS EN 1744-3: Preparation of eluates by leaching of aggregates and MKS EN 1744-1 and Determination of the expansion of steel slag. - From the performed test and obtained results can be concluded that the black slug crushed completely meets the criteria as an aggregate for making asphalt mixtures. - When the process of production and separation of the material starts, and during placing of asphalt, a continuous control of the produced material in accordance with the quality program and the existing regulations have to be performed.

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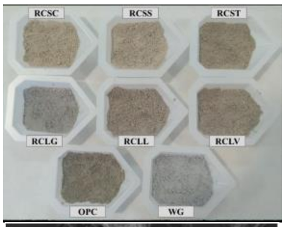
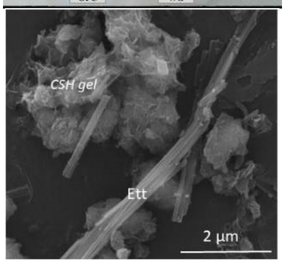
Spain (Madrid-Henares)

Table 18 lists the main outcomes from the Task 5.1 - Requirements and consideration for the use of SRM in new product – for the products to be used in the Madrid-Henares case.

Table 18: Outcomes from task 5.1 - Development and testing of the SRM-based products on the laboratory scale – for the Spain case

SRM-based Product	Composition	Outcomes from Task 5.1: Requirements and consideration for the use of SRM in new product.
MAD - P1: Recycled filling. Combination of SRM1-Recycled mixed aggregates. SRM2-Recovered sand and clay. SRM 5A-Recovered soil and stones		**SRM are suitable for their use in unbound application warranting the physical, mechanical and environmental requirements.** - The use of SRM1 and SRM2 should be limited due to the fines content and the results from the Los Angeles and magnesium sulphate tests. - Regarding the production there are some suggestions and recommendations: o Before the manufacturing, the SRM should be produced and stocked in such a way that the quality of materials remains constant. o The product should be mixed properly to avoid segregation. o It is mandatory not to overload the sieves with the aim of avoiding production of fines. **No leachates problems were detected.**
MAD P7-Artificial graded aggregates. Combination of SRM 5A-Recovered soils and stones and SRM 5B-Reclaimed asphalt pavement		
MAD P3-Eco-cements. Employing micronized SRM from different CDW streams (limestone concrete, siliceous concrete and glass)	 	**New blended cements manufactured with up to 5% of SRM.** - The overall conclusion is that blended cements manufactured with 5 % to 7 % inorganic CDW would comply with standard chemical (sulphate and chloride limits), physical (initial setting) and mechanical (compressive strength) requirements, with performance comparable to that of commercial Ordinary Portland Cement (OPC). - Increase of the heat released during the cement hydration. In the first 6 h, more heat was clearly released by the blended cements than by the reference, with significant differences between the former depending on the nature of the recycled concrete. - If setting time is defined as the difference between the initial and final setting times, the blended cements with SRM set slightly more quickly than the Ordinary Portland Cement OPC - Only minimal differences were observed in consistency between the cement pastes bearing recycled CDW-based additions and the reference OPC. - Both compressive and flexural strength appeared to be similar to the reference OPC.
MAD - P2: Recycled concrete for flooring. **MAD P8-Recycled concrete for road.** Concretes with 20% of coarse recycled aggregates and eco-cement.		**Recycled concretes with SRM from CDW suitable for their use in flooring and road pavement applications.** - The water demand is slightly increased when employing 20 % of recycled concrete aggregates. - No losses of workability were detected when employing recycled aggregates which means that they can be employed without any additional measure as ready-mix concrete. - The fresh density is not affected. - The strength at 7 and 28 days increases with the use of eco-cement, confirming the evidences highlighted during the

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		optimization of the P3 product (eco-cement). - The use of moderate amounts of recycled aggregates (20% of coarse recycled concrete aggregates) even increases the compressive strength at both 7 and 28 days compared to the reference concrete. - The target resistance at 28 days of 25 MPa is widely exceeded, confirming the feasibility of using this product for structural purposes.
MAD P4-Recycled concrete for precast blocks. **MAD P6-Recycled concrete for precast pavers.** Concretes with up to 100% of recycled aggregates and eco-cement. **MAD P5-Recycled mortar.** Eco-cement Up to 50% of SRM3B-Fine recycled concrete aggregates. Up to 50% of SRM4a-Fine recycled ceramic aggregates		**Recycled concretes suitable for their use in non-structural precast elements.** - The resistance at 7 days increases and maintains the properties at 28 days with the use of eco-cement, confirming the evidences highlighted during the optimization of the P3 product (eco-cement). - The use of fine recycled concrete aggregates implies an important increase in the water demand so an especial attention should be taken when formulating the recipes. -Strict control of the fresh properties during the production and casting. - Despite the losses in workability and mechanical behaviour, the total replacement of the aggregates in the concretes for precast elements is possible since the compressive strength at 28 days stays relevant.
MAD P9-Reflective green concrete. Eco-cement 100% of recycled concrete aggregates 20% of fine recycled glass		**Suitable use of recycled glass particles for obtaining reflective properties.** - Reflective properties induced by the introduction of recycled glass particles. - Recycled glass particles content must be very contained to avoid excessive losses of mechanical resistance. The sphericity of the glass particles and the lack of adherence in Interfacial Transition Zone, negatively influence the mechanical resistance of concretes. - Controlled particle size distribution of the recycled glass aggregates in order to provide the reflective properties.

5.3. Outcomes of WP6

During the demonstration activities of the project, different outcomes (considerations, recommendations and precautions) have been extracted for each of the tasks performed and the different Demos carried out. The most relevant ones are listed below.

<u>**Outcomes of Task 6.2. Demonstrations of pilot production of the SRM-based construction products:**</u>

The quality of the pilot production and its products of non-hazardous waste processing must be controlled <u>according to the type of materials</u>. The families of materials that were generated as products of non-hazardous waste processing at the plant are:

- Recycled aggregates,
- Geotechnical materials, and
- Recycled soil.

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What they all have in common is that the suitability of the input components (waste for recovery) needs to be visually inspected, that the recovery products themselves and the pilot production itself needs to be inspected, and that corrective measures needs to be taken, if necessary. Control of all the process is mandatory:

- Production control (production and sampling log),
- Conformity control (results of laboratory tests), and
- Corrective measures (discrepancies, complaints).

Recycled aggregates

Newly produced materials covered by harmonized technical specifications shall be inspected in accordance with the relevant standards. The manufacturer needs to obtain the Production Control Certificate according to the System 2+ of the EN 13242:2003+ A1:2008 - Aggregates for unbound and hydraulically bound materials for use in engineering structures and for road construction, but also according to some other standard.

The System 2+ defined in the Directive 89/106/CE, Annex III(2)(ii), stablishes the methodology for the certification of the factory production control by an approved body on the basis of initial inspection of factory and of factory production control as well as continuous surveillance asses:

Methods for the Notified Body	1. initial inspection of factory and of factory production control 2. continuous surveillance, assessment and approval of factory production control
Methods for the manufacturer	1. Initial type testing (ITT) by the manufacturer 2. factory production control (FPC) 3. testing of samples taken at the factory in accordance with a prescribed test plan

The mentioned standard EN 13242:2003+ A1:2008 in Annex C determines the control over the (pilot) production in the plant. Laboratory tests will carry out continuous quality control of products. The minimum frequency of tests and the types of laboratory tests for recycled aggregates are given in Annexes C.1 and C.2. The tests shall include at least:

- Grain bulk density and water absorption,
- Classification test of recycled aggregates,
- Water-soluble sulphates,
- Granulometric analysis,
- Humus content, and
- Other as needed.

Geotechnical materials

Like materials from the families of concrete and composites, geotechnical materials need to obtain the technical approval as a technical specification for the certification of production according to the 2+ system.

Recycled soils

A special product is recycled soil, which is not produced and certified according to technical specifications - harmonized standards or issued technical approvals. A special pedological analysis should be prepared for it, a production quality control (Figure 13) protocol prescribed and instructions for use should be issued.

Figure 13: Mobile crusher and screener (Source: CINDERELA project).

Outcomes of Task 6.3. Revitalization of degraded area with the SRM-based construction products (for example with geotechnical composites)

- It is essential to monitor the moisture content in a heavy fraction on a regular basis, since it is necessary to prepare the geotechnical composite with moisture content, which is as close as possible to the optimal value determined in the laboratory Proctor test (± 5 % of the optimal value).
- The layers of the composite must be additionally moistened on-site of installation by the use of water sprinklers to achieve optimum water content before compaction. This is because water content in the composite is lowering after its preparation due to a constant evaporation (due to wind, insolation, and due to an exothermic reaction inside the composite due to reaction of lime and water).
- The installation procedure (especially optimization of compaction) has to be determined and optimized in a test field installation before the start of construction of a fill and embankment.
- Recommended thickness of a layer of composite for installation is 30 cm, if for example a 15 t cylindrical vibrating roller is used for compaction.
- During the construction works, the properties of the unbound product must be monitored.
- Handling of coal ash and preparation of the composite must not be performed in case of excessive wind conditions (> 5 m/s) to prevent dusting and unpleasant smell emissions.
- Installation of an unbound product must not be performed in case of heavy rain, or other types of precipitation.
- Installation of unbound product must also not take place in case of sub-zero air temperatures and in case of a threat of a negative combined effect of water and frost, which could lead to disintegration of installed composite (Figure 14).

Figure 14: Wearing course manufactured with recycled asphalt aggregates (Source: CINDERELA project)

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6. CINDERELA - EoW Criteria Protocol

6.1. Scope of application

The objective of waste legislation is the protection of human health and the environment against harmful effects caused by the collection, transport, treatment, storage and tipping of waste. To ensure a high level of protection all operations dealing with waste, from its production to its final disposal, should be controlled. Activities such as inspection, authorisation and registration allow the control and trace of waste generation, recovery and disposal.

The definition of European EoW criteria protocols for some specific waste streams could help to mitigate this ambiguity. It should result in a simplification for some specific waste streams to be used as secondary raw materials. It would bring a greater certainty and predictability for the users of recycled products or materials. These should result in an increase in recycling rates avoiding disposal and the use of natural resources.

By using the information from other EoW criteria applied in the different European countries and the knowledge gathered from the CINDERELA project, this protocol intends to identify essential elements that should be part of the EoW criteria, i.e., operational procedures, considerations and recommendations associated with the recycling of these waste streams in order to achieve the EoW status.

The proposed EoW criteria protocol is intended for SRM produced from CDW, industrial waste or by-products (iron and steel industry and combustion processes). Types of SRM, possible applications, processing requirements, technical and environmental issues related to these waste streams are proposed in this document in order to guide those countries in the EU that want to implement new or update their EoW criteria.

The content of the following protocol should be considered as a proposal to facilitate the implementation of EoW criteria.

This protocol intends to visualize the current state of the art in terms of regulations to achieve the EoW status of CDW and industrial waste, by-products for the use, with the highest environmental and technical guarantees, of the valued products obtained.

In no case is it intended to establish restrictions or limitations when developing and implementing regulations in each country or region.

It is further recommended that a well-established and acknowledged methodology based on a stepwise procedure is used to develop boundaries criteria for achievement of EoW status (or for use under waste legislation) for CDW waste. The steps proposed are:

- **Step 1: Stablish the terminology employed in the EoW criteria.**
- **Step 2: Define the possible waste streams than can be employed for obtaining the SRM.**
- **Step 3: Stablish the possible SRM (composition, size, weight and quality).**
- **Step 4: Description of the possible applications type and the imposed conditions (technical and environmental).**
- **Step 5: Description of the limitations (restrictions and prohibitions) of use.**
- **Step 6: Stablish recommendation and good practices for encourage and improve the use of SRM.**

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- **Step 7: Stablish recommendation and good practices for encourage and improve the use of SRM (Processing, manufacturing of the SRM-based product and final implementation).**
- **Step 8: Define a clear and exhaustive quality control procedure.**

This methodology is based on the same principles as the method used to develop other EoW criteria in the EU. The method has been adopted officially in the Basque Country, France, Nordic region, Belgium, and other MS and regions across Europe.

6.2. Terms and definitions

List of official definitions that can be incorporated into EoW criteria are listed in Table 19.

Table 19: List of official definitions that can be incorporated into EoW Criteria

	Terms	Proposed definitions	Source
Wastes and SRM definitions	Waste	Any substance or object which the holder discards or intends or is required to discard	WFD
	Inert waste	Waste that does not undergo any significant physical, chemical or biological transformations. Inert waste will not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm human health. The total leachability and pollutant content of the waste and the ecotoxicity of the leachate must be insignificant, and in particular not endanger the quality of surface water and/or groundwater.	Landfill Directive
	Hazardous waste	Waste which displays one or more of the hazardous properties listed in Annex III of the WFD.	WFD
	Non-hazardous waste	Waste which is not covered by the previous point	WFD
	By-product	A substance or object resulting from a production process the primary aim of which is not the production of that substance or object is considered not to be waste, but to be a by-product if the following conditions are met: - further use of the substance or object is certain; - the substance or object can be used directly without any further processing other than normal industrial practice; - the substance or object is produced as an integral part of a production process; and further use is lawful, i.e., the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts.	WFD
	EoW Status	Waste which has undergone a recycling or other recovery operation is considered to have ceased to be waste if it complies with the following conditions: - the substance or object is to be used for specific purposes; - a market or demand exists for such a substance or object; - the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and the use of the substance or object will not lead to overall adverse environmental or human health impacts.	WFD
	CDW	Waste generated by construction and demolition activities	WFD
	SRM	SRM can be identified as materials that can be recycled and then injected back into the economy as new raw materials (COM(2015) 614).	COM(2015) 614
	Waste producer	Anyone whose activities produce waste (original waste producer) or anyone who carries out pre-processing, mixing or other operations resulting in a change in the nature or composition of this waste	WFD

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	Terms	Proposed definitions	Source
	Waste holder	The waste producer or the natural or legal person who is in possession of the waste.	WFD
Type and composition of SRM	Aggregate	Granular material of natural, manufactured or recycled origin used in construction.	hEN
	Natural aggregate	Aggregate from mineral sources that has been subjected to nothing more than mechanical processing.	hEN
	Recycled aggregate	Aggregate resulting from the processing of inorganic mineral material previously used in construction.	hEN
	Manufactured aggregate/ Artificial aggregate	Aggregate of mineral origin resulting from an industrial process involving thermal or other modification.	hEN
Aggregates size	Aggregate size	Designation of aggregate in terms of lower (d) and upper (D) sieve sizes expressed as d/D	hEN
	Particle size fraction	Fraction of an aggregate passing the larger of two sieves and retained on the smaller.	hEN
	Declared value	Value or range of values that a manufacturer is confident in achieving, taking into account the precision of test methods used, the variety of the production processes and the product performance	hEN
	Grading	Particle size distribution expressed as the percentages by mass passing a specified set of sieves.	hEN
	Coarse recycled aggregate	Designation given to the larger aggregate sizes with D greater than 4 mm and d greater than or equal to 1 mm.	hEN
	Fine recycled aggregate	Designation given to the smaller aggregate sizes with D less than or equal to 4 mm and d = 0	hEN
	All-in aggregate	Aggregate consisting of a mixture of coarse and fine aggregates with D greater than 4 mm and d = 0	hEN
	Fine	Particle size fraction of an aggregate that passes the 0,063 mm sieve	hEN
	Filler aggregate	Aggregate, most of which passes a 0,063 mm sieve.	hEN
Production and treatment	Waste management	the collection, transport, recovery (including sorting), and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer or broker	WFD
	Waste collection	the gathering of waste, including the preliminary sorting and preliminary storage of waste for the purposes of transport to a waste treatment facility	WFD
	Prevention	Measures taken before a substance, material or product has become waste, that reduce: - the quantity of waste, including through the re-use of products or the extension of the life span of products; - the adverse impacts of the generated waste on the environment and human health; or the content of hazardous substances in materials and products.	WFD
	Re-use	Any operation by which products or components that are not waste are used again for the same purpose for which they were conceived	WFD
	Segregation / Separate collection	The collection where a waste stream is kept separately by type and nature so as to facilitate a specific treatment.	2018/C 263/30
	Treatment	Recovery or disposal operations, including preparation prior to recovery or disposal.	WFD
	Common industry practices	Those usages, customs, or practices which are ordinary, normal, or prevalent among businesses, trades, or industries of similar types engaged in similar work in similar situations in the community.	Others
	Recovery	Any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil	WFD

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	Terms	Proposed definitions	Source
		a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy. Annex II sets out a non-exhaustive list of recovery operations	
	Material recovery	Any recovery operation, other than energy recovery and the reprocessing into materials that are to be used as fuels or other means to generate energy. It includes, inter alia, preparing for re-use, recycling and backfilling	WFD
	Recycling	Any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.	WFD
	Preparing for re-use	Checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing.	WFD
	Best available techniques	Best available techniques as defined in Article 2(11) of Directive 96/61/EC.	Directive 96/61/EC
	Extended producer responsibility	A set of measures taken by Member States to ensure that producers of products bear financial responsibility or financial and organisational responsibility for the management of the waste stage of a product's life cycle.	WFD
Applications	Use/application	Means any processing, formulation, consumption, storage, keeping, treatment, filling into containers, transfer from on container to another, mixing, production of an product or any other utilisation.	REACH Regulation
	Restriction of use	Any condition for or prohibition of the manufacture, use or placing on the market.	REACH Regulation
	Backfilling	Any recovery operation where suitable non-hazardous waste is used for purposes of reclamation in excavated areas or for engineering purposes in landscaping. Waste used for backfilling must substitute non-waste materials, be suitable for the aforementioned purposes, and be limited to the amount strictly necessary to achieve those purposes.	WFD
	Disposal	Any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy. Annex I of the WFD sets out a non-exhaustive list of disposal operations.	WFD
	Unbound application	Use of compacted granular materials in layers for the execution of various civil works units, without adding any binder	ORDER of 12 January 2015 – Basque Country
	Waterproofing layer	Execution of layers designed to prevent water from penetrating into a structure.	
	Permeability	A measure of the ability of a material (such as soils) to transmit fluids	
	Draining application	Those applications intended to the artificial removal of water, both surface and sub-surface.	
Others	Leachate	Any liquid percolating through the deposited waste and emitted from or contained within a waste facility, including polluted drainage, which may adversely affect the environment if not appropriately treated.	2004/C 109/07
	Impurity	Means an unintended constituent present in a substance as produced. It may originate from the starting materials or be the result of secondary or incomplete reactions during the reaction process.	Others
	Substance	An element or compounds hereof, natural or made industrially, containing such additives as are necessary for maintaining the stability of the substance, and such impurities that result from the manufacturing process, except for solvents that can be separated without impacting the stability of the substance or changing its composition.	REACH Regulation
	Batch	Production quantity, a delivery quantity, a partial delivery quantity (railway wagon, load, lorry load, ship's cargo) or a stockpile produced at one time under conditions that are presumed uniform.	Others

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6.3. Input material

Origin of materials that can be potentially used as SRM in the construction sector are listed in Table 20.

Table 20: List of input materials that can be potentially used as SRM in the construction sector

Origin	Wastes		EWC
CDW	Concrete and other cement-based products		17 01 01
	Bricks, tiles and ceramic products		17 01 02 /17 01 03
	Mixtures of concrete, bricks, tiles and ceramics Other mixed construction and demolition wastes		17 01 07 / 17 09 04
	Track ballast		17 05 08
	Soil and stones		17 05 04
	Excavated material		17 05 06
	Bituminous mixtures		17 03 02
	Gypsum based construction materials from construction cuttings and demolition wastes		17 08 02
	Glass waste		17 02 02
Iron and steel industry	Blast furnace slag	Granulated blast furnace slag	10 02 01 / 10 02 02
		Air-cooled blast furnace slag	
	Steel making slag	Electric-arc-furnace (EAF) slag	
		Ladle slag	
		Basic-oxygen-furnace (BOF) slag	
Foundry Industry	Foundry sands		10 02 01 / 10 02 02

6.4. Types and composition of the SRM

6.4.1. Types of SRM according to the composition

Different types of SRM can be obtained from the waste list presented in section 6.3. It is very important to take into consideration the different ways of obtaining SRM products depending on whether they come from CDW or industrial waste / by-products (Table 21).

Table 21: Stages for the obtention of SRM products from industrial activities and CDW.

	Industrial activities	Construction and Demolition activities
WASTE	Slags	CDW
↓	Treatment at the industrial location	Transport or valorisation in-situ
	Application of **common industry practices***	Valorisation process through a waste manager
	Quality control	Quality control
SRM PRODUCT	Manufactured Aggregates - Slag aggregates**	Recycled aggregates

* No needs of intermediate waste manager.
** The term of by-product normally refers to the final product obtained after applying common industry practices at the end of the production process.

We can consider two major typologies of SRM obtained from CDW and industrial waste or by-products:

- Recycled aggregates from CDW;

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- Manufactured aggregates from industrial processes.

Recycled aggregates from CDW

As explained in the Section 3.2, recycled aggregates from CDW are classified according to their physical composition from the percentage by weight of each of the components according to the standard UNE-EN 933-11 (Table 22).

Table 22: Components of coarse recycled aggregates according to EN 933-11

Component	Description
Rc	Concrete, concrete products, mortar Concrete masonry units
Ru	Unprocessed aggregates, natural stone Aggregates treated with hydraulic binders
Rb	Clay masonry units (i.e., bricks and shingles) Calcium silicate masonry units Non-floating aerated concrete
Ra	Bituminous materials
Rg	Glass
X	Others: cohesive (i.e., clay and sand) Various: metals (ferrous and non-ferrous), non-floating wood, plastic and rubber Plaster
FL	Floating Particles

Following the already defined SRM products structure the following definitions apply:

- *Recycled Concrete Aggregates (RCA):* recycled aggregates obtained mostly of concrete from CDW (Figure 15);
- *Recycled Mixed Aggregates (RMA):* recycled aggregates composed of concrete and ceramic from CDW;
- *Recycled Ceramic Aggregates (RBA):* recycled aggregates obtained by processing predominantly ceramic material from CDW;
- *Recycled Asphalt Aggregates (RAA):* aggregates obtained from the milling operations of old bituminous pavement;
- *Recycled plaster (RP):* secondary raw material from CDW composed of recycled gypsum with purities greater than 99% and X≤1% of improper content;
- *Recycled glass (RG):* secondary raw material from the valuation of glass from CDW with purities greater than 99% and X≤1% of improper content;
- *Combined Recycled Aggregates (CRA):* mixture of natural aggregates and recycled or artificial aggregates.

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Figure 15: Recycled Concrete Aggregates (RCA)

Table 23 summarize the typology of the recycled aggregates from CDW proposed.

Table 23: Possible types of recycled aggregates and composition proposal

Type of Recycled Aggregates proposed		Proposed qualities	Composition (%)					
			Rcug Rc + Ru + Rg	Rb	Ra	Others		FL
						Rg	X	cm^3/kg
RCA	Recycled concrete aggregates	Upper limit*	≥ 95	≤ 5	≤ 5	≤ 1	≤ 1	≤ 1
		Lower limit**	≥ 90	≤ 10	≤ 10	≤ 2	≤ 1	≤ 5
RMA	Recycled Mixed Aggregates	Upper limit*	≥ 70	≤ 30	≤ 5	≤ 1	≤ 1	≤ 1
		Lower limit**	≥ 50	≤ 50	≤ 10	≤ 2	≤ 1	≤ 5
RBA	Recycled Ceramic Aggregates	Upper limit*	≤ 20	≥ 80	≤ 5	≤ 1	≤ 1	≤ 1
		Lower limit**	≤ 30	≥ 70	< 10	≤ 2	< 1	≤ 5
RAA	Recycled Asphalt Aggregates	Upper limit*	≥ 90 Rc+Ru+Ra	-	≥ 70	≤ 1	≤ 1	≤ 1
		Lower limit**	≥ 90 Rc+Ru+Ra	≤ 10	≥ 50	≤ 2	< 1	≤ 5
RP	Recycled plaster	≥ 99% (Gypsum)	-	-	-	-	< 1	≤ 1
RG	Recycled glass	≥ 99% (Glass)	-	-	-	-	< 1	≤ 1
CRA	Combined Recycled Aggregates	Customized mixture of natural aggregates and recycled or artificial aggregates.						

* Corresponding to an aggregate with higher quality

** Corresponding to an aggregate with lower quality

Manufactured aggregates (MA)

Aggregates of mineral origin resulting from an industrial process that involves thermal or other modification are proposed to be considered here.

The composition of the MA will depend on the nature of the original by-product or waste obtained from the different industries.

Iron and steel slag aggregates are the most common industrial products. They are manufactured under extensive quality controls in order to obtain suitable products for the construction sector

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with no organic impurities, clay, shells, or similar materials and with reduced expansiveness. For both fine particles and coarse particles, the chemical composition is completely uniform. In addition, this aggregate contains no reactive silica, which is one cause of chemical reaction with alkali aggregates. It reduces environmental impacts, preserves precious natural resources needed to maintain ecosystems, and can reduce the energy that is consumed in mining, stone crushing, and other activities.

The three main types of iron and steel slag aggregates are:

- Granulated blast furnace (GBF) slag aggregates: GBF Slag Aggregates;
- Electric-arc-furnace (EAF) slag aggregates: EAF slag aggregates;
- Basic-oxygen-furnace (BOF) slag aggregates: BOF slag aggregates.

6.4.2. Types of SRM according to the weight

Based on their weight the following classification applies:

- *Normal Weight Recycled Aggregates (NWRA):* Aggregate of mineral origin with a particle density not less than 2000 kg/m^3 and not more than 3,000 kg/m^3;
- *Light Weight Recycled Aggregates (LWRA):* Defined as light weight recycled aggregates the aggregates of mineral origin with a particle density not greater than 2,000 kg/m^3.

6.4.3. Types of SRM according to the size

Based on the particle size the following classification applies:

- *Coarse recycled aggregates*: Designation given to the aggregate sizes with *d* equal to or greater than 2 mm and D equal to or greater than 4 mm;
- *Fine recycled aggregates*: Designation given to the aggregate sizes with *D* equal to or less than 4 mm;
- *All-in aggregate*: Aggregates composed of a mixture of fine and coarse aggregates with a continuous PSD;
- *Fines*: aggregates with particle size which passes the 0,063 mm sieve;
- *Ballast*: Designation given to the coarser aggregate sizes with *d* equal to or greater than 40 mm and D equal to or greater than 150 mm.

6.5. Potential permitted uses for SRM

Three possible scenarios according to the level of environmental protection:

- **Scenario 1: Bound applications.**
- **Scenario 2: Unbound applications under impervious or semi-impervious covering layers.**
- **Scenario 3: Unbound applications without any waterproofing protection.**

6.5.1. Bound applications

Scenario 1: Use of granular materials mixed with any type of binder that confers cohesion to the whole by encapsulating the aggregates within an inorganic matrix, where their exposure to the environment and the release of components are considered null or negligible.

1) Structural concrete
   - ready-mix concrete
   - precast concrete elements: blocks, pavements, barriers, pipes, etc.
   - concrete caissons for docks
2) Non-structural concrete:
   - levelling concrete
   - infill concrete
3) Concrete for roads and flooring:
   - concrete for pavements
   - vibrated concrete
4) Cement treated material for foundation courses: gravel-cement (slag-cement).
5) Bituminous mixtures (hot, warm and cold) for the execution of roads surface courses, bicycle´s paths and pedestrians´ paths.
6) Capping layers.
7) Masonry products.
8) Supplementary cementitious materials.
9) Filler for the manufacture of cement-based products
10) Gypsum based products.

6.5.2. Unbound applications

Scenario 2: Underlaying courses of capped pavement or shoulder sublayers. Covered with a surfacing layer considered impervious or semi-impervious. Use of compacted granular materials in layers for the execution of different civil works units, without adding any binder, under coverings of not fully or fully impervious materials:

1) Engineering embankments.
2) Phonic protections for infrastructures.
3) Surface courses: wearing and binder courses for roads.
4) Foundation courses: base course and sub-base course for roads, pedestrian paths and cycle paths.
5) Subgrade courses.
6) Shoulder sublayers.
7) Urbanization projects.

Scenario 3: Unpaved or uncapped usages. Satisfying more restrictive environmental conditions. Use of compacted granular materials in layers for the execution of different civil works units, without adding any binder and without any type of waterproofing protection:

8) Surface courses: wearing and binder courses for roads.
9) Uncapped pavement or shoulder sublayers.
10) Engineering embankments associated with road infrastructure or for uncovered shoulders.
11) Preloading fills.

It is highly recommended to avoid the backfilling and the use in landscape restoration of degraded areas, mining holes or similar applications since it does not align with the circular economy paradigms.

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6.5.3. Possible uses of the different SRM

Error! Reference source not found. shows a relation of possible uses of SRM in the different applications. This list has been prepared from the current state of the art based on the different regulations and on the demonstration projects that have been successfully carried out up to date. The following proposal is dynamic and is established without prejudice to new uses that may be included as technological improvements are implemented.

Table 24: Possible uses of SRM in different applications

Suggested uses	All-in						Coarse Recycled Aggregates						Fine Recycled Aggregates						Fines (mineral powder/filler)					
	RCA	RMA	RBA	RAA	AA	CRA	RCA	RMA	RBA	RAA	AA	CRA	RCA	RMA	RBA	RAA	AA	CRA	RCA	RMA	RBA	AA	RP	RG
Bound applications																								
Structural concrete							X				X	X					X	X						
Non-structural concrete							X	X	X		X	X	X	X	X		X	X	X	X	X	X		
Concrete for roads and flooring							X				X	X					X	X						
Cement treated material for foundation courses	X	X			X	X					X	X					X	X	X	X	X	X		
Bituminous mixtures										X	X					X	X	X						
Masonry products							X	X	X		X	X	X	X	X		X	X	X	X	X	X		X
Capping layers	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Supplementary cementitious materials																			X	X	X	X	X	X
Filler for the manufacture of cement-based products																			X	X	X	X		X
Gypsum based products																							X	
Unbound applications covered with a surfacing layer considered impervious or semi-impervious.																								
Foundation courses	X	X		X	X	X	X	X		X	X	X												
Surface courses	X	X		X	X	X	X	X		X	X	X												
Engineering embankments	X	X		X	X	X	X	X		X	X	X												
Subgrade courses	X	X		X	X	X	X	X		X	X	X												
Shoulder sublayers	X	X		X	X	X	X	X		X	X	X												
Phonic protections	X	X		X	X	X	X	X		X	X	X												
Urbanization projects	X	X		X	X	X	X	X		X	X	X												
Unbound applications. Unpaved or uncapped usages.																								
Uncapped pavement or shoulder sublayers	X	X		X	X	X	X	X		X	X	X												
Surface courses	X	X		X	X	X	X	X		X	X	X												
Engineering embankments	X	X		X	X	X	X	X		X	X	X												
Preloading fills	X	X		X	X	X	X	X		X	X	X												

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6.6. Restrictions and prohibitions of use

a) The recycled aggregates will have the CE marking in those uses for which it is required by the applicable technical legislation and must comply with the rest of the conditions established in the aggregates´ regulations in force.

b) The recycled aggregates may not be used for applications other than those permitted in the decree, unless authorized by the environmental body, and prior justification of the suitability of the material.

Those aggregates that have not reached the end-of-waste condition may not be used by not complying with the technical and environmental parameters.

Unless otherwise advised by an expert hydrogeologist or the authorization by the environmental body, the use of alternative materials should not be allowed in the following scenarios as listed in Table 25.

Table 25: Restrictions and limitation of use of SRM

Nature of the limitation	Restrictions and prohibitions of use
Environmental limitations	• In spaces or places that present any figure of special protection contemplated in the regulations on the conservation of nature. • In draining applications or in places where water flows temporarily. • In flood-prone areas; • In places located less than 30 m from any watercourse, including lakes and ponds; • In the protection perimeters of drinking water supply catchments; • In areas covered by an established public utility easement; • In natural aquifer areas where the flow of water con be continuously or temporarily modified in the structure or its immediate environment. • In the production of recycled aggregates, CDW from industrial ruins that have suffered potentially soil-polluting activities may not be used
Technical limitations	• The recycled aggregates will have the CE marking in those uses for which it is required by the applicable technical legislation and must comply with the rest of the conditions established in the aggregates´ regulations in force.
Limitations related to the implementation of the SRM	• The storage of recycled aggregates on site must be temporary and accepted by the site management. • Temporary storage capacity on site limited to 1,000 m^3
Other limitations	Limitation due to aesthetic, social, availability, logistic or economic reasons.

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6.7. SRM Requirements

6.7.1. Acceptance or rejection criteria of the SRM on site

Before receiving the recycled material on site, it is recommended to take into account some considerations to ensure that the material has been properly treated and has the qualities and properties necessary for the application you want to give it.

➢ **What relevant aspects must be taken into account from an administrative point of view?**

- The use of SRM must be considered from the basic engineering project.
- The characteristics required to the SRM must be included in the Technical Prescription Specifications of the engineering project.
- All the documentation corresponding to the correct management of the SRMs must be provided to the corresponding administrative body.

➢ **How can we know if an aggregate has been correctly recycled?**

- SRM must always be supplied by authorized waste managers.
- Authorized waste managers must prepare and facilitate the DOP for SRM within the scope of the CE Marking. This information must include, in addition to the technical characteristics, to the extent required by the applicable environmental regulations, the following representative analytical results of the SRM supplied:
    - Leaching analysis.
    - Analysis of the total contents of organic and inorganic compounds related to the prevention and correction of soil contamination.

➢ **How can we know that the final application of the SRM is allowed and that the conditions are appropriate?**

- The permitted uses and the conditions under which the permitted uses must be given must be correctly defined by the regulatory framework. In addition, it is convenient for the authorized manager to indicate to the user if the intended use is in accordance with those contemplated in the applicable regulations.
- SRM must meet technical and environmental thresholds set out in current legislation. Compliance with these parameters will imply the acceptance or rejection of the SRM on site.

6.7.2. Technical requirements.

- The need to test and declare all the properties detailed in this section is limited according to the end use of the SRM and the specific technical specifications of each country.
- The qualities of the aggregates must be certified by CE marking.

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Beyond the tests established in the CE marking, a proposal of physical, chemical and durability properties to be analysed in order to guarantee the quality of the SRM are summarized in Table 26.

Table 26: Proposal of physical, chemical and durability properties to be analysed

Test	Standard
Geometrical properties	
Determination of particle size distribution - Sieving method	EN 933-1:2012
Determination of particle shape - Flakiness index	EN 933-3:2012
Physical properties	
Classification test for the constituents of coarse recycled aggregates	EN 933-11:2009
Determination of the water content by drying in a ventilated oven	EN 1097-5:2008
Determination of resistance to fragmentation of coarse aggregates	EN 1097-2:2010
Determination of the resistance to wear (micro-Deval)	EN 1097-1:2011
Assessment of fines - Sand equivalent test	EN 933-8:2012+A1:2015
Determination of particle density and water absorption	EN 1097-6:2014
Determination of loose bulk density and voids	EN 1097-3:1998
Determination of liquid and plastic limits	ISO 17892-12:2018
Test for free swelling	
Determination of the polished stone value	EN 1097-8:2020
Chemical properties	
Total sulphur content	EN 1744-1:2010+A1:2013
Water and acid soluble sulphates	EN 1744-1:2010+A1:2013
Chlorides content	EN 1744-1:2010+A1:2013
Gypsum content	
Soluble salts content	
Organic matter content	
Volume stability of steel slag aggregates.	EN 1744-1:2010+A1:2013
Durability properties	
Determination of resistance to freezing and thawing.	EN 1367-1:2008
Stability of aggregates and rock fragments against collapse in water action	NLT 255:1999
Magnesium sulphate test	EN 1367-2:2009

6.7.3. Environmental requirements

Table 27 presents a proposal of the limiting values range for the different scenarios of application according to the analysis made on the different countries studied.

Table 27: Proposal of leaching, organic compounds and inorganic compounds limit values

Compounds	Leaching criteria - Limit value. (mg/kg of dry matter. L/S=10 l/kg) EN 12457-4	
	Unbound applications covered with a surfacing layer considered impervious or semi-impervious	Unbound applications. Unpaved or uncapped usages
Arsenic (As)	0.9	0.5
Barium (Ba)	25	5
Cadmium (Cd)	0.05	0.025
Chromium (Cr) Total	2	0.5

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Chromium (Cr) VI	0.4	0.1
Copper (Cu)	3	0.5
Mercury (Hg)	0.01	0.005
Molybdenum (Mo)	2.8	0.5
Nickel (Ni)	0.75	0.1
Lead (Pb)	2.3	0.5
Antimony (Sb)	0.3	0.06
Selenium (Se)	0.6	0.1
Zinc (Zn)	10	2
Fluoride	55	10
Chloride	5,000	600
Sulphate	6,000	1,000

For those countries/regions that want to incorporate limits to the organic and inorganic compounds values, a proposal is given in Table 28. Those limit values are incorporated in very few European regions, so it is recommended that they be taken into account in those places where it is required by environmental regulations.

Table 28: Proposal of organic compounds and inorganic compounds limit values

Compounds	Organic compounds Total content criteria - Limit value range. (mg/kg of dry matter)
Asbestos	100
Tar-containing asphalt (PAHs)	16-50
PCB	0,5-1
BTEX	6
Mineral oils	50-1,000
EOX	10
Hex.	10
Hep.	1
Octa.	90
TOC	30,000
Compounds	**Inorganic compounds Total content criteria - Limit value range. (mg/kg of dry waste)**
Arsenic (As)	10-250
Cadmium (Cd)	0.2-12
Chromium (Cr) Total	200-10,000
Chromium (Cr) VI	8
Copper (Cu)	40-10,000
Mercury (Hg)	4-5
Molybdenum (Mo)	75
Nickel (Ni)	110-250
Vanadium (V)	1,000
Zinc (Zn)	120-10,000

6.7.4. Other requirements

➢ **What other acceptance and rejection criteria must the project manager consider?**

- The regularity of the material supplied must be ensured in such a way as to avoid the reception of SRM that does not comply with the CE marking within the same batch. It may happen that, for the same batch of material certified with CE marking, there are quality

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deviations between the different shipments. To avoid this problem, it is recommended to visually inspect, paying special attention to the content of the different shipments.

- The project manager or the person responsible for ensuring the reception of the materials, must prevent acceptance of inappropriate SRM and, in case of detecting possible deviations from the thresholds established by the technical regulations, they must reject that batch of material or require additional tests that allow assuring the qualities.
- From an aesthetic point of view, the use of SRM with bulky improper fractions that are exposed to view, can cause a negative social perception. The use of SRM with improper that cause a negative visual impact should be avoided, even if the material meets the established technical and environmental thresholds.

6.8. Main characteristics of the SRM and challenges for their improvement

Due to the fact that some of the properties the SRM differ from those of natural ones, they should be kept in mind and controlled since these differences, due to the nature of SRM, will influence in one way or another in the manufacture of new products and their applicability on work site.

SRM face several challenges in competing with primary raw materials for reasons not only related to their safety, but also to their performance, availability, and cost.

The properties of SRM depend on many factors such as the type of construction and demolition waste, the demolition process used, the treatment of the aggregates, etc.

It is advisable to consider some particularities of the SRM that will influence the manufacturing process of new materials and their implementation on work site (Table 29).

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Table 29: Main characteristics of the SRM and challenges

Typology of SRM	Property	Singularities of the SRM	Challenges for the improvement
Recycled Concrete Aggregates and Recycled Mixed Aggregates	PSD	○ Higher content in fine fractions than natural aggregates.	○ To improve this value it is advisable to minimize the fine content of the recycled aggregates by means of appropriate sorting technologies. ○ It is also suggested to avoid contact with land and soils that can contaminate them during their storage.
	Sand equivalent	○ Mixed recycled aggregates may have low values of the equivalent sand index directly related to the highest content of fine <0.063mm (usually greater than 6%).	
	Particle shape - Flakiness index	○ The particle shape coefficient of the recycled aggregates is similar to natural aggregates and may have a lower percentage in certain cases. ○ The particle shape coefficient of the mixed recycled aggregate is generally higher than recycled concrete aggregates due to the higher content of ceramic fractions. ○ The texture of recycled aggregates is usually rough and porous, due to the presence of cement mortar attached to the natural aggregates and brick particles.	○ The segregation of ceramic fractions should be maximized by means of appropriate sorting technologies.
	Resistance to fragmentation	○ The coarse recycled fractions (> 4 mm) show a resistance to fragmentation value (Los Angeles test) between 25-45%, higher than natural aggregates. ○ Within the coarse fraction of the recycled concrete aggregates, the size of the aggregate influences the resistance to fragmentation value, decreasing with the particle size due to the lower concentration of adhered mortar in coarser fractions. ○ The friability of the mortar and cement paste adhered to the natural aggregate results in the generation of fine particles during the different recovery stages: transport, processing, manufacturing and final installation that alter the initial properties of the aggregates.	○ There are two major challenges for improving the resistance to fragmentation: ○ Remove the cement paste adhered to the original natural aggregate by means of innovative processing technologies. ○ Remove, through innovative sorting technologies, gypsum particles (soft) and segregate as much as possible the ceramic fraction that reduce the fragmentation resistance due to their greater angularity.
	Density	○ The density of recycled aggregates from CDW is generally lower than that of natural aggregates, with the lowest densities being obtained in ceramic materials and mortar particles. The densities range between 2.100 kg/m^3 and 2.400 kg/m^3. ○ The density of the recycled concrete aggregate is very similar to the original concrete and somewhat lower than the density of the natural aggregate used for the production of the concrete, between 5-10% lower. In the case of recycled sands, the density value is	○ The main challenge to improve density and reduce water absorption is to remove as much as possible the cement paste adhered to the original natural aggregate using innovative improvement technologies.

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		slightly lower than the coarse fractions, due to its higher content of adhered cement paste.	
	Water absorption	○ The most important difference between the properties of recycled aggregates and conventional ones is the water absorption. The water absorption is usually between 4 - 10% for coarse recycled aggregates increasing up to 7 - 12% for fine fractions.	
	Environmental issues	○ Possible contaminants can alter the concentration of mineral salts, heavy metals and dangerous substances present in recycled aggregates. ○ The critical parameter is the sulphate content, mainly due to the gypsum contaminants and to a lesser extent to the sulphates contained in the bonded mortar.	○ The main challenge is to minimize the gypsum content to avoid sulphate hazards: • By improving segregation at source with selective demolition techniques. • By employing innovative sorting technologies. ○ The regulations limit these risks applying leaching limits that must be respected by the products obtained from the recycling processes. Products that do not meet the prescribed parameters should not be accepted.
Recycled Asphalt Aggregates	PSD	○ Particle size distribution suitable for the main applications in construction. It is advisable to adjust the lower fractions (0-4mm) as they can present a deficit of fine particles.	○ To improve this aspect, it is convenient to complete the fine particle size fraction with other fine aggregates (recycled or natural).
	Resistance to fragmentation	○ Similar values to the original natural aggregates. During milling operations, the asphalt aggregates obtained may be contaminated with those obtained accidentally from lower layers, with lower qualities.	○ It is important to carry out milling operations as precise as possible to avoid contaminating the different layers with lower quality materials.
	Density and water absorption	○ Smaller particles from milled materials tend to absorb more water than natural ones. ○ Although the presence of water does not affect the quality of the final bituminous mixture, since it is evaporated during the mixing process, it reduces the performance of the mixing process due the higher energy necessary to increase the temperature of the mix.	○ Make stockpiles as protected as possible from external elements.
	Environmental issues	○ They present higher values than natural aggregates in those parameters intrinsic to the material and related to the bitumen used (PAHs).	○ This characteristic is very difficult to reverse. It is convenient to analyse the environmental viability of these resources and demonstrate that they do not pose any type of environmental risk.
	Others	○ The aged bitumen adhered to the original natural aggregates will condition the manufacture of new mixtures and their implementation.	○ Rheological rejuvenating agent can be employed.

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Artificial Aggregates (Steel Slag Aggregates)	Volumetric stability	○ Due to the presence of free lime and magnesia, the artificial aggregates can present expansiveness.	○ The slag cooling and aging process, optimized in recent years, makes it possible to obtain iron and steel slag aggregates without any type of expansiveness or with harmless values for their use in construction applications.
	Density	○ High density between 3,000 and 3,500 kg/m^3 above the density of natural aggregates.	○ It is advisable to pay attention when dosing, transporting and installing this product. Check that the structural design is adapted to the densities.
	Water absorption	○ Greater absorption than natural aggregates, around 3 times higher due to its greater porosity.	○ Since it is very difficult to reduce the absorption of these aggregates, the new products containing this SRM will be dosed, manufactured and installed taking into account the recommendations established in Sections 6.10 and 6.11.
	Environmental issues	○ The use of iron and steel slag aggregates in unbound construction applications represents a potential environmental impact linked to the possible release of its harmful components. For this reason, several requirements must be established for guaranteeing an acceptable behaviour of this product and preserve the environment from this potential risk.	○ The regulations limit these risks applying leaching limits that must be respected by the products obtained from the recycling processes. Products that do not meet the prescribed parameters should not be accepted.

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6.9. Processing considerations and challenges

6.9.1. Considerations and challenges for the correct treatment of CDW (except asphalt)

A. Treatment of CDW in a mobile plant

Mobile crushing plants that are moved from site to site. They are especially suitable for those works in which the recycled material is aimed to be employed in-situ. They are generally composed of a crusher and screens to classify the processed material.

The limitations related to these simple technologies should be considered since complex treatment processes cannot be applied to obtain high-quality SRM. In this sense, the treatment of CDW with mobile plants should be limited to clean waste streams, i.e.:

- Concrete and other cement-based products (17 01 01),
- Bricks, tiles and ceramic products (17 01 02, 17 01 03),
- Track ballast (17 05 08),
- Soil and stones (17 05 04),
- Excavated material (17 05 06).

B. Treatment of CDW in a valorisation plant.

The use of new materials and new construction techniques makes the composition of CDW increasingly complex. This complexity requires the application of advanced solutions and strategies for increase the efficient recovery of resources from this waste stream, since conventional processing (crushers, screens, air separators, magnets and eddy separators) only achieves a basic level of separation.

To carry out a correct processing in a valorisation plant and thus obtain aggregates of the highest quality, three main basic processing stages must be guaranteed. Consideration for the improvement and challenges for each step are described below:

- Pre-treatment on discharge: prior visual inspection and selection of the CDW. The purpose of this operation is to increase the percentage of waste that can be recycled, by removing bulky waste. Many of the CDW entering to the facility includes elements whose dimensions allow them to be removed manually (planks, large metal objects, plastics, etc.) or by using a heavy machine fitted with a gripper.
- Sorting phase: it consists of the treatment of mixed CDW free of bulky improper and composed of a mixture of inert, plastics, wood, paper, metals, etc. In this phase, those wastes that are not stone and / or ceramic fraction are separated which will be subsequently treated by crushing and screening. The sequence of treatment usually is:
  - Feeding: the material to be processed, pre-cleaned and separated into different stockpiles according to categories, is loaded with a loader that pours it into the receiving hopper.
  - Screening of fine fractions: materials of smaller size (generally <40mm) are separated and collected for shipment to their final destination (for uses with very low added value).

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- Light fraction removal by air: before the waste passes to the sorting cabin, it is processed through a blower that removes the lightest fraction (small plastic elements, paper, dust, etc.).
- Magnetic and eddy current separator for metallic elements.
- Separation of the different waste streams. Two techniques are commonly used:
  - Manual sorting of plaster, heavy plastics, wood, etc. The waste (plastics, wood, aluminium, etc.) is manually classified, leaving exclusively stone materials and selecting the different fractions of improper items in separate containers. For the separation of plaster, certain plants have densimetric bathtubs.
  - Separation through advanced technologies: Use of different types of technologies to separate the unwanted fractions (plaster, plastic, wood, etc.), the grey fraction (natural aggregate, concrete and mortar) and the ceramic fraction (bricks, tiles, sanitary ware, etc.).

- **Final classification:** It consists of the final stage of crushing and classification to obtain recycled aggregates with suitable particle size distribution for their final application.

C. New trends in processing technologies for advanced recovery of CDW

New trends are opting to include advanced technologies for improving the sorting phase and for the quality improvement of the aggregates in order to obtain high quality recycled aggregates for their use in high added value application. A list of innovative technologies that are suggested to implement in the recycling processes is listed in Table 30. It is highly recommended to promote and encourage the use of these technologies to obtain high quality aggregates and avoid technical and environmental problems when applying them.

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Table 30: New trends in processing technologies for advanced recovery of CDW

Type	Technology	Functional principle	Advantages	Obtained SRM	TRL For CDW
Mechanical sorting technologies	Magnetic separators	Magnetic separators for the deferrization of ferrous metals by mean of last generation magnets and for the separation of non-ferrous metals by means of Eddy currents, including more efficient detection sensors (LIBS or others).	Removal of ferrous and non-ferrous metals.	Applicable to all types of mineral streams.	9
	ADR sorting technology	Advanced Dry Recovery sorting technology that allows, through the application of kinetic energy through the blades of a rotor and subsequent injection of air, the breaking of capillary bridges in wet granular materials and the separation of fine particles.	Separation of fine particles from coarse fractions in those granular materials with high moisture content that cannot be classified by traditional screening. Obtention of clean coarse fractions.	Coarse recycled concrete aggregates RCA.	9
	High frequency sieves	Dry high energy efficiency sorting of fine products with Particle Sizes Distributions up to < 45 µm. They can be linear or circular vibrating screens.	Technology to classify particle sizes of a wide range of sizes reaching very fine particles of up to 45 µm.	Applicable to any type of dry aggregate.	9
Hydraulic sorting technologies	Gravimetric sorting using densimetric tables	Density tables are used for efficient sorting of dry materials due to density. Separation is achieved by vibrating movement on the surface of an inclined treatment table. The rising air flows from below through this surface together with the vibration causes the separation of the particles.	Separation of particles by density in such a way that light particles are removed, and the stony materials are separated by densities (concrete, ceramic and plaster).	Coarse particles: RCA RBA RP	7
	Gravimetric sorting by differential acceleration (JIG)	Differential acceleration equipment works with currents of water or air in turbulent regime and differential action. According to this principle and for very short cycles, the solid particles are subjected to upward and downward currents, motivated by alternating pulsations given to the fluid, either by a piston or a diaphragm. In this way, a separation of the particles by density is achieved, with stratification of the different materials, so that the lightest ones go to the surface, while the heaviest ones go through the bottom of the screen.	Separation of particles by density in such a way that light particles are removed, and the stony materials are separated by densities (concrete, ceramic and plaster).	Coarse particles: RCA RBA RP	7
	Gravimetric separation by concentrating spirals	The spiral concentrator consists of a helical chute. Its operation can be compared to that of a conical pan, where the light particles are moved by the action of the water towards the edge and the heavy particles are concentrated in the centre. Especially suitable for CDW fine fractions by optimizing the separation.	Very low cost and highly efficient separation for fine fractions. Light improper separation and removal of fine gypsum particles.	Fine particles: RCA RBA RP	7
	Cyclonic classifiers	Classification of products with granulometry between 10 and 300 µm using hydraulic cyclones. A cyclone separator is an equipment	Cheap and efficient technology for classifying very fine particle sizes.	Applicable to any type of dry fine	9

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		used to separate solid particles suspended in air, gas or liquid flow, without the use of an air filter, using a vortex for separation.		aggregate <300 µm.	
	Hydrocyclone Technologies	Hydrocyclone technologies to separate plasterboard from plasterboard.	Allows effective separation of cardboard and plaster for post-consumer waste. This produces recycled gypsum streams with very high purity levels.	RP	5
Optical sorting technologies	Optical sorting using VIS + NIR	Optical sorting that allow to automatically identify and separate different types of materials, by composition (NIR), colour (VIS) and / or shape (deep learning). Identification of the different fractions using optical sensors and separation of the identified fractions by air pulses.	The automatic sorting by sensors allows to treat a greater quantity of material, considerably increasing the performance of the plant and reducing handling costs. In addition, a selected high-quality material is obtained. Obtention of coarse recycled aggregates free of improper light and free of coarse gypsum particles.	Coarse particles: RCA RBA RMA RP	9
Drying and Thermal Activation Technologies	Rotary dryers	They consist of slightly inclined rotating cylinders into which hot air is injected and circulated through the moving cylinder.	Drying of large volumes of material to obtain moisture-free aggregates.	Applicable to any type of aggregate.	9
	Fluidized bed dryers	Drying through fluidized bed reactors is a very efficient method of drying solid particles. The surface of each individual particle is exposed for drying by suspending it in airflow, resulting in better heat transfer and shorter drying time.	Among the most efficient drying methods, due to the excellent contact between the drying air and the particles, with high heat and mass transfer coefficients.	Applicable to any type of fine aggregate.	9
	HAS technology	The HAS (Heating Air System) technology consists of a vertical cylinder fed from the top in such a way that the particles pass through the cylinder by gravity. The burner, which reaches temperatures of up to 700 °C, is located in the central part of the cylinder. The novelty of the HAS technology is the incorporation of a grid that hinders the passage of the particles, increasing the residence time and the interaction with the heated air in the fluidized bed.	Among the main advantages are the drying of the aggregates quickly and efficiently; the calcination of organic particles; the activation and recovery of the cementing properties of the treated ultrafine particles; reducing water absorption and increasing the density of processed fine aggregates by eliminating part of the cement paste adhering to the original natural aggregate.	Applicable to any type of fine aggregate.	7
	Spouted bed technologies	Spouted bed technologies consist in very high efficiency gas-solid contact systems (greater than 90% efficiency) that achieves optimized conditions for the transfer of mass and energy with the aim of drying fine and ultrafine mineral fractions.	The vigorous and characteristic movement of the particles in the spouted bed contactors allows a high efficiency gas-solid contact and, therefore, a higher drying and reaction kinetics with a shorter residence time of the solids in the reactor. It has the same advantages in recycled aggregates as HAS technology.	Applicable to any type of fine aggregate.	7
Transformation and improvement	Milling technology.	Particle size reduction employing mechanical comminution processes using bar or ball mills.	Obtention of fines from different CDW streams with hydraulic or pozzolanic potential for their use as a Supplementary Cementitious Material.	Applicable to any type of dry aggregate.	9

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technologies	Improvement technology through attrition	High energy efficiency technologies based on mechanical abrasion that generates very high differential stresses between cement paste and aggregate, inducing delamination of the cement paste.	Obtention of recycled concrete aggregates improved with lower content of cement paste and therefore higher density and lower water absorption.	Coarse recycled concrete aggregates.	5
	Improvement technology through chemical additives	It consists of applying pore-blocking chemical additives at the end of the recovery process to reduce the absorption of aggregates.	Obtention of recycled concrete aggregates improved with reduced water absorption.	Coarse and fine recycled concrete aggregates.	5
	Carbonation technologies	Technologies based on accelerated carbonation of portlandite and hydrated calcium silicate (C-S-H) present in concrete aggregates.	Two main advantages: on the one hand, the direct capture of CO2 in the RCA to reduce the environmental impact caused by concrete in buildings and, on the other, a qualitative improvement of these aggregates by reducing their porosity.	Coarse and fine recycled concrete aggregates.	4-5
	Microwave technologies	Microwave-based technologies for clinkering cement paste at a lower temperature. They are also used to separate concrete phases or fibres within concrete due to the effect of microwaves in the interfacial transition zone.	High energy efficiency technologies that manage to eliminate the cement paste adhering to the original natural aggregate and separate other phases adhered to the concrete such as fibres, ceramics or plaster.	Coarse and fine recycled concrete aggregates.	4
	Technologies for wood and plastics (solvolysis, pyrolysis, ...)	Chemical transformation processes that make it possible to transform the organic waste streams (wood and plastics) present in the CDW into products with high added value such as fuels, bio-resins, etc.	Technologies that allow the recovery of organic waste streams.	New products	5
Digital technologies	BIM-based technologies	Technologies based on Building Information Modelling (BIM) oriented to improve pre-demolition audits, plan selective demolition and improve the management of generated waste.	Technologies to improve the segregation at source of CDW in such a way as to improve the quality of recycled aggregates after the treatment process.	Applicable to all waste streams	8
	Traceability technologies	Digital tools for the traceability of resources throughout the entire value chain.	Guarantees the traceability of mineral resources from the demolition to the final application, improving the confidence of the different agents involved in the value chain.	Applicable to all waste streams	6-7
	Quality analysis technologies	Use of optical sensors combined with Deep Learning for the automatic identification of mineral resource typologies and quality analysis.	Guarantees the identification of different types of resources and their quality in real time.	Applicable to all waste streams	4-5

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6.9.2. Considerations and challenges for the correct extraction and preparation of recycled asphalt aggregates

Extraction stage

- It is convenient to maximize the control of the extraction operations since the milling of the unwanted (lower layers with lower qualities) reduces the physical properties of the milled materials by including poorer quality aggregates.
- It is recommended prior to the milling process, whenever possible, to extracts probes to verify the depth of the layer to be milled to adequately limit the action of the milling machine.

Treatment stage

- The material should be crushed and sieved in small quantities (those that are going to be used in the short term), so that the homogeneity can be verified and have the material properly identified, to use it quickly before it can be wetted by rain or contaminated by other external agents. Another possibility is to carry out the treatment operation directly on a production line.

Homogenization stage

- It must be considered that the properties of the reclaimed asphalt pavement can change from one section to another in the same road. Even the milling machine employed can modify the characteristics of the material obtained depending on the section milled. Therefore, the fact that the material is from a single source is not a sufficient guarantee that it is homogeneous. In case of manifest heterogeneities, they should be homogenized.
- It is recommended to use fine granulometric fractions 0-4mm to complete the lack of this fraction and improve the granular skeleton of the material.

Process digitization

- When there is a certain volume of stocks of different types, it is advisable to digitize the stocks to have each one of them properly identified.
- In general, milled materials are stored without any type of traceability and the different batches are mixed, causing quality losses.
- Good practices recommend storing the Reclaimed Asphalt Pavement differentiated according to quality parameters. It is therefore recommended to better control the origin of the milled materials and to have greater traceability and quality control of the whole recycling process.

6.9.3. Considerations and challenges for the correct preparation of the Manufactured Aggregates

Slag from the steel industry and other industries should not be used without a proper treatment process that safely transforms it into artificial aggregates. These tasks must be carried out by the waste manager before putting the product on the market.

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Not all slags must be processed in the same way, but in general the slag recovery process, which leads to its transformation into artificial aggregate, consists of various stages until the volumetric stability, qualities and sizes of the resulting aggregates are guaranteed. for commercial use in different construction applications:

- **Discharge during the slag phase**.
- **Cooling and stabilization** of compounds by spraying water or other procedures that guarantee sufficient volumetric stability of the granular material. Depending on the final construction application, the volumetric stability must be more rigorous.
- **Crushing**. Slag is crushed in impact mills or other crushing technologies to reduce its size and facilitate subsequent iron removal.
- **Iron removal**. In order to remove as much of the ferrous elements as possible, after the initial crushing, the resulting particles pass through powerful electromagnets that trap the metallic elements. Depending on the design of each treatment plant, one additional step may be necessary in the treatment line
- **Sieving and final classification**. The granular material is transported through belts to the screens, classifying it by sizes, according to market requirements.

6.10. Recommendations for the use of SRM

6.10.1. Recommendations for the correct manufacturing of the SRM-based products

The manufacture of products in the manufacturing plant or at work site, including dosing, mixing and transport is essential to obtain good quality product. The manufacturing process changes completely when it comes to manufacturing products using SRM. Therefore, a special attention must be paid to each stage of the production process in order to obtain and supply high quality products.

Table 31 lists some considerations to keep in mind in order to improve the manufacturing of SRM-based products and obtain the highest quality products.

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Table 31: Recommendations for the correct manufacturing of the SRM-based products

Type of SRM-based product	Manufacturing stage	Considerations
Bound applications: Concretes, Mortars and Cement treated material.	Adaptation of manufacturing facilities	**Aggregate storage hoppers:** The aggregate storage hoppers must have advanced humidity sensors to control the humidity of the recycled aggregates in real time and continuously. As a recommendation, quality sensors for recycled aggregates should be installed to analyse in real time the critical properties of the new recycled concretes. **Mixer:** The mixer is the heart of a concrete plant. When designing the new plant for producing concrete with recycled aggregates, it is recommended to include all possible sensors in order to better control the mixing process (wattmeter, speed, viscometers, temperature, moisture, etc.). **Control equipment:** The control equipment and software must be as advanced as possible so that they take into account all the new variables that may affect the manufacture of concrete with recycled aggregates. It is recommended that the control software captures, analyses and stores all the information so that self-learning algorithms can improve the formulations and the process in future batches based on the properties of the aggregates, the environmental conditions and the transport to the site.
	Dosage	**Constituents:** The biggest challenge when dosing concrete with recycled aggregates and iron and steel slag aggregates is the control of mixing and effective water due to the higher porosity of these types of aggregates. Correctly dosing the water and the superplasticizer is of vital importance to obtain a concrete that does not segregate, workable, that maintains the rheology until the installation and that guarantees the required mechanical properties. **Moisture of recycled aggregates:** Generally, it is not recommended to manufacture concrete with saturated aggregates due to the disturbances that it can introduce in the concrete plant elements and the exudation that these aggregates can cause during the curing process. On the contrary, it is recommended that the recycled aggregates have a high humidity (without saturation) to avoid absorption after mixing and losses of workability. In any case, the variation in water demand depends a lot on the humidity and the absorption of the aggregate, so it is convenient to have in-line humidity and absorption sensors that allow adjusting the dosages in each batch. **Dosing methods**: The usual dosing methods for conventional concretes are valid for recycled concrete with recycled aggregate. However, it is recommended to carry out the dosages in volume instead of in weight due to the differences in density with respect to the natural aggregates of recycled aggregates from CDW (lower densities) and recycled artificial aggregates from steel and iron industry (higher densities). **Dosage control**: It is recommended to control in real time the characteristics of recycled aggregates so that the dosage can be adjusted in real time.
	Manufacturing process	**Mixing time:** The mixing time is defined as the time from the end of the introduction of the last component in the kneader until the opening of the flap for emptying the mixer. It is the main parameter of the mixing process that manufacturers consider. The regulations do not establish in general a minimum time for mixing concrete with recycled aggregates, but recommend increasing the time compared to conventional concretes since it may require more time to achieve a correct dispersion of the constituents and adequate wetting of the recycled aggregates. **Manufacturing temperature:** Extreme temperatures affect to a greater or lesser extent the properties and behaviour of cement-based materials. The most affected parameters are workability and resistance to compression due to macro and microstructural factors. In this case, the kneading time is also strongly affected by the manufacturing temperature, being shortened at higher temperatures. **Mixing speed:** The mixing speed also influences the mixing process and the possible fragmentation of the aggregates. Increasing the mixing speed for reducing the mixing timer required implies greater efforts and stresses that favour the fragmentation of the recycled aggregates. It is therefore essential to find a balance between mixing speed and mixing time.

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	Transportation and supply	**Transport variables:** GPS; Distance and time to the site works; Traffic conditions; Temperature and humidity; Engine power; Tank speed; Water and additive adjustments during transport. **Transport operation:** The transport stage is crucial for any type of fresh concrete and especially important in the case of concretes with recycled aggregates. During transport, it must be ensured that the rheology of the fresh concrete is maintained until commissioning. **Control of the material during transport:** In order to control the variables during transport, it is advisable to use trucks equipped with GPS devices, temperature, humidity, engine power sensors and water/additive dosage, as well as a data transfer system in real time with the central in such a way that the variation of the properties can be evaluated and corrected as far as possible during transport.
Bound applications: Bituminous mixtures.	Dosage	**Design and dosage:** The design and dosage of new mixtures with recycled material must follow, as far as possible, the same guidelines as for conventional mixtures. The proportion of recyclable material that can be used is limited by the temperature to which the aggregates can be heated. Generally, it is not feasible to exceed 275 °C for economic or technical reasons (excessive temperature can deteriorate the bitumen). The maximum temperature of aggregates is usually limited to 220 °C. **Dosing method:** It is recommended to carry out dosages in volume instead of weight due to the differences in density with respect to the natural aggregates of the iron and steel slag aggregates (higher densities).
	Manufacturing process	**Adapted manufacturing techniques:** Special techniques and technologies are required for processing and manufacturing bituminous mixtures with recycled asphalt aggregates. These techniques will depend on the manufacturing process of the mixtures, whether continuous or discontinuous, and the type of mixture, hot, warm or cold.
	Transportation and supply	**Transport operation:** Conventional procedures and equipment can be used for transporting, installation and compaction. The only difference is that mixtures with a high percentage of recycled material may be less workable than conventional ones. **Humidity:** During transport and commissioning, it is recommended to avoid the loss of humidity from the warm bituminous mixtures in order to not affect the workability of the mixtures. **Measurement:** It is recommended to take into account the density of bituminous mixtures manufactured with iron and steel slag aggregates when quantifying the work units. Due to the high density of steel slag aggregates, traditional measurement and quantification formulas must be adjusted to avoid downward estimates of mixtures.
Unbound applications.	Manufacturing process	The manufacture of recycled aggregates for use in unbound applications will be carried out directly at the recycling plant. The recycled aggregates from CDW produces a lot of dust due to its high content of fines. When the recycled aggregates are supplied dry, the water incorporated on site is quickly absorbed. For this reason, it is recommended to provide the necessary moisture at the valorisation plant, which implies a mixing of the recycled aggregate-with water. This process is difficult to achieve on work site.

6.10.2. Recommendations for the correct implementation on work site of the SRM-based products

During the execution of the works, SRM and the SRM-based products must be treated in the same way as their conventional equivalents, following the precautions and recommendations indicated in the technical specifications of the works and the technical framework for each region.

In addition, as specific aspects of implementation, the following recommendations and considerations are presented (Table 32).

Table 32: Recommendations for the correct implementation on work site of the SRM-based products

Type of SRM-based product	Type of SRM employed	Considerations and mitigation actions
Bound applications: Concretes and Mortars.	In the case of using iron and steel slag aggregates, the installation of recycled concretes does not differ, in general terms, from that of conventional concretes. It is important to bear in mind some considerations related to the increase in the density of concrete due to the use of iron and steel slag aggregates.	<u>Dosage</u>: As the density is higher than in conventional concrete, this increase in density should be kept in mind when calculating the necessary concrete volumes. <u>Commissioning machinery</u>: commissioning machinery must consider and be adapted to the increases in densities of the bituminous mixtures manufactured with iron and steel aggregate. The volumes of material put into work must take into account this increase in density.
	In the case of concretes manufactured with CDW recycled aggregates, when the substitutions are less than 20% of the coarse aggregates, the performance and characteristics of the concretes are maintained compared to conventional ones. In the case of major substitutions of both coarse and fine aggregates, the parameters and characteristics of the concrete are strongly altered. Special attention must then be paid to the manufacturing process and installation.	<u>Workability</u>: The loss of workability of recycled concrete is greater than in the case of conventional concretes. To guarantee the workability of recycled concrete, it is therefore advisable to: • Loss of workability must be alleviated by adjusting dosages and never by adding extra water on site. • Minimize the times between mixing and installation on work site. • Request more fluid consistencies in anticipation of losses until commissioning. <u>Setting</u>: It is advisable to take special care of the setting of recycled concrete, avoiding the loss of moisture. It is recommended to exhaustively control the setting process through irrigation, implementing systems to prevent moisture loss, surface treatments, etc.
Bound applications: Cement treated material.	Both recycled concrete aggregates, mixed recycled aggregates and combined recycled aggregates can be used for this type of application, substituting 100% of the natural material.	<u>Curing:</u> It is advisable to avoid excessive watering of the materials after installation, as it can cause undesirable consequences for the treated material (segregation, loss of resistance, etc.). In the case of using recycled aggregate, this consideration must be especially considered since, due to the high absorption of recycled aggregate, it must be watered more frequently.
Bound applications: Bituminous mixtures.	The installation of hot, warm or cold bituminous mixtures with recycled asphalt aggregates or iron and steel slag aggregates does not, in general terms, present any difference with	<u>Moisture of the mixture:</u> It is advisable to take precautions to avoid the loss of humidity of the warm bituminous mixtures manufactured with recycled asphalt aggregates. Avoid installation at high temperatures and avoid prolonged insolation of

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	respect to conventional ones. However, it is recommended to take into account some considerations.	the mixtures before being installed in order to maintain their workability. **Commissioning machinery:** The commissioning machinery must consider and be adapted to the increases in densities of the bituminous mixtures manufactured with iron and steel slag aggregate. The volumes of material must take into account this increase in density.
Unbound applications.	The implementation of granular materials in unbound applications does not present great differences with respect to natural aggregates. However, some general considerations must be taken into account to guarantee the quality of the execution of the work unit.	**Irrigation:** Due to the high absorption characteristic of recycled aggregates, irrigation must be abundant, close to waterlogging, until the expected degree of compaction is achieved. This operation will be carried out by uniformly wetting the materials, preferably at source and completing during installation. **Compaction:** Once the most suitable humidity is achieved, the layer will be mechanically compacted until reaching the optimal compaction density determined by the Proctor test. The control will be carried out by the finished product control method, through in situ determinations in the compacted material of density, moisture, and strain modulus. **Climatic conditions:** If the temperature and insolation conditions of the work environment are adverse, the result will be that the humidity can be lost and the surface will dry very quickly. As far as possible, installation in hot weather should be avoided, and if this cannot be avoided, humidification considerations should be increased in a hot environment. **Performance considerations:** The use of recycled concrete aggregates and recycled mixed aggregate in unbound application, contrary to what can be expected, leads to an increase in initially planned mechanical performances due to intrinsic properties of the materials that are not taken into account during the design phase and installation aspects: • After compaction, fragmentation resistance of the recycled aggregates can be considerably improved due to the release of cement paste adhering to the natural aggregate due to the action of dynamic compaction. • The fine concrete and ceramic particles from the recycled aggregates and from the fragmentation derived from compaction, provide cementing properties to the mix and an increase in the bearing capacity of the material.

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6.11. Quality control procedures and frequencies

In order that SRM cease to be wastes, it is fundamental that characteristics of the final product are highly reliable. The materials' qualities must match the requirements specified by the product manufacturers.

Quality management is a set of techniques that help in the control of the manufacturing process and the product's quality, ensuring that it satisfies the declared criteria in a consistent manner. The properties of products are consistent and reliable thanks to quality assurance and control systems.

Quality assurance standards recognized by Member States must be met as a basic requirement for the quality management system. To validate the producer's declared properties, the system should incorporate both internal and external testing. Third parties recognized by Member States should externally monitor and inspect the quality assurance system.

In accordance with the requirements established in the framework of EU Regulation No. 305/2011 of the European Parliament and of the Council, of 9th March 2011, which establishes the harmonized conditions for the marketing of construction products, SRM from CDW and industrial waste or by-products must be supplied with the CE marking for the uses typified in this protocol.

Bound applications

The SRM that are used in bound applications must comply with the specifications established in the corresponding European product standard and will have the CE marking based on the harmonized standard EN 13242, fulfilling, at least, the conditions required for the System 2+ for the certification of conformity.

Unbound applications

The SRM for the execution of unbound applications will have the CE marking based on the harmonized standard EN 13242, fulfilling at least the conditions required in the System 2+ conformity certification.

The manufacturer will obtain the Production Control Certificate according to the System 2+ of the EN 13242:2003+ A1: 2008 - Aggregates for unbound and hydraulically bound materials for use in engineering structures and for road construction, but also according to some other standard.

The System 2+ defined in the Directive 89/106/CE, Annex III(2)(ii), stablishes the methodology for the certification of the factory production control by an approved body on the basis of initial inspection of factory and of factory production control as well as continuous surveillance asses:

Methods for the Notified Body	1. initial inspection of factory and of factory production control 2. continuous surveillance, assessment and approval of factory production control
Methods for the manufacturer	3. Initial type testing (ITT) by the manufacturer 4. factory production control (FPC) 5. testing of samples taken at the factory in accordance with a prescribed test plan

In order to provide information regarding the harmonized standard for producers and consumers

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of SRM, the minimum tests and tests frequencies which have to be carried out at the factory production are listed in Table 33, according to the European standard EN 13242:2003+A1:2008.

Table 33: Minimum tests and tests frequencies

Property	Notes	Test method	Minimum test frequency		
			Natural aggregates	Recycled aggregates	Manufactured aggregates
Grading	-	EN 933-1	1 per week	1 per week	1 per week
Shape of coarse aggregates	Test frequency applies to crushed or broken aggregates. Test frequency for rounded gravel depends on the source and may be reduced.	EN 933-3: 2012 EN 933-4	1 per month	1 per month	1 per month
Percentage of crushed particles	Only for coarse gravel	EN 933-5	1 per month	1 per month	1 per month
Fines content	-	EN 933-1	1 per week	1 per week	1 per week
Fines quality	-	EN 933-8:2012+A1:2015/1M:2016.	1 per week	1 per week	1 per week
Resistance to fragmentation	-	EN 1097-2	2 per year	2 per year	2 per year
Resistance to wear of coarse aggregates	-	EN 1097-1	2 per year	2 per year	2 per year
Particle density and water absorption	The test method depends on the particle size of the aggregates	EN 1097-6:2014	1 per year	1 per month	1 per year
Classification of the components of coarse recycled aggregates	-	prEN 933-11:2021	*N.A.*	1 per month	*N.A.*
Classification of plasticity, consistency and fluidity of fine aggregates	-	EN ISO 17892-12:	-	-	-
Classification of the free swelling	-	-	-	-	-
Acid soluble sulphates	-	EN 1744-1:2010+A1:2013	*N.A.*	1 per month	*N.A.*
Water soluble sulphates	-	EN 1744-1:2010+A1:2013	*N.A.*	1 per month	*N.A.*
Total sulphur content	-	EN 1744-1:2010+A1:2013	*N.A.*	1 per month	*N.A.*

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Chlorides content	-	EN 1744-1:2010+A1:2013	*N.A.*	1 per month	*N.A.*
Gypsum content	-	-	*N.A.*	1 per month	*N.A.*
Soluble salts content	-	-	1 per month	1 per month	*N.A.*
Organic matter content	-	-	1 per month	1 per month	*N.A.*
Volume stability	-	EN 1744-1	*N.A.*	*N.A.*	2 per year
Hazardous substances	-	EN 12457-4:2003	*N.A.*	4 per year in production less than 30,000 t/year 1per month in production over 30,000 t/year	4 per year in production less than 30,000 t/year 1per month in production over 30,000 t/year
Resistance to freezing and thawing	-	UNE-EN 1097-6:2014, EN 1367-1	1 every 2 years	1 every 2 years	1 every 2 years

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