

Article

Building of the Al-containing Secondary Raw Materials Registry for the Production of Low CO₂ Mineral Binders in South-Eastern European Region

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Abstract: The bottleneck in the process for increasing production of low CO₂ mineral binders, based on BCSA (belite sulfoaluminate) clinkers, is the availability of Al-rich raw materials. For that purpose, a new registry of Al-containing secondary mineral residues (industrial and mine waste) has been developed and is presented in this paper. The methodology of creating the registry consists of three main steps: Gathering ideas, consolidation of ideas, and implementation. In order to achieve this, the following methodology was adopted: Analysis of similar registries by potential end-users and seeking potential solutions and tools to be used, and conducting 3 rounds of stakeholder consultations via workshops in order to determine crucial parameters and features the registry needs to contain. The key discussion points were about which data the registry needs to contain, who shall be the potential users, and what are the stakeholder's expectations from the registry's portal. Potential individual registry variables were identified as being relevant/irrelevant or available/unavailable, and potential solutions for the registry's sustainability were explored. Each Al-rich waste/residue data entry is divided into 10 slots, describing legal status, location, quantities, chemical (REE included), mineralogical, physical and radiological properties, life-cycle assessment, additional data, and data relevancy. The registry will act as a matchmaking tool between producers/holders of Al-rich secondary raw materials and potential producers of cement clinkers.

Keywords: cement; belite sulfoaluminate clinkers; waste; by-product; stakeholder consultations



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1. Introduction

The global cement consumption is expected to reach 4.42 billion tons in 2021, with a growth of 2.96% between 2018–2021 [1], or more than 500 kg per capita. The most used cements globally are based on Portland clinkers, which are synthesized at around 1450 °C. Significant environmental footprints caused by the cement industry is the consequence of large demand for cements, as well as that high temperatures are needed for their production. CO₂ emissions, which are released during the burning of fuels to reach sintering temperature and breakdown of carbonates in the process, are the ones worth mentioning. A lot of studies have been focused to reduce such footprints by using alternative cement binders. One of such binders are cements based on Al-rich belite sulfoaluminate (BCSA) clinkers, which are synthesized at around 100–200 °C lower temperatures [2,3]. Since the raw material to produce the clinker has less carbonate components, the total reduction of CO₂ emissions per unit produced is around 20–30% [4].

On the other hand, high Al content is the main pain point for the production of Al-rich mineral binders due to the high demand for valuable natural resource bauxite. While ordinary Portland cement (OPC) clinkers contain 4–7% of aluminum [5], BCSA clinkers require 15–25% of aluminum in their composition [6]. Natural occurrences of Al-rich materials are laterite remains of weathering of host rocks (i.e., bauxites), specific types of felsic

igneous rocks (i.e., nepheline syenite), or weathering remains of such rocks (i.e., kaolinite clays) [7–9]. The availability of natural resources which provide Al is limited [10], and hence incapable to supplement the large-scale production of such cements. Moreover, the use of natural Al-rich raw materials for cement production is also usually not economically feasible, mainly due to long transportation costs and high prices of such materials, therefore more localized resources need to be used. One solution is to use secondary raw materials (wastes, by-products), considering that the appropriate materials are locally available and are in high-enough quantities. The latter is usually the bottleneck for the industrial production of BCSA clinkers [2,4]. By using secondary raw materials for cement production, we also contribute to a more resource efficient economy and help reduce the environmental footprints [3,11]. This is also promoted by the Raw Materials Initiative [12], adopted by the European Commission, since the third pillar of this initiative aims at promoting resource efficiency and the supply of ‘secondary raw materials’ through recycling, and it is also in line with the European Green Deal, which aims at making the European Union climate neutral until 2050 [13].

The secondary raw materials, such as coal combustion residues [14–20], steel slags [21,22], and red mud [23] are proven to be useful raw materials for the production of BCSA clinkers. BCSA clinkers from fly ash were also demonstrated to be even more reactive than clinkers prepared from the reagent grades [15]. The improved reactivity can mainly be attributed to lower ferrite formation temperature and modifications of the solid-state reaction rate, which is influenced by the foreign ions incorporated into the main clinker phases from secondary raw material [24–26]. Such ionic modifications can be beneficial for the hydraulic properties of BCSA cement [14,16,21,27,28].

To determine if there is enough of such material available for BCSA clinker production on an industrial scale, an international investigation had to be organized and the project RIS-ALiCE: Al-rich industrial residues for mineral binders in ESEE region (2019–2022, <http://ris-alice.zag.si/>), which is funded by the EIT RawMaterials, was initiated. The scope of the project is three-fold: (1) Creating a network of stakeholders in the field of using Al-rich industrial and mining residues for low CO₂ mineral binder production in the EU, with special emphasis of knowledge transfer from western EU countries to the Eastern European area; (2) mapping and valorization of mineral wastes and by-products for the production of BCSA clinkers and (3) creation of the registry of such secondary raw materials to be used by cement plants in order to locate potential raw materials for the production of such cements. The latter is the topic of this paper. While a variety of existing registries are focused on natural and secondary raw materials, geological and other types of data, they do not contain adequate information to support decisions in the cement industry regarding the potential sources of primary or secondary raw materials for the production of cement clinkers. However, in most cases, only basic information on locations is provided together with geographical coordinates and types of material. As the existing registries do not contain detailed data about the materials, for instance its chemical and mineralogical composition, a new registry specifically tailored to suit the needs of the cement industry is needed.

The aim of this paper is to present the whole process of creating the registry of Al-rich wastes and by-products, which was designed in many stages, including organization of workshops, consultations with stakeholders, and registry implementation. The methods and results presented in this paper can be useful for researchers who would like to establish similar registers and would like to use knowledge gained from past experiences, as well as for all researchers from the field of cement binders, secondary raw materials, or environmental protection.

2. Materials and Methods

At the project’s preparation stage, the following raw materials were considered as the primary target materials for the registry, and thus the next steps were subordinated accordingly: Slags, ashes, construction and demolition wastes, wastes connected with the

extraction and processing of mineral resources (overburden, mine spoils, tailings, etc.), and other wastes or by-products created at different industrial processes. The primary target groups which were set-up in the proposal were cement plants and waste holders and producers. The geographic target was Eastern Europe.

The design of the Al-rich secondary raw materials registry started by reviewing similar existing registries, followed by an extensive stakeholder's consultation process. This was necessary to assure that all stakeholders' requirements were met, and that the registry is tailored for the designated target groups. The implementation of the registry followed "The Result Optimisation Model" [29]. In this project management model, the project time is divided into three equal sequences (loops) of equal length. Each loop represents a miniature project consisting of three phases: Gathering of ideas, consolidation of ideas into the concept, and implementation (Figure 1). By completing all three loops, the project is continuously improving, and after the third loop, the project is ready for the presentation. This paper presents only the activities conducted within the first loop, and the results of these activities. The first two loops will be implemented during the RIS-ALiCE project, while the third loop will be implemented by the company/partner, which will take over the registry after the end of the project.

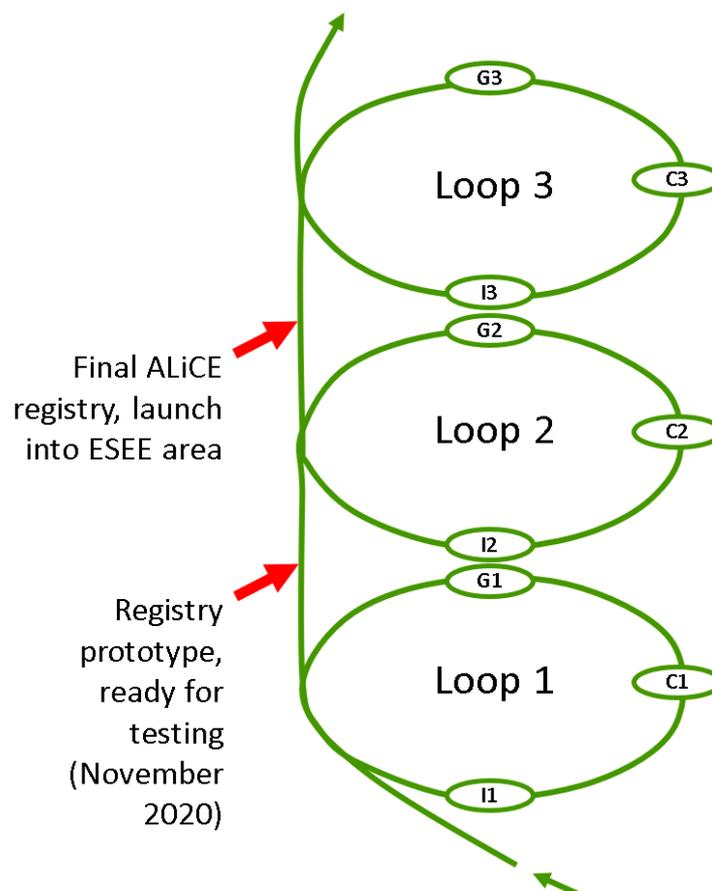


Figure 1. The schematic presentation of "The Result Optimisation Model" (modified after [29]).

Stage 1—gathering of ideas consisted of two phases:

- The review of 18 registries around the globe;
- workshop about the registry concept, data structure and functionalities.

Stage 2—consolidation of ideas, was conducted following the next steps:

- Workshop regarding refining of ideas;

- the refining of registry data structure by the key industrial stakeholders (cement plants);
- preparation of registry blueprints and the review of this document by RIS-ALiCE project partners.

Stage 3—implementation was done by creating the registry prototype and presenting it to project partners and different potential end-users (stakeholders).

The Stage 1 review of 18 registries around the globe consisted of extensive analysis of similar registries from similar fields as the ALiCE registry, including those developed within different European projects and institutions from the topic, by industry or waste companies, or by national geological surveys. These include registries from the field of geological data services, map servers, pollution registries, waste registries, and similar. Table 1 contains a set of selected registries which were included in this review. A selection was made to cover a variety of registries, including registries presenting official data, registries created by the research institutions or industry, all being either very complex or simple, offering a variety of tools to the end-users. The analysis was focused on the following components [30]:

Registry's purpose: Whether it is relevant for RIS-ALiCE project;

content of the registry: Its features and tools for users;

internal database structure: Search and querying options, data content, etc.;

reporting data, data content, and data validation: Whether to include, modify, or remove data, or whether data is up to date and relevant and similar to the RIS-ALiCE project;

map overview: Features of map viewer (if existing);

metadata information availability;

feedback: Can users provide any kind of feedback;

opinion from the perspective of registry end-user (cement plants);

opinion from the IT expert.

Table 1. The list of registries and databases which are reviewed in D4.1. All registries were assessed during the period of May–June 2019.

	Register/Database	Link
1	eGeologija	http://egeologija.si/geonetwork/srv/slv/catalog.search#/home
2	Registry of boreholes in Slovenia (beta version)	https://e-vrtina.si/
3	Registry of Slovenian holders of mining rights	https://ms.geo-zs.si/
4	Register of Al- and Si-rich industrial waste in Slovenia	no link (.pdf form)
5	Register of secondary by-products, steel waste enriched with metals, and Al- and Si-rich industrial waste	no link (.pdf form)
6	European Pollutant Release and Transfer Register (E-PRTR)	https://prtr.eea.europa.eu/#/home
7	European Geological Data Information portal (EGDI)	http://www.europe-geology.eu/
8	European Minerals Knowledge data Platform (EU-MKDP)-Minerals4EU	http://minerals4eu.brgm-rec.fr/
9	IGME (Spanish geological Survey) geoscientific web sites and data catalog	http://info.igme.es/catalogo/catalog.aspx?catalog=2&shim=true&shdt=false&shtb=true&shtp=false&shfp=false&shsf=false&shfo=false&master=infoigme&lang=spa
10	IGME Advances search system (ISE)	http://info.igme.es/ise/
11	MAP Viewer	http://info.igme.es/visorweb/
12	IGME Map services	http://mapas.igme.es/servicios/default.aspx?lang=eng

Table 1. Cont.

	Register/Database	Link
13	Italian mining waste registry	http://www.isprambiente.gov.it/it/banche-dati/strutture-di-deposito-di-tipo-a
14	OneGeology	http://portal.onegeology.org/
15	FLYASHDIRECT	https://www.flyashdirect.com/
16	Global Coal Plant Tracker	https://endcoal.org/tracker/
17	NTPC fly ash registry	https://www.ntpc.co.in/en/ash-availability
18	EURARE	http://www.eurare.eu/countries/mediterraneanBauxites.html

At the same time as the Stage 1 analysis of registries, 2 workshops were also organized. The first workshop was implemented at the project kick-off meeting, with the main goal to answer the following questions:

1. Which data shall the registry provide?
2. Who should be the main users of the registry?
3. What are your expectations from the registry's portal?

During this workshop, 17 participants from 14 organizations were divided into three equal groups. Three stations with moderators were set-up, where each station was covering one topic. Each group started at a designated station, and after 20 min of discussion, all groups moved to the next station. The process was repeated after 15 and 10 min, forming a "carousel", so that each group visited each station. During the station visit, all group members were engaged in brainstorming activities about the station topic, and the station moderator recorded the key ideas. Moderator's role was also to keep the discussion on-topic, and to present the key ideas from the previous group(s) to the next group, so that the same ideas were not repeated. After the "carousel" was finished, each station moderator summarized the key ideas to the whole group before the selection process. In this last phase, the relevance of ideas was selected by voting. Each partner received 6 votes for each of the three stations (18 votes in total in the form of stickers) and was invited to cast a vote to the idea, which is the most relevant for their company. Two votes per partner could be cast to an idea they might find particularly relevant. Votes were color-coded to identify specific requirements of each target groups: Research organizations (5 organizations), Universities (2), Cement plants (2), Waste producers (3), and other companies (2). This way the most relevant brainstorming ideas were selected for the consolidation phase.

The consolidation process started with a workshop, where participants had an open plenary discussion about registry concepts, functionalities, and data structure. The input to this workshop were ideas (features) which were identified as potentially relevant for the registry of Al-rich residues. These features were either registry functionalities (i.e., registry tools), registry concepts (IPR rights, user management, multilingual concept, etc.) or specific data that the registry is supposed to contain. The participants of this workshop received a list of 44 such features before the workshop, so that they were able to prepare in advance. During the moderated discussions, each of the 44 features were placed in a virtual 2D field, where x-axis represented relevancy of specific items ranging from not relevant to very relevant for the ALiCE registry, and y-axis represented whether its implementation in the registry is expected to be from very challenging to very easy. This way the virtual space was divided into 4 quadrants (Figure 2). The space coordinate axes were plotted on a large sheet of paper and presented to the audience. Individual features were written on the sticky notes and placed into the appropriate space according to the discussion by the moderator. The features, which were placed in the green area (quadrant a in Figure 2) were considered as the best candidate features for the implementation phase. Special attention will be paid at the implementation phase to the features, which were placed into

the blue area (quadrant b from Figure 2), while features, which were placed in the red area (quadrants c in Figure 2) were decided to not be implemented in the registry prototype.

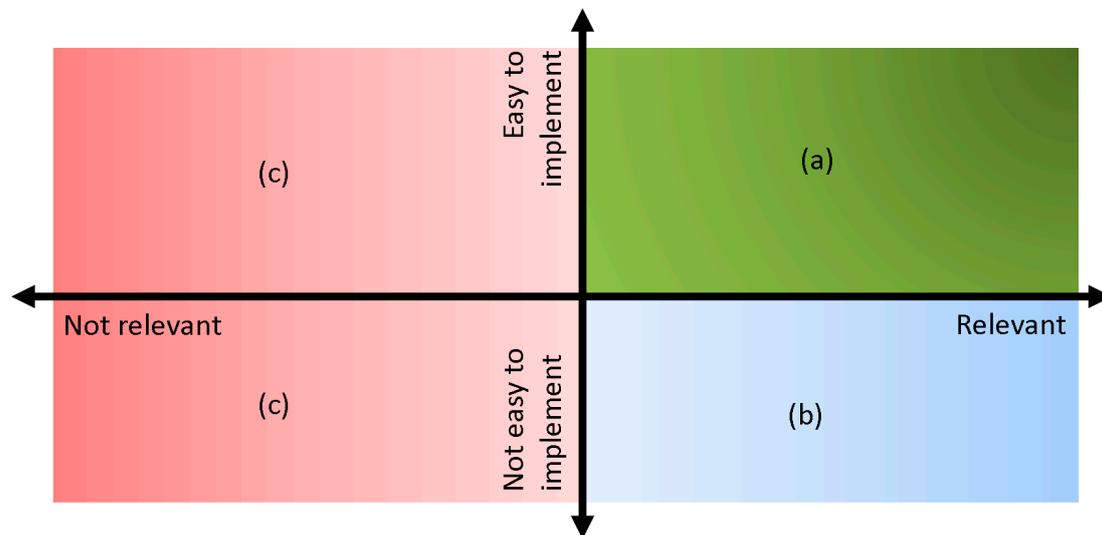


Figure 2. The virtual space for registry features. They were placed into this space during the moderated discussion; (a) best candidates for implementation; (b) a special attention shall be placed before implementation; (c) features which shall not be implemented in the registry.

The next stage of the consolidation process included consultations with the registry's end-users, cement plants, to refine and make final adjustments to the registry data strings. The draft data string was prepared according to the results from the workshop, and afterwards the cement plant representatives made comments and proposed necessary modification. Two cement plants were involved in this process: Salonič Anžovo d.d., and Cementarnica Usje AD. The final stage of the consolidation process was the preparation of the draft document Registry prototype blueprints [31], which was sent to the whole RIS-ALiCE project consortium for comments and final adjustments. After the finalization of this document, it was possible to begin with the implementation phase of loop 1 of creating the ALiCE Registry.

The registry implementation was executed by the company Lucis d.d.. The waterfall model for software development [32] was used, consisting of five steps (Figure 3; [33]). The input of this process was the Registry prototype blueprints [31] document, which set up the requirements for software development company. The system design stage included the development of high-fidelity wireframes, representing mockups, and defining the data model based on requirements. Implementation was done by using well-documented open access software, allowing continuous upgrades and easy registry maintenance in the future by potential third parties, as well as enabling potential expansion of the registry's functionalities in the future. Web development was done using PHP 7.3 scripting language. The database was implemented on a relational MySQL database, which provides fast-loading and real-time search. Besides detailed search options, a general search using a simple but powerful context search is also available. The application is built on OctoberCMS platform, using PHP technology, with Laravel 5.5 at its core. The technology stack runs on Linux operating system. Map viewing tool uses OpenStreetMaps project. To assure fast-loading, the map is loaded only upon user request. Verification consisted of two phases: Internal, done by Lucis d.d., and external, done by Geological Survey of Slovenia (GeoZS) and other RIS-ALiCE consortium partners. More information is available in [33]. An aliceregistry.eu domain was purchased, together with server space for 3 years by an external provider. Maintenance and upgrade will be conducted by the company Lucis d.d. until the end of the RIS-ALiCE project, and afterwards by a company which will take over the registry after the end of a project (to be defined).

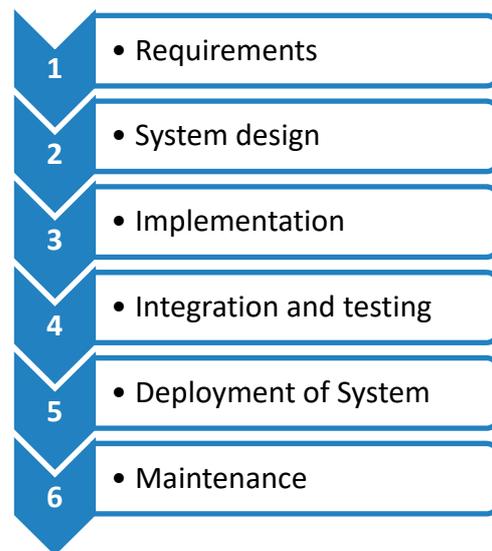


Figure 3. The waterfall model of software development used for RIS-Alice registry prototype implementation.

3. Results

In this chapter the results of the whole process during each of the stages are presented.

3.1. Gathering of Ideas

The analysis of similar registries provided an insight about the structure and contents of comparable registries around the globe, from the perspective of ALiCE registry end-user representatives (cement plants). The following features were identified to be the most valuable for ALiCE registry implementation [30]:

The registry needs to be simple and user friendly;
 it needs to contain instructions on how to use it;
 the registry needs to include a search option;
 a map and tabular form of data presentation;
 a data export option;
 English as the core language;
 a singular data form to allow data comparability;
 the registry also needs to contain instructions on how the data can be used;
 the registry needs to allow users' feedback.

One of the most important properties of every useful registry/database is that it is user friendly, using simple, transparent, and logic user interface. The registry also needs to offer the possibility of advanced searches and queries, with the most important search fields being keywords, type of material, location/country, and field/topic. Very helpful features are also the instructions on how to use the registry and which functions and search options are available. These can also be part of the FAQ—frequently asked questions section. The data needs to be presented in a tabular or in a map form. Standardized data format is needed to allow the end-user to easily compare information. Comprehensive and clear instructions about data entry are also needed. An important function of the registry is also the option to update or remove data, as well as the ability that users provide feedback about the application or about the data, either via email or via short survey. The rating option is also advisable feature. The quantity of data contained in the registry can vary depending on the registry's purpose. However, for the purpose of ALiCE registry, it needs to contain at least the following information [30]:

Type of material;
 chemical composition of the material;
 description of the material, which also includes the legal status of material;
 location of the waste origin and storage of the material;

name and address of the producer or provider;
 contact of the producer or provider (contact person/department);
 the available quantities of material.

Implementation of a fast and reliable search engine is crucial. Because search performance depends on database performance and design, it is recommended to use a relational database and optimize search performance using database indexes. The same is also valid for the map viewer and the map render tool, which should also produce fast results. The conclusion of this stage is that a good registry is user-friendly, navigation is easy and logical, data is relevant, up to date and easy to find, help and other information is available, and users can provide feedback, while poor performing registry does not have search options, data is missing, irrelevant, or obsolete, no help is provided, structure is not logical or easy to follow, and feedback is not possible.

The second part of gathering the ideas stage consisted of the workshop about the registry's concept for the RIS-ALiCE partners and stakeholders. Results of this phase are presented in Table 2, which includes the key ideas as were collected during the brainstorming discussions and voting results.

Table 2. The ideas collected during the Stage 1 Workshop 1. WAS—waste sector; UNI—universities; CEM—cement plants; OTH—other stakeholders; RES—research institutions; SUM—total number of votes per idea.

What are your expectations from the registry portal?						
Statements:	WAS	UNI	CEM	OTH	RES	SUM
Easy access and user friendliness	4	2	1	2	5	14
Complex composite search, to enable to pin down the wanted information	3	2		3	4	12
Contains minerals exact chemical composition with variations	3	1	3	1	4	12
Available quantity of described resource	3	2	2	1	2	10
Multilingual	1	2		2	4	9
All data should be stored in standardized structures, to enable comparison	1	1	1	1	5	9
Info should be updated		2	1		3	6
Correct information			2	1	1	4
Contact information about all the participants	2		1		1	4
Should be able to connect waste (resource) with published papers		2		1	1	4
Location of resources as exact as possible	1		1			2
Supervising instrument						0
Who should be the main users of the registry?						
Statements:	WAS	UNI	CEM	OTH	RES	SUM
Cement plant—research department	2	1	2	1	3	9
Waste transportation sector	4		2	1	2	9
Mining industry	2			2	3	7
Metallurgical industry (waste producer and consumer)		1	1	1	3	6
Construction industry (as producer of waste and consumer of cement)		1	2	2	1	6
Cement plant—production department	2		1	1	1	5
Research institutes-researchers		1			4	5
Policy makers on national level (environment)	1	1	1	1	1	5
Universities—students		1		1	2	4
Waste recycling plants				1	3	4
Permitting authorities (environment)	1		2		1	4
Coal power plants	1		1		1	3

Table 2. Cont.

Aluminum industry (red mud)	1		1	1	3	
Investors	1	1		1	3	
European commission (environment)	2			1	3	
Universities—professors		2		1	3	
Advanced ceramic industry (as consumer)	1	2			3	
European Commission (scoreboard for raw materials)				1	1	
Brick and tiles ceramic industry		1			1	
Mining authorities						
NGOs (environment)						
Exploration geologists						
Cement plant—environmental department						
Chamber of commerce						
Local authorities						
Regional development agencies						
Glass ceramics						
Spatial planners						
Certification bodies						
Which data shall registry provide?						
Statements:	WAS	UNI	CEM	OTH	RES	SUM
Quality (radiology, chemical, mineralogical, physical), Al- content, main elements, alkalis, heavy metals, TOC, XRD data, form of Al (silicates, metallic, oxides, melting points)	3	3	2	3	5	16
Company name, contact	2	1	2	1	5	11
Location	3	2	2	1	3	11
Amount	2	1	2	1	5	11
Legal status (hazardous, non-hazard, inert), acc. to which legal document/countries, documentation (proof)	3	0	2	2	3	10
Type of waste/origin of raw material	1	1	2	1	3	8
Availability/type of transport	4	0	0	2	0	6
Environmental permits, concession, links to legal institutions	0	0	0	0	3	3
Data on previous treatment	0	1	0	1	0	2
Source of information	0	1	0	0	1	2
Basis for other intended uses, recovery, suggestion to further use	0	0	0	0	1	1
Open access to upload (checking)	0	1	0	0	0	1
Upgradable	0	1	0	0	0	1
Data of potential end-users	0	0	0	0	1	1
Feedback of end users	0	0	0	0	0	0
Defining the criteria for input to register	0	0	0	0	0	0

This process yielded similar results as the analysis of similar registries. Although some ideas were repeated at 2 different stations, key concepts were revealed during the voting process. The registry needs to be easy to use and user friendly, it needs to contain a complex search engine and relevant information (chemical and mineralogical composition, quantity of available resources, company information and location, legal status, etc.). The

importance of harmonized data structure was also highlighted. Many key users were identified: Cement plants, waste transportation sector, mining, the metallurgical and construction industry, and other waste producers and holders. Less relevant ones were research and educational institutions, decision- or policy-making bodies, and similar.

Considering the main identified end-users, this process also identified key recommendations for the registry. The most important data that the registry needs to contain, which were recognized by the cement plants are: Quality of the material, company name and contact, location, amount of the material, material legal status, and type of waste (origin). The top choices regarding which data needs to be included in the registry for waste producers were the availability/type of transport, quality, location, and legal status of waste/by-product.

The final result of this process was a list of 13 registry features, and 31 different types of data (e.g., quality of the material, location, etc.) that the registry needs to contain for each of the waste or by-product material.

3.2. The Ideas Consolidation Stage

The consolidation of ideas started with the workshop dedicated to refining the ideas collected in the previous stages. This was done during the moderated workshop at month 6 of RIS-ALiCE project, which aim was to place the ideas about the registry concept and data structure on a virtual 2D space representing relevancy on x-axis and easiness of implementation on the y-axis. Table 3 presents the results of the discussion.

Table 3. The results of the mapping of ideas about the registry portal and data structure, collected within the ideas collection stage. Numbers in the table means: 1 = relevant or easy to implement; 0 = neutral; −1 = not relevant or hard to implement.

	Relevancy	Implementation	Comment
Registry web portal features			
General information	1	1	
Reports and documents	−1	−1	
Data viewer (table)	1	1	
Data viewer (map)	1	−0.5	
Search and query	1	1	
Data upload tool by users	1	−0.5	Only via moderator
Forum/discussion board		consensus was not reached	
AliCE document repository	−1	−1	
Public level	1	1	
User level	1	1	
Multilingual	−1	−1	
User feedback on web portal	1	1	Through moderated forum
User feedback on data contained	0.9	−0.5	- Through forum - To moderator - Directly to data provider - Allow users to mark the data as not reliable

Table 3. Cont.

	Relevancy	Implementation	Comment
Data			
Company basic info	1	1	
Type of company	1	1	
Type of material	1	1	
Waste loading option	1	1	
Legal status of material	1	1	Shall also include ownership and information whether it is waste or by-product
Type and content of Al	1	1	
Type and content of Si	1	1	
Type and content of Ca	1	1	
Type and content of Fe	1	1	
Type and content of Mg	1	1	
Type and content of S	1	1	
Mineralogical composition	1	0	Only for larger quantities
Other main elements	1	1	
Trace elements	1	1	
Redox state and pH	0	0.2	
Moisture content	1	1	
Thermal properties	−0.3	0	
Organic substances	1	0	
Potentially toxic elements	0.5	−0.5	
Alkaline ions	Will be determined by cement plants	Not discussed	
Alkali ions	Will be determined by cement plants	Not discussed	
Radioactivity	1	0.5	
Leaching tests	1	1	
Homogeneity	1	1	
Measurement method	0.8	0	
Annual quantity & in stock	1	0.5	
Data protection level 3 levels	Not discussed	Not discussed	
Date of obtained data	0	0	
Lab. anal. certificates	−0.8	−0.8	
Other certificates	1	1	
Photographs	0	1	

It was concluded that RIS-ALiCE registry needs to contain parameters, which are the most relevant and easy to implement during this workshop (Table 3). It was suggested to discard parameters which are not relevant for the case, and to place special attention on the parameters which are relevant, but not so easy to implement (Table 3). It was also recognized that the consortium cannot properly rate some parameters and features, and that the main decision needs to be made by the consulting cement plant representatives.

The final stage of the consolidation of the ideas process was done via email exchange between the representatives of the Geological Survey of Slovenia (GeoZS) as the responsible partner for the registry blueprints preparation, the representatives of Slovenian National Building and Civil Engineering Institute (ZAG) as the coordinator of the project, and representatives of two cement plants: Salanit Anhovo d.d. and Cementarnica Usje AD. The solutions to all the open issues were suggested, and the final refining of data structure was made. As a result of this process, the document titled The Registry Prototype Blueprints [31] was prepared. It specifies all the features of the registry: Web portal, database, search, query, and data download (table and individual reports) tools, definition of intellectual property rights, upload tool (web form), user management system, means of providing the users a feedback (on portal, on specific datasets) section and help and FAQ section. It also tackled the registry sustainability after the end of the RIS-ALiCE project by addressing SWOT analyses of 6 different registry sustainability scenarios. Registry data structure is divided into 10 sections: Company information, data protection, legal status, transport options, quantities, data relevancy, mineralogical, chemical, and radiological properties, life-cycle assessment parameters, additional data, and user feedback. The blueprints were presented during the M12 project meeting, and afterwards circulated through the RIS-ALiCE consortium for the final comments. After the document was finalized, it was possible to start with the implementation phase.

3.3. Implementation

Registry can be accessed via URL: <https://www.alice-registry.eu/>. However, during the implementation stage, which was done according to the registry's blueprints, a few changes were made. This was necessary because only after all the ideas are implemented, the registry's blueprints shortage of specific details became apparent, and that solutions proposed in the blueprints need to be modified in order to improve the user's experience with the portal. This way, the intellectual property rights policy was slightly changed, but the most changes were made on the data structure concept, to make it easier to comprehend and to make it more intuitive.

4. Discussion

Although the design of the registry of Al-rich wastes and by-products was made from the scratch, the inspiration for it was taken from other similar registries around the globe. It was clear that the web portal must be user-friendly, needs to have a simple and intuitive design, and the tools and features should also be easy to find. It is very important to implement only a minimum number of tools and features, only those that are necessary. Data needs to be presented in a clickable map and in a tabular form, with options of data export in a commonly known formats (pdf, xlsx, csv). The core functionalities are data entry, browsing, modification, and search. Intellectual protection policy and rules of data use, help and FAQ section, means of providing users feedback, and log-in and registration for new users also need to be easily identified on the home page.

At the beginning of the registry design, all options on how to implement the registry of Al-rich residues were considered. Several industrial companies developed their own registries. Even though many of them are only for internal use and are in the form of .pdf document or Excel spreadsheet, they are still useful for the company's decision-making process. Some of the registries created by private companies or non-governmental organizations are made for different purposes and are publicly available on the internet. For example, the Global Coal Plant Tracker's aim is to develop collaborative informational resources on coal impacts and alternatives. The aim of FlyAshDirect and NTPC fly ash registries is to develop reliable markets for fly ash and other coal combustion by-products, just to mention some of the relevant ones. Such registries have only a limited number of tools, and its content is generally edited by the central organization, which focuses only on specific topics. Initial ideas on how to implement the ALiCE registry of Al-rich residues were also pointing towards having a very simple interface, even in tabular form, which can

be downloaded from the ALiCE project web page. However, the ambition of the RIS-ALiCE project team was beyond that and the vision of all the project partners was to develop a registry which will be continuously updated, even after the project ends. For that, a decent pool of end-users is needed. Long-term vision is that the ALiCE registry becomes the marketplace for secondary mineral materials. To achieve this vision, the registry must be more than only a simple downloadable table. It needs to be based on easily upgradable platform, with available tools and relevant and upgraded data, necessary to fulfil its purpose. Therefore, a set of registry features and data strings which are contained therein were defined through several steps in the consultation process, including easy and intuitive user interface, data upload tool, data viewer (tabular and map form), comprehensive query tool, user management system, intellectual protection rights policy (copyright), registry data structure, and help section.

During the review of similar registries, a very useful feature which was identified was the help section, or a list of frequently asked question—FAQ, as contained, for example, within the E-PRTR registry or Global Coal Plant Tracker. However, in the RIS-ALiCE registry, this section is called the “Read me” section, because there are not many questions from the users yet. However, after the “infancy” period is over, possibly having a FAQ section might contribute positively to the user’s experience. It was also identified that even though the registry contains a map viewer, users might still want to export raw data (if the license allows this). A map viewing tool, data viewer, and export tool in tabular form are also implemented in other registries, for example in E-PRTR registry, FLYASHDIRECT, Global Coal Plant Tracker, etc., while some have data presented only in a list form (e.g., NTPC—A Maharatna company, Register of Al- and Si-rich industrial waste in Slovenia, Register of secondary by-products, steel waste enriched with metals and Al - and Si -rich industrial waste, for example).

Some registries are also multilingual. Unfortunately, in many cases, only a registry web portal is translated, but the content (data) is not. This limits the usefulness of the registry to the people not speaking that core language. One such example is the registry of Instituto Geologico y Minero de Espana—users can choose between five different languages (ES, EN, FR, DE, PT), but datasets are mainly available only in Spanish language. Because the translation of all content in many languages requires a clear definition of responsibilities for the translations, involving many people, as well as a control mechanism, it was decided that this would be too big of an organizational challenge for the ALiCE registry. Multilingual features of the ALiCE registry would also prevent making quick changes or adjustments to the web portal if necessary. Therefore, it was decided that ALiCE registry would not be multilingual, even though it primarily targets the South-Eastern Europe, which is very linguistically diverse.

To fulfil the aim of the registry, as set-up in the European green deal, it was also decided that the ALiCE registry shall go beyond the scope of the RIS-ALiCE project. Therefore, external data providers shall be motivated to contribute their own data on a voluntarily basis. To achieve this, comprehensive and clear instructions on how to enter the data in the registry are needed first, and the implementation of data entry, modification, and data removal tools are also needed. The instructions were implemented in the data input tool itself in the case of the ALiCE registry, and the authors anticipate that they are self-explanatory and intuitive. However, if this is not the case, the instructions will be prepared at a later stage. Two other practices are also worth mentioning. The E-PRTR registry has published a special guidance document that provides information on various reporting processes. This document is available in 22 different languages. Contrarily, the FLYASHDIRECT registry has published only a contact form where you can obtain information on how to add data into the registry, but the data entry in this case is done by the registry moderator. Both solutions were not found to be useful for the ALiCE registry.

A clear licensing and intellectual property right policy is also needed to motivate private companies and enterprises to provide their data to the registry. Without clear statements about permission to reuse the published content, many users will be unable

or unwilling to use this registry. One recognized way is using variations of Creative Commons (CC) license (<https://creativecommons.org/licenses/by-sa/4.0/>). Even though CC licenses are recognized and widely used globally, such licensing cannot cover all the potential cases. Especially if the other party is the co-owner of some of the data, its entry into the registry would need their approval. This may be the case when, for instance, the data was acquired during some project by a third party. To bridge this gap, it was decided to implement three different levels of data protection. All three levels allow the commercial use of the data, but they differ at the access and modification policy. The most open data model allows the modification of work, and such data are displayed to all visitors of the registry. This model can be used for non-sensitive data. Data in the restricted level is shown only to other registered users and cannot be adapted to make other works. This level can be used for sensitive data. Datasets in the third level of data protection is also revealed to other users, but these datasets only contain information regarding the existence of a specific waste material, but the information about its composition or properties is not placed in the registry, but data exchange is managed directly between data provider and interested party outside of the registry. This model can be used for very sensitive data, or for data where details about chemical and mineralogical composition are not yet available.

Another important issue was raised regarding who can add, modify, or remove specific data entries. It was suggested that the registry portal shall contain browse, search, upload, and modify data tools, but it was not clear who exactly shall have the permissions to do such operations. Several options were discussed, varying from the option that the registry moderator is the only person having the full control (as in the case of many registries around the globe), to the option that every registered user can have a complete control over the dataset. Giving the fact that some data which is, for instance, provided by private companies, might be sensitive, it was decided that it is best to give full control to the data they want to share. Other users and the registry's moderators shall not have permissions to add, modify, or remove data provided by the companies, and this needs to be clearly stated. This way, the registry administrators, or any other users, cannot be liable for any use of the data contained in the registry, and this is also clearly stated in the portal.

To properly manage the data according to the data policy, the registry also needed a clear system of users, which follows the paradigm set up in the consultation process. Four user levels were defined. System administrators (point 1 of Figure 4) are responsible for the uninterrupted functionality of the registry, prompt fixes of errors and software updates, and to assign registry administrators (point 2 of Figure 4). The main role of the latter is to check every new registration. When a registry's visitor wishes to add/modify data or view the restricted section of the registry, the company he is representing needs to register first. This can be done by providing information about the company he/she is representing. This information is then reviewed by the registry administrators, who can activate the company. The basic principle for new user activation is that only those stakeholders who show a clear interest, whether to provide or use the data, can be registered users and can thus also access the restricted parts of the whole dataset. However, it is the registry administrator's expert judgement if a new registration is such a case or not. If necessary, a registry administrator can ask the potential new registered user to provide more information about the company. When the new company's registration is complete, a person who registered that company becomes the company's administrator (point 3 of Figure 3). The company's administrators can add, view, or modify data connected to that specific company, and use other tools, including viewing the restricted area and downloading data. However, the company's administrator is also able to add new end users (point 4 on Figure 3) which can represent this specific company. Such a user system is somewhat novel and is not commonly used in any of the reviewed similar registries, but it is used in registries containing sensitive information, for example, in registries containing medical information. Visitors (point 5 of Figure 3) are individuals who are not registered and can only view the public part of the registry. An implemented user system is shown in Figure 4.

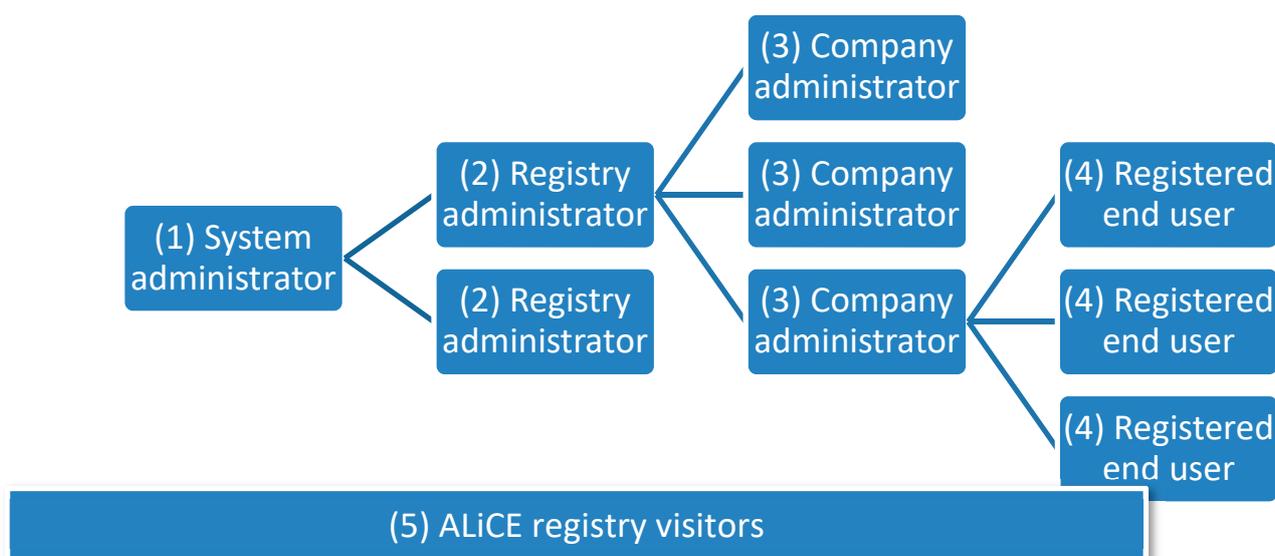


Figure 4. User system in the ALiCE registry.

Some of the registries include instructions on how to use/quote their data (i.e., Registry of Instituto Geologico y Minero de Espana or borehole viewer developed by GeoZS). This was mainly the case of data collected using public funding. However, in the case of ALiCE registry, the data is supposed to be (mainly) collected from private funding (except for the data collected within the RIS-ALiCE project). Therefore, it was decided that such instructions are not necessary in this case.

To implement the fully functional and useful ALiCE registry, the developed prototype needs to be tested by many end-users. Their ideas will allow the upgrade of the registry, allowing implementation of also the second, third or any other loops of collecting ideas, consolidation, and implementation. Therefore, a clear way for users to provide their feedback is needed. A lot of analyzed registries have the option for the users to give their feedback about the application or presented data. There are several different ways to get their feedback: Through email (e.g., registry of Instituto Geologico y Minero de Espana), via short survey (e.g., E-PRTR registry), or by using the option to rate the data content (by marking the appropriate number of stars, e.g., eGeologija). For the ALiCE registry, it was decided that the users can provide feedback via email, clearly stated on the landing page, or via a special form implemented in a web portal. A comment about specific data string can also be added by the users.

Registry (Figure 5) was implemented by using commonly used programming tools, which produce results that can be transferred to different servers (Windows, Linux). They allow fast loading and do not consume a lot of processing time. Basic editing (text, figures, user management, etc.) must be made easy to use for an “averagely literate” computer user. The use of plug-ins needs to be limited only to the necessary ones. Therefore, it is advised that the map is loaded only upon user’s request. Registry is also made in a way that new features can be added, if the users find them useful or necessary, including dashboard, a user forum, document repository, AI-rich waste and by-product valorization tools, or similar. High-fidelity wireframes, which were made before the coding, made the process of implementing the registry more straightforward and faster, as the developers could follow a graphic representation of the end-product. The backend tool allows System and Registry administrators easier registry management and upgrades.



Figure 5. ALiCE registry landing page (<https://www.alice-registry.eu/>).

The ALiCE registry data structure compiles various components (Figure 6). Each component has a specific role in the overall process of BCSA clinker production, from the raw material to the final product. The required company information enables the communication and matchmaking between the producers/holders of Al-rich secondary raw materials and their potential users. In the Alice registry Upload section, the following tabs are available: Legal status, Location, Quantities, Chemical, Mineralogical, Physical and Radiological characteristics of the material, Life-cycle assessment parameters, Additional data, and data relevancy.

The legal status parameters (protection level, type of material, legal status of the material, and ownership of the material) are primarily intended for data transparency. In a case of hazardous waste, the hazard needs to be specified. For a better overview of the data, a material classification code can be added. Location of waste and available quantities on an annual basis are crucial parameters of the raw material valorization process for cement production. Transportation options are one of the main limitations, as they can significantly increase the cost and therefore the use of such materials that may no longer be economically feasible. As cement plants commonly produce several thousands of tons of cement clinker per day, sufficient and constant amounts of raw materials for clinker raw mixture are required.

Alice Registry parameters of chemical characteristics of the material are the ones which are needed for the formulation of BCSA clinker mixture: Al_2O_3 , SiO_2 , Fe_2O_3 , CaO , and SO_3 . MgO is also an important chemical parameter in cement raw materials because free MgO in the form of periclase in clinker in the presence of water converts to $\text{Mg}(\text{OH})_2$, which increases solid volume expansion [34]. In OPC, higher cement amounts of P_2O_5 in raw materials are not desirable because P_2O_5 can bind with Ca and thus modifies targeted phase composition (decreases the amount of alite). In BCSA clinkers, P_2O_5 incorporates in belite phase, which has been reported to reduce compressive strength of cement binders [35].

Heavy metals, for example Cr_2O_3 , are commonly contained within secondary raw materials, especially in ferrous slags. Although heavy metals are mainly incorporated in the clinker phases, they might be released from the kiln system in small quantities [36]. Similarly, chlorides and fluorides are mainly incorporated into clinker, but in small extents they can be adsorbed on dust particles [37]. In some cases, in the cement kiln chlorides may react with alkalis, forming fine particulate matter, which is difficult to control. If chlorides react with ammonia from limestone feed, they form a visible detached plume with high ammonium chloride content [38]. Moreover, excess of sulfur, alkalis, and chloride contents can have negative effects on kiln operation, because they can cause build-ups and blockages in the kiln system and limit the recycling of kiln dust itself. On the other hand, increased alkali content is desired in BCSA clinker raw mix, as alkalis improve clinker reactivity [15].

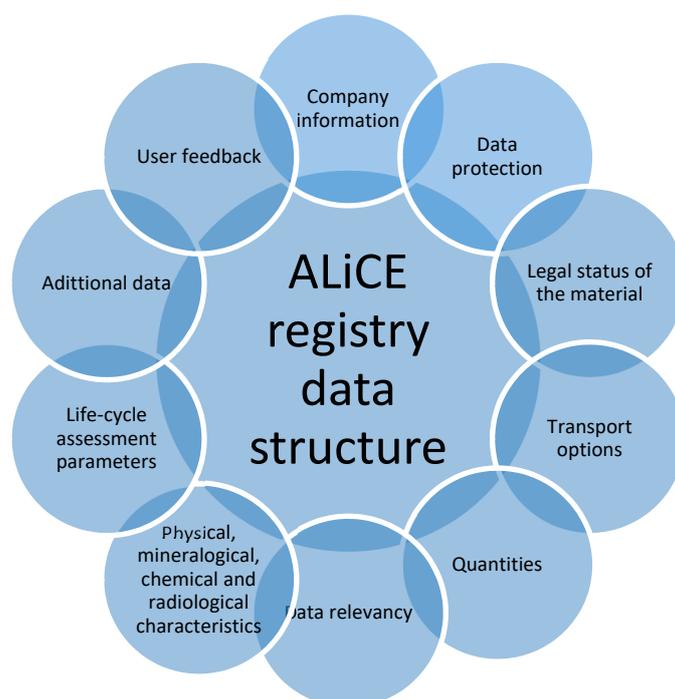


Figure 6. ALiCE registry data structure.

Industrial processes, such as coal combustion and metallurgy, among others, can also generate Hg, which could also be presented in the secondary raw materials for cements. Because of its significant negative effects on human health and the environment, Hg wastes are recognized as hazardous wastes, for which special precautions are necessary in order to avoid emissions and releases of Hg into the environment. As an extremely volatile metal, Hg concentrates at the upper end of the kiln and is therefore not incorporated in clinker. Consequently, it can be released from the kiln system into the air [36].

Waste raw materials can also contain organic components. During the clinker production they produce CO_2 emissions, but also CO, total organic carbon (TOC), and dioxin/furan emissions in some cases [38]. Moreover, hazardous pollutants such as polychlorinated biphenyls (PCBs, PAH) can be presented as admixture to organic substances. Such hazardous components can desorb in the preheater and can be released into the environment [39]. Secondary raw materials can also contain radioactive elements and isotopes. In such materials, the radioactivity is either naturally presented (NORM) or it has increased and concentrated during industrial processes (TENORM), and thus needs to be monitored.

Mineralogical composition of secondary raw materials, intended for clinker raw mixtures, is important mainly from the material preparation point of view. Minerals have different hardnesses, which influence the grinding process. Similarly, physical character-

istics (bulk density, moisture content, particle size distribution) define the preparation processes and related energy consumption. If the overall moisture content of the secondary raw materials in the clinker raw feed is high, it may also increase energy consumption [39]. Life cycle assessment parameters address environmental impacts related to the overall process of the use of Al-rich secondary raw materials for the production of BCSA clinkers.

All of the abovementioned parameters were thus considered as important for the valorization of secondary raw materials for the production of BCSA cement and are thus included in the ALiCE registry.

Future Plans

Registry is at the time of the preparation of this paper (December 2020) still in the prototype version. There could be some errors, so all readers of the Sustainability journal are warmly welcome to test it and to provide feedback. Any company which has an appropriate Al-rich or any other waste or by-products, which could be useful for cement industry, is warmly welcome to register the company on the portal and contribute data.

In the near future, the registry will contain two types of data—ones which will be collected within the RIS-ALiCE project, and the ones which will be contributed by the interested stakeholders outside the RIS-ALiCE consortium. The first type of data will be entered until the spring 2021. However, we anticipate also attracting the interested industrial companies to provide their own data. After that stage, the registry will be tested comprehensively in three test areas: Slovenia, Hungary, and BiH during the workshops with stakeholders. This action will be the beginning of loop 2 of the Results optimization model, presented in chapter 2. Together with the other users' feedback, the next stages will be the consolidation of new ideas, and finally, the implementation stage—the creation of the final version of the registry, ready to be officially launched to the South-eastern European region in late 2021 or early 2022.

The long-term vision of the registry is to become a self-sustainable global marketplace for Al-rich secondary raw materials, that will contribute to better resource-efficiency and help reduce environmental footprints to the environment and fast track decarbonization in the cement industry. Therefore, the launch of the registry can also be viewed as one small step towards a goal of “robust and integrated single market for secondary raw materials and by-products”, as set-up in the European Green Deal document [13].

Providing required amounts of locally available materials which are suitable for cement production is a challenge for cement plants. On the other hand, there are a lot of secondary materials which have a low recycling rate and are therefore disposed as waste, which could potentially be used for the cement production. The aim of the registry is to serve as a user-friendly tool for linking different stakeholders, producers, and holders of Al-rich waste or by-products on one side, and potential consumers of such waste on the other side. It is not intended to be a trading tool, but rather a hub where cement plant operators can find relevant information needed to support their decisions in their production process. The mid-term vision of the registry is to become a widely recognized tool by relevant stakeholders in Europe and globally, who wish to trade (buy or sell) mineral waste and by-products. The long term vision (by the year 2030) is that the registry would hold at least 20 different registered cement plants, which would use its data for the basis of their decisions, and at least 100 different registered providers of Al-rich waste and by-products, and that at least 10 trades would be established as a direct consequence of the registry. If necessary, the registry can also be upgraded to other types of materials needed by the cement industries. To achieve this, the RIS-ALiCE partners will launch an extensive promotion campaign in the South-Eastern Europe countries with the intention to attract users. When the registry has a large enough pool of users and it contains enough dataset, as well as the users' experience being improved, the consortium will focus on its global promotion, potentially with the help of multi-national companies in the field of cement production (i.e., Geocycle or similar).

5. Conclusions

The Al-containing secondary mineral raw materials registry was developed to be used for cement production, especially in the belite-sulfoaluminate cement clinker production, which is considered as a new generation of low CO₂ binders. However, with respect to OPC, higher amounts of aluminum are needed for their production. Aluminum is commonly provided by adding bauxite to the mixture, but it may also be replaced by Al-rich waste and/or by-products, e.g., slags, red mud, coal ash, mine waste, etc.

Based on different actions during the design phase of the registry, registry blueprints were prepared and reviewed by potential end-users. The synthesis results show that the most important feature of the registry is that the data provider has a complete control over what data, linked to the data provider, is entered into the registry. The registry must have good search and data retrieval engines, as well as the user interface shall not be complicated and needs to be user friendly. The platform on which the registry is built needs to be open, trusted, and tested, with a decent user community, to allow implementation of upgrades, as well as registry maintenance by potential third parties in the future.

We tailored the ALiCE registry data structure in a way that each parameter has a specific role in the overall process of BCSA clinker production, from raw materials to the final products. The required company information enables communication and matchmaking between producers/holders of Al-rich secondary raw materials and their potential users. In the registry Upload section, the following tabs are available: Legal status, Location, Quantities, Chemical, Mineralogical, Physical and Radiological characteristics of the material, Life-cycle assessment parameters, Additional data, and data relevancy.

The authors believe that the registry is user-friendly and its structure is logical and easy to follow. It is also easily upgradable, so in the future it will not be limited only to Al-containing residues. The authors anticipate it will serve as a long-term “marketplace” of secondary raw materials for their potential use in cement production, and thus will serve as a matchmaking tool between the producers and potential end-users of mineral residues, contributing to the global resource efficiency and circular economy. Authors would like to welcome all readers of this paper to have a look at it in the following link: <https://www.alice-registry.eu>, and if a company is a holder or a producer of appropriate mineral wastes, we encourage it to register and contribute with their data.

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