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Substitution strategies guide for R&D&I

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Summary

Substitution strategies guide for R&D&I

Approval

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SCRREEN

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Solutions for CRitical Raw materials - a European Expert Network

Substitution strategies guide for R&D&I

Author : Etienne Bouyer

CONTENT

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SUMMARY

The deliverable 5.2 deals with on a guide for substitution strategies of CRM. It first draw a list of the substitution approaches and on the tools (index,..) allowing to measure the substitutability. It Provides a guide not only for scientists and researchers but also for industrial and business operators and political decision-makers.

Since the actual index measuring the substitutability of a given substance, material could be considered as too fixed, this deliverable proposes another manner to follow a substitution solution according to its maturity, its feasibility. The Substitution Readiness Level (SRL) is really complementary with the existing substitutability indexes. SRL is detailed in its construction. SRL could help to solve many substitution issues, but is no panacea. SRL has to be seen as a mean to ask the right questions at each step of development of potential substitution solutions. These questions have to be answered in a collective manner, i.e. by all the actors involved in the value chain of the substitution solution. At the end the aim of using SRL is to show that the substitution solution is able to fulfill (or not) the requirements (e.g. function, properties, manufacturing readiness, industrial & end-user uptake).

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CURRENT STATUS

To overcome the issues of critical raw materials (CRM) several strategies are considered. The reduction of their use, their recycling and their substitution (partial to full replacement).

Four principal sustainable strategies are required at the same time to mitigate supply chain risks for CRM within the EU:

- Increasing primary supply, e.g. by opening new European mining production or by-product extraction;
- Ensuring access to resources from third countries;
- Reuse, recycling and waste reduction;
- Substitution, including better material use.

Substitution act as an important mitigation strategy to overcome the potential disruption in the supply of critical raw materials: it covers the partial substitution (minimization of CRM) to the complete substitution (full replacement).

Substitution of CRM covers several aspects as established in the European CRM_InnoNet project. Four types of substitution aspects are depicted below (Fig. 1).

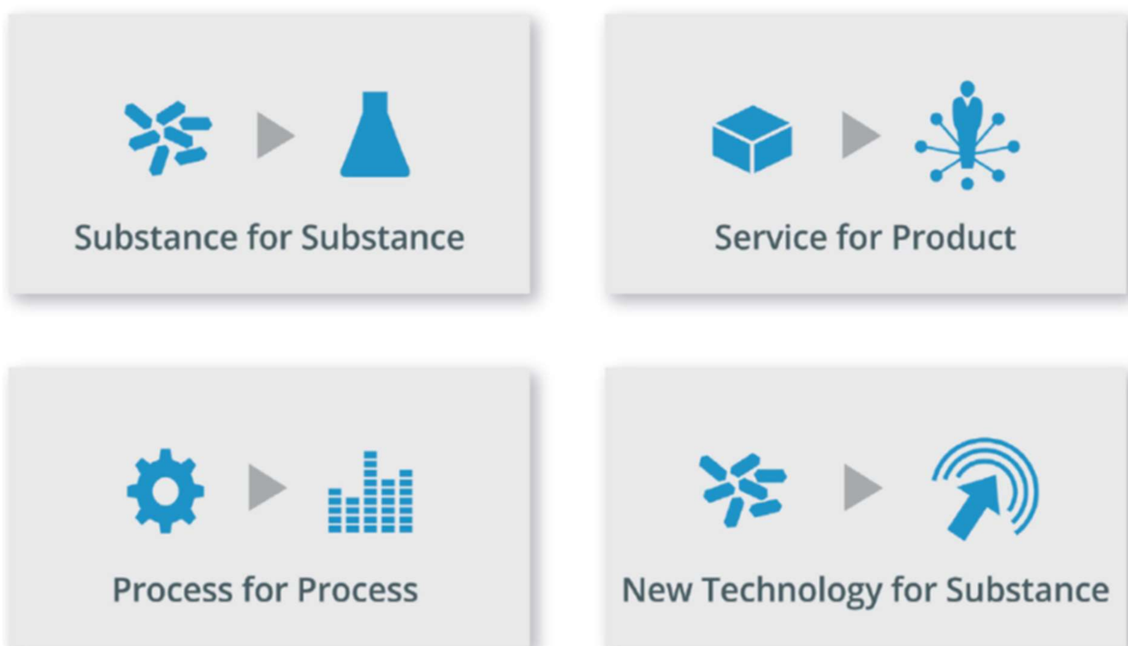

Figure 1 – Substitution approaches [1]

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These four strategies are complementary and cover a lot of potential solution which would fit with different context.

Research on material-by-material substitution is above all risky and lengthy endeavour taking anywhere from 5 – 15 years without any guarantee of success due to unforeseeable fluctuations in raw materials prices and at the same time customer demand as well as new products and services introduced by direct competitors and other companies. Regarding substitution, one observation is that CRM, especially PGM and REE are often to some extent interchangeable, and thus substitutable to a degree, but substitution with more abundantly available materials is more challenging in many cases.

Key findings on substitution [2]:

 The issues concerning the CRM involve the strong and growing demand for the raw materials, as well as their geographic concentration and volatile supply.

 However, due to the ongoing evolution of industry, the criticality of raw materials is subject to change in the mid to long term.

 With present technology, the CRM are hard to substitute without loss of performance or resource efficiency.

 The majority of substitutes are currently in the research and development stage, and market ready solutions are scarce.

 The lead time from research idea to market may be very long, 5-15 year starting from basic research on properties of materials to be substituted to a new product with equivalent properties.

 Some CRM are already recycled, but improving process efficiency and recycling may offer opportunities to alleviate the problem over the short term.

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Commitment	Material for substitution	Overall objective
Critical Raw Materials Innovation Network (CRM_Innonet)	Several	To create an integrated community driving innovation in the field of substituting critical raw materials for the benefit of EU industry
European NAtural Rubber Substitute from Guayule (EU-NARS-G)	Natural rubber	To develop a basis for commercial guayule cultivation in European countries, implementation of plant extraction pilots, economic feasibility study to provide the basis for a larger-scale extension
New affordable stainless steel for extreme conditions (NASSCO)	Titanium, cadmium, chromium	To develop substitutes for CRM-based alloys with improved performance and longer lifetime in aerospace applications
Raw elements substitution in electronic and optoelectronic technologies (RESET)	Rare earth elements, indium	To create an efficient platform dedicated to the sustainable substitution of rare earth elements in photodevices and substitution of indium in transparent conductive layers
Recycled carbon fibres substitute for natural graphite and industrial applications (CARBOCYCLE)	Graphite	To scale up and bring to market a substitute such as carbon-fibre-reinforced plastic for natural graphite
Substitution of CRM – place for graphene in EIP on RM (SUBGraph)	Graphite, rubber, magnesium	To develop a graphene-based elastomer and polymer composite for a wide range of applications
Sustainable substitution in extreme conditions (SUBST-EXTREME)	Tungsten, cobalt, niobium, ruthenium	To identify and develop substitutes for CRM in metal alloys and hard materials used in energy, aerospace and mining industries
Critical raw materials: their role in nanotechnology-based value chains. Nanotechnology as a vehicle for substitution (RAW-NANOVALUE)	Several	To investigate how nanotechnology can foster the substitution of CRM in the main EU industrial value chains

Figure 2 – example of EIP's raw materials commitments (RMCs) linked to the priority area: substitution of raw materials [3]

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SUBSTITUTION & SUBSTITUTABILITY

Concerns about supply security, the consequences of supply restrictions and the environmental impact of raw materials have led to numerous studies to evaluate the criticality of materials. Various methods and methodologies are used to assess criticality, which are developed for monitoring the materials flow and helping decision-makers to prevent or mitigate the effect in case of supply shortages. Until now, there has not been a single approach to quantify criticality because of the different objectives criticality studies try to accommodate or studies which are specifically designed to meet the purpose of a company, country or region, for a specific application or regional economic sector. Therefore, the results of these studies are highly influenced by the adopted methodology and selection of indicators. Several factors/parameters are more commonly taken into account when assessing the criticality of raw materials:

- Supply factors (geological/economic availability, recycling);
- Geopolitical factors (policy and regulation, geopolitical risk, supply concentration);
- Demand factors (future demand projections, substitutability);
- Vulnerability to supply restriction;
- Other factors (environmental performance, cost impact, economic importance, etc.);
- Substitution or substitutability at material level is often used as a sub-indicator for assessing criticality.

At present, there are no comprehensive quantitative data on the substitutability of raw materials because too many parameters can influence the degree to which a critical material is substituted. Similarly, there is no consensus in the attribution of substitution and substitutability in criticality assessments. Some studies assign substitutability to the supply-risk dimension, others to vulnerability to one or even both dimensions.

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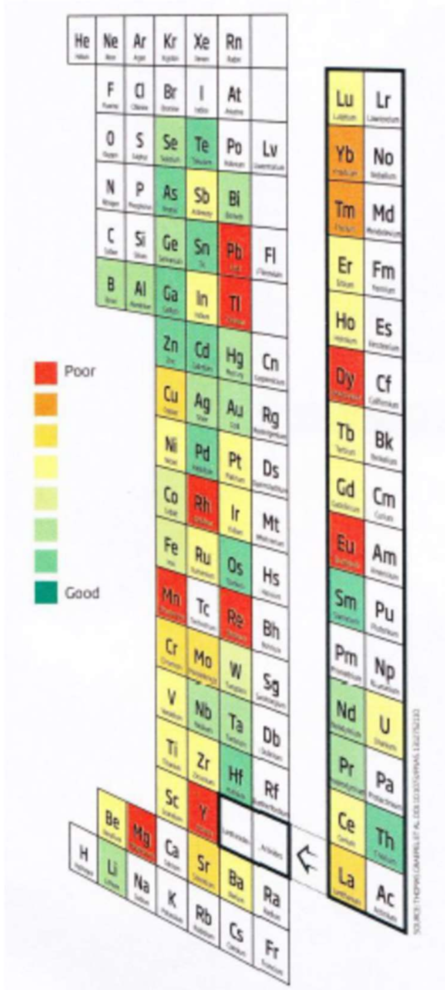

Figure 3 – Substitutability scale (from “Poor” to “Good”)

The "Substitutability index" is a measure of the difficulty in substituting the material, scored and weighted across all applications. Values are between 0 and 1, with 1 being the least substitutable.

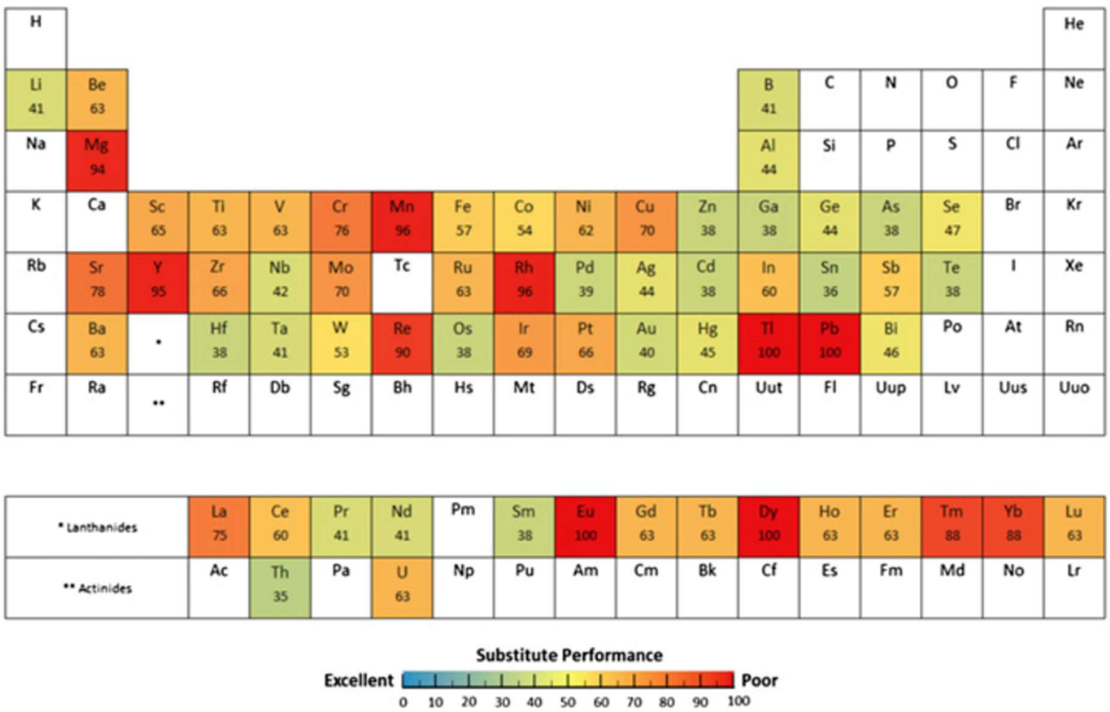

Figure 4 - The periodic table of substitute performance [4]

In fig. 4, the substitute performance results are scaled from 0 to 100, with 0 indicating that exemplary substitutes exist for all major uses and 100 indicating that no substitute with even adequate performance exists for any of the major uses. It is worth to note that for most of the elements studied the substitute performance varies from poor to medium.

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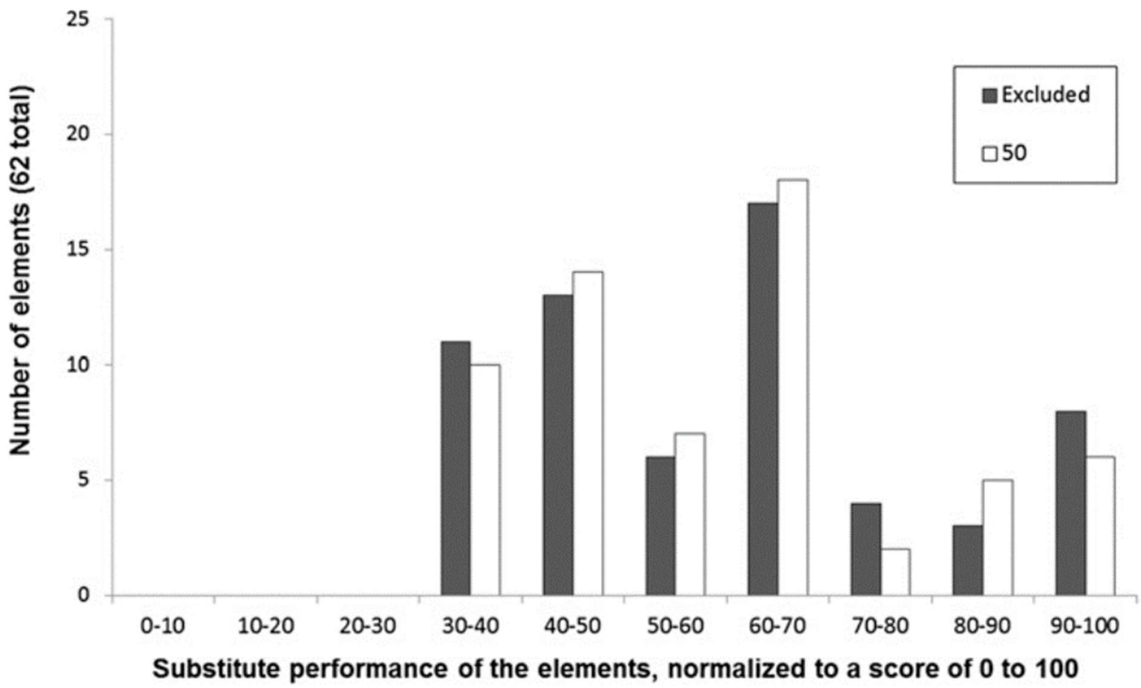

Figure 5 - Aggregated substitute performance scores [4]

As shown in fig. 5, aggregated substitute performance scores for the 62 metals investigated showing distributions of substitute performance across all applications where white bars represent “other” categories set at a default value of 50 and black bars represent the exclusion of other categories. A substitute performance score of 100 indicates extremely poor substitute performance or lack of substitutes, whereas a score of 0 indicates excellent substitute performance.

The previous indicators are not enough to describe the capability of a solution to replace the current one. It is more a theoretical approach which is not sufficient since it does not give a practical indication of the dynamic of its implementation. This is a strong limitation of such indicator that cannot help the decision makers in a practical manner.

The question to answer is not only if it is possible to substitute but rather if it is feasible and how much effort it takes to make it.

In order to be more pragmatic the idea is to switch from a simple indicator to the use of a substitution readiness level (SRL) to follow the maturity of the solution. It also measures the remaining effort to be done to make the substitution solution possible and real.

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The task 5.2 aims to:

- Establish a map of the existing tools or approaches (substitutability index, substitute performance,…) allowing somehow a measurement of substitutability, identify their advantages and drawbacks.

- Propose a Substitution Readiness Level (SRL) like the Technology Readiness Level (TRL) developed initially for the aerospace industry.

To set up a SRL indicator, one has first to answer few questions on this indicator to better define the perimeter for the use of this SRL.

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A SUBSTITUTION READINESS LEVEL FOR WHAT ?

There is a need for the evaluation of the maturity of a substitution solution/approach. The maturity can be understood as the ability to implement the substitution solution. This is crucial for industrials to measure the effort, the investment still to be done in order to uptake the substitution solution. The SRL draw from the TRL (Technology Readiness Levels) which were originally conceived at NASA in 1974 and formally defined in 1989. The original definition included seven levels, but in the 1990s NASA adopted the current nine-level scale that subsequently gained widespread acceptance, see fig. 6.

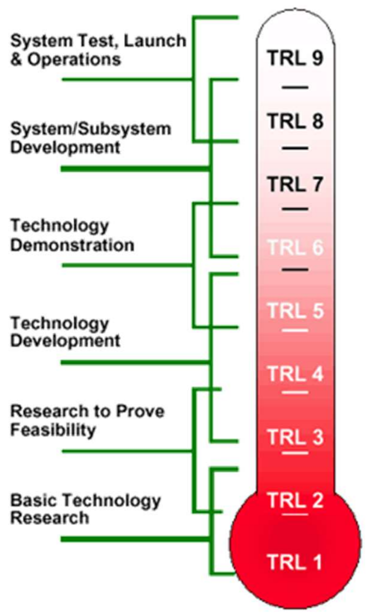

Figure 6 - NASA Technology Readiness Levels

Assessing technology readiness levels does leave some major questions unanswered:

- Is the level of performance reproducible?
- What will these cost in production?
- Can these be made in a production environment ?
- Are key materials and components available?

Substitution readiness assessments (SRL) address these unanswered questions in order to reduce substitution risk.

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Manufacturing Readiness Level (MRL) could also inspire the setting up of a SRL. MRL is a measure developed by the United States Department of Defense (DOD) in 2005 to assess the maturity of manufacturing readiness, see Fig. 7.

MRL	Definition
1	Basic manufacturing implications identified
2	Manufacturing concepts identified
3	Manufacturing proof of concept developed
4	Capability to produce the technology in a laboratory environment.
5	Capability to produce prototype components in a production relevant environment.
6	Capability to produce a prototype system or subsystem in a production relevant environment.
7	Capability to produce systems, subsystems or components in a production representative environment.
8	Pilot line capability demonstrated. Ready to begin low rate production.
9	Low rate production demonstrated. Capability in place to begin Full Rate Production.
10	Full rate production demonstrated and lean production practices in place.

Figure 7 - MRL as developed by DoD.

A SRL for what ?

SRL would:

- Provide a common and comprehensive state of a particular substitution technology
- Manage the risk
- Help to take decision on substitution technology development
- Help to take decision on substitution technology transfer

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A SRL for whom ?

SRL should be used by actors of both R&D and innovation who aims to solve CRM issues based on substitution solutions. It also should help actors all along the value chain to take the right decision in due time to select a substitution solution according to specific market, sector constraints. Policy makers could become users of such SRL for deciding whether to support a breakthrough substitution solution versus another one (e.g. a less disruptive) according to the benefit it could bring and the expected time to market.

How to measure it ?

What kind of parameters could be integrated in this SRL, hereafter are some (non exhaustive) key points:

- The performance reached by the substitution solution versus the current one
- The substitute material availability
- The substitute processability, compatibility with the current production & manufacturing facilities
- The price ratio between the substituted material and the substitute
- The acceptability of industry to uptake the substitution solution
- The easiness to implement the substitution solution

The SRL should integrate several dimension such as the sector where the substitute material is implemented, since the acceptation is sector & application dependent. In other words the SRL is not universal but rather specific to each sector, each applications.

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Define & establish a scale

We must harness the potential of this idea. The SRL is a declination of both the TRL and the MRL, the substitution readiness level is the one that measure the path, the effort to be done until the market introduction and the customer acceptance.

The scale can range from 1 to 9, from low maturity to the highest one. From the basic idea to the production of the substitution solution at the industrial scale. Such a scale provide the critical steps towards the establishment of a viable substitution solution taking into account various key & crossed parameters (scientific, technological, industrial, economical,…).

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Proposed Substitution Readiness Level scale

The table below described the 9 levels of the SRL scale following the development of a substitution solution from the basic idea to the full industrial deployment. This SRL would be applicable for the four substitution generic approaches mentioned by the CRM InnoNet project.

1. Basic principle observed and reported for the substitution solution	Lowest SRL. Scientific research starts to move towards applied research. Examples could include paper studies and basic properties of the substitution solution that compare the current solution.
2. Concepts or applications of the substitution solution formulated	Shaping of the substitution solution starts, application could be identified. Examples are still limited to paper studies.
3. Proof of concept of the substitution solution	Active R&D on the substitution solution are initiated. This include laboratory studies to evaluate the substitution solution (check the provided function in comparison to the current solution to be replaced). Examples cover components that are not yet fully integrated nor representative.
4. Laboratory validation of the substitution solution	Components of the substitution solution are integrated in order to verify they can operate together. Examples include ad hoc integration of substitution solution at laboratory scale.
5. Validation in a relevant environment of the substitution solution	The maturity of the substitution solution grow significantly. Tests like comparison with the current solution are done at laboratory scale.
6. Demonstration in a relevant environment of the substitution solution	The substitution solution is tested in a relevant environment, it means that industrial (manufacturing) tools are available to make real this substitution solution. This is a major step forward for the substitution solution maturity. Examples cover prototype test in at least simulated operational environment.
7. Demonstration of the substitution solution in	The substitution solution is tested at prototype scale to demonstrate its soundness and viability in an operational environment. At this

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operational environment	stage the existence and the robustness of the substitution solution supply chain is assessed.
8. Full substitution solution qualified	Proof has been furnished that substitution solution brings the same performance than the original solution (to be substituted) at full scale. The functional specification for the substitution solution are fulfilled at the real scale. This scale represents the end of development stage.
9. Full substitution solution approved, accepted and deployed	Highest SRL. All the conditions for the large scale (e.g. industrial) deployment of the substitution solution are fulfilled: Readiness of the industrial tool to produce/provide cost competitive substitution solution, acceptance of the customers to uptake the solution. This is at least true for a substitution solution applied in a given specific sector, i.e. this is not generic since not applicable to all sectors where the substitution solution could apply.

Table 1 – Definition of the SRL

Positioning the substitution solutions allow to measure the effort still needed. This would help decision makers to promote a substitution solution versus another ones according to the shortest way to the market of this solution. No scale is perfect, this SRL is not since it does not include some parameters that could be important for some sectors, for some companies, for some industries or end-users.

As an example, this approach does not integrate the sustainability of the substitute as such. However, while there is a tremendous interest in raw material substitution, the lack of a simplified approach to comparing the materials' sustainability and effective legal frameworks make final market applications extremely challenging. The market for new raw materials can only be established if industrial sectors are appropriately sensitized and stimulated [5].

It is clear that nowadays, industrial and business operators are more looking for a way to evaluate raw materials' substitution sustainability.

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CONCLUSIONS

There are various paths to substitute CRM. There are several ways to evaluate or measure the substitutability of CRM, the related index are fixed whereas substitution is something dynamic since it implies development work to set up reliable substitution solution. Using such frozen index, there was no possibility to quantify the effort needed to make feasible the substitution approach or solution. The deliverable propose a novel and complementary approach based on Substitution Readiness Level which give a good overview at a given point in time of the development in all its dimensions of the substitution solution.

SRL is just a practical tool (it is not a goal it is a mean) that accompany and could guide developers (scientists, researchers), decision makers such as industrials and end-users involved at different stage of the setting up of substitution solutions of CRM. The establishment of the SRL scale is inspired by other currently used scale such as TRL and MRL.

One of the basic idea is to involve as soon as possible most the actors of the value chain to verify if all the bricks needed to deploy the substitution solution are existing and are connected between themselves.

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