Deloitte Sustainability

REACH and CRM INTO LCA - Integration of REACH- and CRM-related supply risks into the LCA Methodology

Executive summary

Draft version

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ABSTRACT:

This executive summary presents the methodology developed for the assessment of REACH and CRM related obsolescence risks at pre-design stages of space missions. First, the pre-requirements that drove the methodological choices for the proposed risk assessments method are presented.

For the REACH assessment, the proposed method relies on both ESA's existing Life Cycle Assessment (LCA) framework and the Materials & Processes Technology Board (MPTB) Database. Then, the method was structured in three steps:

- Firstly, a commonality is found between the LCA and MPTB databases: ECSS classes, that help define small groups of materials defined as "clusters", are used to "bridge the gap" in terms of level of precision between the LCA model of a space system and the MPTB database;
- Secondly, the LCA database is complemented with REACH-related information thanks to the use of the clusters aforementioned;
- Lastly, once the LCA database contains the REACH-related information required, a methodology to assess the risk in the context of a space mission is proposed.

Then, this methodology was applied and tested on a case study on the structure subsystem of a satellite, which helped fine-tune the risk evaluation process and provided an illustration of the method on a concrete example. Recommendations were provided for future updates of the methodology and implementation in ESA systems.

A methodology was also defined to identify potential supply risks due to the use of Critical Raw Materials (CRM) by the European space sector. The objective of this work was to develop a CRM supply risk indicator for the space sector based on the latest JRC methodology and the supply risk linked to resource depletion.

The supply risk indicator developed for the European Union was adapted to the European space sector and a resource depletion parameter was included into the formula to discriminate which elements are the most easily available in the long run. Indeed, the supply of non-renewable materials also depends on the remaining amount of extractible material at global scale. A ranking of raw materials, based on the new supply risk indicator, was defined. A method based on the new supply risk formula was implemented into an LCA software to test the feasibility of the approach and identify future developments to implement. Finally, recommendations for future developments of the methodology and its implementation within ESA's eco-design framework were proposed.

Finally, this executive summary presents the "LCA into REACH" part of the project: in this part, the relevance of using LCA in REACH evaluations was discussed. In particular, the project team analysed whether LCA would be able to support the authorisation process.

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Introduction

Context

An obsolescence risk in the space industry can be defined as **any possibility of impairment of quality and reliability** or even loss of critical technologies for qualified materials and processes, which is induced by a substance's unavailability or substitution threat (as a substance on its own, in mixtures and / or in articles, together also "products"). In that context, the project focusses on two main areas which may impact the space supply chain : the REACH regulation and the Critical Raw Materials (CRM).

REACH poses two major forms of obsolescence risks for space activities:

- the **regulatory obsolescence risk**, mainly due to the legal ban for non-registered or non-authorised substances and their uses, respectively;
- the **commercial obsolescence risk**, for example when suppliers modify or discontinue products used by the space sector. These changes can be induced when larger sectors stop using the product; and this in spite of the high potential for REACH authorisation or derogations from restrictions for the space sector.

When looking at the complex value chain of space systems, another obsolescence risk is a critical issue for the space industry and needs to be investigated and anticipated: it is the obsolescence risk due to the use of critical raw materials (CRM). Presently, there is a growing challenge of securing access to those metals and minerals needed for economic production. Indeed, many materials are not only essential for the production of a broad range of goods and applications used in everyday life, but also for the development of high tech products and emerging innovations, which are necessary for the space sector.

Objectives and activities of the project

There were three main objectives for this project:

- The first main objective was to develop and validate an adaptation of the LCA methodology to identify, flag and classify the obsolescence risks due to REACH related substances and Critical Raw Materials (CRM) use through the complete life-cycle of space products: "REACH into LCA".
- The second was to define the methodology to assess the CRM obsolescence risk and to integrate it in ESA's eco-design framework at pre-design stages.
- The third objective of this study was to establish how LCA can support REACH risk management efforts (e.g. REACH authorisation process) and demonstrate through one specific case study: "LCA into REACH".

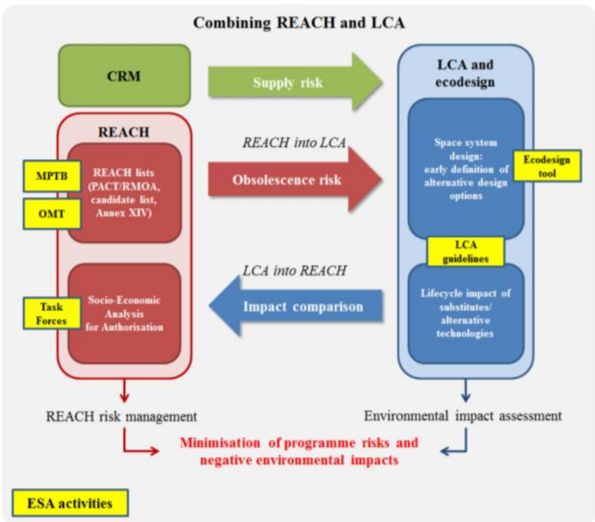


Figure 1: Illustration of the main goals of the project and the combination of CRM, REACH and LCA

REACH into LCA

Context: challenges and existing framework for the study

Industrial challenges for identifying potential REACh-related obsolescence risks for space systems

The "REACH-related obsolescence risk", i.e. the potential risk of supply disruption due to the use of REACH-targeted substances, imposes diverse challenges for the space industry.

- **Timeframe of space missions**

The first challenge is the discrepancy between the long timeframe of the design and exploitation of a space system and space programme and the timeline of the REACH regulation. Indeed, for satellites, the platform design (or at least part of it) is generally standard, which ensures heritage of the key systems to customers. A platform design can be exploited 15 to 20 years without significant modifications. Moreover, the overall lifecycle (conceptual / preliminary design, detailed design, construction, exploitation, etc.) can be as long as 40 years. When the design is qualified, as little system requalification as possible is planned and production has to be sustainable until the end of the programme. In parallel, it can take from 5 to 20 years between the proposal that the use of a chemical substance be subject to authorisation under REACH and its effective restriction. Moreover, since a significant amount of time is needed for this authorisation review and renewal processes, it seems clear that REACH can affect a space mission which did not face any restriction in its early phases. In short, the anticipation of REACH-related obsolescence risks, in particular at preliminary design stage, is challenging but necessary.

- **Complexity of the space supply chain**

Furthermore, the supply chains of the space industry are extremely complex. Indeed, thousands of pieces are required in a spacecraft and hundreds of suppliers are involved. It means that the visibility on upstream materials and processes and the possible use of REACh-targeted substances is low, which increases the dependence of Large System Integrators and space mission operators on upstream suppliers to take actions to avoid supply chain disruptions. Another specificity of the space industry is that because of its relatively low size, the alternatives are typically driven by requirements from non-space sector.

Therefore, the methodology developed within this project needed to integrate all these challenges to be tailored for ESA and the space industry in general. Since it is critical to evaluate the risk as soon as possible, the objective of this activity was to elaborate a **methodology to be applied at pre-design stage, which refers here to the preliminary design at system level and corresponds to phases 0 and A of space projects**.

Existing framework for the study: ESA's LCA and ecodesign framework and MPTB database

- **ESA's LCA and ecodesign framework**

ESA has implemented the Clean Space initiative since 2012 as a framework for its activities related to the eco-design of space systems and space debris remediation and mitigation. In order to better understand the environmental impacts of European space programmes, ESA successfully applied Life Cycle Assessment (LCA) to assess the environmental impacts of space projects over their whole life cycle. One significant achievement of this pioneering activity was the elaboration of the "Space system Life Cycle Assessment (LCA) guidelines" which is a handbook elaborated by ESA to perform the LCA of a space system. Based on the knowledge acquired through LCA and using the environmental assessment framework set up through this initial activity, ESA has adopted an eco-design approach to design future space missions in a more environmentally friendly way. Eco-design is a preventive approach to mitigate the environmental impacts of a product (good or service) as early as possible in the design phase. **The LCA model which is meant to be built to study the environmental impacts of a space system is an interesting basis to identify potential future REACH-related obsolescence risks as it provides an overview of the industrial activities over the entire**

value chain of the space system and, more specifically, carries information on which materials and processes are used throughout the full life cycle of the space system.

- **The Materials and Processes Technology Board (MPTB)**

Many of the REACH related risks are managed co-ordinately in the European space sector by the Materials and Processes Technology Board of the European Space Components Coordination (ESCC MPTB), a partnership between ESA, national space agencies and space industry, chaired at present by ESA. From the first early M&P Working Group (WG) meetings (May 2009) the urgency of dealing with the risks presented by REACH was recognized. Therefore, a specific splinter group was created, that held its first meeting in June of the same year. Following this first meeting, the members of this splinter group agreed on the need to create a common **database of Articles, Preparations and Substances (APS) used in the space sector** in Europe and then to identify those at risk due to REACH and other obsolescence factors. The database would allow, for each targeted substance, to quickly identify the products using the substance and the companies using the products. In this project, we refer to this database as the *MPTB database (MPTB DB)*. For each APS, it provides the substance(s) which is(are) present and sometimes additional details such as the ECSS class, the product type or the chemical nature of the APS. **The MPTB DB carries the REACH information of interest for the project, as it identifies which substances (identified by their CAS numbers) are included in which list of the REACh regulation (candidate list, annex XIV, annex XVII, etc.)**.

Main methodological challenge of the project: the discrepancy in granularity between a typical LCA model and the MPTB database

- **Generic vs. specific**

The gap in terms of granularity between the LCA database (and a typical LCA model of a space system) and the MPTB database was the main methodological challenge for this activity. Because of a lack of very precise information, Life Cycle Assessment often uses generic and "high level" models to evaluate the environmental impacts of processes and materials: when data is not available, it is common practice to build generic proxies to reflect the actual system. In LCA, this approach is acceptable as long as it can be assumed that there is no significant difference in environmental impact between e.g. different technological routes to produce the same material or different materials or processes providing the same service. However, this assumption is questionable for the REACH related risk assessment. Indeed, it only takes one dangerous substance – even in low quantity – used in a given material but not in the equivalent material to have very different risks. On the other side, the MPTB database provides a list of APS but does not specify for which subsystem, component, process or material they are used. Therefore, one of the main methodological challenges of this activity was to be able to make the two entry points of the project - i.e. the two databases – communicate, or in other words to bridge the gap between them.

- **The specific case of predesign**

The fact that the risk assessment is to be performed at predesign stage reinforces the difference in granularity between the LCA model and the MPTB database. Indeed, the intrinsic lack of knowledge at early design stage on which materials and manufacturing processes will be used throughout the life-cycle of the future space system affects the quality of the LCA model. While using available generic LCA models can still be relevant to assess the environmental footprint of a space mission at pre-design, the question of whether this level of information is suitable for a preliminary risk assessment is more complex. At pre-design stage, there is an intrinsic uncertainty related to the choices of the materials or processes which will be used in the considered space mission because technological choices are often made later in the design. One of the major challenges of the study was to take into account this uncertainty and develop a methodology flexible enough to adapt to diverse levels of knowledge of a space mission. This uncertainty reinforces the gap in granularity levels previously mentioned.

Overview of the methodology

> *The project team developed a methodology able to map spacecraft components with their constitutive chemicals and then identify and rank the resulting REACH-related obsolescence risks.*

Based on the constraints explained above, a three-step methodology was developed:

1. Clustering of the APSs and mapping of the clusters with LCI datasets. This step aims to make the two databases communicate.
2. Addition of REACH-targeted substances in the LCI database. This purely technical step concerns database management and therefore will not be discussed in this executive summary.
3. Risk evaluation, meaning the proper assessment of the obsolescence risk for a space mission.

Figure 2 below presents this general workflow and when each step is performed.

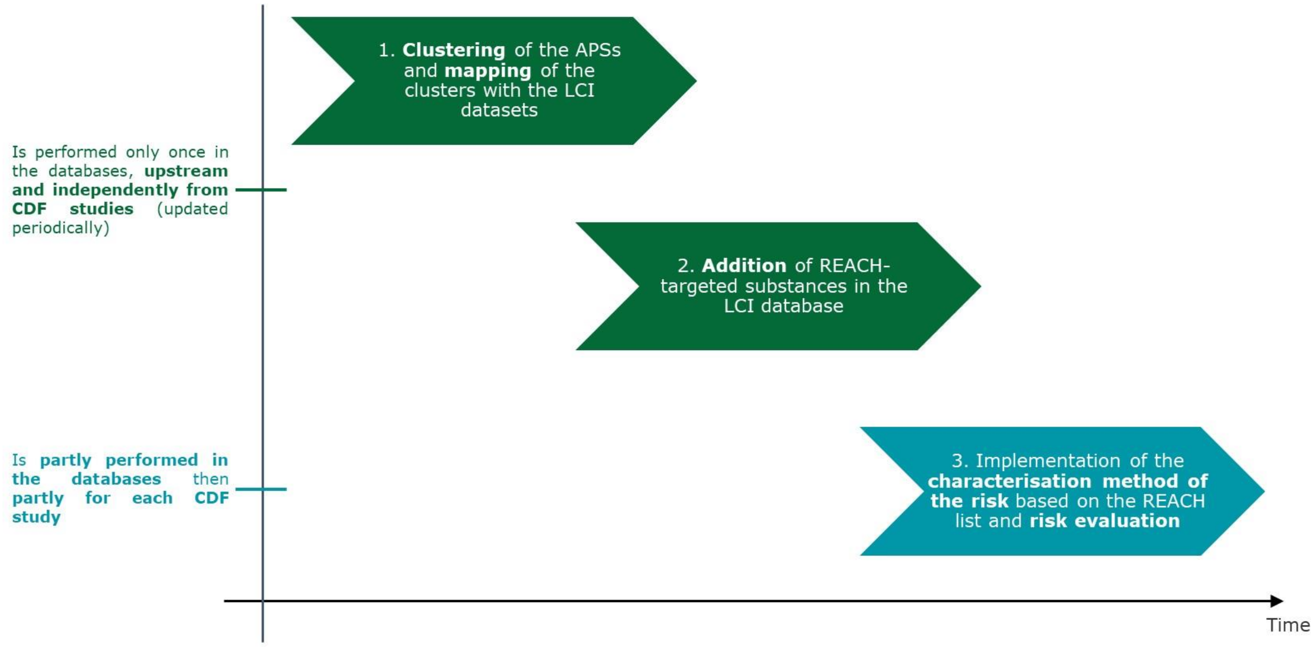


Figure 2: General workflow of the methodology

Clustering and mapping

The question answered by the clustering and mapping phase is simple but still critical: **How does one know which APSs are used in the space mission?** Once this question is answered, it is then possible to assess the obsolescence risk related to REACH. The principle scheme is represented Figure 3 below.

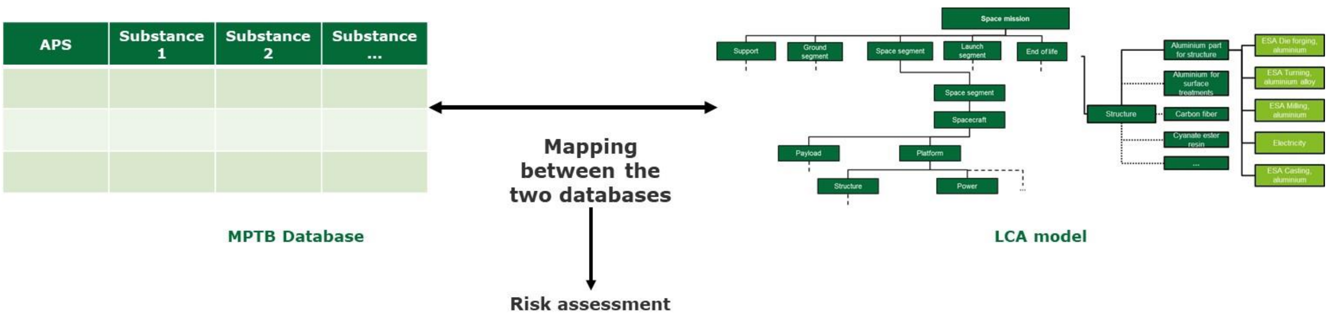


Figure 3: Principle scheme of the methodology - focus on the mapping phase

As the two databases carry different levels of information, it was necessary to develop a sort of adapter to make these different levels of information coincide.

To enable the mapping, it was decided to gather the APSs into groups called clusters (e.g. coatings). Indeed, an LCA model should have the information of which category of APS will be used at a certain point in the life cycle of the space system (e.g. a coating has to be applied on an alloy of the structure), while the model should be often unable to specify which specific APS will be used (e.g. is this coating Alodine? Another one?). The method is based on the fact that one and only one APS of the cluster is used when the cluster is mapped to an LCI dataset (e.g. one coating only is applied to the alloy of the structure). To ensure a consistent mapping, the following conditions need to be respected:

- Each APS has to belong to one and only one cluster.
- The criterion to define a cluster has to be unambiguous.
- The smaller the cluster, the more precise the evaluation. Indeed, if a cluster gathers many APSs (e.g. 100 or more), the loss of information when switching from APSs to clusters will be higher.

This theoretical definition of a cluster needs to be applied on the actual databases. Since the information on the APSs is only present in the MPTB DB, the clustering criterion needs to be adapted to the information present in the MPTB DB. After analysis of the database, it was decided to use the ECSS classes as clustering criterion. Indeed, gathering the APSs based on their ECSS fits all the requirements presented above. It appeared that in some cases there were too many APSs in a single cluster (e.g. ECSS class 12 Paints and inks). Therefore, it was decided to create subclasses when needed.

Once the clustering is performed, a mapping between clusters and LCI datasets can be performed. Figure 4 shows the workflow of the clustering-mapping process.

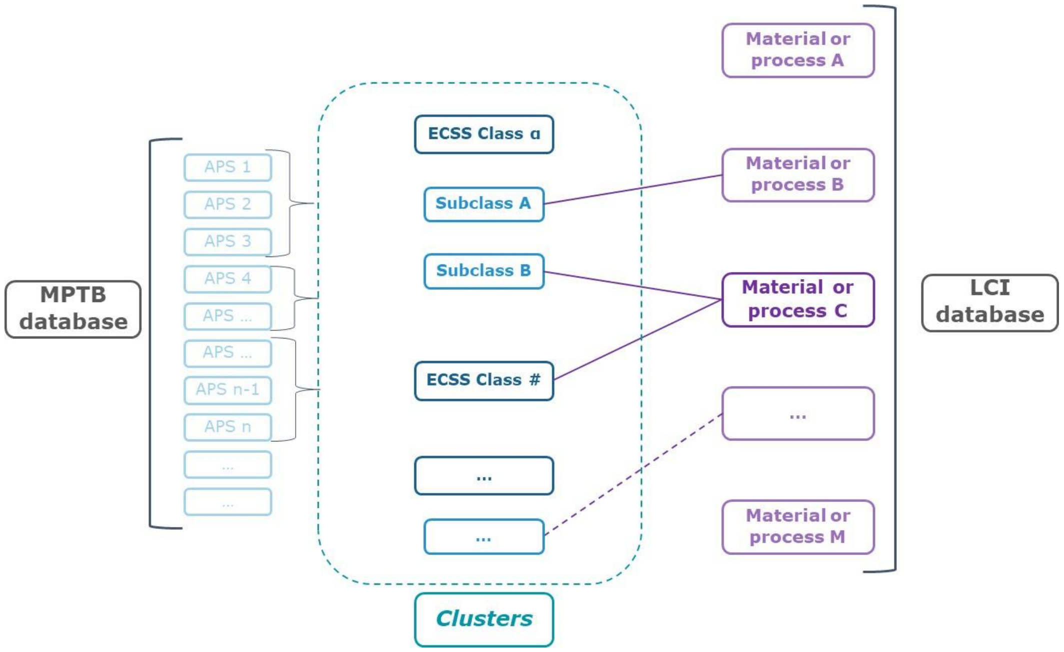


Figure 4: Clustering-mapping workflows

As presented on Figure 3, once the clustering-mapping is performed, the risk assessment can be performed.

Risk assessment

A differentiation can be made between an individual risk related to a given substance targeted by REACH and the overall REACH-related risk which is the risk resulting from the assessment of the combination of individual risks and their impacts on each other, in the context of the whole project. The approach developed in this section details how to assess an *overall* REACH risk. An individual REACH risk score is used to measure the magnitude of the risk for a given targeted substance; it is a **combination of the likelihood of occurrence and the severity (level of impact), where scores are used to measure likelihood and severity**. It must be noted that the likelihood captures the probability that the APS from a cluster is used and NOT the probability of obsolescence *per se*.

Therefore, the *severity* and the *probability* (likelihood) have to be defined to determine the risk. The REACH information is carried at substance level but the obsolescence risk has to be determined not for a given chemical but at least at subsystem level. Therefore, an aggregation is essential to upscale from a located risk to a risk at higher level in the space project’s structure. Figure 5 below presents the risk assessment process proposed in this project.

The project team identified that the risk assessment should allow to establish a hierarchy of the obsolescence risks between the different subsystems of the spacecraft under study, and to see which subsystem requires the most effort in terms of awareness raising and, potentially, initiation of an obsolescence risk management strategy. **Therefore, the outcome of the proposed risk assessment is a quantitative ranking of the subsystems based their obsolescence risk, complemented by a detailed analysis of each subsystem and cluster risk to identify precisely the source of the hotspots and initiate mitigation actions**.

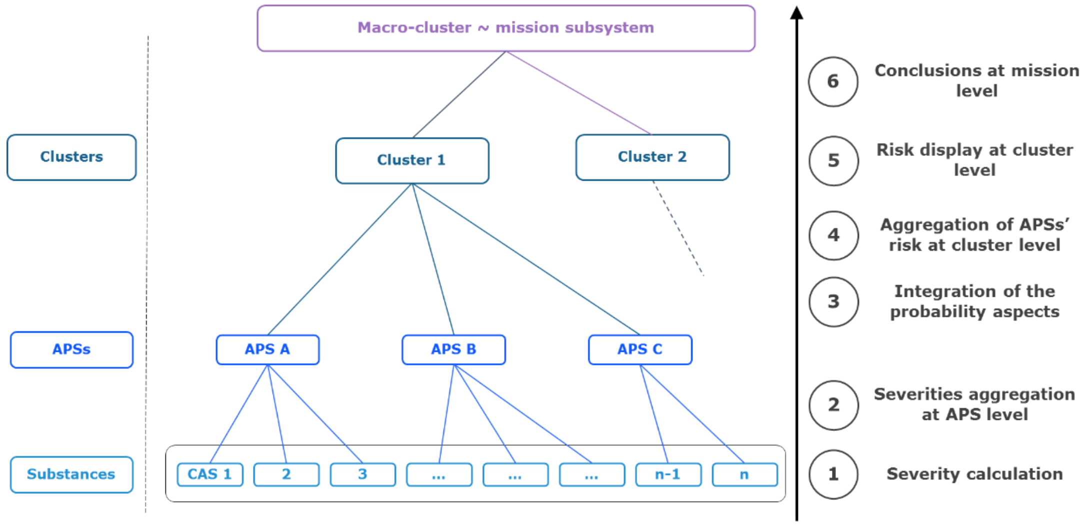


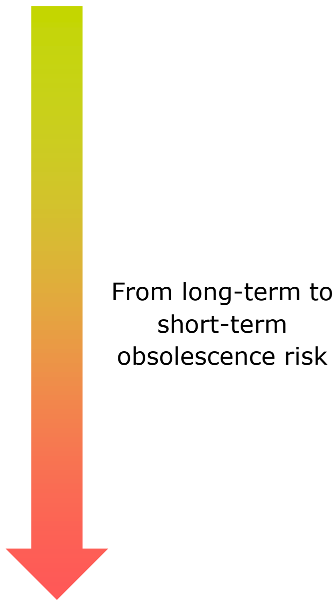
Figure 5: Risk assessment workflow

Severity evaluation

- **The REACH blacklists**

The severity aims to capture the consequences on the space supply chain of the use of a substance – or the use of an APS containing this substance. The first criterion to consider is of course how the REACH legislation considers this substance. Since the REACH process is performed step-by-step, the substances are classified by lists (referred to as blacklists in this project), as presented below:

- The Community Rolling Action Plan (CoRAP) for substances to be evaluated to clarify a risk;
- The Public Activities Coordination Tool (PACT) for substances for which a Regulatory Management Option Analysis (RMOA) or an informal toxicity hazard assessment is either under development or has been completed.
- The ECHA Registry of SVHC intentions, which lists substances for which a Candidate List proposal has been or is planned to be submitted by an EU Member State or ECHA (on request of the Commission)
- The Candidate List (CL) for Substances of Very High Concern (SVHC), that are candidates for possible inclusion in the Authorisation List (Annex XIV)
- ECHA recommendations for inclusion of CL substances in Annex XIV
- The Authorisation List (Annex XIV) for substances which cannot be placed on the market or used on their own, as part of mixtures or for the incorporation into articles after a given date ("sunset date"), unless authorisation is granted.
- The Restriction List (Annex XVII) which limits (including but not limited to bans) the manufacture, the placing on the market or the use of certain substances presenting an 'unacceptable risk'.



On top of REACH-related lists maintained by the EU regulators (ECHA, EC), the SIN (Substitute It Now) List is a project driven by a NGO, ChemSec, to speed up the transition to a toxic free world. The list is a globally used database of chemicals likely to be banned or restricted in a near future. The chemicals on the SIN List have been suggested by ChemSec to be identified as Substances of Very High Concern (SVHC) based on the criteria established by REACH. It also includes non-registered substances.

- **Definition of the severity factor for substances**

The obsolescence risk of a substance progressively increases as it follows the REACH process. Indeed, each step brings closer the moment where a final decision will be made while increasing the chances for a substance to be restricted. Therefore, the challenge is to **capture precisely the obsolescence risk of a substance solely based on the blacklist it belongs to**. In order to allow a quantitative assessment, severity factors were set for each blacklist, as presented in Table 1 below.

Table 1 - Empirical severity factors for the selected blacklists

'Blacklist'	Qualification of obsolescence risk	Severity factor proposed
SIN List	Vaguely long-term	1
PACT-RMOA List	Possibly mid-term	2/3*
Candidate List	Probably mid-term	4/5
Annex XIV Recommendation	Probably short-term	8
Annex XIV List	Imminent and high	10
Annex XVII List	Depending on the restriction/use	1-10**

**The factor only applies if the suggested follow-up is "Identification as SVHC (authorisation)" or "Restriction (Annex XVII List)".*
***The risk may range from 1 to 10 imminent, e.g. in case of a ban implying a substitution pressure. If a derogation is foreseen for space applications, the risk tends to be lower (but there is still a commercial risk).*

- **Severities aggregation at APS level**

As previously stated, an APS is composed of at least one substance. In order to capture at best the severity of an APS, the project team selected two pathways to determine the severity of an APS:

Table 2: The two severity aggregation pathways

Pathway 1: The severity of an APS is the sum of the severities of its constitutive substances	Pathway 2: The severity of an APS is equal to the highest severity in the group of substances.
$\text{Severity}_1\ (\text{APS}_i) = \sum_{j=1}^{n} \text{Severity}\left(\text{CAS}_{i,j}\right)$ (where $\text{CAS}_{i,1}$, …, $\text{CAS}_{i,n}$ are the constitutive substances of APS_i)	$\text{Severity}_2\ (\text{APS}_i) = \text{MAX}\left(\text{Severity}(\text{CAS})_{i,j\ j\in(1,n)}\right)$ (where CAS_1, …, CAS_n are the constitutive substances of APS_i)

The case study proved that both approaches are relevant and complementary for the purpose of the study:

- Summing the severities could be considered as an estimation of a "diffuse" obsolescence risk;
- Considering the highest severity could be considered as an estimation of an "acute" obsolescence risk.

Integration of probability aspects

As a reminder, all APSs (characterised by their severity level) are grouped in predefined clusters. In most cases during the predesign of a specific space mission, it is unclear which APS of a given cluster will be used. To integrate this aspect, it was proposed to define a probability factor for each APS of a cluster. By default, the use of all APSs is supposed to be equiprobable. The default factor can be modified case by case when there is knowledge on a given space mission. For example, when the exact information of which APS is used (e.g. specific alloy) is known, the case is simple since the probability of this given APS within its cluster is set to 1 and the others to 0. **It is important to remind that those factors capture the probability that the APS from a cluster is used and NOT the probability of obsolescence properly speaking**.

Table 3: The two default probability factors

Case 1	Case 2
Probability factor = 1 / (number of APSs in the cluster) **i.e. the inverse of the number of APSs in the cluster**	**Probability factor =** • **1 for the APS with the highest severity** • **0 for the others**

Risk calculation and aggregation at cluster level

Once the probability factor is set for each APS, knowing its severity, the risk can be calculated:

Risk (APS_i) = Severity (APS_i) * Probability factor (APS_i)

Since there are 2 pathways for the severity evaluation and 2 cases for the default probability factors, in means that in theory the risk of an APS can be determined in 4 different manners. In reality, only 2 risk calculation methods at APS level make sense:

1. Risk 1: Combining the "average" approaches (pathway 1 and case 1); and
2. Risk 2: Combining the maximising approaches (pathway 2 and case 2)

Following this logic, two different risks can be defined at cluster level:

Average REACH obsolescence risk	*Acute* REACH obsolescence risk
$R_{Average} = \sum \boldsymbol{Risk}\ \mathbf{1}\ (\mathbf{APS}_i)$	$R_{Acute} = \mathbf{MAX}(\mathbf{Risk\ 2}(\mathbf{APS})_i)$
It represents the arithmetic average risk of the APSs (when the default probability factor is used) or a weighted average (when adjusted probability factors are used), severities being calculated by summing the severities of the substances.	It means that the risk of a cluster has the same value than **the** severity of the substance of the cluster with the highest severity. It captures an "acute" risk.

Figure 6: Risks at cluster level

Risk aggregation at subsystem and mission level

$R_{Average}$ and R_{Acute} were the two main indicators developed to understand for which cluster the obsolescence risk is the most critical. Having two indicators can make the identification of hotspots more complex. Therefore, the project team proposed to use a dimensionless single score to allow for a direct comparison: for each cluster of a given subsystem this single score called $R_{Cluster}$ is defined as: $\mathbf{R_{Cluster} = R_{Average}}$. While allowing for a direct comparison between clusters, this does not prevent from looking at the individual results of both $R_{Average}$ and R_{Acute} as these two indicators provide complementary information.

Before looking at mission level, the risk needs to be aggregated at subsystem level (e.g. subsystem power, subsystem structure, etc.). It was proposed to perform this aggregation by summing $R_{Cluster}$ of all clusters of a given subsystem. This means that the more clusters a subsystem includes, the more complex it is and hence the higher the REACH obsolescence risk is expected to be. Therefore, considering a subsystem with m clusters, the formula is the following: $\mathbf{R_{Subsystem}} = \sum_{i=1}^{m} R_{Cluster\ i}$

As explained, $R_{Subsystem}$ helps rank subsystems at mission level. Once this step is performed, the user has to dig deeper to understand the situation in each of the riskiest subsystems. Therefore, the risk display at subsystem level should include all the detailed information for each cluster.

Risk display

The previous steps help rank quantitatively the subsystems of a space mission. However, it is essential to be able to delve into the specificities of each subsystem and cluster to refine the hotspots. To do so, the project team proposed the following:

- For one given subsystem, to place all the clusters on a two-dimensional ($R_{Average}$; R_{Acute}) graph.
- For one cluster, to present additional indicators to provide further information on its typology, as presented in Table 4.

Table 4: Definition of the ratios used for risk display

Ratio	Comment / description
$X_{Blacklisted}{}^{APS} = \dfrac{\textbf{Number of APSs with blacklisted substances in the cluster}}{\textbf{Total number of APS in the cluster}}$	$X_{Blacklisted}{}^{APS}$ allows to determine if the global risk of the cluster is carried by many APSs or only one APS or a small fraction.
$X_{Blacklisted}{}^{CAS} = \dfrac{\textbf{Number of blacklisted substances (CAS numbers) in the cluster}}{\textbf{Total number of substances (CAS numbers) in the cluster}}$	$X_{Blacklisted}{}^{CAS}$ allows to determine if the global risk of the cluster is carried by many substances or only one substance or a small fraction.
$X_{Diff.Blacklisted}{}^{CAS} = \dfrac{\textbf{Number of } \boldsymbol{different} \textbf{ blacklisted substances (CAS numbers) in the cluster}}{\textbf{Total number of blacklisted substances (CAS numbers) in the cluster}}$	$X_{Diff.Blacklisted}{}^{CAS}$ allows to determine if the global risk of the cluster is carried by many different substances (risk diffuse) or by only a small fraction.

Example of application: case study of the structure subsystem

> *The methodology is applicable to a given subsystem and allows to identify precisely the REACH-related obsolescence risk.*

Presentation

In the frame of this project, it was agreed with ESA to test the methodology on a test case corresponding to a recurrent subsystem of a space mission: the structure of a satellite.

Deployment of the methodology

- **Mapping – clustering and risk assessment**

The following clusters were selected for this case study.

ECSS Class	Name of the class	Subdivision of the ECSS class in subclass needed?
1	Aluminium and Al- alloy	No
4	Titanium and Ti-alloys	No
10	Adhesives, coatings and varnishes	**Yes**
15	Reinforced plastics	No
18	Thermoset plastics	No

After the mapping – clustering step, the methodology presented in the previous sections was applied to the structure.

Results of the case study

The two figures below present the outcomes of the case study.

Risk display – structure subsystem

$R_{Subsystem\text{-}Structure} = 14.06$

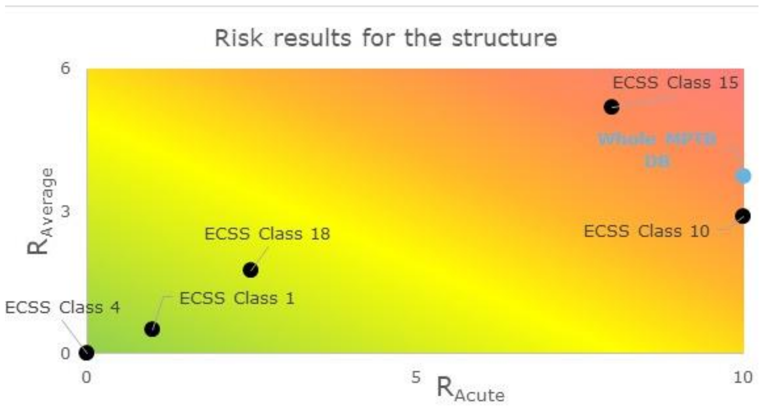


Figure 7: Risks results for the structure

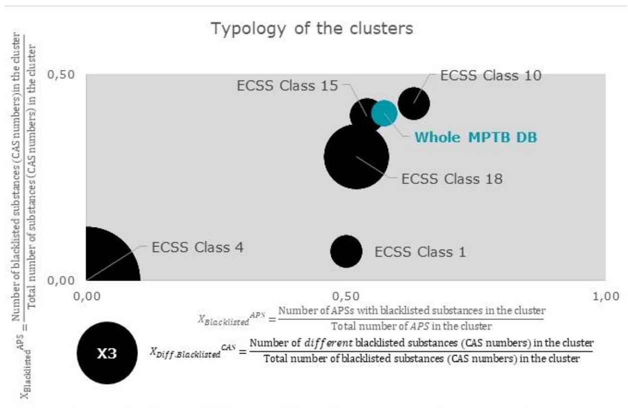


Figure 8: Typology of the clusters

For this subsystem, based on Figure 7, it appears that the ranking of the riskiest clusters is close but not identical whether the user considers R_{Acute} or $R_{Average}$. Indeed, R_{Acute} of ECSS class 15 is lower than the one of ECSS class 10 but the $R_{Average}$ of ECSS class 15 is higher. Therefore, both classes should be considered as first priority, but with different strategies. Indeed, for ECSS class 10, the acute risk is high, meaning that mitigation actions should be initiated in a short notice because there might be substances (and therefore APSs) likely to be obsolete in the short term. However, since the diffuse risk is also high, the user should in parallel adopt an enhanced surveillance of the substances present in its APSs, and not only the ones belonging to the most severe blacklists. For ECSS class 15, the acute risk is lower (even if some substances are present in the recommendation list) but the average risk is high, meaning that measures have to be taken on the whole class to reduce its obsolescence risk step by step.

As presented in Figure 8, the typology of the two riskiest clusters (ECSS class 15 and 10) is relatively close. However, it remains possible to state that risk mitigation strategies would be slightly easier to implement for ECSS class 10. Indeed, both proportion and number of APS with blacklisted substances are higher than in ECSS class 15. The ratio of blacklisted substances and the ratio of *different* blacklisted substances is also higher for class 10. However, since the diffuse risk of ECSS class 15 is high (c.f. Figure 7) and that more than 50% of the APSs have a blacklisted substances, this means that the user cannot focus only on a couple of APSs but should rather adopt an exhaustive approach.

Recommendations for future work

> *Suggestions for further improvements and implementation in ESA systems were proposed.*

A series of recommendations were proposed on areas for improvement of the methodology and how it can be deployed and implemented in ESA systems.

Recommendations for the finalisation of the methodology

- **Potential for improvement of the risk assessment methodology**

The methodology could be refined on several aspects:

- The severity evaluation could be improved with more precise (and complex) approaches, e.g. specific scores per application of an APS and not only based on the lists the substances belong to, or the maturity of potential substitutes.
- More generally, the existence and technological maturity of substitutes to REACH-targeted substances have not been considered within this study and might be considered for an improved version of the methodology in the future.

In the existing methodology, the subsystems are classified based on the $R_{Average}$ score. This approach is coherent to assess the risk of a cluster but it has some limitations. For example, in a fictive case where a cluster would have many substances not belonging to any REACH list but only a couple belonging to Annex XIV, $R_{Average}$ will be low even though there might be an imminent obsolescence risk. A single score combining $R_{Average}$ and R_{Acute} or a range was investigated but no satisfactory solution could be found in the frame of the project. At this point, the consideration of both is $R_{Average}$ and R_{Acute} needed.

- **Additional data requirements for the MPTB database**

The methodology considers the ECSS classes as clustering criterion because that makes sense from the technical point of view but also because other types of groups in the MPTB database are not exhaustively filled (Product type, Chemical nature), i.e. not filled for all APSs. Therefore, we recommend that each APS should be characterised at least with its ECSS class, its Product type and its Chemical Nature.

Recommendations for the methodology deployment in ESA systems

- **Proposition for an automated mapping between the LCA database and the MTPB database**

The constitution of a cluster should not be changed from one assessment to another: it is a generic step, which should be performed once for all (except in case of an update). Therefore, a possibility (once the clustering is done) could be to add product flows to LCI datasets that correspond to clusters instead of substances. Then the calculation in relation with the APSs and the substances could be handled in a separate file (e.g. MS Excel file) or in a dedicated section of the eco-design tool (e.g. SPACE OPERA) with an automated mapping to be implemented within the eco-design tool. The advantage of implementing the clusters in the form of product flows instead of substances is that potential addition / suppression of APS in a cluster would not impact the LCI dataset but the separate calculation file, which allows much more flexibility. Even if the information behind a cluster mapped as a product might not be transparent for the user, this automated mapping would make the risk evaluation process more efficient and adaptable.

- **General proposed approach for the use of the methodology**

Figure 9 presents the steps for the implementation of the REACH obsolescence risk assessment methodology. This figure is articulated in three columns:

- "Done in": mentions the tool(s) used or modified by the step of the proposed deployment approach;
- "Done when": distinguishes the generic steps from the CDF study-specific steps.
- "Done by": mentions the person or office in charge of leading the implementation of the step

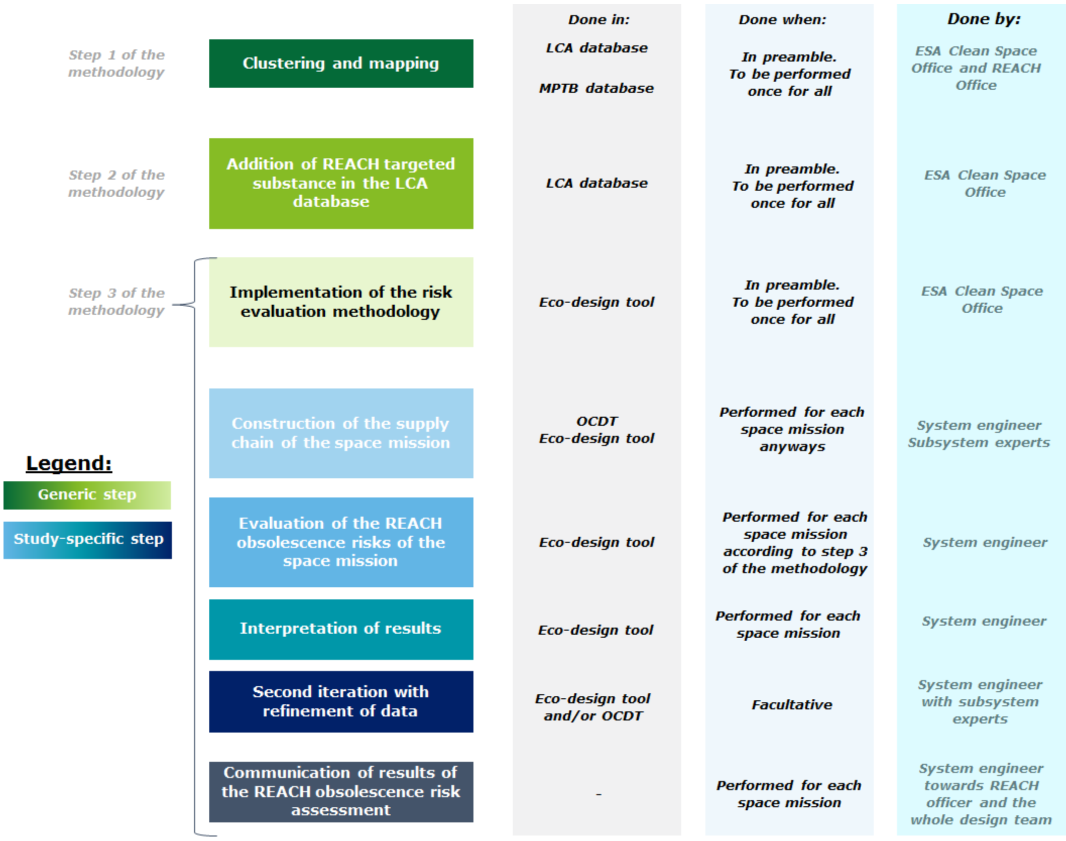


Figure 9: Approach for the integration of the REACH obsolescence risk assessment in ESA's eco-design framework

- **Implementation of a fourth step: 2nd iteration**

As previously stated, this methodology is deemed robust enough to evaluate a generic obsolescence risk of any space mission. Furthermore, it is adaptable enough to evolve and integrate case-by-case modifications when more information is available. , It is proposed to let the possibility open for the system engineer to fill in more specific information on the materials, processes or substances used to improve the robustness of the assessment.

For example, the upstream steps – before the CDF study – which can be periodically refined are:

- The criteria to define clusters if the level of information in the MPTB database increases;
- The severity factor which could be selectively defined for each substance, and even for each couple substance-application.

A case-by-case, CDF study-specific refinement is possible for the following steps of the method: the severity factor can be adjusted for the substances in Annex XVII; the probability factor can be adapted when there is a good level of knowledge on the space mission.

Cooperation with other industrial sectors

Interviews performed in the frame of the project with Renault, Schneider Electric and CETIM showed that other companies and industrial sectors have already developed methodologies to include the identification of REACH-related obsolescence risks in the design of (mass consumer) goods. A first finding from the interviews was that the approach proposed in the frame of this project was rather coherent with what had been performed by these actors. Even though the space sector has its own specificities, ESA could further investigate the relevance of having a closer collaboration with other industrial sectors already advanced on this matter.

CRM into LCA

Goal of the space supply risk indicator

The European space supply risk indicator aims at **assessing the supply risk related to the use of CRMs by the European space sector.** ESA foresees to use the supply risk indicator as a decision-support tool to identify potential future risks in order to monitor the risks and identify mitigation actions (e.g. recycling actions, substitution). This section summarises the methodology to assess the obsolescence risk and how it can be integrated in ESA's eco-design framework.

Criticality methodology for the EU

Introduction

In 2008, the European Commission launched the European Raw Materials Initiative. The aim of this initiative was to secure and improve access to raw materials for the EU and led to the establishment of a list of critical raw materials (CRM) for the EU. In the methodology developed by the Joint Research Centre (JRC) for the European Commission in 2017 to assess the criticality of raw materials, the criticality of a raw material is calculated as a combination of two parameters:

- **Economic Importance (EI)** - describes the importance of a given material in the EU end-use applications and performance of its substitutes in these applications.
- **Supply Risk (SR)** – is based on factors that measure the risk of a disruption in supply of a given material (e.g. supply mix and import reliance, governance performance, trade restrictions and agreements, existence and criticality of substitutes).

In this study, **only the supply risk was used to assess raw material criticality and to build a supply risk indicator for space.** Indeed, it was agreed with ESA that **the economic importance was not relevant in the frame of this project**, as in the context of LCA, which is a product-level evaluation, the extent to which materials are used is already quantified by the LCA.

Short description of the Supply Risk (SR) parameter of the European Commission

The Supply Risk parameter in the 2017 criticality methodology for the EU is based on:

- the market concentration of supplying countries;
- the governance;
- trade characteristics of those countries.

These parameters are considered for the world supply mix (or global supply) and for the EU supply mix respectively. The following formula is applied:

$$SR = \left[(HHI_{WGI-t})_{GS} \times \frac{IR}{2} + (HHI_{WGI-ta})_{EUsourcing} \times \left(1 - \frac{IR}{2}\right)\right] \times (1 - EoL_{RIR}) \times SI_{SR} \qquad 1$$

Where:

- $(HHI_{WGI-t})_{GS}$ and $(HHI_{WGI-ta})_{EUsourcing}$ are the supplying countries concentrations for global suppliers, at a worldwide level (GS) or the supplying countries for European suppliers ($EU_{sourcing}$).
- IR is the import reliance.
- EoL_{RIR} is the recycling parameter or end-of-life recycling rate.
- $SI_{SR-space}$ the substitutability of a raw materials.

The Supply Risk parameter was used as a basis to build the supply risk indicator for space. **Some modifications were necessary to better fit with the European space sector supply risk.** Given that the 2017 JRC formula was defined for a geographical area and not for an industrial sector, new data were needed to adapt the EU supply risk indicator to the space sector.

Adaptation of the EU supply risk parameter

The EU supply risk parameter was modified to make the supply risk formula more specific to the space sector.

Challenges

Adapting the supply risk parameter to the European space sector required data that are not easily available, such as the supplying route of each material, trade agreements… But much information from the EU criticality formula can be directly used. Indeed, the European space sector is closely related to the EU economy and has a minor economic importance in Europe. Therefore, some parameters as defined and calculated in the EU CRM list can be directly applied rather than recalculating them with European space-specific data. Considering this, it was agreed to use the HHI_{WGI}, the IR and the EoL_{-RIR} *as calculated* in the 2017 JRC methodology for the European sector.

Two modifications were applied to make the supply risk formula more specific to the space sector:

- The **Substitutability index**, by including only space-relevant substitutions.
- The physical scarcity of natural resources in the Earth's crust was not included in the 2017 JRC criticality indicator. Therefore, a **resource depletion parameter** was proposed to be able to discriminate which elements are the most easily available in the long run, based on their extractable amount and production rate. This was done taking inspiration from an LCA resource depletion indicator.

Substitutability index adaptation

The substitutability index from the 2017 CRM study was adapted to only consider the materials which can be used in the space sector. The substitutability index of each substitute was recalculated to solely consider relevant substitution materials for the space sector. The materials used for applications such as automotive transport, high tech engineering, rubber, plastics and paint production, ceramics and alloys, electronics and optic equipment were assumed to be relevant substitutes for the space sector (even if temperature and pressure conditions are very different in those terrestrial applications). Based on this new share, the SI was calculated for each material covered by the 2017 criticality methodology.

Integration of a resource depletion parameter

The integration of a resource parameter to the supply risk indicator allows to discriminate which elements are the most easily available in the long run, based on their extractable amount and production rate. The integration of a resource parameter allows to bring more visibility on the long-term, which is relevant in a pre-design context, since the space missions designed at the CDF are manufactured 5 to 10 years later.

The resource depletion parameter in the supply risk indicator for the space sector was based on CML's Abiotic Resource Depletion Potential (ADP). The ADP method calculates the abiotic depletion potential as a function of the rates of extraction of the mineral resource and the amount of natural resources in the Earth's crust. Only the core principle of the ADP was used, considering the ratio of stocks on deposits in the environment. The reserve, defined as the part of the geological stock of a natural mineral material which can be currently economically extracted, was used for the resource depletion indicator in the supply risk formula. The parameter "Extraction on reserves" (ER) gives the inverse of years of reserve left.

$$ER = \frac{Extraction\ rate}{Reserve} = \frac{1}{years\ of\ reserve\ left} \qquad 2$$

In the JRC methodology, the supply risk parameter (SR) ranges from 0.1 to 5.75. The resource depletion factor (ER) varies greatly from material to material, from 1/10 to 1/1000. If the SR is multiplied directly by the ER, the ER will have a too strong influence on the SR value. Hence the contribution of the ER was defined and adapted to include it in the SR formula. Based on our expertise, we suggested to allow the resource depletion factor to have a maximal influence of 10% on the SR.

Another aspect to consider is the fact that having a lot of supply does not reduce the supply risk (the supply can still be disrupted due to e.g. geopolitical issues). However, not having a lot of stock induces an additional supply risk. Therefore, the ER should be seen as a factor increasing the supply risk (SR'=SR+X).

Based on this constraint, the resource depletion factor (RDF) included in the SR formula as a multiplier for the raw material i was defined as:

$$RDF_i = 1 + \alpha \cdot \frac{(ER_i - ER_{min})}{(ER_{max} - ER_{min})} \quad 3$$

Where:

- ER_i is the years of reserve left for the material i
- ER_{max} and ER_{min} the maximum and minimum years of reserve left for all raw materials considered
- α is a dimensionless coefficient which defines the maximum contribution of the ER to the SR (set to 10%).

Overview of the supply risk indicator for space

Based on the methodological adaptation proposed in this report, the supply risk indicator for the European space sector SR_{sp} was defined as:

$$SR_{sp} = \left[(HHI_{WGI-t})_{GS} \times \frac{IR}{2} + (HHI_{WGI-ta})_{EUsourcing} \times \left(1 - \frac{IR}{2}\right)\right] \times (1 - EoL_{RIR}) \times SI_{SR-space} \times RDF$$

Where:

- $(HHI_{WGI-t})_{GS}$ and $(HHI_{WGI-ta})_{EUsourcing}$ are the supplying countries concentrations for global suppliers (GS) or European suppliers ($EU_{sourcing}$). The supplying countries concentrations defined in the 2017 JRC methodology for the European sector are directly applied IR and the EoL-RIR calculated in the 2017 JRC methodology for the European sector
- IR assess the import reliance. The factors from the 2017 JRC methodology for the European sector are used
- EoL_{RIR} is the recycling parameter or end-of-life recycling rate. The rate defined in the 2017 JRC methodology for the European sector is directly applied
- $SI_{SR-space}$ represents the substitutability of a raw materials. This indicator has been adapted to the space sector, by considering solely the materials which can be specifically used in the space sector.
- RDF is the resource depletion factor that is added to the initial formula as a multiplier.

The following table displays the values of the supply risk as calculated for the JRC methodology (SR_{EU}) and adapted for the European Space sector, for materials used in the space sector (SR_{sp}):

Table 5 : Supply risk factor for European Union and space sector

Material	SR_{EU}	SR_{sp}	Difference between SR_{EU} and SR_{sp}
Aluminium	0.49	0.51	+4%
Antimony	4.33	4.33	0%
Barite	1.56	1.45	-7%
Bentonite	0.25	0.27	+7%
Beryllium	2.41	2.40	0%
Bismuth	3.82	3.83	0%
Borates	3.01	3.22	+7%
Cerium	5.75	5.76	0%
Chromium	0.90	0.93	+3%
Coking Coal	1.02	0.99	-3%
Copper	0.21	0.21	-2%
Dysprosium	5.19	5.26	+1%
Europium	3.4	3.66	+8%
Feldspar	0.65	0.65	0%
Fluorspar	1.27	1.03	-19%
Gadolinium	5.08	5.15	+1%
Manganese	0.92	0.92	0%
Molybdenum	0.86	0.78	-9%
Natural Cork	1.07	1.14	+6%
Natural Graphite	2.88	3.06	+6%
Neodymium	4.81	4.71	-2%
Nickel	0.34	0.34	+1%
Niobium	3.08	3.18	+3%
Palladium	1.71	1.59	-7%
Phosphorous	4.06	4.50	+11%
Platinum	2.15	2.23	+4%
Praseodymium	4.64	4.38	-6%
Refined cobalt	0.90	0.95	+6%
Rhenium	0.95	0.98	+3%
Rhodium	2.49	2.51	+1%
Ruthenium	3.43	3.62	+6%
Samarium	4.45	4.42	-1%

Material	SR_{EU}	SR_{sp}	Difference between SR_{EU} and SR_{sp}
Gallium	1.43	1.52	+6%
Germanium	1.9	1.90	0%
Gold	0.22	0.21	-3%
Hafnium	1.31	1.31	0%
Helium	1.60	1.74	+9%
Ho, Lu, Yb, Tm	5.42	5.44	0%
Indium	2.39	2.44	+2%
Iridium	2.81	2.82	0%
Iron ore	0.78	0.81	+4%
Kaolin	0.50	0.58	+16%
Lanthanum	5.38	5.36	0%
Lead	0.10	0.10	+2%
Limestone	0.12	0.13	+10%
Lithium	1.04	1.12	+8%
Magnesium	3.98	4.03	+1%

Material	SR_{EU}	SR_{sp}	Difference between SR_{EU} and SR_{sp}
Scandium	2.87	2.94	+2%
Selenium	0.37	0.37	0%
Silicon metal	0.99	0.99	0%
Silver	0.53	0.57	+8%
Talc	0.42	0.43	+2%
Tantalum	0.97	0.97	0%
Tellurium	0.75	0.73	-2%
Terbium	4.77	4.78	0%
Tin	0.75	0.84	+13%
Titanium	0.33	0.32	-2%
Tungsten	1.75	1.76	0%
Vanadium	0.56	0.56	+1%
Yttrium	3.75	3.80	+1%
Zinc	0.35	0.35	+1%

For information, the JRC arbitrarily defined the list of CRMs based on thresholds of 2.5 for the economic importance and 1 for the supply risk. In the table above, the following colour code was used:

- materials with a supply risk higher than 1 are in red.
- since this threshold of 1 is arbitrary, materials with a supply risk comprised between 0.9 and 1 are in orange, considered in an "intermediate" zone of criticality.

Example of application

> *The supply risk indicator can be implemented into an LCA framework and allows to show how CRM are used in the value chain of a space mission.*

Presentation

A simplified test case was performed to assess the CRM obsolescence risk of a space mission within a LCA framework.

First, a characterisation method assessing the supply risk of materials was implemented into the LCA software SimaPro, with the characterisation factors corresponding to the values of the supply risk indicator for space, called "supply risk factors" below.

Then, the space mission Sentinel 3b assessed in the "GreenSat" project was selected as a test case to study the results of the supply risk indicator on a space system. The scope of the analysis was restricted to specific elements of the space mission (production of payload components; production of platform components; propellant production; balancing masses). This choice was made to focus the assessment on space-specific parts of the studied system. Other activities occurring in the life cycle of the space mission related to design activities, to the Launch and Ground Segments were deemed out of scope of this assessment.

Implementation of the supply risk indicator for space in the LCA software

The supply risk indicator for space was directly implemented into the LCA software as a new characterisation method. Each elementary flow corresponding to a critical raw material was mapped to its corresponding supply risk factor. When a single material had several corresponding elementary flows (e.g. lead can be found in the flows "Lead"; "Lead, Pb 0.014%, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, in ore" and "Lead, Pb 3.6E-1%, in mixed ore"), all the corresponding elementary flows were added to the characterisation method with the same supply risk factor.

The results of the characterisation should be dimensionless, since the aim is to know where a critical raw material is used in the supply chain independently of the quantity used. However, it was not possible in the frame of the test case to establish a LCA calculation procedure that would not consider the masses of materials; hence the results given by the LCA software were provided in kg of CRM per FU.

Results and interpretation

Two types of results can be exported from the LCA tool:

1. **A ranking of elementary flows, based on their contribution**: The table below displays the ten materials with the highest value. The materials defined as "critical" by the EU, i.e. with a SR_{sp} above 1, are shown in **bold**.

Table 6 - Extract of SimaPro results

N°	Substance	Supply risk kg raw materials/FU
1	Aluminium	342
2	**Fluorspar**	206
3	Iron	99
4	**Phosphorus, 18% in apatite, 4% in crude ore**	87
5	Chromium	35
6	Copper, Cu 0.38%, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Pb 0.014%, in ore	35
7	Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore	26
8	Copper, 0.59% in sulfide, Cu 0.22% and Mo 8.2E-3% in crude ore	22
9	Copper, 0.97% in sulfide, Cu 0.36% and Mo 4.1E-2% in crude ore	21
10	**Germanium**	21

When looking at the results, several limitations of this method appear:

- The supply risk factors are multiplied by the amount of material consumed. This implies that materials such as Aluminium that are used in large quantities for various structural elements on the S/C appear with the highest value. However, Aluminium is not a particularly critical raw material, which is a limitation of the method.
- Copper appears several times in the top ten list since the elementary flows extracted from ores at various concentrations are distinguished in SimaPro, but this information is not needed to assess the supply risk.

2. **A mapping that gives a useful view on how specific materials are used in the modelled value chain of the space mission**. Hereunder is one example of mapping for phosphorous, a material defined as critical by the European Commission. This mapping is a simplification of the results provided by the LCA tool, to ease the interpretation.

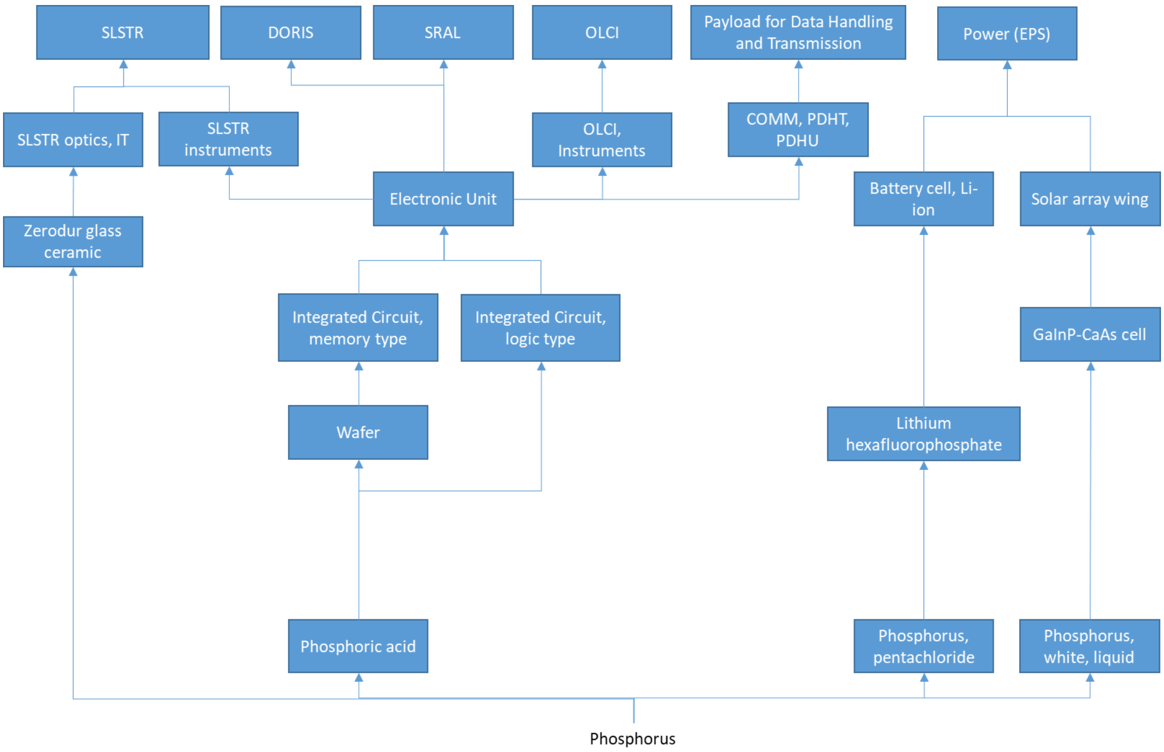


Figure 10 – Mapping of the sources of phosphorous consumption

This type of mapping shows that a same material is used for the production of several parts of the system.

Conclusion

The adaptation of the Supply Risk formula developed by the JRC to the space sector highlighted many challenges and also enabled to establish new parameters adapted to the space sector supply issues. Based on the JRC methodology, the substitution factor was adapted to only consider relevant substitutions and a resource depletion factor was added to the SR formula to consider the resource depletion aspect.

By including these adaptations, variations of most raw materials are comprised between -5% and +5% compared to the initial values published by the JRC. For some raw materials in particular though, the outcomes of the supply risk calculation are significantly different than the formula developed for the European Union, with a variation between -19% and +16%. Finally, the most critical raw material in terms of supply risk is cerium, which is used for the manufacture of chemicals, glass, optical instrument, iron, steel and ferroalloys, batteries and accumulators. The proposed supply risk indicator was tested over a whole space segment and implemented into an LCA software. Several ways to exploit and present the results were also presented, by listing the hotspots or by displaying the value chain of a given targeted CRM.

Limitations and recommendations for future work

Characterisation method

- **Limitations of a criticality threshold**

In this project, the materials with a supply risk value higher than 1 were considered as “critical”. However, the criticality shall not be viewed in a binary way: raw materials with a supply risk of 0.9 can be considered as being in a “grey area”. Therefore, several possibilities to apply the proposed methodology exist: all materials studied, as was done in the test case; all materials which supply risk is higher to 0.9 and all materials which supply risk is higher than 1.

- **Inclusion of the quantity of materials**

It was seen that LCA tools do not yet include calculation procedures that only take into consideration the presence of an elementary flow in the LCA model independently of the quantity used, which limits the relevance of the results of the supply risk indicator. A binary calculation approach (with 1 in the case of a use of a given elementary flow, 0 otherwise) would be more appropriate: This would make the obsolescence risk increase with a higher number of occurrences of a given CRM, rather than high quantities of this CRM.

- **Level of confidence into the flow nomenclature of the background LCI database and LCI data on raw materials extraction**

Several elementary flows in the LCI database correspond to the same raw material, implying that this raw material appears several times in the results. Hence, the mapping of the flows should be done so as to gather all elementary flows related to a same raw material. A more critical limitation is the fact that background LCI datasets related to raw materials extraction such as rare earth elements (REE) extraction are of poor granularity. That issue needs to be explored in more detail to clarify whether some materials are really consumed in the system or if they are co-products of the extraction of the materials actually consumed by the considered activity in the foreground (e.g. piece of equipment). In addition, the supply risk can also occur not at the extraction level but at a refining step. This differentiation is not possible if we rely solely on elementary flows, which by definition correspond to material flows from the biosphere to the technosphere, i.e. extraction flows only.

- **Scope of the supply risk indicator for space**

In this study, a part of the space mission was selected to only assess a space-specific system, and to avoid assessing activities in the background system that are not relevant for the pre-design stage. This requires to define more precisely what is considered in the scope of the supply risk assessment of a space mission. Since the lever of action for ESA occurs at earlier design stages of space systems, our proposition would be to include ***"every hardware designed by the space sector for the space segment***" in the scope of the supply risk indicator.

Implementation in ESA's LCA and eco-design framework

- **Specific mapping of CRM flows into space LCI datasets**

The limitations described above imply that the relevance of the connection between an LCA model and a CRM-related obsolescence risk assessment methodology is limited to the identification of hotspots within the value chain of the specific space mission studied. To overcome these limitations, it may be required to perform a specific "mapping" step of CRMs with ESA LCI datasets, just like what was proposed for the REACH obsolescence risk from the beginning. It would consist, for each LCI dataset developed by ESA in:

- looking at the criticality hotspot analysis to sort out hotspots that do not belong to the defined scope (e.g. a hotspot related to a background process such as electricity production or transportation).
- implementing additional product flows related to the use of a given critical raw material.

Alternatively, it might be that the limitations mentioned above are fine considering that the methodology aims to be used at early design stage. Additional test cases may be needed to have a clearer idea of the robustness of the proposed methodology, e.g. test cases on other typologies of space missions.

- **Proposition to implement the methodology in ESA's eco-design tool**

The case study performed here was done in SimaPro. However, since it mostly aims to be applied at early design stage, the project team recommends to deploy the methodology in SPACE OPERA, the eco-design tool connected to the OCDT. The advantage is that it would be easier to implement IT developments in SPACE OPERA, SimaPro being less flexible for ESA.

- **Propositions for future updates of the supply risk factors for space**

The list of CRMs is regularly updated by the European Commission. So far, it has been updated every three years. Based on that, ESA could envisage to update the terms of the supply risk following the same time horizon. For terms like the Substitutability Index (SI), an update could be carried out independently, for instance every six years given the time scale of new developments in the space industry. It could be the same for the Resource Depletion Factor (RDF), unless LCA resource depletion indicators make considerable progress in the meantime, which would deserve attention and, potentially, to be included into the calculation of this term.

Other recommendations for future work

- **Relevance of a simplified approach in the short-term to identify CRM obsolescence risks at early design stage**

In practice, the design engineer could use the supply risk indicator for space in two different ways:

1/ It could use the list of CRM elaborated in this study as a checklist of CRMs to be avoided, and
2/ It could derive a mapping of the corresponding components or equipment for used CRMs, using this information to communicate with domain experts. This could be done via a mapping of the use of CRM in space system equipment, a first version of which can be based on LCA information. Such a mapping could be an acceptable first level of information, given the uncertainties related to early design. This mapping could be progressively performed according to a prioritised list, based on the list of CRMs ranked by their supply risk factor.

However, the system engineer may not know which raw material is used in each equipment. It could be interesting to create a factsheet that lists the CRM used for each type of equipment or material. These factsheets could also help inform the design community on the CRM supply risks.

It would be particularly interesting to apply this approach for the development of new technologies rather than in the context of the early design of space missions.

- **Establishment of a state of the art of CRM used in the space sector**

The European Space Industry does not have a state of the art of its main obsolescence risks related to CRM. Therefore, to raise awareness about the challenges related to the use of CRM and to initiate obsolescence management strategies, it would be interesting to perform a similar study as the criticality assessment performed by the EC at European level but focusing on the European space sector only. The assessment of the supply risk of each material at sectorial level would be complemented by an assessment of the Economic Importance. This would consist in the identification of the use of CRMs depending on the type of equipment and the application. Moreover, the calculation of the Economic Importance could help establish an "absolute" hierarchy between CRMs (i.e. not in the context of a specific space project). The benefit of such a work would be that it could help the European Space Industry implement mitigation actions towards CRM obsolescence risk at a broader level than the design of a space mission.

- **Potential collaboration with other industrial sectors**

As for the REACH obsolescence risk topic, it may be valuable for ESA to initiate collaborations with other European industries to mutualise efforts in the challenges related to CRMs. Several structures gathering NGOs, academia, industry and public authorities already exist at the European level.

- **Use of the LCA framework for CRM-related decisions**

LCA has been identified at the European-level as an interesting approach to support policy objectives related to resources and to CRM, hence developments in that direction are to be expected in the next few years. These evolutions could help further develop the methodology proposed in this report.

LCA into REACH

The objective of the task "LCA into REACH" was to establish how LCA can support REACH risk management efforts undertaken by ESA, namely support in the authorization and restriction processes.

Combining LCA into REACH processes is not a well-researched area, which was evidenced by lack of studies found during literature review. However, references to LCA were found from ECHA guidance documents for Authorisation. In those guidance documents, ECHA does not give practical advice on how to utilise LCA in AfA process but rather identifies it as one potential tool used to assess impacts. In order to get more clarity on ECHA's LCA references, ECHA was consulted via email and direct phone interview. During the consultations ECHA clarified that they have received 4 applications for authorisation where "light" LCA had been used. ECHA noted that the LCA used in these four AfA was not critical in the opinion making process of SEAC. ECHA also repeated the statement that was also included in the guidance document references, which said that including a full LCA into an application for authorisation could include would add another layer of complexity to the application.

REACH and LCA processes have different scopes, which makes aligning them difficult. If LCA is used to provide additional information for an AfA, the applicant should try to align the scope of the LCA with the applied-for-use scenario of the hazardous substance. In order to test how the alignment of the two processes would be done in practice and how the results from LCA could be utilised in an AfA, a case study was performed on hydrazine and alternative propellants (HPGP and H_2O_2 98 %). The results of the case study showed that HPGP has the highest impacts in 10 out of 13 categories, including notably global warming potential (GWP). However, it also showed that overall, H_2O_2 98% environmental impacts are lower than for the two other propellants. In order to better compare the results of the case study, a single-score value was derived for all three propellants. The single-score of HPGP was the highest of the three propellants assessed, but the single-score of H_2O_2 98% indicates that the alternative propellant has the smallest impacts of all three propellants. This is in line with the midpoint results of the assessment.

Whether the results from the conducted case study can be used in an AfA or not have to be assessed case-specifically. In this particular case study LCA results showed that alternative HPGP had bigger environmental impacts than hydrazine, whereas H_2O_2 98% had the smallest impacts of them all. Thus results from the LCA could be used to argue for discarding HPGP as an alternative, but the same cannot be said of H_2O_2 98%. It is noted that most often alternatives in an analysis of alternatives are discarded based on their technical or economic feasibility. Environmental impacts are very rarely even presented in an AfA to argue for not substituting into a specific alternative. However, it is still possible that a situation would occur where an alternative would be technically and economically feasible but its environmental impacts are so severe that the alternative should be disregarded on these grounds. Therefore, if a company has the capability to perform LCA or similar environmental impact analysis for substances subject to authorisation, they may decide to utilize it.

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