Development of a methodological framework for the sustainability evaluation of the Flemish moonshot innovation programme

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Context of the assignment

In November 2021, the assignment *'Development of a methodological framework for the sustainability evaluation of the Flemish MOONSHOt innovation programme'* started. This project was carried out by VITO in collaboration with Deloitte, University of Antwerp, Catholic University of Leuven (KUL), and Ghent University, commissioned by VLAIO and Catalisti. Specifically, the assignment involved *'putting forward a harmonized methodological framework that allows for the analysis of projects proposed and implemented within the MOONSHOT innovation programme in terms of their potential economic feasibility and environmental impact'*. The economic feasibility involves examining the calculation of total costs (both operational and investment), revenues, and profitability of the project. The environmental impact focuses on the contribution to the fight against climate change, i.e., the project's contribution to the Flemish objectives regarding carbon reduction.

The assignment takes place in the context of the Climate Strategy of the Flemish government, which sets the ambition of making the Flemish industry CO_2-low and carbon circular by 2050. This climate and energy challenge cannot be solved with incremental innovations alone; radical innovations are also needed to achieve the transition to a low-carbon economy and society. Therefore, the MOONSHOT programme, an innovation programme in which the Flemish government invests 400 million euros over a period of 20 years, brings together the forces of the Flemish industry, knowledge institutions, and government agencies. The goal is to develop ground-breaking technologies by 2040 to create new climate-friendly processes and products by 2050 that contribute to achieving the Flemish climate objectives.

The assignment arose from the need for an independent, objective, transparent, and comprehensive analysis method for the MOONSHOT projects. Specifically, the various stakeholders (scientific, policy, and business) expressed a need for more uniformity and insights regarding the sustainability analysis of new technologies. There was a need for clear guidelines on the approach to this analysis. Such a framework that can be directly applied to the MOONSHOT innovation programme did not exist before this assignment.

Given the economic, societal, and ecological importance of this study, it is important to be able to share the results widely. This publication is the culmination of the assignment and will provide a summary of the main elements of the developed methodological framework and explain its importance and purpose. Furthermore, this publication can be used to show other parties within the innovation landscape (e.g., other spearhead clusters, research institutions, funding agencies, companies) that they can also rely on the principles of the proposed methodological framework.

The MOONSHOT innovation programme

The MOONSHOT innovation programme aims to develop ground-breaking technologies by 2040 to support the Flemish climate strategy through innovative research within Flanders. Within the MOONSHOT initiative, the refining, chemical, iron, and steel industries are highlighted because these sectors play a central role in the Flemish industrial landscape. Their wide range of products is used in almost all downstream sectors (e.g., for the production of lightweight transportation materials, installations, insulation materials for homes, transportation fuels, etc.) and therefore are a significant source of CO_2 emissions.

The MOONSHOT innovation programme has defined four major research lines or MOONSHOT Research Trajectories (MOTs):

1. **Biobased chemistry**: This research trajectory focuses on exploring how renewable and climate-friendly resources such as biomass can replace fossil resources. Projects supported within this trajectory include those related to lignin (a type of natural waste material), sugar as a raw material, and biorefineries.
2. **Circularity of carbon in materials**: Within this MOT, the emphasis is on research into recycling and reusing plastics. Specifically, the initial projects revolve around the recycling of plastics and other carbon-containing materials.
3. **Electrification and radical process transformation**: The goal of this trajectory is to electrify industrial processes and make them CO_2-smart. The Flemish Government has previously supported projects related to the electrification of polyolefin and ammonia production, conversion of CO_2 to CO, and CO_2 capture.
4. **Energy innovation**: As the Flemish industry is highly energy-intensive, sustainable energy is a central focus in this fourth research trajectory. This includes research on topics such as hydrogen transport and storage, hydrogen production, advanced heat systems, energy flexibility, and bringing together different sectors to make the energy-intensive industry more sustainable. There is a close collaboration with Flux50, the spearhead cluster for energy.

Within each research line, specific technical, economic, and environmental objectives and key performance indicators (KPIs) have been defined to support the development of more sustainable solutions. The MOT-specific objectives and KPIs can be consulted on the MOONSHOT Flanders website[1].

Chemicals and plastics play a crucial role in reducing CO_2 emissions and providing necessary solutions to other sectors to make their products and processes more sustainable. That is why the Flemish government has entrusted Catalisti, the spearhead cluster for the Flemish chemical and plastics industry, with taking the lead in implementing the MOONSHOT initiative. Catalisti works closely with the other Flemish spearhead clusters, including De Blauwe Cluster, Flanders' FOOD, Flux50, VIL, and MEDVIA, in setting up and executing the MOONSHOT initiative. Specifically, Catalisti is responsible for the operational management of MOONSHOT and ensures that projects are carried out in a high-quality manner and that research results find their way into applications throughout the Flemish industry.

Further, the governance of the MOONSHOT innovation programme is carried out by the MOONSHOT Governance Board (MGB), supported by the Scientific Advisory Board (WAR). The collaboration between all these parties and other stakeholders emphasizes the importance of having a uniform framework to analyse the economic feasibility and environmental impact of projects within the MOONSHOT innovation program. This framework can be used during both the application phase and the execution phase of the project.

[1] *https://MOONSHOTflanders.be/MOONSHOT-research-trajectories/*

Work performed

Brief summary of the assignment and the deliverables

The assignment involved creating a harmonized methodological framework that allows for the analysis of projects proposed and implemented within the MOONSHOT innovation programme, including their economic and environmental impact. This was done in several stages.

First, the current state of play ('state-of-the-art') of methodologies for sustainability assessments was described. To ensure broad acceptance of the methodological framework and template, a number of interviews and working groups were organized with various stakeholders. During these sessions, the research needs and expectations of the assignment were identified. Based on this, a specific methodological framework was developed for use within the MOONSHOT innovation programme. The framework, which includes methodological guidelines to support sustainability evaluation, was also translated into a template that is publicly available and intended to provide applicants and project partners of the MOONSHOT innovation programme with a unified approach. The methodological framework and template were tested on ongoing MOONSHOT projects to demonstrate their applicability.

Through this publication, we aim to inform the public about the main elements of the proposed methodology and the benefits of its use. It also provides an estimation of the required time, resources, and competencies for evaluating MOONSHOT projects, as well as expanding the methodology to evaluate project proposals within other supporting instruments.

Table 1: A multi-phased approach with the principal deliverables per project phase

Consultation of and feedback with stakeholders and experts	Phase and deliverable
	Description of the state-of-the-art
	Overview with description of existing methodologies (incl. SWOT, benchmark, databases/parameters, information per TRL), challenges regarding harmonization and gap analysis of available and needed methods and tools.
	Development of the methodological framework and template
	Description of the elaborated methodological framework for analysing economic and environmental impact during different stages of technology development.
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	Explanation of the importance and purpose of the methodological framework including an understandable summary of the main elements and next steps around its use.

1.1. Description of the state-of-the-art[2]

There are already a number of methodologies available for analysing the economic and environmental impact of new technologies and processes. This phase of the project involved describing the state-of-the-art of the main methodologies that align with the main objective and scope of the MOONSHOT programme in a publicly available

[2] Cf. *State-of-the-art of sustainability assessment methodologies and methods and their fit for the evaluation of MOONSHOT initiatives*

report. Specifically, the purpose and scope of the different methodologies were defined, and their advantages, disadvantages, and differences were identified.

The selected methodologies were categorized into five types of assessments:

1. Technical assessments

These methodologies quantify physical flows but do not include any further cost or benefit analysis.

Technical assessments often form the basis of economic and ecological sustainability evaluation methods. They can be used to calculate indicators (i.e., parameters that allow for monitoring a process) such as the recycling rate or energy consumption of a product or process.

2. Economic assessments

The second group of evaluation methods focuses on the economic feasibility and sustainability of new technologies. In this evaluation, the costs and benefits of new technologies and processes are quantified.

The most commonly used methodologies are aimed at calculating the total cost of a product or process. They are also used to determine typical investment parameters such as net present value or payback period.

3. Environmental assessments

The third group of evaluation methodologies focuses on the environmental impact assessment of new technologies, processes, and products. These methodologies go beyond technical assessments as they quantify the burden of physical flows on the environment.

The most well-known example is conducting a life cycle assessment (LCA), which examines the impact of a product or process on climate, resource use, acidification, etc.

4. Integrated assessments

A fourth group of evaluation methods combines both economic and environmental impact to identify trade-offs and mutual benefits.

One example of this is eco-efficiency, which looks at both the environmental impact and economic feasibility simultaneously.

5. Uncertainty analyses

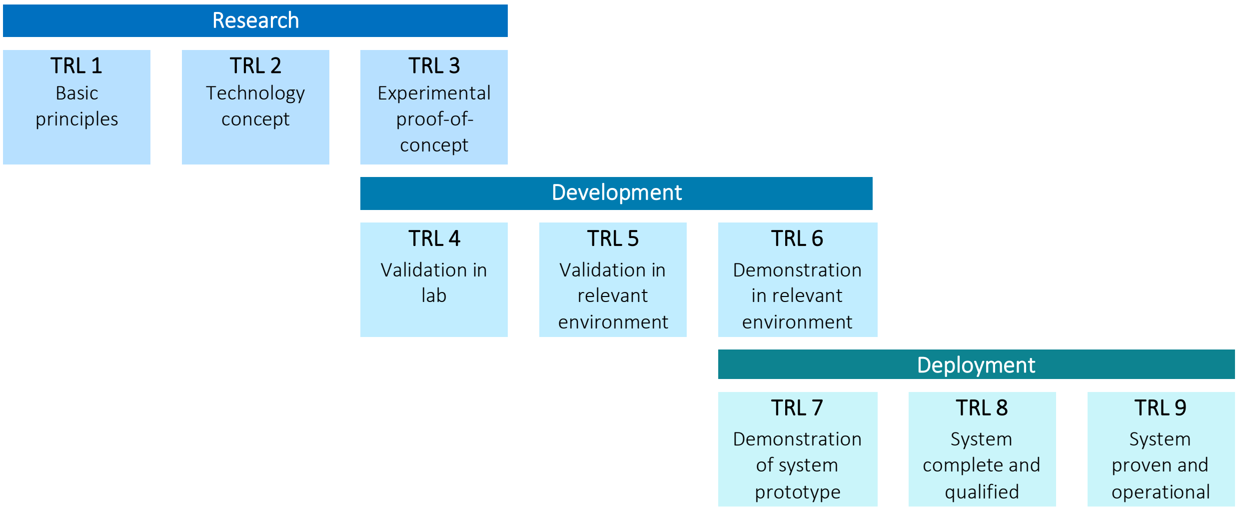
Uncertainty analyses are often used in the above-mentioned methods because the results of economic feasibility or environmental impact do not provide 100% certainty for new technologies. This is because the assessments are based on choices and assumptions, as well as available data that inevitably contain uncertainties.

In many cases, the sensitivity of a specific decision parameter to a change in an input parameter is examined. For example, one might investigate how sensitive the payback period of a process is to a change in raw material prices. This can be accomplished through scenario analysis, which includes optimistic, pessimistic, and base scenarios.

The state-of-the-art report provides a general description of sustainability methodologies and lists the indicators commonly used for the quantitative assessment of sustainability impact. Additionally, the report provides an overview of available methodological guidelines and tools. For each methodology, the key strengths and limitations are described. Finally, each chapter concludes with a summary of the available databases that can be consulted.

Within the MOONSHOT innovation programme, the projects are in an early stage of development, which is measured by the "technology readiness level" (TRL) - a classification for the level of development of a technology[3]. The development stage can indicate whether the technology is still in a laboratory, pilot, demonstration, or industrial development stage. Specifically, the MOONSHOT projects have a TRL lower than 6 (on a scale of 1 to 9). This has some implications as a result.

Figure 1: Overview of the different Technology Readiness Levels (TRLs)



Assessing the economic feasibility and environmental impact of new technologies is crucial but can also be challenging. Existing assessment methods often require large amounts of data and time, which can be a problem for technologies that are still in the early stages of development (i.e., low TRL). Conducting sustainability assessments during these early stages poses some significant challenges. Specifically, these challenges include defining methodological choices (e.g., determining the goal, functionality, and system boundaries i.e., which processes in the value chain are included in the evaluation), finding high-quality data, and dealing with uncertainty. For these reasons, caution must be exercised when directly using results to compare technologies and make decisions.

For these reasons, existing assessment methods are not directly suitable for assessing new technologies in the early stages of development, such as those in the MOONSHOT programme. Instead, these methods are used to identify key parameters that can further optimize the technology. This way, technological development can be guided towards the most sustainable endpoint, even though the exact value of this endpoint is still uncertain.

Therefore, a specific selection of indicators (i.e., assessment criteria) was made, taking into account the purpose and scope of MOONSHOT. Examples of indicators include payback period, average project cost, climate impact, and energy use per ton of avoided CO_2 emissions. The required level of detail may increase depending on the stage of development and the phase of the project. Assessing the sustainability potential requires both time and data availability. Therefore, the requested level of detail should be aligned with what can reasonably be expected in different project phases and stages of development. Furthermore, the sustainability evaluation can be used to define clear roadmaps for guiding technological developments and setting research goals.

In the next phase of the project, the above findings were translated into concrete methodological guidelines.

[3] *https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf*

1.2. Methodological framework and template

There are various assessment approaches for the economic and environmental impact of products, processes, and services. However, there is no harmonized framework for evaluating innovation projects with a focus on new technologies that aligns with the purpose of the MOONSHOT innovation programme. Based on the state-of-the-art description and consultation with various stakeholders, a selection of methodological guidelines and indicators was therefore made.

In the **application** phase of the projects, before the MOONSHOT selection is made, the sustainability evaluation consists of both qualitative and quantitative components. The quantitative part provides insights into both the economic and environmental impact with the aim of identifying the key influencing parameters. In the application phase, a number of accompanying questions are also asked to help researchers gain the necessary insights. This allows for determining the initial research objectives that will influence future go/no-go milestones. The goal in this phase is therefore not to map out the exact economic and environmental impact since this is not yet possible with the limited resources available at that time.

The methodological framework and accompanying template are primarily aimed at researchers in the **implementation** phase of the MOONSHOT innovation programme. The main goal of the sustainability analysis is to gain a clear understanding of the potential sustainability impact of an innovation and the steps needed to achieve it. The framework serves to guide researchers towards the most sustainable configuration of their development, given the MOONSHOT context. This is done by establishing clear research objectives and helping determine the technological roadmap for implementation. The methodological framework for sustainability analysis fully meets the demand of the MOONSHOT innovation programme to:

1. Have **a standardized evaluation framework** for **sustainability** analyses;
2. Have an evaluation method that can provide a **benchmark with alternative concepts;**
3. Have an evaluation method that can provide a **quantitative translation into the KPIs** of the different **MOONSHOT research trajectories** (MOTs);
4. Have an evaluation method that **allows for adjustments throughout the project duration**.

The majority of the methodological guidelines are based on the principles of techno-economic evaluation (TEA) and life cycle assessment (LCA), as these are most suitable for the MOONSHOT innovation programme. The guidelines follow the key steps of these methodologies but are not intended to provide a new standard for these existing methodologies. Instead, the aim is to utilize the best practices of these existing assessment methods to support the goal of the MOONSHOT innovation programme. This means that following the methodological framework does not result in calculating the absolute economic and environmental impact, nor does it aim to compare unrelated projects in terms of sustainability impact.

Complementary to the methodological framework, a template (in Excel format) was developed to support project applicants in the submission and uniform analysis of research projects within the measurable objectives of the MOONSHOT innovation programme. Instructional videos were provided to support users in filling out and using the template, while a dashboard displays the results. Finally, the feasibility of the methodological framework and template was tested through a proof-of-concept phase. This was applied to four ongoing projects (specifically, one project per MOONSHOT research trajectory), and final feedback on the clarity and applicability of the methodological guidelines and template was collected from the research groups.

The proposed methodological framework includes clear agreements on system boundaries (i.e., which processes in the value chain are included in the evaluation), methodological choices, decision criteria to be used, and standard values necessary to evaluate projects in an independent, objective, and transparent manner. The guidelines provide information on how the evaluations should be conducted depending on the MOT and the technology readiness level (TRL).

As mentioned earlier, the specific TRL (Technology Readiness Level) of a project has a significant influence on the availability and quality of data, and therefore also on the accuracy of the sustainability evaluation being conducted. For projects within the MOONSHOT programme, it is important to determine the TRL in order to correctly apply the methodological framework. The specific guidelines differ between low and high TRL levels. The methodological framework allows for supporting technology developers in setting research goals and continuously assessing and adjusting them throughout the development process.

The same applies to the party asking the question, meaning that a government agency or grant provider will require different information than a technology developer. In addition to evaluating "hard" KPIs (Key Performance Indicators) that focus on environmental aspects such as CO_2 emissions, sufficient attention must also be given to the technical and economic feasibility of further developments. The development of this methodological framework enables support in allocating (follow-up) projects and budgets, as well as facilitating communication among all stakeholders.

The intended application of project results is to support R&D, identify new technological trajectories, and support the valorisation of technology. An important consideration is that the goal of the projects and their subsequent results should support the further improvement, development, and/or implementation of the analysed system. By evaluating, for example, the economic feasibility and the impact on climate change of a process and identifying the processes/emissions that contribute the most, the system can be further adjusted to improve its performance. Such an analysis can then support the development towards the MOT objectives.

For the MOONSHOT innovation programme, the overall goal is to compare the development with the state-of-the-art and new technologies, identify hotspots for further improvement, and demonstrate the contribution to the specific objectives and KPIs of the MOTs. It is important to further specify this overall goal for each project. The more specific the objective, the more transparent and comparable the results will be.

When evaluating the environmental and economic performance of a new system, it is important to do so for an expected future industrial scale. The reason for this is twofold: on one hand, scaling up the technology brings economies of scale and further optimization of the process, which can lead to better performance (efficiency), lower costs, and effects. On the other hand, the technology can be compared with its mature counterpart already on the market and applied on a commercial scale. Comparisons of technologies at different scales would not be consistent and would yield biased results. The methodological framework enables the definition of such a scale.

Finally, this uniform methodological framework not only encompasses the different TRLs but also provides an overarching view of the entire value chain. This value chain approach is crucial in evaluating technologies to ensure that favourable effects (i.e., economic, environmental, and/or social) are not undone in other stages of the value chain.

Work to be carried out following the assignment

In defining the follow-up trajectory, it will be necessary to evaluate in the future whether the current template and further implications regarding its operation and process need to be updated. For example, there are standard values (or default values) provided, which will need to be updated based on new insights or economic trends. Additionally, it will be indicated whether these standard values would come from a potentially payable database and what costs are associated with it. This information is also subject to an evolving landscape. In addition to the values of the selected parameters, the importance and relevance of the parameters themselves will need to be periodically re-evaluated. The same applies to the visuals that have been added: do they still represent the appropriate visualization for the chosen parameter? In summary, the template in the assessment process and during project evaluation must be continuously monitored and adjusted as needed.

Finally, the establishment of a specialized expertise centre with a limited number of dedicated experts within the MOONSHOT innovation programme will be considered. These experts can be involved in filling out the template. This allows for cross-pollination between different projects, resulting in an additional drive towards rapid development and adoption of climate-friendly technologies. In this way, the expertise centre will eventually provide added value beyond just the MOONSHOT (and its underlying) projects. For example, the expertise centre can also be approached for VLAIO-cSBO projects (strategic basic research) and projects of spearhead clusters (Catalisti, Flux50, Blue Cluster, VIL, Flanders Food, and MEDVIA).