

Proposal Evaluation Form

	EUROPEAN COMMISSION Horizon Europe (HORIZON)	Evaluation Summary Report (Review task) - PATHFINDER - OPEN
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Call: HORIZON-EIC-2025-PATHFINDEROPEN
Type of action: HORIZON-EIC
Proposal number: 101258806
Proposal acronym: STOREDGE
Duration (months): 54
Proposal title: Anti-ferroelectric-based unified information and energy storage at the Edge
Activity: HORIZON-EIC-2025-PATHFINDEROPEN

N.	Proposer name	Country	Total eligible costs	%	Grant Requested	%
1	ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE	CH	730,127.5	23.18%	730,127.5	23.18%
2	UNIVERSITA CA' FOSCARI VENEZIA	IT	367,875	11.68%	367,875	11.68%
3	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	FR	699,986.5	22.22%	699,986.5	22.22%
4	INSTITUTUL NATIONAL DE CERCETARE DEZVOLTARE PENTRU FIZICA MATERIALELOR	RO	350,000	11.11%	350,000	11.11%
5	UNIVERSITEIT TWENTE	NL	501,527.5	15.92%	501,527.5	15.92%
6	THE UNIVERSITY OF LIVERPOOL	UK	206,125	6.54%	206,125	6.54%
7	SCIPROM SARL	CH	294,375	9.35%	294,375	9.35%
Total:			3,150,016.5		3,150,016.5	

Abstract:

STOREDGE proposes a ground-breaking multifunctional on-chip platform that unifies high-density energy storage, multi-bit non-volatile memory and neuromorphic devices in a single, ultra-compact architecture based on doped hafnium oxide (HfO₂). Through the innovative integration of ferroelectric (FE) and antiferroelectric (AFE) layers, interleaved with dielectric (DE) barriers, we create an entirely new class of hybrid devices for use in future energy-autonomous electronics, highly demanded in edge computing nodes with key applications in Industry 4.0, environmental monitoring and smart wearables. Unlike conventional architectures that separate energy and information storage, we consolidate both functions into a single CMOS technology platform. To achieve these goals, we leverage the consortium's expertise in materials engineering, advanced characterization, and silicon-compatible integration. Through innovative strategies for tailoring the properties of CMOS-compatible oxides, we employ common hafnia/zirconia-based functional layers to implement three distinct device types: multi-bit memories, on-chip supercapacitors, and neuromorphic components. Close integration on the same chip unlocks novel functionalities that transcend those of conventional ferroelectric and antiferroelectric devices. We will i) deliver a validated prototype of a multifunctional HfO₂-based non-linear supercapacitor-memory hybrid, ii) demonstrate AFE-based planar and 3D structured supercapacitors, iii) produce reliable multi-bit logic states under low-voltage operation, iv) demonstrate and benchmark AFE vs FE memristors for neuromorphic synapses, and v) deliver a roadmap for FE and AFE industrial-scale process integration in Si foundries and flexible electronics platforms. STOREDGE thus represents a paradigm shift in the way co-development of materials and architecture lead to sustainable innovation in nanoelectronics and puts Europe at the forefront of next-generation semiconductor technology.

Evaluation Summary Report

Evaluation Result

Total score: 4.55 (Threshold: 0)

Panel comments on proposal

The Evaluation Summary Report comprises the final score, a comment that summarises the assessment by the evaluation committee as well as any additional comments, possibly including advice not to resubmit the proposal. The evaluation committee drew its conclusions on the basis of the individual evaluation score and the outcome of its consensus discussions. While not necessarily subscribing to each and every opinion expressed in the individual evaluation reports, the evaluation committee finds that the comments from the evaluators provide a fair overall assessment, indicating both essential strengths, shortcomings and weaknesses identified in the proposal.'

According to the predefined scoring scale the proposal is excellent.

The project proposes to develop a HfO₂-based platform that combines memory, neuromorphic computing, and energy storage, within a single CMOS-compatible system. At the core of the project is the exploitation of antiferroelectric materials' unique properties, particularly field-induced phase transitions and double hysteresis loops, to achieve both high-density energy storage and multi-bit memory integration. Overall the project combines previously explored concepts in a novel way that could enable breakthrough technologies for niche applications requiring local data processing. While the reviewers appreciated the innovative approach and recognized the potential to achieve unprecedented levels of integration and performance, particularly for edge computing, they raised two key concerns: (1) the pathway toward market creation is not clearly articulated, and (2) the choice of Hf-based materials, which are considered critical raw materials, lacks justification and comparative benchmarking against alternative ferroic systems. Overall, the panel considers this proposal to be of excellent quality. However, based on the combined set of criteria used in the assessment it was not sufficient to be retained for funding.

The evaluation panel agrees with the opinion of the evaluator that the AI aspects are sound and comprehensive, explicitly addressing the challenges of developing autonomous cognitive chips.

Criterion 1 - Excellence

Score: 4.50 (Threshold: 4 / 5.00 , Weight: 60.00%)

The following aspects will be taken into account, to the extent that the proposed work corresponds to the description in the work programme:

Long-term vision: How convincing is the vision of a radically new technology and relevant potential solutions, towards which the project would contribute in the long term?

The project presents a compelling long-term vision centered on the development of autonomous cognitive chips that integrate sensing, memory, learning, and energy storage at the edge. By leveraging doped-HfO₂ to combine FE and AFE functionalities, the project aims to create a multifunctional platform-on-chip capable of unprecedented energy efficiency and miniaturization. This vision aligns with the growing demand for Edge AI and IoT applications, where low latency, high performance, and power autonomy are critical. The proposed technology demonstrates the potential to positively impact industries such as smart wearables, robotics, and environmental monitoring by enabling self-powered, intelligent systems.

The project proposes a very appealing new technology: a multifunctional on-chip platform device which combines functionality with self-sustainability: a high-density energy storage, multi-bit non-volatile memory device with neuromorphic functionality on a single, compact architecture. These functionalities will be achieved by combining (anti)ferroelectric thin films on CMOS-compatible platforms. The proposal is very well written and identifies the challenges to be overcome, delivering a first-of-its-kind which may open a whole new front in semiconductor technology.

The vision brings together ideas that have already been explored individually in the past, but their combination may lead to a radically new technology, and offers potential solutions in specific niche applications, where data needs to be processed near the source rather than in a centralised server. The choice of HfO₂ and ZrO₂ as the materials systems appears to be based on the experience of some of the partners with these systems, and there is no other rationale for that choice rather than that. One would expect to see those material systems benchmarked against other potential ferroic materials, as to corroborate that choice. This bearing in mind that Hf is a critical raw material.

The project vision is convincing: research on ferroelectric and antiferroelectric materials is a novel, trending topic that, in this proposal, has been combined with the development of a new technology enabling the realization of 'edge computing' applications.

Science-towards-technology breakthrough: How concrete, novel and ambitious is the proposed science-towards-technology breakthrough with respect to the state-of-the-art? What advancement does it provide towards realising the envisioned technology?

The project presents a concrete and highly ambitious science-towards-technology breakthrough by developing a multifunctional HfO₂-based platform that simultaneously integrates memory, neuromorphic computing, and energy storage on a single CMOS-compatible chip. This approach represents a significant leap beyond current state-of-the-art technologies, which typically implement these functions as discrete components. The project's core aspect lies in exploiting the unique properties of AFE materials—particularly their field-induced phase transitions and double hysteresis loops—to enable both high-density energy storage and multi-bit memory within a unified material system. By engineering the novel system, the project aims to achieve unprecedented levels of integration and performance for edge computing applications.

The proposal bridges very well basic science into applications, transforming fundamental knowledge into a novel technology. The idea is new and ambitious. A memory device that also serves as an energy storage source, and may also display neuromorphic functionality, may very well lay the foundation towards a very interesting application.

The science-towards-technology appears fragmented. One can perceive very concrete and ambitious steps within the project, however the connections between those steps lack sufficient detail, to follow how they would exactly sustain a successful new technology. The proposed work as an overall idea of creating a multifunctional platform is novel, but how that multifunctionality will be achieved in reality is not fully articulated.

The proposed Science-towards-technology breakthrough is significant: the project aims to integrate the envisaged technology into standard CMOS processes. This would unlock synergies unavailable with other state-of-the-art technologies. The proposed approach is concrete and ambitious: integration with reliable, legacy, silicon-based applications could provide all the functions that FE/AFE technology could not provide directly. The project's expected technological advancements are remarkable: two of the proposal's objectives, RO3 and RO4, aim to realise working prototype devices.

Objectives: How concrete and plausible are the proposed objectives? To what extent are high-risk/high-gain research approach for achieving them? How sound is the proposed methodology, including the underlying concepts, models, assumptions, appropriate consideration of the gender dimension in research content, and the quality of open science practices?

The project outlines clear, measurable objectives that systematically progress from fundamental material development to complete system integration, each supported by specific performance targets. It embraces a high-risk/high-gain strategy, particularly in its pursuit of multifunctional AFE/FE co-integration, which is a largely unexplored frontier. The methodology presents a shortcoming, as it relies on the unproven ability to stabilize AFE phases in HfO2 at BEOL-compatible temperatures. AFE formation is known to require higher temperatures, creating a fundamental materials science challenge for integration. The gender dimension is minimally addressed. The open science practices are robust, with comprehensive plans to share all research data and protocols through public repositories using standardized licenses. The AI aspects are sound and comprehensive, explicitly addressing the challenges of developing autonomous cognitive chips.

The objectives are well laid out, concrete, and well articulated among themselves. The fundamental idea and, while being high risk, it also exhibits a good level of feasibility. The high-gain aspect is sure, the technology envisaged here could very well provide a spear head for Europe semiconductor initiatives. The methodology is solid, and adequate to pursue the work plan proposed (including experimental techniques & characterization combined with theoretical calculations). Open Science practices are correctly addressed, with standard practices and effective solutions. A gender dimension does not apply to this type of research.

The proposed objectives for each workpackage are concrete and plausible, however how they link to each other to deliver the envisaged proof of principle is somehow missing. The risks were clearly identified, and some are categorised as likely and severe, which is a good assessment, however the mitigation is not convincingly presented. The methodology follows mostly well-established techniques, for which the partners have a good wealth of experience, therefore it is appropriate to pursue the individual objectives set for each workpackage. Gender dimension is not relevant in this proposed project. Finally, open science practices meet standards from the European Commission.

The proposed objectives are concrete and plausible. Due to its challenging research topics and the very high rewards on successful completion, the project is definitely 'high-risk/high-gain'. The methodology is clearly explained. The measures for implementing open science practices are convincing. As stated in the proposal, sex and gender analysis is not relevant to this project.

Interdisciplinarity: How relevant is the interdisciplinary approach from traditionally distant disciplines for achieving the proposed breakthrough?

The interdisciplinary approach of the project is a significant strength, innovative, and essential for achieving its ambitious goals in cognitive edge computing. By effectively bridging traditionally distinct fields—materials science, semiconductor engineering, neuromorphic computing, and energy storage—the project establishes a unique framework to address challenges requiring expertise beyond any single discipline. The seamless collaboration among materials scientists developing advanced doped oxide films, device engineers translating these into functional memory and energy architectures, and theoretical modeling guiding experiments ensures a cohesive approach to co-integrating memory, computing, and energy storage in a unified platform.

Interdisciplinarity here is a must, combining materials science, engineering and fundamental theoretical capabilities. The work plan could not be tackled otherwise. Well laid approach.

The interdisciplinary revolves essentially around simulation and experimental approaches conducted by experts that work in the niche area of ferroic materials, and not from revolutionary distant research communities, however the approach is sensible to achieve the individual objectives.

The project is not particularly interdisciplinary, as the research fields involved (material science, microelectronics, energy storage and artificial neural networks) are already closely related. The project goals are inherently related to AI, since one objective is to fabricate neuromorphic computing devices. However, the project activities do not include the development of a complete system that exploits this technology; they only aim to fabricate prototype devices. Anyway, project activities include the use of machine learning techniques to ease molecular dynamics and NEGF computations.

Criterion 2 - Impact

Score: 4.50 (Threshold: 3.5 / 5.00 , Weight: 20.00%)

The following aspects will be taken into account, to the extent that the proposed work corresponds to the description in the work programme:

Long-term impact: How significant are the potential transformative positive effects that the envisioned new technology would have to our economy, environment and society?

The project has the potential to deliver significant transformative effects across the economy, environment, and society. Economically, the development of autonomous cognitive chips integrating energy storage, memory, and neuromorphic computing could revolutionize industries such as IoT, edge computing, and robotics. The technology's CMOS compatibility is a pathway for scalability and cost-effectiveness, positioning Europe as a leader in next-generation semiconductor innovation. Environmentally, the proposed AFE supercapacitors offer a sustainable alternative to batteries, with longer lifespans and reduced material waste. Societally, the technology may enable energy-efficient, self-powered devices for healthcare, environmental monitoring, and smart infrastructure. However, the project's dependence on Hf, a critical raw material with limited supply chains, lowers the overall long-term impact.

The long term impact of this technology could be very high. In the era of miniaturization and clean energy, the multifunctional device proposed could become a new cornerstone in the field of self-sustained CMOS memories. The materials proposed are already well known from the fundamental standpoint and industry is looking forward for avenues to exploit them into novel architectures. This project will undoubtedly contribute to this aim.

The proposal addresses some aspects of the long term impact but it is rather generic. It merely reproduces some of the EU set ambitions. Details on the specific impact on economy, environment and society, even if only speculative, are not given.

This technology can have a significant indirect impact on the environment, society and the economy. The proposed applications are in the field of neuromorphic electronics, which could enable artificial intelligence applications to consume a fraction of the energy required by currently available technologies.

Innovation potential: How adequate are the proposed measures for protection of results and any other exploitation measures to facilitate future translation of research results into innovations? How suitable are the proposed measures for involving and empowering key actors that have the potential to take the lead in translating research into innovations in the future?

The technology holds disruptive potential by merging memory, neuromorphic computing, and energy storage into a single CMOS-compatible platform, which may redefine edge AI systems by enabling autonomous devices with higher efficiency. The project identifies relevant KERS, including co-integration workflows and on-a-chip supercapacitors, targeting markets like semiconductor manufacturing and IoT. Protection measures are robust, with patents, open-access publications, and strategic licensing to industry partners. The proposal emphasizes empowering early-career researchers and fostering gender balance, ensuring talents to drive future innovations. The clear roadmap for commercialization, including spin-off creation and industry partnerships, is a notable strength. The comprehensive IP strategy strikes a balance between open science and proprietary innovation. The focus on talent development and stakeholder engagement (e.g., foundries, AI hardware firms) is also well-articulated.

The potential to achieve significant and relevant innovation is very satisfactory. the technology proposed is new and interesting, and the team is perfectly poised to achieve their plan. It is very likely that the outcome of the proposed research will translate into technical innovation. They are very serious about it, as noticeable from the very detailed plan for protection of intellectual property and different avenues for patenting and other IP strategies.

The measures for protection of results are appropriately described in the intellectual property management. Exploitation measures to facilitate future translation of research results into eventual innovations are also considered, with suitable measures involving key industrial stakeholders and the next generation of researchers has been described. Nevertheless, the pathway envisioned to create a new market is not fully articulated.

The envisioned new technology has the potential to generate substantial innovations in the development of the 'Internet of Things', which is regarded as a rapidly growing market. The proposed measures for protecting the results are adequate, and the consortium has the capacity to train young researchers in new technologies and exploit the project's outcomes. In particular, the proponents plan to meet with companies that have the capacity to exploit the research results and develop them into products.

Communication and Dissemination: How suitable are the measures to maximise expected outcomes and impacts, including communication activities, for raising awareness about the project results' potential to establish new markets and/or address global challenges?

The project employs a multifaceted dissemination strategy to maximize impact. Scientific results will be published in high-impact journals and presented at major conferences to ensure visibility within academia and industry. Outreach encompasses a public website, social media campaigns, and workshops designed to target stakeholders, including manufacturers and policymakers. The emphasis on open-access data and public engagement (e.g., videos, flyers) enhances transparency and societal awareness. The project demonstrates strong alignment with Open Science principles, fostering collaboration. It also features tailored messaging for diverse audiences, from researchers to the general public, and proactive industry engagement through workshops and demonstrations. The proposal implicitly addresses stakeholder needs through technical benchmarks, but it lacks a systematic approach to iterative feedback. It may hinder the technology from meeting global challenges from the beginning.

The avenues for communication and dissemination of results are effective and standard. A very positive aspect is that different strategies have been laid out to enhance the visibility of results in different groups, from scientists and engineers to industry, markets and finally to the general public.

The scientific dissemination is ambitious in terms of publication in internationally leading journals, the engagement of industry is a bit optimistic by assuming that the sector will be approaching the consortium and not vice-versa. The strategy to attract the industrial stakeholders is not proactive, it appears to expect that industry will be looking for the activities of the consortium. Also the engagement with the public appears rather generic and not specific to this specific project, as details are not provided.

The proposed actions for disseminating the expected outcomes and maximising their impact are appropriate. Several target groups have been selected, ranging from the scientific community and industry to the general public. The appropriate communication channels will be used for each target group, such as scientific publications, participation in international conferences, websites, social media posts and press releases. In particular, the consortium will participate in international events focused on specific topics in order to reach a wide range of industry-related stakeholders and raise awareness of the market potential of the project's results.

Criterion 3 - Quality and efficiency of the implementation

Score: **4.75** (Threshold: 3 / 5.00 , Weight: 20.00%)

The following aspects will be taken into account, to the extent that the proposed work corresponds to the description in the work programme:

Work plan: How coherent and effective are the work plan (work packages, tasks, deliverables, milestones, timeline, etc.) and risk mitigation measures in order to achieve the project objectives?

The project presents a well-structured and coherent work plan that effectively supports its objectives. The project is organized into clearly defined phases, each targeting specific research aspects while maintaining strong interdependencies. Early phases focus on material engineering and characterization, while later stages transition to device prototyping, benchmarking, and CMOS integration. This logical progression ensures systematic advancement toward the project's goals. The timeline is overall realistic, with strategically placed milestones that enable iterative feedback and course correction. Risk mitigation measures address potential challenges such as CMOS incompatibility; however, the proposed solutions are not always convincing. Contingency plans, including alternative 3D structures, demonstrate foresight in managing technical uncertainties. Deliverables are concrete and aligned with KPIs, ensuring measurable progress.

The work plan is coherent and clear, laid out in six reasonable work packages which include an ordered list of tasks, deliverables and milestones which flow into each other. The chronogram seems appropriate. A contingency plan with risk mitigation measures is presented. It may seem scarce, but it includes potentially tricky aspects with reasonable strategies.

The work plan is sensible and realistic in terms of the objectives and deliverables set for each workpackage. The sequence of tasks within each workpackages is logical and is feasible to be achieved following the methodology proposed, as it is based on well-established experimental methods. The issue is how those workpackages will contribute to the ultimate objective of the project, because on their own they are sensible, but how they will provide the complete knowledge to achieve the ultimate goal, this is unclear. The risk mitigation is not always convincing, in particular how a potential failure to achieve an AFE behaviour will be circumvented.

The work plan is both coherent and effective. The project's risks have been identified and appropriate mitigation measures outlined. Although the implementation risk list includes items with high severity, this should be regarded just as a minor shortcoming in a 'high risk/high gain' project.

Allocation of resources: How appropriate and effective is the allocation of resources (comprising person-months and other cost items) to work packages and consortium members?

The project's resource allocation is well-balanced and appropriately aligned with its priorities. Personnel effort is distributed logically, with significant emphasis on materials development and characterization in early stages, while later phases focus on device integration and testing. This phased approach ensures that expertise is applied where most needed throughout the project lifecycle. Key strengths include the strategic use of internal resources, such as cleanroom facilities, which minimize reliance on external subcontracting and ensure control over critical processes. The allocation of personnel reflects specialization, with experts assigned to tasks matching their competencies.

The allocation of resources is adequate and the tasks are well distributed through the participant institutions and researchers. The budget in general appears reasonable, although the clean room costs seem high. This may be due to the heavy load of tasks involving device fabrication.

The allocation of resources appears to be appropriate, however some of the partners only request person-months and no other items, which is a bit surprising. Hence, one can only assume that all resources are available to those partners.

*The total costs presented are appropriate and balanced.
The number of person-months allocated to each activity is appropriate.*

Quality of the consortium: To what extent do the consortium members have the necessary capacity and high quality expertise for performing the project tasks?

The consortium composition is a notable strength of the project, bringing together partners with complementary expertise and proven capabilities. Academic and research institutions contribute deep scientific knowledge in advanced materials and device fabrication, while industry-relevant players enhance practical applicability and integration potential. The consortium benefits from strong track records in relevant technologies, particularly in HfO₂-based devices, ensuring a solid foundation for the project's technical ambitions. However, considering the project vision, the heavy reliance on academic partners, while ensuring scientific rigor, may present shortcomings in addressing industrial translation needs. The absence of direct industry partners in the core consortium may impact strategic decisions, though planned advisory board engagement helps mitigate this concern.

The quality of the consortium is high. All key expertises are present, adding to the feasibility of a correct work plan. The consortium members are capable and the different responsibilities and tasks are correctly assigned to capable teams.

The consortium members bring an excellent track record of working in the field of ferroics materials, therefore they have the capacity to complete both the theoretical and experimental work proposed in each of tasks of the workpackages considered.

*The consortium's expertise is very relevant and perfectly adequate for achieving the project's goals.
The previous research activities of the participants provide all the necessary background knowledge required to fulfil the objectives of the proposal.
The consortium has a very high capacity, and all its members have the practical ability and resources to fulfil their roles successfully.*

Scope of the application

Status: Yes

Comments (in case the proposal is out of scope)

Not provided

Exceptional funding

A third country participant/international organisation not listed in [the General Annex to the Main Work Programme](#) may exceptionally receive funding if their participation is essential for carrying out the project (for instance due to outstanding expertise, access to unique know-how, access to research infrastructure, access to particular geographical environments, possibility to involve key partners in emerging markets, access to data, etc.). (For more information, see the [HE programme guide](#))

Please list the concerned applicants and requested grant amount and explain the reasons why.

Based on the information provided, the following participants should receive exceptional funding:

Based on the information provided, the following participants should NOT receive exceptional funding:

Not provided

Use of human embryonic stem cells (hESC)

Status: No

If YES, please state whether the use of hESC is, or is not, in your opinion, necessary to achieve the scientific objectives of the proposal and the reasons why. Alternatively, please state if it cannot be assessed whether the use of hESC is necessary or not, because of a lack of information.

Not provided

Use of human embryos

Status: No

If YES, please explain how the human embryos will be used in the project.

Not provided

Activities excluded from funding

Status: No

If YES, please explain.

Not provided

Do no significant harm principle

Status: Yes

If Partially/No/Cannot be assessed please explain

Not provided

Exclusive focus on civil applications

Status: Yes

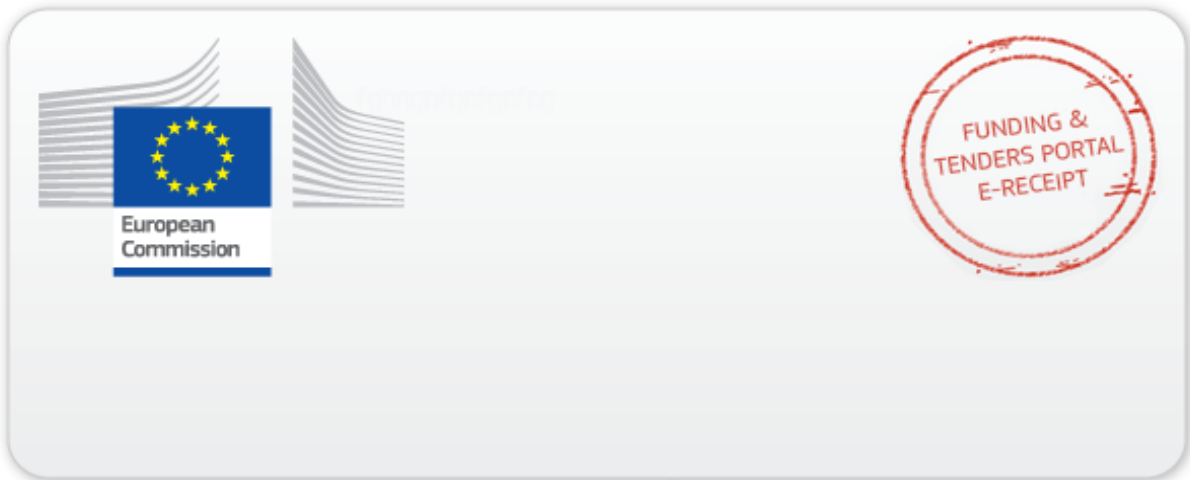
If NO, please explain.

Not provided

Artificial Intelligence

Status: Yes

If YES, the technical robustness of the proposed system must be evaluated under the appropriate criterion.



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