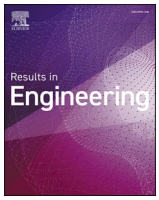
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Research paper

Artificial intelligence reveals unbalanced sustainability domains in funded research

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ABSTRACT

To meet the 2030 Agenda for Sustainable Development, all Sustainable Development Goals (SDGs) must receive adequate and balanced funding. This study applies artificial intelligence to analyze research proposals accepted between 2015 and 2023 in the European Union and the United States, focusing on datasets from the European Research Council and the National Science Foundation, respectively. Despite the growing application of Artificial Intelligence (AI) in various domains, there remains a lack of comprehensive analysis that applies AI to examine funding allocation across SDGs and gender disparities in scientific research. This study addresses this unmet need by using AI to uncover imbalances in funding distribution, offering insights into current funding instruments. We reveal critical coverage disparities across SDGs, with both funding instruments prioritizing SDG 9 (Industry, Innovation, and Infrastructure), highlighting a potential overemphasis on this goal. Additionally, we document pronounced gender imbalances among principal investigators across nearly all SDGs, except for SDG 5 (Gender Equality), in which female researchers are comparatively better represented. Our results indicate an urgent need for more inclusive and balanced approaches to achieve sustainable development, starting with allocation of research funding. By providing a nuanced understanding of funding dynamics and advocating strategic reallocations, this study offers actionable policy design and planning insights to foster a more equitable and comprehensive support system for sustainability-focused research endeavours.

1. Introduction

In the face of escalating global crises, such as climate change, biodiversity loss, political instability, and security threats, the urgency for systemic transformations cannot be sufficiently emphasized. Basic and applied research drives transformative societal and environmental changes by strategically directing investments towards social value. This study uses AI to analyze funding allocations within the ERC and NSF to address gaps in sustainable development [1]. By answering the question, 'What is the problem we want to solve?', research investments shape mission-oriented policies [2], channelling resources towards ambitious but realistic objectives. A focus on individual challenges does not support holistic policies. Therefore, research efforts and their connected resources must enable synergies across domains to generate solutions to multifaceted problems.

The 17 Sustainable Development Goals (SDGs) of the 2030 United Nations (UN)Agenda were launched in 2015 to respond to this call, providing a joint roadmap described by 169measurable socio-economic, environmental, technological, and governance targets, all addressing the need to advance sustainable development. The identification of links and spillovers across various dimensions has received considerable attention from scholars over the past decade [3–6]. Significant efforts

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have been made to determine positive and negative interactions at both the goal [3] and target levels [7]. These studies reveal insights about non-obvious interconnections, which can redefine how to channel resources and capabilities toward the most urgent needs. However, this study has two limitations. On the one hand, these works suffer from low replicability, as documents deployed in the analyses are often collected via expert-based and collective processes, which require significant time investments [4]. However, some of the existing efforts are limited to academic production, reducing the external validity of the findings.

Artificial intelligence (AI) refers to the use of advanced algorithms to perform tasks that require human intelligence, such as data analysis, pattern recognition, and decision-making [8]. In this study, we utilized AI to analyze large datasets of research proposals from the European Research Council (ERC) and the National Science Foundation (NSF). AI's advanced capability to process unstructured data at scale allows the identification of funding trends and systemic imbalances in SDGs. This provides a more nuanced understanding than traditional statistical methods. Simple statistical analysis cannot effectively reveal these complex patterns because of the sheer volume and complexity of the data. AI methods, particularly natural-language processing (NLP), can overcome some of these bottlenecks [9,10], and recent applications have shown that when tested on policy documents [11], climate research [12], and social media [13], these methods can generate operational tools for policy design and planning. AI tools applied to the study of SDG interactions, synergies, and trade-offs can generate time- and cost-effective, scalable tools for decision-makers, which serve a wide spectrum of actors, including politicians and funding agencies, which support basic and applied science through grants. This knowledge can support a well-planned research funding mechanism to accelerate innovation [1] while positively affecting inclusive progress toward the 2030 agenda. A balance across multiple domains is essential for boosting research in different areas at the same pace.

Insufficient or unbalanced funding across Sustainable Development Goals (SDGs) creates gaps in addressing global challenges [14]. When funding is allocated to popular goals, such as health (SDG 3), less visible but equally important goals, such as water security (SDG 6) and inequality reduction (SDG 10), are underfunded, limiting their progress [15]. This misalignment between funding and development needs leads to imbalances and missed opportunities for holistic solutions, considering the interconnected nature of SDGs. Government funding agencies, as key players in shaping research priorities, may worsen these gaps when they allocate resources unevenly across sectors. A recent analysis of international funding systems reveals that publications supported by national agencies such as the National Science Foundation (NSF) and the National Natural Science Foundation of China (NSFC) tend to achieve higher citation impacts, underscoring the importance of strategic funding [16]. However, imbalances in this support can lead to less progress in underfunded areas, delaying the achievement of the 2030 agenda. Therefore, equitable funding strategies are essential to ensure that all SDGs receive adequate support for global sustainability efforts. The ERC's Mapping Frontier Research report [17] underscores the underexplored research domains, aligning with this study's findings of uneven funding allocations across SDGs. This imbalance makes it essential to identify and highlight such disparities in our study, as it sheds light on critical gaps in the research focus that need attention.

This study evaluates imbalances in funded research proposals by examining their alignment with the SDGs to identify systemic prioritization trends across sustainability dimensions. We used large AI models to capture how funded research encapsulates SDGs and their hidden connections. We focus on research proposals funded by the ERC (Europe) and by the NSF (United States) over a period of nine years (2015–2023). Funding agencies, such as the ERC and NSF, play a critical role in contributing to the creation of competitive advantages for the future, which may, in turn, reshape the global landscape. Understanding how these agencies distribute funds and the disparities that may arise is crucial for promoting a more balanced and inclusive research landscape that addresses SDGs in a holistic manner. This provides deeper insights than manual scanning, and transcends self-reported data and basic statistical analyses.

We aligned each proposal with the two most relevant SDGs per content without ranking them. We then analyzed the distribution of funded proposals across the 17 SDGs and compared them with the associated disciplinary domains, as indicated by the respective funding agency. Beyond checking systematic imbalances across different SDGs, we also revealed biases in the gender distribution of the principal investigator (PI) per SDG. Following the literature [18] and to facilitate the interpretation of the results, we grouped the SDGs into three pillars of sustainable development: Society, Economy, and Environment.

2. Methods

We collected funded research data from the official archives of the ERC [44] and NSF [45]. Owing to restricted access to full proposals, our analysis relied on approximately 120,000 abstracts spanning 2015 to 2023. The dataset contains metadata on the project: principal investigator (PIs), discipline, country, budget allocation, year, and university. To identify the gender of Principal Investigators (PIs) in cases where metadata lacked this information, we used Genderize.io [46], a tool widely validated across disciplines such as artificial intelligence, sociology, and medicine [47–50]. More specifically, the topic of gender bias in peer review was analyzed in [50], utilizing genderize.io to assign genders to authors and reviewers. The results revealed that male authors submitted more manuscripts than did female authors.

Additionally, papers with all-female authors were significantly fewer than those with all-male authors, indicating an existing sex disparity in submissions. Genderize was also employed in [50] to analyze a dataset of 10,558 original research articles. This study explored the association between gender, scientific fields, geographical regions, and collaboration scope. The results revealed a consistent underrepresentation of women, particularly in senior author positions, with significant country-specific variation. Finally, the reliability of the model can be validated by its public datasets, with the most recent one from Olympic Games participants, which had 94.35 % accuracy in gender prediction, as can be seen on Genderize. io's website [46].

The original idea behind this work is to employ our in-house code ASDG [54]. We used two procedures to test our methodology: labelled databases and expert validation. First, we used the database of Wulf and Meier [55]. This database comprises 9172 news articles published on the SDG Knowledge Hub website [56]. Each news article was tagged with labels indicating the specific SDGs it addressed. Second, we selected a small subset of the data. This subset was chosen randomly and was sufficiently small to allow manual labelling by the authors of this study. Using both labelled databases, we identified limitations with SDGs 9, 14, and 17. More precisely, our code could not detect the SDG17. In the case of SDG9, we could identify only 20 % of the labelled SDG9. This lack of accuracy prevents us from using them.

We evaluated multiple Large Language Models (LLMs), including Llama [58] and ChatGPT. However, owing to regional limitations on Google's Gemini, we selected GPT-3.5-turbo-01,125 [53] for its superior performance in analyzing abstracts via OpenAI's Application Programming Interface (API). Again, this test is based on labelled database outputs. Several Python routines were developed to handle the data, submit queries, download the output, and post-process the data to better use the API.

We conducted prompt testing using the three databases to ensure robustness and reproducibility. Key considerations include the optimal number of SDGs to be assigned, prompt length limitations, and terminology. Assigning two SDGs per project balanced information retention and minimized hallucinations, while the term "importance" yielded consistent results across outputs. Second, we did not provide a broader context for LLM owing to restrictions on the prompt length. We also refrained from fine-tuning or domain-specific training, as this procedure

may also be problematic, as recently proven in Ref. [59].

Finally, we tested different words to indicate why the most important SDG should be identified. We tested words' prominence, relevance, dominance, and importance. The results of this test were the same, so we decided to use the term "importance." We also observed that ChatGPT changed its output format several times. To overcome this issue, we developed several routines to consider different outputs and simplified the output as much as possible.

After all this procedure, the prompt's main characteristics were the 1st Two SDGs, 2nd "importance" as a keyword, 3rd Use of the LLM's own training, and 4th simple output. Under this umbrella, the final prompt is "Assign Sustainable Development Goals (SDGs) to each paragraph. Give two SDGs, highlighting only the most important. Do not explain it." After analyzing the database, we decided that the information about the most important SDG was probably biased in some runs, so we did not use it in any part of this work.

The accuracy of our AI model was validated against the Wulf and Meier dataset [55], achieving 84 % consistency for primary SDG assignments and highlighting its reliability in structured data scenarios. We expected an accuracy equal to the square of this probability (i.e., approximately $(84\ \%)^2 = 70\ \%$). The lower accuracy performance can be explained by the partial coverage of the two SDGs for every news item: 25 % of the database is related to an SDG only.

Discrepancies between expert-assigned labels and our methodology often stem from interpretation differences. For instance, SDG9 and SDG17 frequently overlap, as SDG17 initiatives may indirectly address the objectives linked to SDG9. Such variations highlight the challenges inherent in aligning automated and expert classification. However, in our methodology, if a particular SDG is mentioned in the text, apart from the initiative related to SDG 17, the text is linked to that SDG. This discrepancy is common across all SDGs. Regarding SDG4, there was complete alignment in all cases within the database, where SDG4 was the sole label. However, the primary issue with this SDG arises when GPT3.5 categorizes it as SDG4 upon encountering keywords related to lifelong learning or strategies for implementing new methods, which ultimately facilitate teaching. It is worth noting that most projects from the NSF incorporate language about disseminating project knowledge at every level of the educational system.

To overcome the limitations of SDG9 and SDG4, we complemented our analysis with another labelled database, namely the OSDG Community Dataset [57]. This dataset was curated with thousands of text excerpts labelled by volunteers who were tasked with either accepting or rejecting the suggested SDG labels without specifying particular ones. Each text was evaluated by multiple volunteers to ensure comprehensiveness of the labelling process. However, there are two limitations associated with this database: it only covers SDGs 1 to 16, and each text is labelled with only one SDG. Despite these limitations, the confusion table for the two SDGs demonstrates the validity of the procedure. Although the labelling accuracy for SDG4 is notably high, as shown in Table S1, the challenge with SDG9 persists because of its broad definition.

Because none of the available databases directly aligns with the objectives of our study, we conduct expert labelling for a subset of the projects. This subset differs from that employed in the early stages of the project to avoid bias. This expert labelling was again carried out by the authors of this manuscript. We stratified the NSF projects by selecting 10 % of the projects associated with each SDG, ensuring a minimum of 20 projects per SDG. The results are shown in Fig. S2. Furthermore, the only inconsistency arises with SDG9 owing to its widely interpretable definition. Note that abstracts are typically very precise, clearly identifying the project's objectives. Nevertheless, our expert labelling agrees with our methodology in a very large percentage of the other SDGs.

To enable a direct comparison of scientific disciplines funded by the ERC and NSF, we standardized their classification systems. For example, Life Sciences from the ERC were merged with Biological Sciences from the NSF, while Physical Sciences and Engineering from the ERC were aligned with NSF categories such as Geosciences and Mathematical Sciences. This harmonization ensured consistency and facilitated meaningful cross-agency analyses.

- **Life Sciences** in the ERC were merged with **Biological Sciences** from the NSF because both categories encompass similar fields related to biology and life sciences.
- **Physical Sciences and Engineering** in the ERC were combined with NSF categories such as **Computer and Information Science and Engineering, Engineering, Geosciences**, and **Mathematical and Physical Sciences** because these areas collectively cover similar technical and physical research domains.
- **Social Sciences and Humanities** in the ERC were aligned with NSF categories such as **Behavioral and Economic Sciences** and **Education and Human Resources** as both focus on societal, behavioral, and educational research.

This merging of categories facilitates a direct comparison between the two funding agencies and ensures that similar research areas are equally assessed. Without this standardization, comparing funding allocations across distinct categories would be inconsistent and may not provide accurate insights into the differences or similarities between the ERC and NSF funding practices.

3. Results

3.1. Charting different priorities

Analysis of the SDG distribution revealed distinct funding priorities. Both the ERC and NSF emphasize economic SDGs (e.g., SDG8, SDG9, SDG10, SDG12), prioritizing SDG9, while divergences emerge in their approach to social and environmental goals. Along with the mission-driven approach that inspires the new Horizon Europe Programme [19], the ERC finances proposals aimed at accelerating action toward healthy societies (SDG3), climate-compatible (SDG13), smart (SDG9) economies, and healthy soils (SDG2). Research on water and ocean systems, primarily associated with SDG14, remains underfunded and represents a critical gap that requires immediate attention, as flagged by the European Commission in its interim evaluation report [20] (this mission still lacks a fully-fledged policy package).

Fig. 2 highlights the disciplinary composition of ERC and NSF-funded research, showing that the ERC allocates more funding to life sciences, particularly in health and climate-related research, whereas the NSF focuses more on engineering and physical sciences, emphasizing infrastructure and security. This distinction suggests that ERC-funded projects emphasize biological and ecological sustainability approaches, while NSF-funded projects lean toward technological and engineering-driven solutions. The ERC also shows greater integration between life and social sciences, whereas NSF's structure reflects a more segmented focus on applied sciences.

Research plays a crucial role in addressing the urgent gap between current funding practices and the goals outlined in the 2030 Agenda for Sustainable Development [21]. Interdisciplinary research bridges funding disparities, offering data-driven insights to identify and address underrepresented SDGs. For example, interdisciplinary research across different scientific domains can advance knowledge of how funding is allocated and identify the critical areas that are underrepresented. This study can also guide the alignment of policies with sustainability objectives more effectively, thereby supporting a more equitable funding distribution. The NSF adopts an approach tailored to national priorities, reflecting a decentralized funding landscape shaped by diverse agencies. Our findings (Fig. 1) reveal a strong focus on education (SDG4), which matches one focus area the agency lists as a priority [22] but also highlights a marked contrast with EU trends. In particular, the ERC proposals reflect more vigorous attention on transforming our economies towards one powered by low-carbon technology (SDG7) and

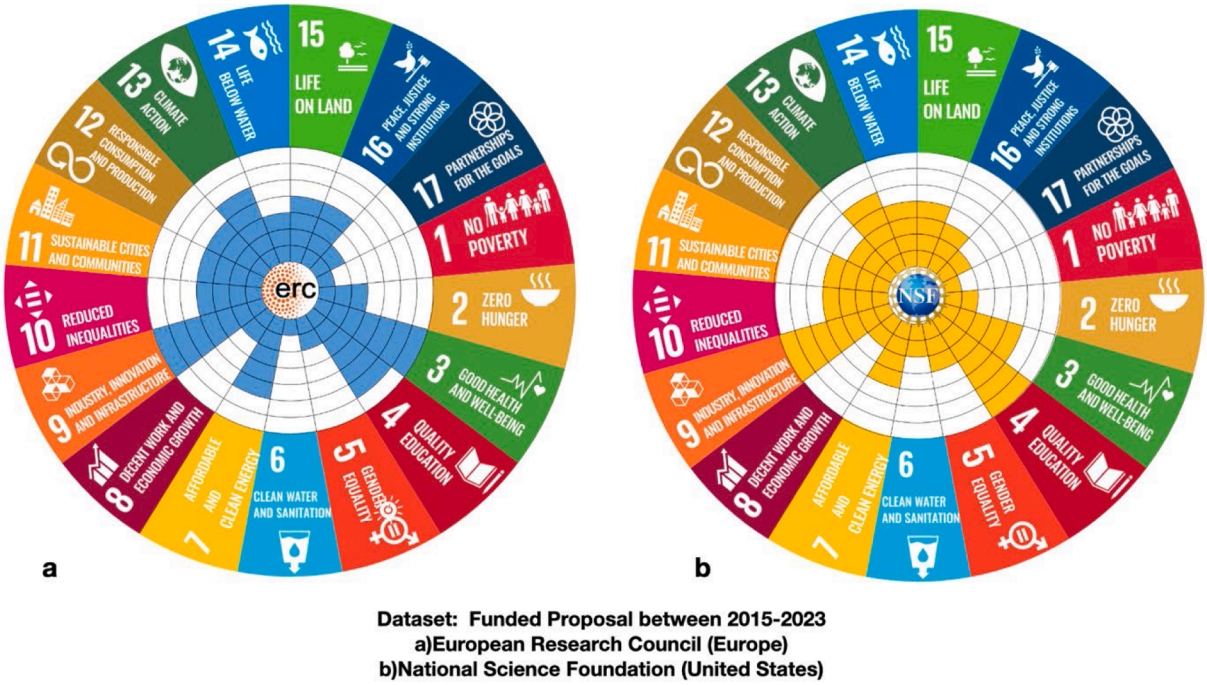


Fig. 1. Distribution SDGs cross funded projects by the European Research Council (a) and the National Science Foundation (b). Each project is allocated to two unranked and the most dominant SDGs. The polar graph has thresholds(0.5, 1, 2, 4, 8, 16, and 32 %) that describe how represented each SDG is.

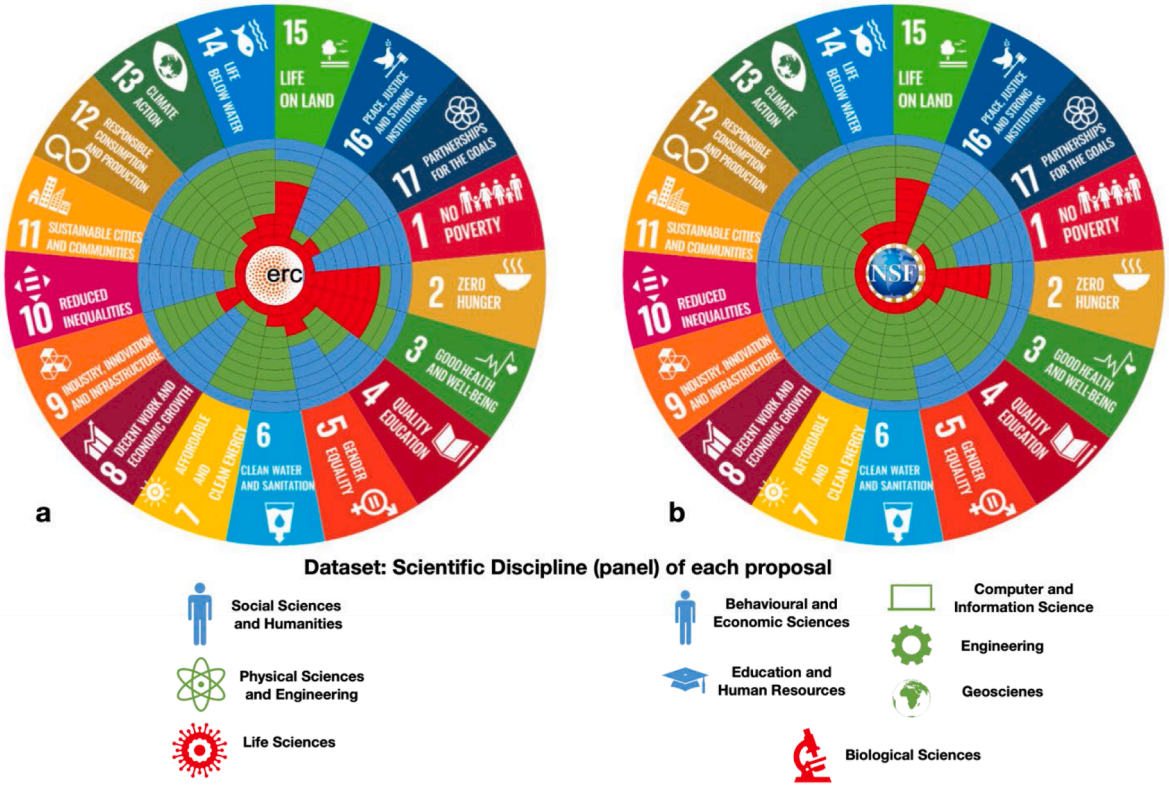


Fig. 2. Distribution of scientific disciplines per SDG and funding instrument. Disciplines are harmonized for comparability according to the legend. The European Research Council pool is more involved in life sciences than the National Science Foundation. The US-funded research ensemble follows a more physical and engineering-based approach, particularly in SDG3, SDG11, and SDG16. While crucial differences exist in the mandate and mission of each institution, the intense physical science base reveals attention to security (SDG16 and SDG6) and a more mechanised vision of societies (SDG3). For each graph, concentric circles represent a 10 % increase.

following more sustainable production and consumption models (SDG12). This is consistent with tracked SDGs progress [23], where the US has improved but still lags behind some of its European counterparts. Furthermore, it perfectly aligns with other policy packages governing the EU landscape: the European Green Deal [24] and the Long-Term Vision for the EU's rural areas [25], to name a few.

The decentralized structure of US policy agencies contributes to the limited allocation of research proposals addressing SDG16, in contrasting to the European Commission's unified strategy. The European collectively emphasizes peace, justice, and strong institutions. In contrast, US funding priorities are shaped by a fragmented framework that often relegates SDG16 to non-governmental organizations, such as philanthropic foundations. Notably, SDG16 reflects differences in methodologies: ERC-funded projects primarily adopt a social science lens, while NSF proposals focus on physical and engineering sciences (Fig. 2). This disparity aligns with the NSF's emphasis on the material and physical sciences, influencing its research agenda [22].

Gender disparities in research funding are evident across both agencies. Fig. 3 shows that SDGs 7 and 9 exhibit the highest gender imbalance, with over 80 % of PIs being male. These SDGs are heavily rooted in physical sciences and engineering (Fig. 2), disciplines where female representation remains significantly lower due to systemic barriers such as implicit biases in funding selection, career progression limitations, and lower participation rates in engineering and technology fields [51,52]. Policies aimed at increasing gender diversity in these areas could help address these imbalances. Furthermore, Fig. 3 provides insight into the gender breakdown across SDGs, highlighting the stark contrast in female participation between more socially driven SDGs and those in technical fields. These findings suggest that targeted interventions, such as mentorship programs and funding incentives, may be necessary to increase female participation in engineering and technology-focused SDGs.

These funding priorities are further reflected in agencies' focus on specific disciplines, as detailed below. NSF allocates twice as much funding as the ERC to water-related initiatives (SDG6), aligning with recent efforts to advance equitable and sustainable water resource management [26]. However, similarities in SDG distribution per agency trigger reflections and calls for action. In particular, social SDGs require more investment with bottlenecks in SDG1, SDG2, SDG5 and SDG17. As the world faces multiple crises, there is a growing need to support the most vulnerable groups out of the poverty line and discrimination. Achieving these goals requires fostering synergies among SDGs through interdisciplinary approaches rather than isolated, siloed efforts [27]. Examples of synergistic actions include focusing on the water-energy-food nexus, which the NSF strongly supported in 2015 [28]. Consistent with the literature, we also find a stronger interest in the water-energy link [29]. However, the inclusion of SDG2 into the equation can achieve the goal of inclusive development.

The two agencies also display similarities in the allocation of proposals to SDG8. We explain a lower focus on the vocational characteristic of the funding mechanisms: PIs present the novelties of their ideas based on previous literature and propose advancements that may or may not end up in new jobs and employment opportunities. While we acknowledge the need for research to be partly free from real economic considerations, the two agencies may be interested in encouraging a more tangible academic practice bridge. This will be particularly important for the ERC pool (Fig. 2) to shift the focus of these topics from economics and social sciences and engage more in the areas of life and physical sciences.

Achieving inclusive, sustainable development requires equitable representation in research. An analysis of the PI sex distribution across the SDGs (Fig. 3) highlights significant disparities. Both ERC and NSF suffered from substantial underrepresentation of female PIs, with the highest imbalance for SDGs 7 and 9, with peaks of over 80 % of men in both distributions. The dominance of male PIs in SDGs 7 and 9, heavily rooted in physical sciences and engineering (Fig. 2), underscores the need for academic institutions to implement strategies that promote gender diversity, thereby fostering positive systemic impacts. SDGs focusing on inequality (SDG5 and SDG10) are far from female PIs trying to shift the narrative through their work. A similar pattern is envisioned in SDG1 and SDG2, which typically focus on the most vulnerable groups in the population.

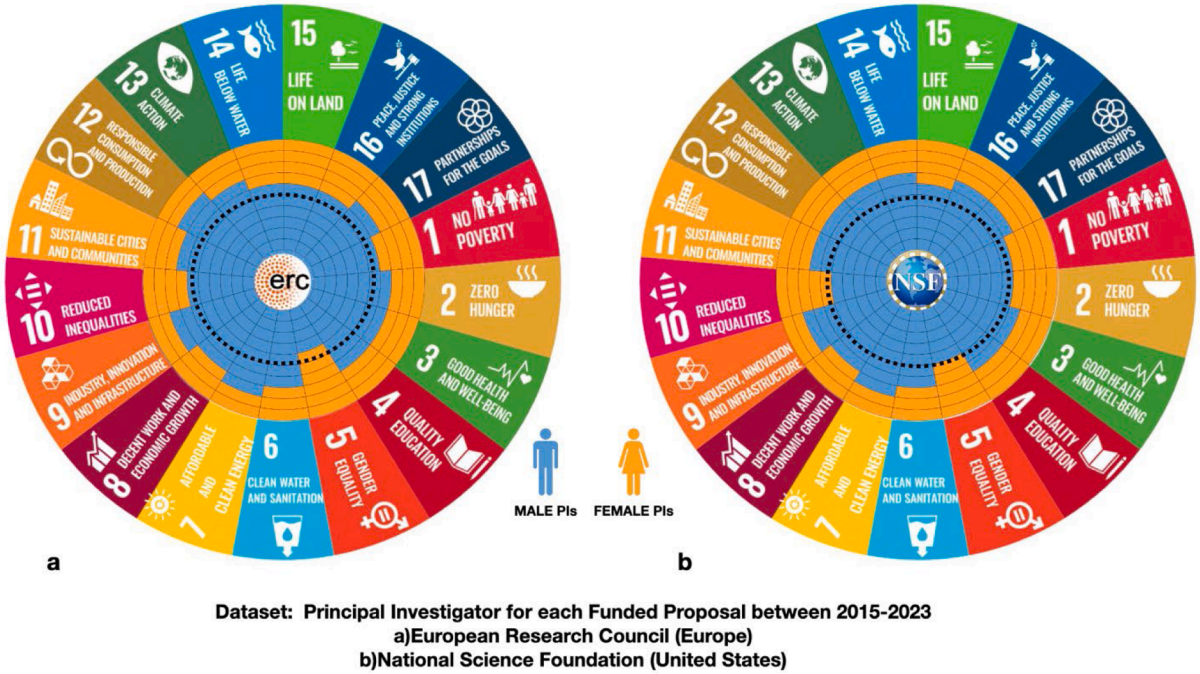


Fig. 3. Gender biases in scientific funding for European Research Council (a) and National Science Foundation (b). For each graph, concentric circles represent a 10 % increase. Colour codes correspond to the gender of the PI. While every SDG is largely dominated by male PIs, SDG5 is by construction female-led opening to a reflection about the importance to widen the conversation.

4. Discussion

4.1. Research as the driver of a balanced, integrated, and inclusive sustainable development

Our work highlights the varying priorities in SDG-focused grant allocations and offers insights for assessing and monitoring the contribution of publicly funded research to the 2030 Agenda for Sustainable Development [30]. While grant allocation is traditionally based on merit and scientific criteria, alternative allocation strategies such as the portfolio approach offer valuable opportunities [31]. Unlike conventional systems that evaluate individual project performance, the portfolio approach considers the collective impact of multiple projects, with the aim of maximizing societal benefits and addressing broader public needs. By focusing on the aggregated outcomes of research initiatives, funders can develop strategic portfolios that advance SDG priorities and align scientific innovation with societal demands [32]. This approach promotes diversity in research pathways, fosters interdisciplinary collaboration, and strengthens regional cooperation, which are key elements for achieving the SDGs. By adopting a sustainable development agenda as a guiding framework, funding agencies can better align basic and applied scientific efforts with collective well-being.

The current EU mission-oriented policy would benefit from an SDG-informed and sustainability-inspired funding allocation mechanism to detect and measure what must be done to help people and the planet. To avoid potential trade-offs between SDGs, interdisciplinary research combining insights from economics, natural sciences, engineering, and ecology to address the complex challenges of sustainability is essential [33]. The US Inflation Reduction Act [34] is another example of a public policy that aims to advance innovation via public investments. According to the latest Sustainable Development Goals report, some SDG targets are deteriorating, while others can continue to improve with the right policies.

This study underscores the pivotal role of funding agencies in shaping progress across SDGs. By leveraging AI for the dynamic monitoring and strategic realignment of funding priorities, agencies can address disparities and enhance the impact of their investments. AI enables real-time monitoring to detect funding imbalances early, offering actionable insights into resource reallocation. This capability allows funding agencies to swiftly adapt to changing global priorities and ensure equitable support across the SDGs. As such, funding agencies can establish data-driven flexible strategies that align with rapidly evolving global priorities.

In addition, our findings advocate a broader interdisciplinary approach to research [35]. Promoting cross-disciplinary projects can unlock synergies between interconnected SDGs [36], such as climate action (SDG 13), infrastructure (SDG 9), gender equality (SDG 5), and strong institutions (SDG 16) [37]. However, trade-offs also exist [3], for example, between affordable energy (SDG 7) and goals such as poverty alleviation (SDG 1) and health (SDG 3), signalling the pressing need for solutions that align with social goals without exacerbating environmental pressures [37]. Finally, in the context of ongoing global crises, including COVID-19 and the Russo-Ukrainian conflict, which have intensified inequalities and further disrupted balanced SDG progress, the need for continuous monitoring of evenness becomes critical without ensuring an even and balanced advancement across all SDGs, and the ambitious goals of the 2030 Agenda will remain difficult to achieve [38].

The differences in funding allocation across SDGs indicate the need for more flexible and responsive funding strategies. Our SDG assessment of project proposals can inform the next waves of calls for funding and become a cost-effective tool to scale up actions. By breaking ties between different grants, our approach could promote interdisciplinary and cross-sectoral research, which must also be encouraged as it is pivotal in addressing the complex, interconnected challenges encompassed by the SDGs [39]. Encouraging multidisciplinary approaches will help bridge the gaps between theoretical research and practical applications, enhancing the societal impact of scientific endeavors. Further, fostering global collaboration, especially between large funding bodies such as the EU and the US, could lead to a more harmonized approach to tackling sustainability issues. Such cooperation would reduce redundancies, create synergies across regions, and maximize the impact of funding allocation by ensuring that overlapping priorities receive concerted support. Building transnational networks that align research priorities across borders can facilitate knowledge exchange and encourage shared solutions to common challenges.

Funding agencies, policymakers, and academic institutions can include AI-driven tools to continuously monitor funding distribution to ensure that all SDGs are adequately addressed [40]. This would balance support across various sustainability dimensions and enhance the agility of funding mechanisms in responding to emerging global challenges. Targeted policies are essential to strengthen inclusivity, particularly in SDGs dominated by the physical sciences. Encouraging diverse participation can bridge the existing gaps and foster equitable research landscapes. This should include support for early career researchers and institutions in developing regions, ensuring a fairer and more diverse scientific community. Funding frameworks should facilitate collaboration among diverse research teams, leading to more holistic and innovative solutions to sustainability challenges [41].

Finally, our AI-driven analysis reveals a significant gender imbalance in research funding. Specifically, we found that across nearly all SDGs, female principal investigators were substantially underrepresented. The only SDG in which both funding instruments show equal representation is SDG 5 (Gender Equality). SDG 10 (Reduced Inequalities) also shows equal representation but only for the National Science Foundation. Existing actions to increase female participation in science seem to be less than desired [42]. Our SDG-based routine suggests that the inclusive and synergic use of SDGs can also boost a more gender-balanced research landscape. Our analysis complements the calls to encourage female participation in STEM (Science, Technology, Engineering, and Mathematics) careers and provides evidence of how inclusive development and a closer nexus among SDGs can support a balanced society in the future. While we acknowledge that research cannot and should not substitute policies, we show that theoretical and applied science can support mission-based policies by considering inclusive and integrated sustainable development.

As AI capabilities evolve and tools such as ChatGPT can play a significant role in transforming education [43], future research could explore their potential to simulate different funding scenarios, providing policymakers with insights into how various funding strategies might influence sustainability outcomes. In particular, more granular regional analyses could help identify localized funding needs and ensure that strategies are tailored to specific socioeconomic contexts, thereby maximizing their effectiveness. While this study provides a comprehensive analysis of current funding distributions, future studies could investigate how AI and machine learning could be further employed to enhance transparency and accountability in funding decisions. For instance, algorithms can be designed to flag potential biases in funding allocations, promoting a fairer and more inclusive approach to research support. As the landscape of AI and data-driven policymaking expands, there is also an opportunity for ongoing evaluation to ensure that these tools continue to align with evolving sustainability goals, addressing any new challenges that arise along the way.

4.2. Limitations of the study

While this study provides valuable insights into funding disparities across SDGs and highlights gender imbalances in research leadership, several limitations should be acknowledged. First, reliance on AI-driven analysis, particularly with natural-language-processing models, may introduce biases due to the inherent limitations of these algorithms. LLMs models used in this study may inherit biases present in the training data, potentially reinforcing existing disparities rather than mitigating

them. AI-driven classification of funding topics may reflect biases embedded in the datasets, affecting how different SDGs are associated with research fields.

Additionally, the analysis was constrained to abstracts, which might not fully capture the depth and breadth of each research project. Furthermore, gender identification using tools such as Genderize.io may not account for non-binary or other gender identities, potentially oversimplifying gender distribution analysis. Another limitation of this study is the reliance on AI-driven gender identification tools, such as Genderize.io, which classify names based on probabilistic models. While these tools provide high accuracy for binary gender classification, they do not account for non-binary identities or gender fluidity. Future research should explore alternative methodologies that integrate self-reported gender data to enhance accuracy and inclusivity.

Finally, while this study focuses on data from the ERC and NSF, extending the analysis to include other funding agencies could offer a more comprehensive picture of global funding trends. Additionally, gender disparities in research could be even more pronounced in many developing countries, where systemic barriers such as socio-economic constraints, cultural norms, and limited access to education and research opportunities further widen the gender gap. These factors may exacerbate existing imbalances, potentially leading to an even more skewed global research landscape. Future studies should examine how these disparities impact research funding distributions across different regions and explore strategies for mitigating these imbalances to promote a more inclusive research environment.

Data availability

The datasets used for this analysis are from ERC's [43] and NSF's [44] official archives.

Code availability

The code used to produce the present analysis will be available for open access upon publication of the manuscript.

CRediT authorship contribution statement

Panagiotis Varelas: Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Data curation. **Francesca Larosa:** Writing – review & editing, Validation. **Sergio Hoyas:** Writing – review & editing, Validation, Software, Methodology, Investigation, Data curation. **J. Alberto Conejero:** Writing – review & editing, Software. **Francesco Contino:** Writing – review & editing, Visualization. **Francesco Fuso Nerini:** Writing – review & editing. **Javier García-Martínez:** Writing – review & editing, Supervision, Conceptualization. **Òscar Garibo-i-Orts:** Writing – review & editing, Software. **Alessandro Parente:** Writing – original draft, Supervision. **Ricardo Vinuesa:** Writing – review & editing, Supervision, Project administration, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.rineng.2025.104367.

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