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What makes the contribution of science towards a Sustainable Future so difficult? A Controversy Analysis

Abstract: The time urgency to achieve the Sustainable Development Goals (SDGs) calls for paradigm shift in science to move beyond system boundaries, and produce relevant knowledge that is both practical and broadly actionable. Through investigating deficiencies, tensions and disagreements within science and science systems in supporting the SDGs, we characterize major demand for scientific shifts in its focus, scope, processes, and the role of scientists, and suggestions for strengthening the capacity for science to generate disruption. We then highlight controversies and trade-offs in technological vs. societal advancement, interdisciplinary vs. disciplinary complementarity, global vs. local knowledge creation and innovation, and scientific neutrality vs. objectivity. Deeper understanding and debate around these controversies is indispensable to create a common vision and safe space for transdisciplinary education and collaboration to systematically improve the "disruptiveness" of science in solving global complex challenges of this century. These are also required to ensure the coexistence and complementarity of distinct epistemic communities.

1. Introduction

The polycrisis, transgression of planetary boundaries, the planet's red alert, the war against nature—all these concepts, widely discussed in the scientific and policy realms, underscore the urgent need for transforming current unsustainable pathways that are destroying the very foundations of our existence on Earth (Jørgensen et al., 2024; Richardson et al., 2023; WEF, 2023) and contributing to numerous societal crisis worldwide (Duro et al., 2020; IPCC, 2022; Sullivan & Hickel, 2023).

In view of these pressing concerns, new interdisciplinary and transdisciplinary paradigms and approaches such as "Science for Sustainability" and "Sustainability Science", have been called on to integrate theory and applied science, to contribute to policy and decision making, and to deliver actionable knowledge in order to tackle urgent global challenges such as climate change, resource depletion, urbanization, food, water, and energy security, biodiversity, poverty, and sustainable development (Bettencourt & Kaur, 2011; Lang et al., 2012; Caron et Châtaignier, 2017). Noting that these terms may mean different things to different scholars, researchers, and stakeholders, we have included definitions of key concepts related to science that are most pertinent and discussed in this paper in Table 1. Disruptive science, is implicitly expected in the transformative ambition of the 2030 Agenda for sustainable development – as a global vision and blueprint for societal progress and sustainable development (United Nations, 2015).

In this context, this Agenda made of 17 sustainable development goals (SDGs) has been developed as an evolving framework. It is the only universal and most adopted framework by countries and governments, to assess their sustainable development progress, despite scientific debates around SDGs' effectiveness and their limitations (Gupta & Vengelin, 2016; Hickel, 2019; Latulippe & Klenk, 2020). In practice, we also note that sustainable development has been used more frequently than sustainability by governments in developing economies (Al Qasimi, 2025), and vice versa for advanced economies.

Table 1. Definitions of key concepts related to science as used in this paper.

Terms	Definition
Science	the production of knowledge of all kind", and is responsible for producing knowledge, technology and innovation through the natural sciences, social sciences, applied sciences, humanities and the arts (Kozlov, 2023)
Science System	a particular subset of knowledge systems more generally – including the institutions, practices, routines, structures, mindsets, values and cultures affecting what and how scientific knowledge is produced and used, and by whom (International Science Council, 2021)
Sustainability Science	an integrated field focusing on understanding the interactions between human and environmental systems and developing new approaches for sustainable transition, emphasizing a collaborative and holistic approach to tackle sustainability issues (Clark, 2007)
Disruptive Science	the capacity of science to generate change through disruption in prevailing paradigms, including through and for knowledge generation (Kozlov, 2023); research that departures from the status quo, and creates a new paradigm might differ from those that are used to develop an existing paradigm (Park et al., 2023; Kuhn, 1961).
Interdisciplinary Research	a mode of research that integrates data, tools, perspectives, concepts, and/or theories from multiple disciplines to advance fundamental understanding or to find solutions beyond the scope of a single discipline (National Academy of Science, 2008)
Transdisciplinary Research	a reflexive, mutual learning, method-driven scientific principle (Lang et al., 2012), that aims at solving societal problems characterized by complexity and diversity, when integrating various bodies of knowledge and inputs from a wide range of stakeholders, like community, practitioners, and indigenous perspectives (Heaslip & Fahy, 2018)
Sustainability	the integration of environmental health, social equity and economic vitality in order to create thriving, healthy, diverse and resilient communities for this generation and generations to come. The

	practice of sustainability recognizes how these issues are interconnected and requires a systems approach and an acknowledgement of complexity (UCLA, 2016).
Sustainable Development	development that meets the needs of the present without compromising the ability of future generations to meet their needs, while the 17 SDGs cover the three dimensions of sustainable development: the economy, social development and the environment (United Nations, 2025).
Sustainability Transition	processes of long-term structural change towards more sustainable societal systems. They include profound changes in ways of doing, thinking and organizing, as well as in underlying institutions and values (Loorbach et al., 2017)

At the same time, trust in science and science institutions has become increasingly contested, magnified by the public's expectation of rapid response to urgent issues that often conflict with the inherent, slower timeframes and methodological rigor required by scientific inquiry.

The persistently slow progress in advancing sustainability and sustainable development globally has cast doubt over the institutional and systemic impact of science or sustainability science (Nature Editorial, 2023), calling for significant shifts in approach to better harness science’s effectiveness and inclusiveness in this pursuit (International Science Council, 2021; Tommaso, 2022; Kozlov, 2023).

Evidence points towards a number of conflicting issues and competing interest, relating to the focus of science between disciplinary, inter and transdisciplinary science, geographic differences between developed and emerging economies, between conventional and disciplinary science and systemic and sustainability approaches (Hooke, 1674; Anderson and Johnson, 1997; Ramage and Shipp, 2009), and temporal mismatch between incremental and disruptive science (Kuhn, 1962; Wray, 2011; Park et al., 2023).

Hence, questions arise in the debate among scientific communities and broader contexts in governments, industry, businesses and civil societies. Do science and scientific institutions need to transform themselves to deliver more inclusive, reflexive, and societal impact towards sustainability and the SDGs? What needs to change to address deficiencies in how science is conducted and science systems are managed? Is it necessary for all disciplines to incorporate 'sustainability' elements into their knowledge production and exploration process? Is interdisciplinary and transdisciplinary collaboration a necessity for all scientists? How could we make this happen for scientists who do not have the connections and skill sets for such collaborations? And how should scientists involve relevant actors to co-create this pathway?

The objective and contribution of this paper is two-fold: firstly, drawing attention to current controversies and disputes, we endeavor to initiate renewed interest from the scientific community in exploring the primary research question - why has there been little progress on improving the capacity of science to support Sustainability and the SDGs?. We examine the deficiencies in science to support sustainability and the SDGs, and how science and the science system need to do differently —at the epistemic, relational, and transformational level—to enhance the reflexivity, inclusiveness, and usefulness of science.

Secondly, we highlight 4 key areas of controversy that have impeded the progress of science in transforming itself: technology optimism, disciplinary vs inter and transdisciplinary approach, global vs local knowledge production, and the change of role and scope for scientists. We refer to case studies to illustrate their complexity. Through the lens of scientists, we reflect on the critical role of scientific actors, and the need to enhance their awareness and continuous engagement in exploring collective and inclusive pathways toward sustainability transition.

2. Approach

This study originated from a group of senior scientists from diverse disciplines and countries, exploring the theme "*Disruptive science to meet global challenges*" when participating in a six-month residency at the Montpellier Advanced Knowledge Institute on Transitions (MAK'IT). This theme was in part motivated by the alarm and evidence raised by "*papers and patents have become less disruptive over time*" (Park et al., 2023). Six scientists who are deeply involved in the agri-food, energy, and water related field and research, shared their worldviews and self-reflection through a deliberate inquiry process into controversies and demands for scientific shifts. The group attempted to explore the concept of scientific disruptiveness and major barriers in improving the credibility, legitimacy and usefulness of science in addressing complex global issues.

Adapted from six conditions of system change (Kania et al., 2018), as illustrated in Figure 1, a three-layer logic model is employed to examine the critical components in science and their current deficiencies in addressing global complex challenges.

At the **epistemic** level, we seek to understand constraints in science and the science system to support sustainability and the SDGs, such as policies, norms and goals, incentives, power imbalances, knowledge gaps, and embedded social narratives. We looked into existing literature for the structural and relational characteristics and gaps in science and the science system. The focus is placed on 1) institutional configurations and priorities that guide the direction, scope and focus of science, and actions of scientists, 2) how scientific research is conducted and managed in connection with the knowledge production, dissemination and utilization, 3) how funding, staff, knowledge, information, and other assets such as infrastructure are allocated and distributed at both institutional level, as well as national and global systems. We sought answers to the following research questions: "What has science not achieved so far for sustainability and the SDGs?”, and “What does the literature suggest about what science needs to do differently?".

The relational layer is exercised by actors with their own interests and standpoints. It can be reinforcing, symbiotic or counteracting, having positive or negative influence in achieving a shared or common agenda. Controversies and disputes often arise within these relationships and power dynamics, both inside scientific institutions and involving wider networks such as with external actors, be it public, private, or societal. Some pertinent questions to ask include: Which actors and how are they engaged in the research design and knowledge co-creation? How do power dynamics influence the process and strategies in which scientific products are delivered, distributed and applied? Employing the concept of controversy (Caron, 2025) as a sense-making tool, we reflect on why change in science is slow, despite rapid transition in a number of sectors, such as agrifood and energy, and the elevation of these critical issues at global level for decades.

Finally, **at the transformational level**, while it is widely acknowledged that scientific shifts toward more effective, reflexive, and inclusive regimes demand the recognition and integration of inter and transdisciplinary research agendas and researchers into existing institutions, one can question the reasons for observing slow progress. Similarly, there is little advance regarding a leveled and balanced focus on both technology and society, and a harmonized approach towards global and local knowledge production. We are interested here in the resistance and controversies that hamper change or make it slow and difficult. In response to the call for transformative change in science, we place focus on scientific actors - the originators, mediators, and resolutioners of these controversies - and their mindsets that hold the key to unravel these controversies and disputes.

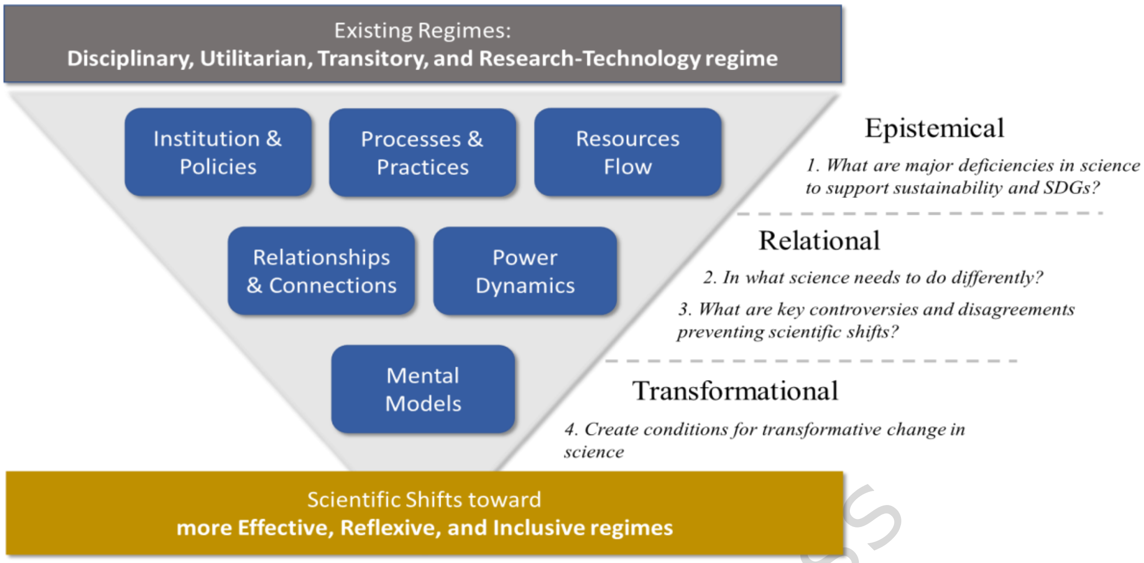

Figure 1. A three-layer logic model for transformative change in science (adapted from Kania, Kramer and Senge, the Water of Systems Change, 2018)

3. What has science not achieved for Sustainability and the SDGs?

Mounting pressure on science regimes to increase their reflexivity capacity to produce in-demand knowledge for practical problem solving has arisen from the changing global landscape, including recognition and commitment from nations and governments to tackle climate crisis, resource depletion, geopolitical pressure, and societal needs. Currently, none of the four existing regimes of science described by Marcovich and Shinn (Marcovich and Shinn, 2011), namely disciplinary regime, utilitarian regime, transitory regime and research-technology regime, are fit for addressing bidirectional relationship between science and society to fulfil societal needs in sustainability and the SDGs. The disciplinary regime focuses on theoretical delivery and disciplinary learning rather than practical problem solving, and its communication mostly within the discipline, while the latter three regimes focus on addressing one directional challenge from problems to solutions, hence their production and diffusion.

Inherently, neither of the regimes provides a global scope, system-level thinking, or a favorable environment for inter or transdisciplinary collaboration to support sustainability and the SDGs. These deficiencies have reflected in some of the shortcomings in knowledge production and its creation process ascribed to science in more effectively supporting sustainability and the SDGs, as discussed below.

3.1 Limited Focus on Sustainability and the SDGs

Academic research around natural science for sustainability, such as biology and chemistry, earth and environmental for sustainability, as well as data science, material science, behavioral science, and community science for sustainability (Miller et al., 2014) has increased rapidly in the last several decades. However, sustainability research accounted for only 10% of global scientific output between 2011 and 2020, of which over 40% were contributed from the USA, Canada, and Europe (Ramakrishna et al., 2022).

Moreover, the link between research output and real-world impact remains challenged when inter- and trans-disciplinary research has limited outlets to be published. Out of over 300,000 journals, only a few hundred of them cover inter- or trans-disciplinary research (ITD Alliance, 2025), despite its crucial role in fostering stronger research-policy-implementation interaction and innovation, and impact-driven research. This highlights a persistent gap where science primarily documents sustainability needs while often focusing on fragmented local issues, rather than delivering actionable knowledge to drive systemic changes (Miedzinski et al., 2022), including resistance to change and pathways to move beyond (Hainzelin et al., 2023).

3.2 Regional disparity

There are significant geographical imbalances in SDG-related research. High-income countries (HICs) account for 68% of SDG-related publications despite comprising only 16% of the global population, whereas low-income countries (LICs) contribute just 0.2% of global research output and 0.02% of patented innovations (Tommaso, 2022). LICs dedicate a larger share of their research to sustainability, yet only 10-15% of global patent filings were by developing countries (excluding China). Wu (2023) pointed out a highly uneven distribution in the Nature Index for south-north collaboration, in which 42 African nations together share less than one-fifth of India who has the biggest share for global-south nations. Moreover, there has been slow progress in technology and knowledge transfer to developing countries, which exacerbates inequity in accessing technologies and acquiring capabilities in transitioning into clean and more sustainable economies for all countries (Gui et al., 2024).

Disparities of nations in achieving the SDG are illustrated in Table 1 (Ma et al., 2025). Countries with low SDG scores show relative advantages in SDG indicators related to overnutrition (2.1, 2.2), embodied social and environmental impacts in international trade (8.7, 8.8, 12.3, 12.4, 12.5, 12.8, 13.2, 14.4, 17.12), resource use (15.2, electronic waste (12.4) and emissions related to industry production (9.4, 13.2). These are controversial themselves since the achievement of the related SDGs is involuntary, often as the result of underdevelopment and overall less well-being (Goals 3 and 4). In addition, despite SDG-related patents worldwide are on the rise now contributing to 31.4% of active patent families worldwide, SDGs where the largest gaps exist between countries with high SDG scores and low SDG scores, namely SDG 1, SDG 2, SDG 4, and SDG 6, only account for 11% of total SDG-related patents (WIPO, 2024).

This finding emphasizes the need for targeted interventions and the consideration of historical context to ensure that all areas of sustainable development receive adequate attention, resources and tailored policies highlighting the complexity of achieving the SDGs.

Table 1. Summary of difference in areas of SDGs for countries with high and low SDG scores (Ma et al., 2025)

	Countries with high SDG Scores		Countries with low SDG Scores	
	Attained	Weak	Attained	Weak
Areas of SDGs	poverty reduction (1.1) , hunger reduction (2.1, 2.2), good health and well-being (Goal 3), wastewater and air pollution treatment (6.3, 11.6), access to clean energy and water (6.1, 7.1), industry, innovation and infrastructure (Goal 9), government administration (16.3,16.6, 16.10)	managing electronic waste (12.4, 12.5), maintaining a low human trophic level (Goal 12), and reducing CO2 emissions (13.1, 13.2, 13.3)	overnutrition (2.1, 2.2), embodied social and environmental impacts in international trade (8.7, 8.8, 12.3, 12.4, 12.5, 12.8, 13.2, 14.4, 17.12), resource use (15.2), electronic waste (12.4) emissions related to industry production (9.4, 13.2)	fresh water access (6.1), urban infrastructure (9.1.), education (Goal 4) face inadequate nutrition across the population (double burden of obesity and sub-nutrition (Goal 2), high poverty indices (Goal 1), limitations in access to employ (8.5), connectivity (17.6), research and development (9.5, 9b, 9c)

	street safety (3.6, 11.2)
	justice (16.3, 16a, 16b) and freedom (16.10)

Additionally, language barriers hinder knowledge dissemination, as English dominates academic publishing, making non-English research less visible (Litre et al., 2022). While digital translation tools are improving, deeper challenges remain in translating knowledge between disciplines, among academic and non-academic actors, across organizational systems, and socio-economical strata, geographies and cultures.

3.3 Limited ability in addressing the interconnectedness of SDGs

Challenges and solutions related to the SDGs are highly interconnected, sometimes with significant tradeoffs. This creates enormous challenges for science, controversial and even contentious situations, as research questions or solutions addressing one area of priorities may lead to deficiencies in other areas of SDGs (Fronza et al., 2023). For example, achieving SDG 7 (clean energy for all) may have ramifications with SDG 6 (clean water and sanitation), SDG 2 (zero hunger), SDG 10 (reduced inequality), SDG 15 (life on land) in relation to the management and uses of water and land for energy, mining, and food production in many regions. Furthermore, there is currently a lack of scientific methods and research into effectively measuring and evaluating the interactions between SDGs (Xiao et al., 2024), creating many challenges in identifying pathways and gaining political support for SDG implementation.

Given the systemic and complex nature and magnitude of the challenge to achieve the SDGs and sustainability, new categories of science have emerged in the last few decades, interacting with multiple systems and multiple SDGs, such as systems science, sustainability science, urban science, circular economy. These disciplines emerging from interdisciplinary approaches call for institutional support and close collaboration among researchers from different disciplines, background and expertise, however often face many challenges finding a collaborative space in a disciplinary environment. When dispersed into the traditional faculty structure, these researchers may feel significant competitive pressure and 'loneliness' if without adequate interdisciplinary support from peers (Pellmar and Eisenberg, 2000).

4. Results: what science needs to do differently

In the quest for disruptive science, the following questions need to be answered by the scientific community: is a scientific paradigm shift possible to help the world to achieve sustainability and the SDGs? What does science need to do differently toward a more effective, reflexive and inclusive scientific regime in view of many grand global challenges?

Through the review of existing literature and self-reflection among the group of scientists, we identified six key themes (summarized in Fig. 2) to understand alleged deficiencies in how science is conducted, science systems are managed, and science outcomes are recognized. Each theme is elaborated below.

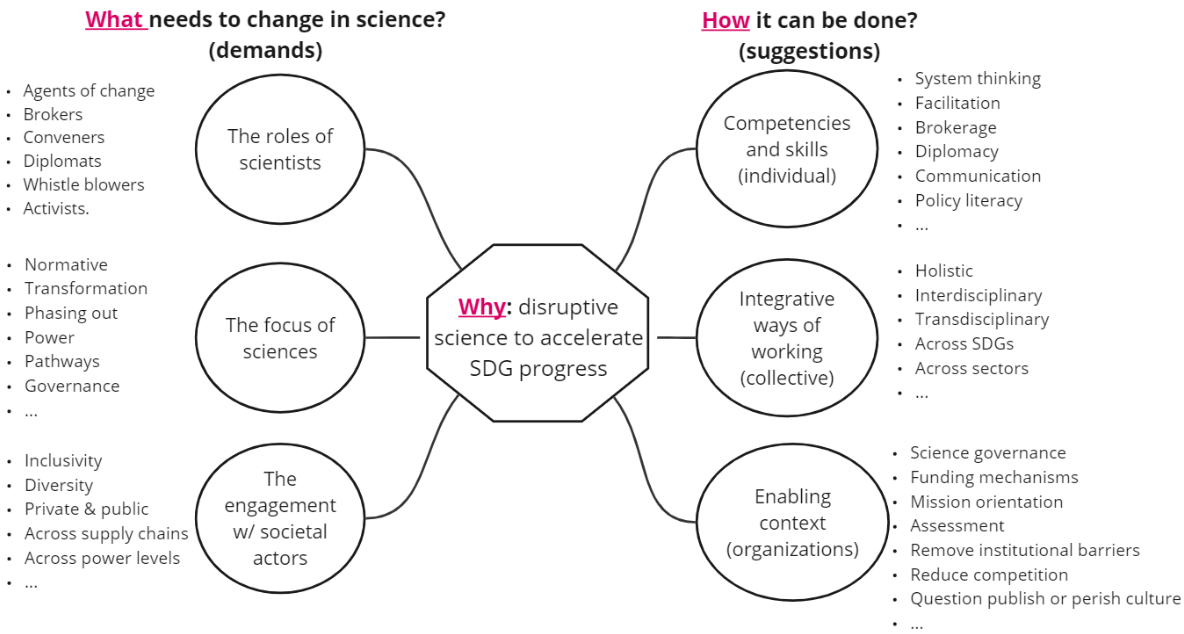

Fig 21: Main themes identified in the literature regarding the contribution of science to SDGs. According to expert literature, for science (and scientists) to become more effective in supporting SDGs (i.e., "why"), it needs to play different roles, change its focus and engage with all societal actors (i.e., "what"). For that, scientists need to master new competencies and skills, and to develop integrative ways of working collectively, but this requires a much more enabling context (i.e., "how").

The first three themes reflect what is being asked of science and scientists in the face of sustainability challenges (what):

- **Scientists as agents of change**. Scientists are increasingly and explicitly called to act beyond academic roles of delivering knowledge —as brokers, conveners, diplomats, whistleblowers, and communicators (Büttner et al., 2023; Editorial Nature, 2023b; Hainzelin et al., 2023). This includes supporting visioning, policy engagement, public debates, and the monitoring of SDG pathways (International Science Council, 2021; Miedzinski et al., 2022). Scientists are invited to balance leadership in enabling transitions with humility, acknowledging that shaping the future is a collective and uncertain endeavor that builds on power games and vested interests. They should avoid blurring the distinction between knowledge providers and decision makers but contribute to their articulation through broader engagement with society.

- **Shifting research focus**. The focus of research must move toward transformational, context-specific, and normative change that supports sustainability transitions (Büttner et al., 2023; Malekpour et al., 2023). Research should address the SDGs holistically (Tommaso, 2022), integrate across socio-technical systems (e.g., energy, food, mobility), and consider interconnections, equity, and long-term effects (Priebe et al., 2021; Leal Filho, 2023). Stronger methodologies are needed for impact evaluation, policy relevance, obstacles to transformation, and the governance of transitions (Kostoska et al., 2019; Scaini et al., 2024).
- **Broader engagement with society.** Inclusive, participatory processes—throughout all research phases—are essential to ensure relevance, legitimacy, and fairness (International Science Council, 2023; Miedzinski et al., 2022). To promote sustainability and engagement, diversity in participation must reflect gender, race, geography, socioeconomic status, and roles across systems (Leal Filho, 2023; Büttner et al., 2023). Scientists are invited to foster multi-stakeholder dialogue and engage more effectively at the science-policy-society interface using accessible and adapted formats and co-creative processes (Hainzelin et al., 2023; Editorial Nature, 2023; Tommaso, 2022).

The following three themes reflect how the literature suggests these demands can be addressed in practice (how):

- **Developing new competencies**: Transformative roles require a new suite of skills, including systems thinking, facilitation, negotiation, communication, and transdisciplinary collaboration (Arnold and Wade, 2015; Wiek et al., 2011; Sajdakova et al., 2020). Scientists need to adapt language and engagement strategies to connect with diverse actors and support decision-making with tools such as modeling, scenario analysis, and participatory design and foresight (International Science Council, 2021; Hainzelin et al., 2023; Miedzinski et al., 2022). These competencies would then be embedded in both academic training and lifelong professional development.

- **Working in integrative ways**: Integration and knowledge co-creation processes across disciplines, knowledge systems, institutions, and governance levels can support a novel learning and reconfiguration process in science and science system, in response to new regime and landscape pressure in addressing pressing global challenges and multiple socio-economic-technological objectives (International Science Council, 2023; Geels and Schot, 2007). This means breaking silos and aligning research behind large-scale, mission-oriented initiatives with coordinated funding and coherent policy (Tommaso, 2022; International Science Council, 2021, 2023).
- **Creating an enabling context**: The evidence draws attention to the fact that risk-taking towards disruptive science is disfavored by risk-averse universities and research institutions (Heinze et al., 2020). Structural changes in the science system are necessary to empower researchers to meet SDG-related demands (Büttner et al., 2023; Tommaso, 2022). These include 1) rethinking funding, institutional incentives, and evaluation criteria beyond publication counts (Thelwall & Sud, 2022; White, 2019), while promoting transparency and stakeholder input; 2) fostering a culture of risk-taking behaviors and willingness to open up new avenues of inquiry, pursue the emerging field of research and investigation for innovative solutions to tackle pressing societal challenges, such as climate change,

natural resource depletion; 3) embracing mission-oriented innovation systems to align resources, actors, and policies (Klerkx et al., 2023).

There have been repeated voices for these demands from both scientific and non-scientific stakeholders. We also recognize that other forces, such as the rise of misinformation (Budak et al., 2024), resources constraints within science, and threats to the legitimacy of scientific expertise (e.g., Sturgis et al., 2021), limit the capacity of science to contribute to sustainability transition. While these dynamics, which have been unfolding for decades (Haerlin et al., 1999; Miller et al., 2025) are themselves debatable, they fall outside the scope of this article. In the following section, we turn our attention to four major controversies within science itself, which we argue are central to understanding why the contribution of science to transformative change has been so slow.

5. Discussion: controversies around science and the current science system

'Controversies' arise from differing beliefs and values; personal, political, social, and economic interests; fears; uncertainties; and moral and ethical considerations, and can become a major consideration in decision making (National Academies of Sciences, 2017). They often involve networks of actors, debating, opposing, resisting, negotiating, in order to advance their own values and interests over time. Controversies emerge at the intersection of issues or at the boundary of the systems interacting during transition processes, such as the interlinks between 'the social', 'the technical', 'the economic', and 'the ecological', between 'water', 'energy', 'agriculture and food', between 'security', 'sustainability', and 'affordability', and between 'resilience', 'efficiency', and 'adaptability' (Latour, 1987). In contrast with the polemic where the question of subject is determinant and where delegitimization of the opponent prevails, the controversy is centered on the object (Wismann, 2015) and aims at confronting different viewpoints to formulate a shared vision of the situation and of the future. This is why we focused on controversies in this section, as a way to identify the best way for science to contribute to sustainability transition despite the many diverging viewpoints about science engagement.

To shed new light on controversies requires systemic analysis and innovative analytical paths and methodologies; such collaborative and participatory processes may constructively contribute to just and inclusive transition pathways (Rossignol et al., 2017; Meyer, 2015; Martin and Richards, 1995).

5.1 Addressing four controversies to stimulate the contribution of science to disruption

In this paper, we delve into four controversies related to institutions and policies, processes and practices, connections and relationships, and mental models illustrated in Figure 1. While acknowledging that many oppositions lie outside the academic world, we leaned toward exploring controversies that arise at least partially within the sphere of control of the science system and its institutions. These controversies are not merely technical disagreements; they reflect different and often competing perspectives, worldviews, and paradigms coexisting within the science system itself, among scientists, academic institutions, funding mechanisms, and governance structures. While this was our primary emphasis, we also acknowledge other debates present in the transition literature, such as diversity versus specificity, productivity versus multifunctionality in science, and the convergence of private and public goods. In this section, we particularly elaborate on competing viewpoints and arguments of controversies, in regards to what kind of knowledge/solutions are prioritized (techno-optimism vs. techno wariness), how science is organized and produced (disciplinary vs. interdisciplinary complementarity), whose knowledge is valued and agenda prioritized (global vs. local knowledge production), and to whom science responds (scientific neutrality vs. objectivity). Here, we provide a high-level description of these controversies as possible impediments or roadblocks to the changes demanded of science, aiming to frame them as critical areas for future inquiry. A comprehensive controversy analysis could help to untangle the underlying drivers, actor positions, and systemic interactions shaping these tensions. By mapping these controversies at a conceptual level, we set the stage for deeper inquiry and practical strategies to navigate them.

Controversy 1. Techno-optimism vs Techno-wariness

Science and technology have contributed to several waves of the industrial revolution and reshaping the global economy, the physical world and society we now live in. The debate on the extent that advanced technologies can contribute to SDG progress arises due to the regional disparity, lack of a balanced approach, and lack of consideration for undesirable consequences (Gonella et al., 2019). Especially in many cases, these technologies are driven by private interests and commercial objectives rather than serving public goods and broader societal needs (Messerli et al., 2019). For example, technologies such as smart farming, precision agriculture, using drones, robots, Artificial Intelligence and data analytics, 3D printing, genetic engineering, and non-thermal technologies can play an important role in a more sustainable and efficient food system (Hassoun et al., 2023). On the other hand, they require additional energy resources, human capital, and significant upfront investment. This is unaffordable for the majority of the small-scale farmers in developing regions, weakening SDG 1 (No Poverty), SDG7 (Clean Energy), SDG 10 (Reduced Inequalities), and SDG12 (Sustainable Production and Consumption) (Leeuwis et al., 2021).

Ensuring affordability, scalability, and equitable access to these technologies and resources in developing regions requires significant technical and financial assistance and capacity-building programs, and ethical norms and frameworks from local or international authorities (Ahmad et al., 2024). If not, technology-driven solutions may exacerbate inequalities, moving away from the assumption of technology neutrality. Scholars have warned of the potential for technological determinism to harm human and ecological systems, leading to inequality and increased vulnerabilities (Eubanks, 2017; Latour, 1999).

Caron (2025) discusses the need for a coordinated global strategy that aligns private and public efforts to produce public goods, such as food, as well as the importance of finding appropriate governance scales to balance local and global interests. Sometimes, this tension is explicit in strong public debates that turn into polemics, like in the case of genetic modification versus more integrated and nature-based approaches in the agrifood sector (HLPE, 2019).

While our fascination around technology is continuing, it is important to recognize that technological advancements may not bring about the most desirable societal advancements without careful deliberation. Furthermore, science has been slow to react in helping to understand inherent risks and long term societal and environmental impacts from these technologies. Thus, research questions should be asked - how should science respond to inherent risks of technologies? under what conditions can universal access to technology become possible in order to achieve the SDGs for all nations and social groups? More broadly, should the role of science and technology be restricted to the design of prototypes, without investigating and being engaged in the assessment of impacts towards sustainability and the identification of conditions for positive impact to take place? Our assumption here is to acknowledge the responsibility of science and scientists and that such responsibility cannot be left to governments, businesses and the society to manage the aftermath of technology and the crisis it may generate.

Controversy 2. Interdisciplinarity substitution vs Interdisciplinarity complementarity

The complexity to achieve sustainability and the SDGs requires holistic integration across disciplines, knowledge systems, socio-technical and socio-ecological systems. For example, transition to clean energy is associated with cross-disciplinary collaboration in public policy and planning, economics, engineering and technology, infrastructure, social and behavioral science, and education. However, energy research from the social science perspective has lagged behind technology-based promotion (Gunes, 2023; Pan et al., 2021), leading to misunderstanding and doubts around the societal and developmental benefits of clean energy transition. This consequently has presented a major barrier for many countries when transitioning away from fossil fuels to achieve SDG 7 (Gui et al., 2024).

In addition, scientific research often remains highly specialized and siloed, when pursued within a disciplinary science framework based on incremental improvements and existing knowledge (Park et al., 2023). The disciplinary boundaries are further strengthened by a rigid career promotion and recognition system that rewards specialization that can rapidly produce a high number of publications, rather than inter- or trans-disciplinary collaboration involving non-academia actors that can lead to larger real-world impacts. These are strongly reflected in the lack of institutional support in interdisciplinary work, with a few dozen interdisciplinary research institutes established around the world and limited international journals targeted for interdisciplinary knowledge products. As a result, many initiatives with the scope for systemic change have mostly been led by multilateral agencies, NGOs, think tanks, and sometimes involving individual academics and researchers that are willing and have the capacity to contribute.

On the other hand, some authors insist that the integration of diverse knowledge systems, while enriching, can dilute scientific rigor and sacrifice academic independence and contribution to theoretical and conceptual progress (Loorbach & Wittmayer, 2025; Aslin & Blackstock, 2010). Additionally, the complexity of managing stakeholder engagement and balancing power dynamics can hinder progress, as dominant interests may overshadow marginalized voices, affecting the fairness and effectiveness of solutions. Another set of criticisms points to the impediments and rigidities for conducting transdisciplinary work that originate in the way in which research is governed, organized, funded and controlled (Cardona et al., 2024; Romera et. al, 2025). The dominant accountability and auditing culture (Hunt, 2009; Shore & Wright, 2003) makes it incredibly difficult to carry out the kind of transdisciplinarity recommended to support the SDGs. If considering the global science system as a socio-technical system itself in transition, change of the institutional context is complex and the ability to manage it faces innumerous challenges driven by diverging views. Acknowledging the value of disciplinary and transdisciplinary organization and activities raise the question of the conditions for coexistence of both regimes. It confronts universities and research institutions with the necessity to create an enabling environment for such coexistence and for complementarity to take place.

Controversy 3. Universal vs Local knowledge creation and innovation

Pathways for sustainable impacts at scale depend on a harmonized design, production and dissemination of both the universal and contextual dimension of knowledge and innovation. Debates exist in the epistemological communities about transfer of knowledge and technology between geographies. Some argue that they can be transferred if enabling environment and funding conditions are met, while others argue that innovation is always context specific and requires a co-design process. Furthermore, they insist on the fact that impact at scale cannot result from the mere reproduction of local success stories, which often prove to be not reproducible.

In this context, ongoing research and development that suits the local conditions are challenging in the developing countries due to limited economies of scale and heightened investment risks (Aguilera & Larraín, 2021). Studies pointed out key challenges in a general shortage of home-grown research and limited knowledge ownership. Mulugetta et al argue that limited local knowledge creation hampers progress in creating optimal local-level implementation approaches and risks the introduction of significant foreign biases when defining Africa's energy and development research agenda (Mulugetta et al., 2022). This, of course, exacerbates the ongoing inequities in scientific production and inadequate science systems to support organic development or translation of science to suit the context of developing nations.

The increasing share of private status of knowledge and technology further complicates this issue (Aguilera & Larraín, 2021), as achieving the SDGs rely in most cases exclusively on public institutions to fund science. Further, many traditional knowledge held by indigenous communities can be marginalized without opportunities to be further developed and evolve, due to limited access to adapting capacity through investment and technology. As a consequence, the lack of a context-dependent scalable solution creates a bipolar world that exacerbates global disparities and gaps in SDG achievement rising, as shown in Table 1.

Without addressing the barriers to scalability (Caron et al., 2025), be it technological, financial, institutional, or socio-cultural, the global community will struggle to achieve the SDGs equitably, and existing disparities will be further entrenched (Ma et al., 2025). Meanwhile, safeguarding from the wealth division of knowledge and technology requires institutional adaptation in science to develop effective global ethical and sustainability frameworks that balance competition and collaboration, market and regulation, and production and dissemination of knowledge and technology. It also calls for better assessment of the complex and interconnected dimensions of impact taking into consideration multiple time and space scales.

Controversy 4. Scientific neutrality vs objectivity: a persistent tension in sustainability science?

Horcea-Milcu et al. (2024) highlight the need to understand the tensions that arise when doing transformative research for sustainability in relation with the existing paradigms of academic research. Their analysis focuses on three tensions: (1) process- and output-orientation; (2) accountability toward society and toward science; (3) methodologies rooted in scientific traditions and post-normal methodologies. The longstanding tension between the descriptive-analytical and transformational modes of sustainability science underscores these concerns (Wittmayer & Schäpke, 2014). If engagement is needed as advocated for in section 4, it is important to ensure the coexistence of different streams of research and their articulation. Additionally, and as advocated by sociologists of science, there should be an increased capacity for reflexivity to consider the influence of society and politics on science and vice versa. Regardless of the research stream, it is crucial to address the balance and tension between independence and influence. While some scientists see interdisciplinary collaborations and new areas of research emerging as opportunities, others may consider them as threats, and continue to hold a view in which science is at best and more effective to remain strictly within disciplinary boundaries.

The appropriateness of a value-driven science remains a contested issue, clashing with the enlightenment ideal of science (alive and well) as a neutral and objective pursuit (Milkoreit et al., 2015). For instance, Büntgen (2024) contends that "*scholars should not have a priori interests in the outcome of their studies*". Yet, focusing on outcomes is precisely what sustainability science is being called to do: to support systemic change and engage directly with society (Bodin, 2021). The normative mission of transformational research is indeed orientating societal change (Horcea-Milcu et al., 2024). Critics warn of potential risks, including the erosion of scientific authority, growing science skepticism, the instrumentalization of science for political ends, and a potential trade-off between societal and academic impacts (Schäpke et al., 2016; Schmid-Petri et al., 2022; Newig et al., 2019; Younger-Khan et al., 2024).

Recognizing that science organization and programming are themselves influenced and shaped by social and political drivers, pertinent questions to ask here would be: are scientists willing to take on such roles? Do they believe it is truly their responsibility to lead in addressing global challenges, such as the SDGs and sustainability? Have the SDGs and the calls for transformational change been meaningfully internalized by a majority of the scientific community? And to what extent should responsibilities for driving change lie instead with political leaders, civil society actors, or community organizers? It is vital that the scientific community reflects on these questions and collectively explore ways to navigate this ongoing and complex controversy.

To end this section however, it is important to recognize that sustainability science is not unique in being guided by normative assumptions. Research oriented toward economic growth (also a demand from governments and funders), for example, is also underpinned by a particular value system. Yet, because this growth-centered paradigm aligns with mainstream worldviews, its normative foundations often go unexamined and escape similar scrutiny. Consequently, its practitioners are rarely accused of lacking objectivity, a critique more frequently directed at scientists working on sustainability and societal transformation.

5.2 Moving forward beyond controversies

In reflection upon these controversies, we recognize the critical role and functions of its actors - the originators, mediators, and resolutioners of these controversies - and their epistemic positions, models and behaviors. To initiate the transformative change in science, maintain its intergenerational relevance, and thus its long-lasting impacts in addressing global challenges, we highlight critical action points at three levels - existing incumbent academic actors, scientific actor networks, and future and intergenerational actors.

5.2.1 Shifting models of existing incumbent actors

For science, as a 'socio-technical' system, dominated by incumbent academia and institutions, and strong disciplinary coalitions, transformation will depend on recognizing the need and preparing for change by its principal actors - scientists and scientific institutions. By presenting diverging worldviews, the controversies discussed in this paper may help scientific actors to place their focuses and priorities, to identify with whom to develop research scope and alliances and how to serve their own and others' perspectives. This is needed to shape the process, pathway, and progress of science to transform itself. Based on literature review, we know that the capacities for the actors to adopt practices for more collaborative and participatory research agenda setting and knowledge production that integrates a variety of local contexts, are critical in advancing science towards solving sustainability and SDG challenges. However, the capacity to organize the coexistence of distinct academic communities to ensure the required complementary of their contribution is also key.

The call for transformative change in science in order to contribute to sustainability challenges has not yet met expectations. The shift needs to be undertaken, owned and supported by the scientific community itself, through attitude and determination to leave behind the safe, the comfortable, and the certain while working in a more open, yet riskier and uncertain landscape. This cannot happen without the engagement of forward-looking scientific institutions to develop structures and incentives that can steward scientists and their effort towards plurality, creativity and initiatives in a more systemic manner across multiple disciplines and domains. This will inevitably involve breaking its inward-looking disciplinary agenda setting, assimilating new players including ‘pracademic’, and ensuring a more structured connection between innovation and impact with careful consideration of socio-environmental impacts at scale.

5.2.2 Engaging with scientific actor networks

A more credible, reflexive and inclusive science system relies on the mobilization of scientific actor networks and the harmonization of their interest, involvement and contributions, including both scientific actors and actors external to science, such as civil society, governments, businesses, NGOs, funding bodies. In the context of sustainability transition, scientists and scientific institutions must rethink possible stakeholder engagement strategies in governance, structures, processes, capabilities, considering stakeholder interest and behavior, to integrate multiple stakeholders’ inputs and contributions into the conceptualization, design and innovation of scientific research. Failing to organize the complementarity of contributions from diverse academic communities or to integrate the value of stakeholders external to science would hamper any progress moving forward. This would strengthen the criticism expressed to disciplinary approaches and technology dissemination, and increase risks of bias perception, mis-information and expanding mistrust in knowledge production.

While initiating change are usually associated with polemics, doubts, inertia, resistance, an initial step can be taken navigating disagreements and controversies through the creation of 'risky safe spaces'. This means the organization of spaces where taking risks is possible and encouraged, in particular risks for scientists to be confronted with different and diverging epistemic positions, the creation of spaces where scientists benefit from such confrontation rather than feel unsafe. As illustrated by the example of the Montpellier process (2025) to explore pathways to engage in food systems transformation, the organization of such spaces require an institutional engagement to provide safety and the adoption of rules based on respect, listening and learning.

In such spaces, all actors, governments, industry, businesses, civil society, academia are brought together, engaging in honest dialogue for debates and negotiation, sharing, exploring and understanding diverse perspectives, normative values, equity and justice, and understanding the interconnected social, economic, and environmental dimensions of sustainability challenges. Bounded by a shared engagement, disagreement can be tabled, and participants are encouraged to confront their own views and roles in the problems to explore the design of a shared vision. This allows for deeper and more meaningful design of solutions, as Caron (2025) states:

> "*Reaching an agreement about disagreements through mediation may enable the parties to engage in collective co-design; negotiation should then allow the parties to move from disagreement on desirable agreement towards agreement on agreement*" (pg. 121).

These spaces may turn controversies into fertile ground. They provide a mechanism to navigate them constructively, complementing the shifts in roles, practices, and enabling environments, as discussed in Section 4. Institutions and networks have an important responsibility in creating and shaping these spaces. Without such deliberate efforts, the science system risks remaining locked in entrenched positions, slowing its capacity to contribute to sustainability transitions and the achievement of the SDGs.

5.2.3 Bridging gaps for future and intergenerational actors

Transformation in science is an intergenerational endeavor. To create broader societal and intergenerational awareness, and prepare transformation to be designed and implemented with cross-generational impacts, education for SDGs encourages teaching and learning for sustainability, emphasizing indigenous knowledge, eco-pedagogy, eco-centric education, empowerment, planetary ethic and responsible consumption (Kopnina, 2020) and co-design. Many initiatives are flourishing here and there. For example, in a novel endeavor, a Responsible and Sustainable Innovation platform has been established in Australia to align scientific education with the society needs in a technology-driven world, through interdisciplinary, transdisciplinary and inclusive design (Jantsch, 1972) integrating technology, innovation, sustainability and behavioral science, societal values and norms (OpenGovAsia, 2025). The transformation in education in such a way should help to build the foundation for future scientists, engineers and policymakers to prevent mistrust in knowledge and technology, navigate the ethical, legal and social challenges associated with emerging technologies when addressing global complex challenges with a sense of social responsibility, foresight, and integrity. Envisioning a future-proof education system, system thinking, resilience thinking, anticipation and visioning, participation and collaboration, socio-demographic diversity and inclusion, reflexivity and empathy are some of the key attributes to tackle global challenges in achieving the SDGs and sustainability (Nusche et al., 2024). Healthy debates involving the scientific community and the society around benefits and weaknesses of technologies, innovations and related controversies, science and science systems should be encouraged in curricula in order to not only advance science but earn public acceptance and trust, enhance social cohesion and harmony for the health of the Anthropocene and prepare the new generation of scientists and experts to address future challenges.

6. Conclusion

In our search for answers to the question, 'Why is there little progress on improving the capacity of science to achieve sustainability and the SDGs?', we identified four key controversies: Techno-optimism vs Techno-wariness, Interdisciplinarity substitution or Interdisciplinarity complementarity, Universal vs. local knowledge creation and innovation, and Scientific Neutrality vs. Objectivity. By drawing attention to these controversies and debates, we aim to provide insights and seek renewed interest from the scientific community and other stakeholders to overcome obstacles and identify pathways for accelerating sustainability transformation and SDG implementation.

As demonstrated throughout this paper, the complexity of achieving sustainability transition calls for a scientific shift and regime change to strengthen effectiveness, reflexivity, and inclusion in science. Exploring divergences in epistemic positions and models of scientific actors is the initial attempt in understanding the reasons for tension and disagreement and identifying common grounds for moving forward. Beyond actors and their models and behaviors, we open up new inquiries for future studies, such as what a novel scientific regime might look like? By understanding what science needs to do differently, we offer the first glimpse into a novel regime in science. How can society exert further landscape pressure onto science and the science system to produce actionable knowledge that is aligned with desired societal and sustainability outcomes? How resource flow and power dynamics may impact the process and pathways for scientific regime change? How can epistemic structure in science be adapted to accommodate new demands in science, and build on the diversity and coexistence of distinct academic communities? None of these are trivial questions, which requires reflexive and innovative capacity in science and technology, and agility and adaptability of scientists and scientific institutions to lead the sustainable pathway and collective action forward.

In conclusion, to ensure the disruptive contribution of science to the achievement of sustainability and the SDGs, we highlight the importance of strengthening the capacity of present and future generations to address the disputes and move beyond controversies presented in this paper. More interdisciplinary education and research will not suffice. Funding and incentives need to be directed towards collaboration across distinct academic communities to foster the contribution of science for impact. As we strive towards these goals, the adaptability and resilience of the present and future scientific community will be essential in learning from experience and navigating the unknown challenges ahead of us.

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Data sharing is not applicable to this research as no data were generated or analysed.

Ethical Approval

This article does not contain any studies with human participants performed by any of the authors.

Informed Consent

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