Sustainability Science (2025) 20:677–689
https://doi.org/10.1007/s11625-024-01616-0

ORIGINAL ARTICLE

The sustainability science approach in sub-Saharan Africa: key lessons from five case studies

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Received: 8 April 2024 / Accepted: 25 November 2024 / Published online: 11 February 2025

Abstract

In 2015, the United Nations adopted 17 sustainable development objectives (SDGs) with goals to be reached by 2030. However, as amply reported in the scientific and development literature, none of the goals are on track to be achieved globally. This is particularly true for sub-Saharan Africa. Under a complex socio-environmental context, it is argued that major transformations and new approaches demand a stronger science–policy–society interface. Given the dynamic, multi- and interdisciplinary nature of the research for and on SDGs, there is a broad consensus that sustainability science is one of the instrumental approaches to their implementation. Based on sociological grounds, and in a framework of innovation systems and knowledge production, this paper aims to analyze the main challenges of five sub-Saharan African countries regarding innovation and knowledge production within the sustainability science approach. Based on primary data arising from field interviews and focus groups, and combined with desk research and bibliometric studies, the paper presents differences and commonalities among the country studies. These are used toward the definition of a set of five principles to guide the uptake of the sustainable science approach in the subregion in the discussion section: fostering intra-regional cooperation; multi- and interdisciplinary research; involving other stakeholders and knowledge systems; reinforcing the science–policy interface; and the evaluation data and methods.

Keywords Sub-Saharan Africa · Sustainable development · Sustainability science · Innovation systems · Research and innovation · SDGs

Introduction

The 2024 Sustainable Development report confirms that the Agenda 2030 including the 17 Sustainable Development Goals (SDGs) is far from being achieved (Sachs et al. 2024). Instead, the number of people suffering from extreme poverty (SDG 1) and hunger (SDG 2) will increase from 575 and 600 million people, respectively, in the coming years (UNDP 2023). These lagging SDGs and the reduction of inequalities (SDG 10) represent the main barriers to achieving the interlinked 2030 Agenda objectives (Chaves-Chaparro et al. 2019). Gender equality (SDG 5) reversed heavily during the COVID-19 epidemic increasing to 300 years the estimations to be achieved. According to the rate of progress since 2015–2023, only 18% of the SDG´s targets are on a good pace globally, which are the SDGs related to Responsible Consumption and Production (SDG 12), Climate Action (SDG 13) and Marine and Terrestrial Life (SDGs 14 and 15) (Sachs et al. 2024).

Within this global framework, Africa is facing urgent and complex sustainability challenges. The region remains the most food deficient worldwide with nearly 282 million people undernourished in 2022, reversing the positive trends observed between 2000 and 2010 and worsening most substantially between 2019 and 2022, with an increase of 57 million people due to the COVID-19 pandemic (FAO 2023). Gender (SDG 5) and income inequalities (SDG 10) that are directly linked to access to food (SDG2), health

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(SDG 3), and peace (SDG 16) have also deteriorated due to the COVID-19 pandemic (UNDP 2022).

Furthermore, internal conflicts in several countries and unfavorable weather conditions such as droughts and flooding in the Sahel, the Horn of Africa, and Southern Africa continue to exert pressure on food security and nutrition with the number of people affected by food crises quadrupling in some areas (FAO 2023). Climate change has reduced food security and affected water security (SDG 6), hindering efforts to meet SDGs (IPCC 2023). Climate injustice is high and varies significantly within the region. Africa has the world's lowest levels of per capita use of modern energy (SDG 7), with a rate of cumulative CO_2 emissions amounting to around 48 billion metric tons in the period between 1884 and 2020, accounting for less than 3% of the world´s in 2020. However, the continent has the highest concentration of the most vulnerable countries to climate change, with 16 of the 20 nations most vulnerable worldwide (IMF 2020). The inequalities in access to energy and carbon emissions are exacerbated within the continent, as only 12 countries represent over 40% of the total CO2 emissions, indicating the big gap among societal groups and countries (IEA 2022).

Although SDG progress presents high variations among countries, the sub-Saharan Africa (SSA) region has a major role in the limited or no progress reports for regional and global SDGs targets. Within the difficult position of the African continent, the sub-Saharan region (SSA) is facing even more aggravated challenges. Chad, Central African Republic, and South Sudan have the world´s lowest 2023 SDGs index scores (Sachs et al. 2024).

In the above context, coupled with a complex world economic and political situation, it is becoming increasingly clear that major transformations and new approaches demand more effective policy responses to correct the current development model that only redistributes a small fraction of the benefits of growth to small segments of society, reproducing inequalities. Such new responses and practices require different approaches to achieve radical improvements in the science–policy–society interface, reconfiguring the flow and use of knowledge between people, organizations, and institutions, the interaction between them, and the incentives that can be established (Crespi and Dutrenit 2013).

Given the dynamic, multi- and interdisciplinary nature of the research for and on SDGs, there is a broad agreement in academia that the concept (and practice) of sustainability science is one of the approaches that is instrumental to its implementation: in particular, to face the present challenging situation in Africa (Gasparatos et al. 2017; Boafo et al. 2019).

This paper presents the status of five African countries regarding innovation and knowledge production within the sustainability science approach to their national development efforts: Ethiopia, Kenya, Rwanda, Tanzania, and Uganda. UNESCO with funding from the Swedish International Cooperation Agency (SIDA), in alignment with the 2030 Agenda, and the Africa 2063 Agenda (AUC 2015), provided the means to conduct studies in these five African countries to understand the situation of sustainability and the measures being taken to face existing development challenges.

The authors abstracted the data analysis of such a UNESCO project to offer an overview of the relationship between national innovation and knowledge production systems and the country's sustainability agenda and SDGs. Such an overview pretends to reflect on how to enhance the science–policy–society interface through the sustainability science approach in the region.

First, this paper sets the theoretical basis for evolving sustainability science, providing conceptual elements incorporated during the last decades of its practical development. Of particular importance are the complexity and the high rate of social change that occurs today, and their reference to the need for a renovated knowledge production and innovation model. Then, the selection of countries for the case studies is justified (namely, Ethiopia, Kenya, Tanzania, Rwanda, and Uganda) and the methodology applied in our study is described. Further, an overview of the socioeconomic situation in Africa as well as some of the key common and specific outputs of the case studies in the five countries are explained. The final section provides five key principles to enhance the science–policy–society interface through the lens of the sustainability science approach in the SSA region.

The complex and dynamic foundations of sustainability science

Sociological foundations of sustainability science

Traditionally, in the theoretical bases of sustainability science, references to sociological theory, specifically from the field of environmental sociology, are scarce. The context explained above manifests the growing importance of the theories of social-environmental complexity and the speed of social change (Catton and Dunlap 1978). Social change has been installed paradoxically, in the social structure as a stable and solid element. Social actors, local and global, require high speeds of response to their challenges, of which the first and most challenging today is climate change and, in general, the environmental crisis. It is the most complex, multidimensional, serious, and urgent problem facing the global ecosystem today. The challenge was sufficiently diagnosed already in the 1970s when sociological theory demanded an urgent paradigm shift in the relationship between society and nature (Catton and Dunlap 1978). Such a shift is yet to occur today. Complexity and urgency trigger different debates about the causes and interpretation of the

problem (Redcliff and Woodgate 2005). During the 1990s, Giddens's theories of reflexivity (Giddens 1994, 2013) and mainly Beck's theory of risk (Beck et al. 1992, 2016) formulated the challenge, to the point of coining a defining term for contemporary society that is still cited in specialized literature: the risk society.

Sustainability science and fundamental knowledge and innovation models

Innovation and knowledge theories try to provide solutions to risk at a less abstract or theoretical level. In a simplified approach, the production of knowledge and applicable, tailored, and practical innovation is key to providing effective responses to socio-environmental crises. Therefore, the territorial element -its context and boundary conditions- are key to fulfilling real knowledge and innovation needs. In this theory, the innovation process integrates multiple stakeholders such as academic and public research organizations, research funding organizations, knowledge and technology promoters, intermediary agents, civil society organizations, or businesses that, in pursuit of their interests, interact with other actors in this network: the innovation system (Carayannis and Campbell 2018; Christopherson et al. 2008). The increasing level of interaction, connectivity, and interdependence, which is so characteristic of contemporary complex societies, complicates much of the distinction between the fields of science, technology, and innovation that became unified areas. This was the corollary of several theoretical models, concluding that the emergence and transformation of the production and management of scientific knowledge are fundamental to sustainable development (Lundvall 2007).

On the other hand, the open innovation models (Dahlander et al. 2018) maintain close affinities with the approaches that Gibbons (Gibbons et al. 1994) formulated in his 'mode 2' of knowledge production. The production of disciplinary-based knowledge, produced from the specific academic culture (often isolated, self-referential), is evaluated by 'peer review'. Its fruits are intended to generate explanatory models of regularities that, while being methodologically correct, may not be successful in providing fruitful, useful, solvent innovation (from the point of view of the actor or network of actors that demands innovation and knowledge to face "their" problem/s or need/s). Precisely because of rapid socio-environmental changes, modeled explanations that aspire to become 'laws' are less and less successful.

Hence, this traditional, secular, and legitimized way of producing knowledge ('mode 1') is gradually being replaced by a more complex way, where the approach is thematic, transdisciplinary, applied, specified in different contexts, and evaluated by other criteria that transcend the mere evaluation of peers, or the recognition offered, autonomously, from the very heart of the scientific community. Criteria such as the economic, environmental, and social impact are already central in the evaluation of innovation. The absorption of knowledge and innovation by beneficiaries is on the way to staying at the center of the scientific impact assessment (Nowotny et al. 2001).

This 'top-down' approach, due to the line of argument raised here, is completed with micro-theories of knowledge production and innovation that tend to be formulated 'ad hoc', in the same environment where the solutions are intended to be applied, to the point that authors such as Funtowic and Ravetz openly advocate expanding the evaluation community (Funtowicz and Ravetz 1994, 2000). They specifically refer to the fact that local communities have now become a necessary source of information, and data, which perfectly completes the external perspective, and ethics, provided by universities, knowledge production centers, and administrations, including companies and other organizations that, depending on the application environment, configure the production and innovation system at the regional or local level.

Responsible research and innovation for sustainability science

This post-normal scientific production format (Funtowicz and Ravetz 1994, 2000) converges and is coupled with open innovation, and also with the theories of the triple helix—later quadruple and quintuple—as well as with theoretical constructions from transdisciplinary areas, with years of scientific, institutional, and community agreement (Carayannis and Campbell 2018). This is the case of sustainability science, whose main aspiration is to encompass and make compatible and complementary efforts and capacities, not only of the different scientific disciplines but also of the different global and local social actors, to face the present environmental challenges. Ethical meanings that support the initiatives have been incorporated into this epistemological map in recent years. This is the case of the so-called "Responsible Research and Innovation" (RRI) promoted by the European Commission as a new knowledge and innovation mode taking into account effects and potential impacts on the environment and society (Von Schomberg 2012, 2019; Von Schomberg and Von Schomberg 2023; Delgado and Åm 2018), ensuring five key elements: ethics, gender equality, public engagement, open access, and scientific communication.

Besides underlining the need to consider common, global, social, and environmental values in moving toward local solutions, RRI has promoted a global institutional movement driven by large non-governmental and governmental organizations. UNESCO, as the UN agency mandated to

promote science as a common good, from a human rights-based approach, launched the 2017 Recommendation on Science and Scientific Research (UNESCO 2018) and the 2021 Recommendation on Open Science (UNESCO 2021) to promote an enabling policy environment toward the transition to a more responsible and impactful science. UN has also promoted sustainability objectives with a global aspiration, but with a contextual, regional contribution, reflected in the SDGs that require scientific evidence to be addressed.

Sustainability science: theoretical convergence for understanding complexity

The above context has led to the adoption of an unprecedented global agreement on sustainability in its more complex and inclusive sense, which seems to be responded to by sustainability science. The original, initial, approach is being completed as an evolving discipline that adopts a comprehensive, solution-oriented holistic approach, to problems and perspectives involving the relation environment–society, referring to sustainability of global systems, and integrating environmental, social, and human systems (Komiyama et al. 2006); UNESCO 2019). It is based on disciplinary, inter- or transdisciplinary, action-oriented, inclusive, and participatory research processes aimed at the co-production of knowledge, technologies, or innovations that can provide effective answers to real socio-environmental challenges and support for the transition to sustainable socioeconomic models and its governance. Sustainability science is along this vision, an expression of academic freedom and responsibility toward societal issues (Lang et al. 2012).

The interest of this concept is in setting the theoretical basis for the current revision of the paradigm of knowledge production and innovation, providing an alternative model to the classic, positivist, and academic one, whose bases we described above. The approach proposed by an updated sustainability science adoption can provide adaptive and tailor-made solutions to SDG´s barriers. Its rationale is in line with the co-design and co-production of knowledge (Pohl et al. 2010) that calls for close cooperation among disciplines and stakeholders to solve complex societal challenges (Komiyama et al. 2006; Manzur 2003; Ruiz-Mallén and Corbera 2013).

Collaborative knowledge and action-making processes are key to achieve just, creative, and durable transformations (Chambers et al. 2022), but requires a complex process for integration of diverse actors and perspectives (Pohl et al. 2021). Transformative transdisciplinary research (TTDR)—defined as research practice within sustainability science—seeks the mix of disciplinary research to co-produce actionable, empowering knowledge that will not only engage, but also provoke radical change in society that encounters yet many challenges (Augenstein et al. 2024). The transdisciplinary work, including non-academic actors, presents a major gap in studies and practical guidance on how to build meaningful, ethical, fair, and trustful integration of diverse knowledge systems—including their paradigm, valuations, epistemologies, and interests—in the Global South (Merçon et al. 2019; Jacobs et al. 2020; Pereira and Erwin 2023).

In this sense, research public organizations and universities, by their teaching role, multi-disciplinary nature, and high local contextualized conditions, are called to play a pivotal role in mobilizing local actors in line with the "third mission" or contribution to society (Uyarra et al. 2017; Goddard and Gilliland 2021; Agusdinata 2022). To do so, they need to get into collective "unlearning" and "de-centering" from knowledge production leaders, allowing more equitable positionings of other actors and practitioners (Alonso-Yanez et al. 2019) in the co-development of sustainable solutions.

Methodological options

Sub-Saharan Africa is one of the most heterogeneous regions in the world. The options to select the five cases for the present study assume countries with one or more dimensions specific to the current theoretical–practical approach to sustainability science. The selection of the countries included four of the five regional hubs in terms of scientific production based on a bibliometric study (at the time of the project) based on for sustainability science. These hubs were: Ethiopia, Kenya, Tanzania, South Africa, and Uganda. South Africa (the fifth hub) is the strongest science producer in Africa with the biggest scientific critical mass and highest full time equivalent (FTE) researchers per million inhabitants accounting for 518 in 2017—according to the UNESCO Global Observatory for Science, Technology and Innovation (STI) policies and policy instruments (GO-SPIN) platform—and therefore, the focus of many publications and studies on sustainability science-related issues. Thus, the country was excluded from the study to increase the comparability in a region with very different STI data and indicators to extract more accurate policy advice and understanding of the path to support the change of scientific paradigm in the rest of the regional hubs. Although the FTE data is not available for the same years, not allowing comparison, the available FTE rates in the GO-SPIN platform at the beginning of the project in 2017 varied from 19 FTE in Tanzania (2013) and 28 FTE in Uganda (2014) to 91 FTE in Ethiopia (2017) and 221 FTE in Kenya (2010). The inclusion of Rwanda as the fifth case study, although it accounted for 14 FTE (2016), was done under the estimations by UNESCO on its potential to increase considerably its capacity as a sustainability science producer, due to the development of a

strong policy for environmental protection and sustainable development as well as for STI. In fact, only three years later, the FTE increased by four, with a total of 59 FTE in 2019. Rwanda hosts the SDG Center for the whole Africa, which supports governments, civil society, businesses, and academic institutions to accelerate progress toward the achievement of the SDGs. Furthermore, the University of Rwanda hosts the Chair of the Sustainable Development Solution Network Great Lakes which focuses on mobilizing scientific and technological expertise to solve problems and create a more sustainable society in Rwanda, Burundi, the Democratic Republic of Congo, Kenya, the Republic of Congo, Tanzania, and Uganda.

For analyzing the cases, the project assumed a mixed methodology combining primary and secondary sources which was undertaken in three chronological steps:

The first step produced the draft national STI profiles of the selected country with a focus on the sustainability science research and innovation (R&I) national capacities. These were structured into four sections: (a) a general overview of the country's political and socioeconomic environment with a focus on their main sustainability challenges; (b) the STI governance (and organigram) and policy framework; (c) a description of the key national innovation system and its human capacity with gender lens; (d) a set of initiatives that would highlight the efforts of the countries to face sustainability challenges from the sustainability science approach. These four sections were part of a common survey template prefilled based on desk research and submitted to the ministries in charge of science and technology to verify/complete the missing information. The desk research reviewed data and reports from various international (UNESCO, World Bank, UNDP, AUC, UNSDSN, etc.) and national organizations (e.g., statistics offices, ministries of STI, NGOs, universities, etc.) as well as from bibliometric studies using SCOPUS database.

Field missions to all territories were co-organized by UNESCO with STI ministries and included primary collection of missing data through semi-structured interviews or focus groups with the main national STI actors as well as national multi-stakeholder workshops. These participatory workshops had three objectives: (a) to complete, review, and validate the draft country capacity maps; (b) to co-construct a SWOT analysis of national innovation systems and capacity gaps; (c) to co-design capacity-building action plans proposing policy measures to address the identified gaps. Stakeholders from universities, research centers, civil society, Indigenous and local communities, policymakers, and industry (among others) participated and contributed to these three aims. This second step produced the final country profiles.

Finally, to promote intra-regional exchange and scientific cooperation to address common sustainability science challenges, an open regional dialog with the participation of key policymakers, researchers, and practitioners from the five country studies was organized. Representatives from the five countries' ministries/universities presented their national reports and capacity-building action plans. Based on them, the open dialog focused on common governance challenges and regional policy interventions to address them.

Knowledge production in innovation for sustainability in selected sub-Saharan countries

The production of knowledge in the five countries is highly determined by the socio-political context at three levels—from global to regional and national—and their evolving complex interactions as presented below.

An overview of the selected countries within the sub-Saharan Africa region

Most African economic indicators have recovered from the impact of the pandemic crisis while trying to adapt to the global uncertainty caused by the Ukrainian war and more recently the Middle East conflict, tightened financial conditions, restrained growth, and climate change (AEO 2023). These multiple and dynamic shocks have reduced the continent's expected growth—although it is above the global average of 3.4%—showing its resilience capacity and economic consolidation projections in the medium term.

However, economic growth (SDG 8) is not effectively and transversally traduced to sustainable development and SDGs, specifically those related to economic competitiveness, social well-being, and the reduction of inequalities. Sustainability science scholars already back in 2016 alerted that the African continent was experiencing striking antitheses: despite high rates of economic growth and long-term efforts to alleviate poverty and inequality, they remain endemic and multi-dimensional in several countries (Gasparatos et al. 2016, Sachs et al. 2024). The African Sustainable Development Outlook (UNDP 2023) emphasizes the urgent need to fast-track climate action and green transitions to lead the continent's inclusive and sustainable development.

Due to poor, unequal, and exclusion systems and the epidemic crisis, the informal sector employment had increased from 79% (ILO 2018) to 85% in SSA, especially young seekers challenging SDG 8 (Decent work and economic growth). The informal sector employment is composed of mostly low-end entrepreneurial ventures and subsistence jobs, which called 'poverty employment'. The general and central SDG moto of "leaving no one behind" is very much compromised

and hampered due to complex social challenges that are neglected or underestimated and not properly researched.

These problems have important socioeconomic and environmental implications. Precarious and vulnerable employment, unemployment, low education and skills, family and sanitary crises, and insufficient political willingness intensify racial, economic, and gender inequalities (SDGs 5 and 10). These social issues have been termed "social exclusion" or the "denial of equal access to opportunities imposed by certain groups of society" and linked to problems such as crime and corruption (Behrman et al. 2003; Hall et al. 2012) challenging SDG 16 (Peace, Justice and Strong institutions). The costs created by social exclusion are not properly translated to market prices, and countries with social instability and weak public sector institutions are unlikely to benefit from economic integration into the global economy (Stiglitz et al. 2009) and do not provide conditions for scientific research.

Despite good progress before the COVID-19 crisis—with Tanzania leading the poverty reduction rate at a 3.2% points per year between 2000 and 2015—the SSA subregion is the most out of track in the fight against poverty (SDG 1) within a continent being the poorest worldwide (Sachs et al. 2024). The health crisis raised by 3% the population that lived on less than US$ 1.90 per day in Africa (in comparison to a No COVID scenario) which affected women more than men (UNDP 2022). At the subregional level, a group of ten countries have a concentration of over 70% of the African poor people. The five countries in the study are part of this unfortunate group, although Ethiopia, Tanzania, Uganda, and Rwanda are among the fastest poverty reducers in the region. By 2030, under the COVID baseline scenario, 30.5% of sub-Saharan African inhabitants will remain poor and 26.6% in the most optimistic predictions (AU 2022).

The fight against hunger (SDG 2), which is directly impacted by SDG1 (poverty), was also severely impacted by the pandemic situation and clearly off-target in SSA. Undernourishment estimations are timidly inflated in the "new normal" due to persistent pandemic challenges such as unemployment, decreasing incomes, the impacts on the food supply chains from lockdowns in 2020–2021 (affecting 26 million people), and, more recently, the Ukrainian conflict. These elements are adding to the stretching pressures from rapid growth of a SSA population which is highly vulnerable to climate change and causing the fastest food insecurity increment in the world (Baptista et al. 2022). Centrally interconnected to all SDGs, poverty and inequality are the biggest challenges to achieving the SDGs in the SSA region (UNESCO 2019), and the situation does not seem yet to have recovered from pre-pandemic rates.

Although following the patterns of their subregion, the five countries of the study are coping better with the new normal, all in the low rank of the classification except for Kenya, in the medium part. The Human Development Index (HDI) indicates that long-term progress—that was low but increasing before the health crisis—is decreasing (Kenya), stagnant (Ethiopia), or recovering very slowly (Tanzania, Rwanda, and Uganda) when comparing the most recent available data from 2022 and generally stagnant in the 2018–2022 period—as seen in Table 1.

The Gender Inequality Index (GII) measures the loss in human development due to inequality between female and male achievements and shows the impact of COVID on women in all five countries (Table 1), particularly Rwanda (79.4%, 12th in 2023, down from the 6th place in 2022) and in Kenya, with a special decline in the women's share of seats in parliament (indicator 5.5.1 for SDG 5). Globally the year of parity, which is only one of the SDG5 targets, is expected for 2154 (124 years later than the 2030 deadline). However, SSA is doing better than East Asia and the Pacific (189 years), Euroasia and Central Asia (167 years),

Table 1 Overview of the main socioeconomic indicators in the selected countries pre- and post- pandemic crisis

Indicators by country pre-and post-pandemic crisis	Ethiopia	Kenya	Tanzania	Rwanda	Uganda
HDI ranking [1]					
2018	173	142	154	158	159
2022	176	146	167	161	159
HDI score [2]					
2018	0.479	0.598	0.525	0.522	0.522
2022	0.492	0.601	0.532	0.548	0.550
GII [3] score					
2018	0.510	0.470	0.522	0.412	0.527
2022	0.494	0.533	0.513	0.400	0.462
EPI [4] ranking					
2018	141	130	119	148	145
2022	143	148	134	138	125
EPI [5] score					
2018	44.78	47.25	50.83	43.68	44.28
2022	31.80	30.80	34.20	32.80	35.80
GII ranking [6]					
2018	n/d	78	92	99	103
2022	126	85	90	102	119
GII score [7]					
2018	n/d	31.1	28.1	26.5	25.3
2022	18.6	27.5	25.6	23.9	20.0

Own elaboration. Sources: [1] Human Development Index ranking out of 189 countries (UNDP 2022) https://hdr.undp.org/data-center/specific-country-data#/countries/UGA; [2] Human Development Index score (0–1) (UNDP 2022); [3] Human Development Index (0–1) (UNDP 2022); [4] Environmental Performance Index ranking out of 180 countries (Wolf et al. 2022); [5] Environmental Performance score (0–100) (Yale/Columbia, 2018 and 2022) https://epi.yale.edu/epi-results/2022/country/tza; [6] Global Innovation Index out of 132 countries (INSEAD, Cornell, WIPO, 2023); [7] Global Innovation Score (0–100). /INSEAD, Cornell, WIPO, 2023)

Middle East and North Africa (152 years), and Southern Asia (149 years) with an expected date of 102 more years to close the gender gap (WEF 2024).

Environmental challenges pose critical breaks to economic growth and improved social conditions. The Environmental Performance Index (Wolf et al. 2022) provides a measure of how well the countries perform on high-priority environmental issues in two broad policy areas: protection of human health from environmental harm and protection of ecosystems (ecosystem vitality). Table 1 provides the ranking for the countries in the study, noting that all five countries rank much lower after the COVID-19 crisis at the world level, although Tanzania, Kenya, and Ethiopia rank among the top 20 in the African region.

As an overview of the situation of research and innovation in the five countries (see Table 1), the Global Competitiveness Index Ranking 4.0 (WEF 2018) and the Global Innovation Index provide a picture of the state of research and innovation and its variation after the COVID 19 pandemic. Despite the increased weaknesses in research and innovation, it is noted that the countries in the case studies for which there is data available occupy a significant rank within the region.

Current situation and prospects for selected countries in sub-Saharan Africa

Sustainability science production is increasing worldwide to support SDGs providing sustainable solutions and evidence for policymaking. Particularly important in this renewed approach is to consider the complexity and interlinkage of the 17 SDGs, which need to be perceived as 'indivisible whole' with various types of interactions between them (Scharlemann et al. 2020). This implies that policies and strategies must be carefully designed to optimize synergies and trade-offs between the SDGs (Renaud et al. 2022). Traditional policymaking can only deliver, at best, incremental progress that is insufficient to divert the journey past a threshold, where the damaging consequences may not be reversed or slowed (Brand et al.2021).

Conscious of this need to inform policy, the scientific community is increasing the studies on SDGs and sustainability. A recent bibliometric study (Raman et al. 2024) analyzing 1433 former reviews on SDGs and sustainability shows a substantial global annual growth rate of 74% in publications and a remarkable 171% increase in total citations from 2016 to 2022, reflecting a growing interest in this area. However, in the African context, interdisciplinary research interlinking two or more SDGs is very scarce. Only studies on SDGs related to SDG1 poverty (declining pattern), SDG5 gender equality, and SDG13 climate action had relatively high scientific outputs—over 350 documents—between 2009 and 2019 and accounted for 50% of the entire literature landscape over that period (Boafo et al. 2019).

According to this study, research outputs related to SDGs on health (SDG3), economic growth (SDG8), and inequalities (SDG10) had seen a faster average annual growth rate of 8% compared to the rest of themes. On the less researched and slowest growing group of SDGs, some of the more interlinked/intersectorial goals are: clean water and sanitation (SDG 6), industry innovation (SDG 9), sustainable cities (SDG 11), and peace, justice, and strong institutions (SDG16), life below water (SDG 14), clean and affordable energy (SDG 7), and responsible production and consumption (SDG 12). This shows regional weaknesses in multi-, trans- and interdisciplinary research and science–policy agendas misalignment.

The expert interviews, focus groups, and SWOT analysis, co-defined in national dialogs under the UNESCO-SIDA project in the five case studies, reveal urgent gaps in terms of science–policy connections and STI policy instruments, funding in particular, required to foster STI to the level required for implementing the SDGs. Stakeholders agree that improved policies, and a better understanding of sustainability science principles by the scientific communities and decision-makers, can be enhanced and have a broader impact on the national, regional, and international development agendas. Along this line, another wide agreement that can be found in the literature on sustainable development and the design of sustainability-oriented policies is the centrality of the production and management of knowledge and innovation (whether economic or social) (Jefferys et al. 2007; Matos and Silvestre 2013).

The conditions to produce knowledge transfer and innovation are closely linked to the conditions of the political, economic, scientific, territorial, and social context, and therefore localized to boundary conditions of specific locations (Funtowicz and Ravetz 2000).

In developing countries in general and the African region in particular, a large fraction of the knowledge is generated in universities and public research institutions. These institutions are key, not only for the more obvious task of capacity building, but also for the mobilization of multiple stakeholders in the exchange, co-production, and dissemination of knowledge for the operationalization and implementation of SDGs from the local, national, and regional levels. Moreover, the third mission or civic mission is part of university culture. A discussion of their role is thus of great importance (Brundenius and Goransson 2010; Goddard and Gilliland 2021) and was the focus of research field methods: interviews, focus groups, and workshops (nationals and regional).

From the comparison of the national reports, particularly the co-designed national SWOT analyses, we can conclude that all five countries present a long-term policy framework that allows for better, even organic approach to interaction

among STI actors and within different disciplines. The interaction with societal groups and individuals, especially with Indigenous and local knowledge (ILK) holders is, however, more complicated, and not systematically included in the existing R&I processes. The ILK system is perceived as a big resource to enhance African knowledge and innovation production, but is not properly mainstreamed into practice.

Furthermore, the high biodiversity and nature´s contribution to people—referring to a broader concept than ecosystem services (Diaz et al. 2018) that was adopted by the Intergovernmental Platform on Biodiversity and Ecosystems Services (IPBES)—are equally understood as a big potential for participatory research in all countries as it is the proven relationship between cultural and biological diversity. In addition, the increasing number of universities and funding around sustainability science, together with the fostering of international cooperation and a green economy supported by the diaspora and the innovative and entrepreneurial spirit of the sub-Saharan population (the youngest worldwide), are perceived as big opportunities for sustainability science in all countries.

The social situation is shared and underlined by the five national multi-stakeholder consultations. Poverty, climate change, and social and digital inequalities, which hit youth, women, and rural populations more strongly, are compromising the STI system's capacity to address SDG and development agendas. The potential to address societal needs, particularly in rural areas, is compromised by the marginalization and undervaluation of women and ILK in science as sustainable solutions producers. The uneven access to information and knowledge is increased by the gender and digital gap in rural areas. The lack of reliable data, with low gender-disaggregated indicators, and national repositories is worse in rural areas, due to the digital gap and restricted access to information and communication technologies (ICTs).

Electricity cuts are still a challenge to maintain databases and open access digital repositories. The legal framework to preserve intellectual protection rights (IPR) is weak and almost missing for ILK, which makes trustful collaboration among formal and traditional knowledge systems difficult. Access to quality education is also an issue, particularly out of bigger cities, and unskilled youngsters can only rely on the agricultural and the informal sector for employment—poverty employment (Buvinić et al. 2004).

The disconnection between the formal competence framework and the market (including the informal one) demands is also reinforced by the higher education and professional training system that has misaligned with societal needs. That fact provokes a high level of unemployment or underemployment in university graduates that discourages students (and girls in particular) to choose science, technology, engineering and mathematics (STEM) careers. In the same background, researchers face—and women in particular—lack of support for stable careers and family conciliation—as well as of infrastructures and technical staff. This provokes a constant switch from public research to private consultancies or internationally funded projects, and institutional capacities have moved away with them. When students move out of the country for tertiary studies, the risk of brain drain increases.

As stated in the 2017 UNESCO Recommendation on Science and Scientific Researchers, in the absence of recognition and stability to the researchers' careers, social engagement becomes difficult to sustain and, therefore, disconnection between social needs and research topics increases. This is especially true in the countries studied where public funding is scarce and fragmented and international donors have a major role in defining the R&I agendas. In addition, the criterion for research career promotion does not break those tendencies. It is based on scientific publications/teachings and does not incentivize the investment of time and energy of researchers required for long and trust-based engagement with society, business, government, or other disciplines/institution researchers that is the basic condition for a more responsible and sustainable science in line with sustainability science.

These common major complex challenges call for a reinforcement of the intraregional scientific cooperation in line with the African Union initiative to create subregional centers of excellence specialized in different research areas allowing for exchange of expertise and production of home growth solutions for the continent. These knowledge hubs are intended to provide also common research infrastructures, career perspectives, and stability to reduce brain drain.

Sustainability science demands in the five selected countries

Although major commonalities were found among the five countries, as a general principle of sustainability science and mode 2 of science production, contextualizing knowledge to specific locations is key to enhancing the societal impact of science and innovation. The selected countries present variations and specific opportunities and demands for scientific production. To cite specific aspects of the different countries analyzed, it could be said that Kenya was the most advanced in its efforts to promote social and grassroots innovation, progressing toward the inclusion of ILK in the STI system and policies. The country has launched some successful initiatives in this area (Onsongo et al. 2019) aiming at reinforcing the resilience of the most vulnerable—rural, unskilled, young populations, to climate change, such as ethical and intellectual property protocols for research with ILK communities through the National Museum, a key research player in the country.

On the other hand, Tanzania (Mgumia et al. 2019) is dealing with governance issues and inequalities between more

than 120 ethnic groups and historical backgrounds, especially between the mainland and the Archipelago of Zanzibar which is translated into differentiated jurisdictions between them that impede more collaborative research over territories. Hosting Africa's highest mountain (Mount Kilimanjaro) and with more than 38% of its land area protected, it needs to develop further its biodiversity research and networking capacities—starting with its neighboring countries. The National Commission for Science and Technology was created, among other related objectives, to manage such issues, undertaking a consultative process both in the mainland and Zanzibar to define the national research agenda. Further, The Nelson Mandela African Institution of Science and Technology in Arusha (NM-AIST Arusha) is one in the network of Pan-African Institutes of Science and Technology located across the continent established in 2010, working with experts from SSA in a transdisciplinary community mindset in line with the sustainability science approach.

Ethiopia's governance system is also having trouble managing the diversity and disparities linked to more than 80 ethnic groups and languages, which has a direct impact on the political stability of the country and scientific and innovative production (López-Avilés et al. 2019). The last is challenged by fragile research systems and policies, lack of public investment in higher education and research—with the University of Addis Ababa being a national hub for R&D, donor-driven research agendas, and brain drain among other major barriers. The country is facing multiple environmental and social challenges that require urgent knowledge and innovation production and political support to reinforce the STI system and indigenous knowledge valorization.

Uganda (Otim-Onapa et al. 2019) is making positive efforts toward more regionally balanced and society-driven decisions, making special progress in research agendas. It has put in place zonal research centers under the National Agricultural Research Organization to align development partner's research funding with the local community's needs. Makerere University is also making efforts to transfer knowledge as the top—by far—national institution by publications. It is undertaking annual joint sector reviews, policy reviews, and national communications to multilateral agreements to assess the performance of STI policies and policy instruments. Uganda Vision 2050 also includes the development of science and technology parks in each regional city that needs to get materialized.

Rwanda (Ntakirutimana et al. 2019), the smallest country in the study, suffers from the impact of its landlocked position and small surface that hampers the development of a critical mass of scientists which is a major challenge. The country is benefiting, however, from strong political will and progressing very fast, e.g., full-time researchers passed from 14 to 59 FTE per million population (UNESCO 2019). This is probably directly linked to the launch of new national funding mechanisms in 2018 that had a quick impact on the attraction of researchers around the University of Rwanda and its university hospitals. The country has an ambition to leverage the transformative potential of STI to become a globally competitive knowledge-based economy as stated in the 2020 National STI policy which was a review of the previous STI Policy from 2005 in line with its Vision 2050 agenda and new sectoral policies on, i.e., digitalization, green growth, and energy. The policy aims at enhancing the STI governance and outputs through the increase of national and international collaborations and funding—mainly for the National Research and Innovation Fund (R&I projects) and the Rwanda Innovation Fund (technology-based SMEs). Finally, the mobilization of other kinds of knowledge systems, values, and community stakeholders is key to achieve national development goals and SDGs. The Rwanda Governance Board is monitoring and supporting—not only academic research, but important home-grown initiatives that contribute to national priorities and value systems. These are traditional community led initiatives as, i.e., *abunzi, imihigo, girinka, or traditional medicine.*

Conclusions

The transition toward sustainable development needs to be supported by an urgent transition in the knowledge production systems toward more inclusive (on both population groups as women and knowledge systems as Indigenous and local), participatory, interdisciplinary, ethical, impactful, open, contextualized, and actionable scientific and innovation outputs. This scientific paradigm shift is required for implementing the global Agenda 2030 and SDGs, the UN Decade of Sciences for Sustainable Development 2024–2033, the UNESCO Recommendations on Science and Scientific Researchers and on Open Science, as well as the regional African Agenda 2063 and the national development agendas in the selected countries.

The analysis performed on the country cases provides at least five closely interrelated principles that need to be better addressed for progressing effectively toward national positions based on the sustainability science approach.

Firstly, the recognition of the complex nature of sustainable development and interlinkage among both its fundamental pillars (environmental, social, and economic) and strategic themes (e.g., 17 SDGs) calls for urgent multi-, trans-, and inter-disciplinary, action-driven, participatory, and community-based research, providing a huge opportunity for sustainability science uptake. The study shows that even if weak, research and innovation systems do exist in the five countries and contribute to solve sustainability challenges. However, there is very low production of the interdisciplinary kind of knowledge able to effectively advise

policy (Gasparatos et al. 2016) and limited interlinkages between African regional policy and scientific production (UNESCO 2019). The Agenda 2030 and the African Agenda 2063 provide a unique opportunity to co-define a common African framework for sustainability science research. It will foster localized home-grown knowledge and solutions, expand mutual learning, and capitalize on the centers of excellence being created by the African Union. It will reinforce the science–policy interface at the regional and national levels increasing regional research capacities and reducing brain drain.

Closely related to the above point, the execution of research, even on a limited scale, being undertaken to provide solutions to given specific environmental problems, requires multi-, trans-, and interdisciplinary mindsets and methods. Nevertheless, improved and more focused policies, as well as a better understanding of research, are needed. Policies should drive programs of inclusive development, and active social policy (combining redistribution and growth in productive capacity), as well as tackling the norms and practices that sustain discrimination and integration of societal actors and researchers in policy formulation. On the other hand, it is observed that research efforts are not properly aligned with established policy and social prioritization; nor is the multi- and interdisciplinary setting strong enough to support the complex nexuses of sustainability policies. 'Excellence' is a concept that should be better contextualized by the scientific communities and decision-makers, to enhance the challenge of understanding and coping with the complexity linked to sustainability in Africa (Tijssen and Kraemer-Mbula 2018, 2022; G).

Also related to the previous two points, there is a need to include new stakeholders in the co-design of knowledge and innovation, mainly underrepresented societal groups and minorities (e.g., women, LGTBI+, migrants, or people with disabilities) as well as in the nexus between traditional and modern knowledge. Research in complex sustainability problems requires constructive input from various communities of knowledge to ensure that the essential knowledge from all relevant disciplines and actors related to the problem is incorporated (Pohl et al. 2010). The role of indigenous and local knowledge pervades the policy declarations in research and innovation of all five countries with different degrees of importance, both at a discursive and practical levels. Additionally, collaborations among scientists from different disciplines and non-academic stakeholders from business, government, and civil society should be considered in such co-production of knowledge and capacities on methods and tools buildup. For results to have an impact, decision-makers need to compound these groups of stakeholders in a very active way, in the sense of increasing legitimacy, ownership, and accountability in the co-production process (Lang et al. 2012; Garba et al. 2023).

The reinforcement of the science–policy interface, in general, and specifically the uptake of scientific evidence by decision-makers for the definition of policies for sustainable development is primordial. Our analysis underlines the need to move beyond the rhetoric and translate high-level governmental commitments and plans into action in line with the requirements of the 2017 UNESCO recommendation on science and scientific researchers. For such a task, there must be robust institutions and fair governance systems to ensure that African regional and related international decisions can be translated into policy changes at a national level and then into action on the ground (Adelie 2016). The poor governance of STI does allow for highly donor-driven and poor socially driven R&I agendas, therefore disconnected and sometimes contradicting the national development agendas and SDGs. Among the main challenges, the lack of coordination between sectors and actors, bureaucracy, the lack of efficient policy instruments, budget in particular, to implement the national research policies, and of monitoring/evaluation of institutional capacities are highlighted.

The latter is also related to the final principle which is the need for more transparency and accountability claimed in all national debates and basic to increase societal trust in science. As an example, the access to information on sources of financing is not evident and the statistics office has difficulties in getting data from the different ministries and research institutions (including the public and private ones) on direct funding from international donors. This lack of coordination and of control over R&I activities at the central administration level does not help in planning research capacities over time to cover needs in different, rapid changing scenarios—as it was the case during the COVID-19 crisis. Although the New Partnership for Africa's Development (NEPAD), UNESCO, and other international and regional bodies support capacity building on monitoring and evaluation, the methods are not properly adapted to the region. A clear example is that the informal sector innovation is not measured—although the sector represents around 79% of total employment in sub-Saharan Africa (ILO 2018) (Fig. 1).

The authors would like to make a final call for action remark, as the five principles exposed in this paper highlight the need to interpret the socio-environmental reality of these countries, and their context (local, national, subregional, African, and global), under the prism of complexity, which involves not only the basis of the generic approach to the science of sustainability, but the ideas that the implementation of the said concept have been generating along the last three decades of sustainability analysis and reflection. It could be named as a necessary ideology in contemporary times, because the sociological and environmental complexity of the early twenty-first century conditions all the ways of facing the challenges involved in adjusting our lifestyle to the cumulative impacts generated

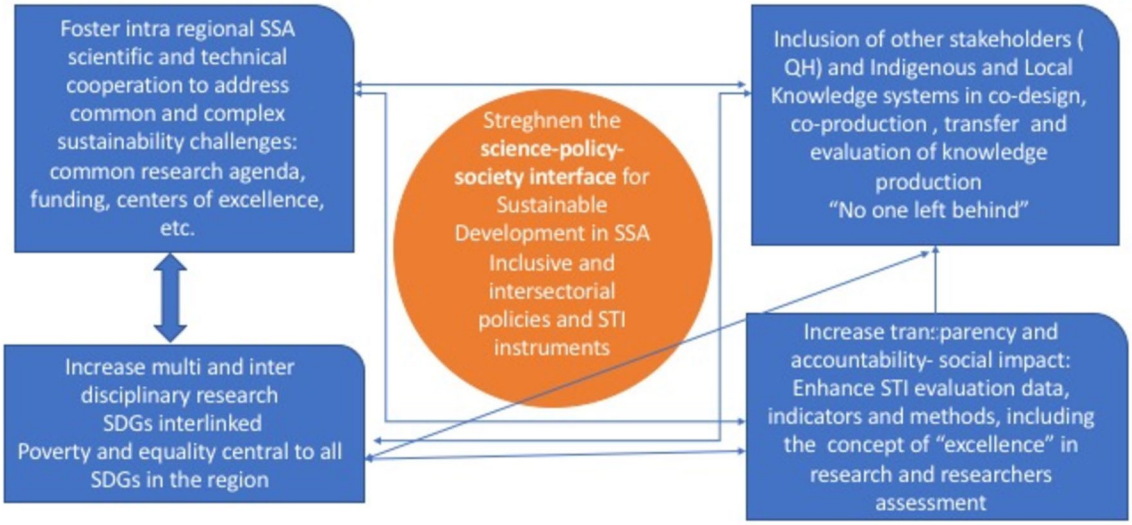

Fig. 1 Five principles to uptake sustainability science in SSA. Source: own elaboration

by it. The ideology of complexity needs, in the current historical context, and especially in the regions of the cases analyzed here, a production of knowledge and innovation that includes social, political, environmental, and economic conditions as starting points, contextualized, shared, and related, as a basis for the construction of customized sustainable solutions and evidence-based policies. New scientific paradigms and new ways of producing knowledge, loaded with contextualization, bottom-up references, transversality, network operation, and ethics of global extension are already known. However, the examples show, not only their contextual related and governance difficulties, but also the momentum and opportunity to apply the principles of sustainability science in the sub-Saharan African continent.

Acknowledgements This paper was made possible by the activities undertaken by the main authors under the UNESCO-SIDA Future Earth Capacity Project. The authors are grateful to its UNESCO project coordinator Salvatore Àrico and to all the stakeholders participating in the field research, specially Ministries of STI, public research organizations, and civil society actors, in particular, the authors of the book published including the five country studies compiled under the UNESCO publication entitled "Co-designing science in Africa: first steps in assessing the sustainability science approach on the ground" and available in open access at: https://unesdoc.unesco.org/ark:/48223/pf0000368900.locale=en.

Funding Funding for open access publishing: Universidad de Huelva/CBUA. No funding to declare.

Declarations

Conflicts of interest No conflict of interests to declare.

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