Framing the Sustainability Dialogue in Research

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Abstract: In this article, we revisit the key aspects that bring in the "sustainability" factor in research by discussing views and experiences on the human interactions and sociotechnical and socioeconomic dimensions of research in relation to the promotion of sustainable development. Real-life issues and their inherent complexities seldom match the traditional disciplinary approaches in applied scientific and technological research designed to study a specific problem and provide solutions to it. The concept of "sustainability" in an applied sciences context is a policy- and action-oriented multidimensional one involving economic security, social well-being, and environmental quality. For these reasons, academic researchers collaborating extensively in multidisciplinary research and projects have to respond to the specific requirements of an issue, if well-thought and adapted solutions have to be developed. This article addresses the salient components connecting research and sustainability in a fresh and holistic manner.

Keywords: multidisciplinary research, social dimensions, sustainability indicators, sustainable development

1 Introduction—Research and Sustainability

The number of countries engaged in international collaboration on sustainability research has been increasing, and the diversity of countries engaged in research collaboration beyond national borders has also risen over the last decade. [1] Research activities on sustainability are significantly different between countries, as each country has its focused fields of research related to sustainability, guided by a number of factors such as financial resources, human resources, cultural influences, political stability, and the actual nature of problems of the country. Still,

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remarkable progress has been made in understanding the functioning of the global system and the impact of human actions on the environment. Societies need to acknowledge that ecological stewardship will allow them to simultaneously adapt to new living patterns, initiate measures to reduce global environmental risks, and also meet economic development goals in an environmentally clean and harmless manner. Ecological stewardship would here refer to a strategy to respond to and shape social-ecological systems (SESs) under conditions of uncertainty and change to sustain the supply and opportunities for use of ecosystem services to support human well-being. [2] Ecosystem stewardship integrates three broadly overlapping sustainability approaches that sum up to the concept of resilience thinking [3–6]: (i) reducing vulnerability to expected changes [2]; (ii) fostering resilience to sustain desirable conditions in the face of discrepancies, perturbations, and uncertainty [7]; and (iii) transforming from undesirable trajectories when better opportunities appear (i.e., transformability). Adaptive capacity contributes to all three sustainability approaches. By building on previous research on vulnerability, adaptation, resilience, and transformation, ecosystem stewardship provides a perspective that better equips society to manage a spectrum of challenges that vary in certainty and benefit or threat to society. [2] Most obviously, answering these questions will require a balanced and unanimous reorientation toward new research that will better allow science and society to address the specific needs of decision-makers and citizens at global, regional, national, and local scales. [8]

In this line of thought, extensive research is also needed to assess the potential impacts of environmental changes on regional economic conditions [9], food security, water supplies, health, biodiversity, and energy security. Furthermore, research is required to understand, explain, and predict to reasonable extents how peoples are likely to respond to such changes in different sociogeographic and cultural contexts, particularly in poor and vulnerable communities. [8] Hence, the goal of scientific research is to generate new knowledge, whereby in the traditional system of university (and other research institutes/organizations) research, the specific manner of knowledge generation has been left up to the individual university boundaries. Bodorkós and Pataki [10] have adroitly defended their thinking that "in democratic societies, science–society relationships should be based on establishing and institutionalizing mutual dialogues, making public concerns not only visible but the public as equal partner." In this line of thinking, the fulfillment of the social responsibilities of academic and research institutions actively involved in regional sustainability initiatives (RSIs) is equally through establishing dialogues with diverse stakeholders [11], and conducting participatory action research (PAR) combined with a robust educational model of service learning. In this article, we reflect on the practice of research based on the discourses of other workers and from our own experiences to solve socioeconomic and environmental issues through sustainable and practical sets of proactive and mitigation measures and strategies.

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2 Significance of Sustainability

The widely accepted definition for sustainability given by the Brundtland Commission is "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concept of 'needs,' in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs." In other words, sustainability has a direct connotation of justice toward nature and its subsystems for its intrinsic value. [12] In a more comprehensive manner, Sachs [13] distinguished between partial sustainability and whole sustainability. To better achieve whole sustainability, the following criteria should be met simultaneously [Sachs, 13]:

- *Ecological sustainability*: conservation of natural capital that comprises both the natural ecosystems used as sinks, and the spatial distribution of human activities and rural–urban configurations.
- *Economic sustainability*: related primarily to the efficiency of economic systems such as institutions, policies, and rules of functioning for ensuring continuous socially equitable, quantitative, and qualitative progress.
- *Social sustainability*: related to the several human-to-human interactions and the human-to-environment interactions in variable cultural backgrounds.
- *Political sustainability*: providing a satisfying overall framework for national and international governance and working toward well-thought and adapted policy goals for socioeconomic growth.

In most of the literature, issues that are dealt with in the context of Sachs' political sustainability are often already covered in social sustainability, thereby limiting the subsequent discussions to environmental/ecological sustainability, economic sustainability, and social sustainability. [14] Sustainability that emerges from the field of industrial ecology has been suggested to be actually the "science of sustainability" [15, 16], due to its assumption that industrial systems which operate like natural ones will be ecologically, economically, and socially sustainable. Natural or "undisturbed" systems are defined as those without significant human modifications. [17] Undisturbed ecosystems are assumed to be sustainable because of their numerous feedbacks which limit populations to available resources, and "recycling" of waste output and dead biomass via species evolved to fill the resource niche created by these outputs. [18] As per Pretty [19], the key principles for sustainability are to (i) integrate biological and ecological processes such as nutrient cycling and soil regeneration, (ii) minimize the use of those nonrenewable inputs, (iii) make productive use of the knowledge and skills of people, and (iv) make productive use of people's collective capacities to work together to solve common natural resource problems. For example, sustainability in agricultural systems

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incorporates concepts of both resilience and persistence and addresses many wider economic, social, and environmental outcomes [19], focuses on the need to develop agricultural technologies and practices that do not have adverse effects on the environment (controlled use of pesticides and herbicides, and monitoring of their fate in the soil and water bodies), and leads to improvements in both food productivity and food security. [20,21]

Many funded research projects have supported various forms of development in society and the environment. Although there are many successes in the implementation of these projects at a local scale and in the short run, others show a lack of a full consideration of what is required to become sustainable beyond the useful project life. This leads us to reflect on the several requisites that need to be fully identified, practiced, and maintained during the project formulation, design, and implementation stages so as to incorporate sustainability. Among these requirements are: (1) fostering an active role of stakeholder participation in the decision-making process which depends on cultural values [22]; (2) contribution to economic benefits; (3) having adequate legal and policy frameworks in place to ensure regulatory compliance with standards in regulations; (4) having sufficient capacity for law enforcement to ensure proper implementation and purposefulness of proposed measures; (5) building robust institutional structures that are beyond leadership changes and unhealthy political influence and lobbying; (6) consolidating the role of the private sector in performing tasks when it comes to contracting and subcontracting of tasks comprising the project realization stage; and (7) the need for consolidated education, appropriate capacity building, and awareness raising to accomplish the tasks in the different work packages in the project phases.

3 Multidisciplinary Research

Real-life issues rarely match the traditional disciplinary approaches in applied scientific research [23], which is aimed at studying a specific problem and providing solutions to it. In the study of environmental problems, the natural sciences have long been adopted as the main drivers of the formulation of solutions. For the past couple of decades, the sustainability concept has been at the center of both the natural environmental sciences (physics, chemistry, and biology), and many subdisciplines in psychology, sociology, economics, law, and philosophy [24], thereby conferring the *multidisciplinary* dimension [25] to the formulation solutions and implementation processes addressing environmental problems. Brewer [26] stated that "*the world has problems but universities have departments.*" University departments tend to stick to their organization along different mono-disciplines because students first have to thoroughly learn a structured set of concepts within a well-defined syllabus. Universities would tend to protect existing "central" disciplines, thus ultimately interfering with the need for interdisciplinary collaboration among departments, and many times between two or more institutions, about critical issues such as social, economic, and environmental threats, which cut across their specific boundaries.

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[23] For these reasons, academic researchers collaborating successfully in multidisciplinary projects have to respond to the specific requirements if well-thought and highly adapted solutions are to be developed for environmental problems. In Canada, the Natural Sciences and Engineering Research Council has developed the Strategic Network Grants (SNGs) program that enables multi-institutional teams of academics (typically 10 to 20 co-principal investigators) to work with industry and government partners on large-scale, multidisciplinary research projects in targeted research areas. [27] The network model is intended to create unique training opportunities and enable researchers to study problems at spatial and temporal scales that could not be addressed with traditional funding. Currently, six of the 30-plus SNGs in Canada are focused on fisheries, aquaculture, and aquatic sciences issues, namely, impacts of hydropower on fish and fish habitat, capture fisheries, integrated multi-trophic aquaculture, healthy oceans, and the spatial ecology of aquatic vertebrates in coastal waters. All the more, with regard to health and sanitation projects, there have been a number of interventions to date aimed at improving malaria diagnostic accuracy in Sub-Saharan Africa. Yet, limited success is often reported for a number of reasons, especially in rural settings. [28] A social entrepreneurship approach (SEA) was hence used to create innovative and sustainable applied health research outcomes to provide a framework for applied research aimed at improving malaria diagnosis using a combination of the established methods, participatory action research, and social entrepreneurship. A multidisciplinary approach requires more than a collection of diverse experts working on the same topic, but rather a team of diverse experts who understand the importance of different perspectives and work together across disciplinary boundaries. A multidisciplinary team, including molecular biologists, public health specialists, gender experts, and physicians was utilized when planning and implementing this research. Planning and research development took place jointly, and resulted in a multifaceted approach to ensuring accurate malaria diagnosis. Not only was there a focus on laboratory techniques and new technologies, but also consideration of patient treatment-seeking behaviors, perceptions influencing laboratory analysis, and physician behavior. [28]

Multidisciplinarity, in the present context, would most appropriately mean that a particular problem is thoroughly considered from different disciplinary angles [23] through active and intensive brainstorming. Uiterkamp and Vlek [23] rightly pointed out that multidisciplinarity eventually brings a vivid and fruitful confrontation of different scientific approaches and disciplines in the hope that together the multidisciplinary research team succeeds in producing a coherent and comprehensive representation of the problem, with plausible and reasonable explanations and justification for it or parts of it, and proposing potential solutions. However, practicing multidisciplinarity is often demanding because it requires in the most genuine, and at times strictest, sense that researchers from different backgrounds have to merge, get acquainted enough, learn to understand, appreciate, and integrate their thinking from each other's viewpoints, and thus finally develop common and all-encompassing motivations. [23] The integration of how different

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ontological perspectives (views about the definition and classes of entities) and philosophical or epistemological perspectives (a set of values concerning truth and validity) influence the integration of different types of knowledge for environmental management through consolidated multidisciplinary research has to be considered. [29] These requirements constitute the real challenge in multidisciplinary research and demand constructive human interactions for securing success.

4 Human Interactions in Research

Over the last two decades, the notion that scientific and technological research can contribute to overcoming sustainability challenges has become conventional understanding among policy, business, research, and political leaders. By corollary, more attention has been given to better understanding the human, social, and political dimensions of science and technology. A better understanding of these dimensions and their interactions will help better identify sustainability challenges and channel efforts to solve them through applied research and development. Vlek and Steg [30] have argued that social and behavioral research are crucial for securing environmental sustainability and improving human living environments, and have accordingly identified population, affluence, technology, institutions, and culture as the driving forces of global environmental change; these are considered in view of critical transitions in the evolution of human society. Vlek and Steg [30] also highlight the necessity of multidisciplinary collaboration and desirable developments in environmental psychology to initiate research efforts that embody the traits of sustainability. Pahl-Wostl et al. [31] highlight that culture is essential in understanding the barriers to the adoption of technologies and new management strategies and a successful exchange of experience and technology-based knowledge between developed and developing countries. According to Pahl-Wostl et al. [31], culture is ultimately and solely an embodiment of perceptions, beliefs, norms, and values, which can be used to explain social practices and social learning curves. Social learning refers to a learning process and to the resulting increased management capacity. Social learning implies a change in the governance paradigm toward more collaboration among all the actors engaged in the sustainable development goal. Social learning also provides a means to support communication instead of just providing expert advice, by being an iterative, multidimensional, and ongoing process that comprises several feedback loops and enhances the flexibility of the socio-ecological system to respond to change. [31]

5 Bourdieu's Theory of Practice

Sustainability can be addressed in the following dimensions in research, namely by considering the environmental, economic, social, and institutional aspects. Among the latter aspects, data from records and literature tends to indicate that the social aspect has been the least worked on, though it is a serious and equally (if not more) dominating factor in effective research efforts. This is because the metrics associated

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with the social dimension are as a matter of fact the least tangible and measurable. Bourdieu's Theory of Practice [32,33] is a particularly appropriate framework that helps to explain how the structural and societal constraints of disciplinary and other ways of thinking impact on multidisciplinary (and transdisciplinary) research. For Bourdieu [32], actions within a research group take place in a "field" governed by culture or norms that place value on thoughts, behavioral patterns, and actions. Value comes in three main forms—economic, social, and cultural—and provides people with symbolic capital, giving them status and meaning, reinforcing their existence in a particular reality and in relation to their fellow peer research group members. Through lifelong interaction with fields, individuals develop a *habitus* [34], which is an innate tendency to act, and react, in certain ways. [35] They come to "know" how to act in certain situations and what is the "right thing to do." [33] Furthermore, multidisciplinary research involves research done by differently trained and experienced people [23], and the research process ideally involves regular (and at times frantic) confrontations, collaborative meetings, coordinated data collection, joint publications and, eventually, active collaboration with regard to practical policy development.

6 Stakeholder-Based Life Cycle Assessment [36]

The Millennium Development Goals (MDGs), agreed to at the United Nations Millennium Summit by nearly 190 countries, established that the environment is a priority by making sustainability one of the primary development goals. The MDGs emphasized that environmental sustainability should be integrated into efforts toward achieving goals such as eradicating extreme poverty, improving maternal health, improving sanitation, practicing sustainable agriculture, and combating diseases. [36] Therefore, according to the targets set for environmental sustainability, integrating the principles of sustainable development into a country's policies and programs is one of the main goals for R&D projects. A major challenge in the development field is cross-sectoral integrated planning and achieving multi-stakeholder consensus for collaborative joint projects, especially when sustainability is a goal. [36] This immediately increases the inherent complexity of the multi-stakeholder interactions in the inception, thinking, formulation, debate, and ultimately decision-making stages. These hence require enhanced mechanisms for stakeholder participation, coordination, and commitment beyond slim self-interest [36] or any kind of lobby. A critical aspect in the decision-making process is to enable stakeholders to not only interpret and make decisions based on expert judgments gathered and presented out of scientific research, but also to appropriately involve the relevant entities in the research and decision-making process. Liu et al. [37] have identified that while scientists often complain that their input is ignored by decision-makers, the latter have also expressed dissatisfaction that critical information for their decision-making is often not readily available or accessible to them, or not presented in a usable form. Hence, scientists need to produce more "usable" information with enhanced credibility, legitimacy, and

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saliency to ensure the adoption of research results. Therefore, scientific analyses in multi-stakeholder contexts have to be more transparent, fully participatory, and also stakeholder-based in order to provide useful information to assist objective and responsible decision-making. Thabrew et al. [36] have diligently proposed Stakeholder-Based Life Cycle Assessment (SBLCA) as an innovative instrument to support development planning and implementation. In essence, SBLCA provides decision support and can be used to structure and analyze stakeholder associations and map those potentially affected by the various economic, social, and environmental aspects of the proposed development. Generating information both quantitative and qualitative together with the stakeholder knowledge contributes significantly to improved understanding, and hence, increased transparency. In terms of applications within a cross-sectoral integrated planning process, the concept of life cycle thinking and a modified life cycle assessment approach can be effectively used in concert with the stakeholders in multiple stages to set goals, analyze and assess the current state and the distance to the target goals for the development, assess alternative scenarios through both qualitative and quantitative sensitivity analyses and using environmental impact assessment, risk assessment, social impact assessment tools (Table 1), and strategic environmental assessment (SEA) [38], develop and select between alternative implementation strategies, and develop indicators for monitoring and evaluating outcomes. [36] According to UNECE [39] the purpose of a SEA "…*is to ensure that environmental considerations inform and are integrated into strategic decision-making in support of environmentally sound and sustainable development*." In order to achieve this, a number of methodological steps have been prescribed, which include scoping, analysis of baseline, and development/comparison of alternatives. Moreover, Garfi et al. [40] have indicated that multi-criteria analysis is a family of decision-making tools that can be used in SEA procedures to ensure that environmental, social, and economic aspects are integrated into the design of human development strategies and planning. To illustrate the latter point, let us take the potential for biomass to contribute to the global energy supply in a low-carbon economy as an example. Elghali et al. [41] have argued that for the biomass-to-energy sector to contribute fully to sustainable development, specific exploitation routes must meet three sets of criteria usually recognized as representing the *tests for sustainability* that would actually attempt to measure the level of sustainability achieved following the implementation of certain measures. Gopalakrishnan et al. [42] have also remarked that current approaches to improving the sustainability of biofuels have typically focused on single issues, such as siting biomass feedstock on marginally productive lands rather than highly productive croplands that could otherwise minimize competition with food production. [43] The land used for feedstock production is an essential factor in determining biofuel sustainability. Many factors, such as agricultural subsidies, affect the cost of food commodities and their impact on the low-income portion of society. Still, the use of food crops for energy and the conversion of agricultural lands from food production to biomass feedstock production have

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Table 1 Essential characteristics and comparison of environmental impact assessment (EIA), risk assessment (RA), and social impact assessment (SIA). Data compiled from Thabrew et al. [36]

Criterion of comparison	EIA	RA	SIA
Assess alternative scenarios	To a moderate extent	To a limited extent	Yes
Clear and easy communication of results	To a limited extent	To a limited extent	To a moderate extent
Salient features on approach	EIA is a systematic process to identify, predict, and evaluate the environmental effects of proposed actions in order to aid decision-making regarding the significant environmental consequences of projects, developments, and programs	RA typically involves measuring two quantities of risk: the magnitude of the potential loss and the probability of occurrence	SIA typically includes a questionnaire-based survey and structured interviews. The questionnaire-based survey is given to the population that is directly impacted by the proposed project and the direct stakeholders in the project
Major criticisms associated	Limited consideration of alternatives and scientifically inadequate impact predictions. EIA applications are single-project based, involving only direct stakeholders (indirect stakeholders and interlinkages of activities are harder to represent)	Methodology of RA is tedious and context specific and has limited usefulness in multi-stakeholder contexts for enhancing knowledge and fostering stakeholder commitment	Used for sectoral project-based analysis and neither does it necessarily reduce uncertainty and transaction costs nor does it facilitate achieving the commitment of multiple stakeholders for joint project development

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the inherent potential to increase these costs and reduce the quality of the lives of people who are in a situation of food insecurity. According to Brindaban [44], most studies indicate that it is quite unlikely to increase agricultural productivity to such an extent that sufficient agricultural land can be freed up for the production of energy crops. The latter authors have also distilled that production of biofuels from biomass to meet the blending targets in 2020 will imply additional demand for land. In this respect, the use of marginal lands is unlikely to create significant volumes of biomass in the near term. Marginal lands often require significant inputs of nutrients and water to maintain productivity [45], but these water and nutrient requirements could be met through the use of municipal wastewater for certain bioenergy crops. [46] With a view to optimizing the sustainable use, or rather reuse of, resources that is essential to minimize discrepancies of all available resource allocation, Gopalakrishnan et al. [42] have proposed a fresh system approach to the challenge of biofuel sustainability by considering the agricultural, energy, and environmental sectors as the key components of a single system.

7 Assessment of Sustainability

Taking on from Elghali et al. [41], the measures of sustainability are (i) *economic viability* in the market and fiscal framework within which the supply chain operates; (ii) *environmental performance*, and (iii) *social acceptability*, with the benefits of the implemented project outweighing any negative social and socioeconomic impacts. [47] Elghali et al. [41] also stress that it is crucial to develop an approach that establishes a sustainability framework for the assessment of the development project (e.g., bioenergy systems). This approach will provide practical advice for policymakers, planners, and the beneficiary sector (e.g., bioenergy industry) and therefore support policy development and dissemination of the outcomes of the project at different scales. Such an approach would be most suitably based on a multi-criteria decision analysis (MCDA) and decision-conferencing [41], which would foster the integration and reconciliation of the interests and concerns of the different stakeholder groups.

8 Sustainability Indicators and Environmental Performance Indices

The literature comprises a wide array of tools and processes to help measure progress toward sustainability. These range from highly aggregated top-down indices designed to facilitate cross-country comparisons of environmental performance, to smaller-scale efforts designed to help individuals understand their impact on the biosphere. Heink and Kowarik [48] distinguish between indicators as ecological components (ecological units, structures, or processes) and as measures (properties of a phenomenon, body, or substance) to which a magnitude can be assigned, and between descriptive and normative indicators. According to Heink and Kowarik [48], this clarification improves communication among stakeholders, and assures the testability of theories and concepts that include indicators. Kotwal et al. [49] define an indicator of sustainability as "*any variable or component of the ecosystem or*

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the relevant management system used to infer attributes of the sustainability of a resource and its utilization. However, the indicator can be quantitative, qualitative, or descriptive and is site-specific in nature. The array of criteria and indicators together, measured over time, can provide a picture of the state of a system toward its sustainable management." Sustainability indicators [50], and the aggregation of which into coherent indices of environmental performance [18], based on local data provide a practical method to monitor progress toward sustainable development. However, since there are many conflicting frameworks proposed to develop indicators, it becomes unclear how best to collect these data [51] and subsequently present the findings for a correct interpretation that matches the actual state of wellbeing of the systems under assessment. It has also become more and more important to consider to what extent sustainability indicators have been integrated into actual policymaking. The literature suggests that while the scientific aspects of indicator development is a versatile area of research [50], the linkages between policy and sustainability indicators are only beginning to be addressed over the last five years.

The idea of indicators to evaluate the degree of sustainability actually appeared in the World Conference on the Environment, Rio 1992, in one of its final documents, Agenda 21, that registers in Chapter 40 [52]. One of the most important contributions to the development of a sustainability indicator was given by Rees [53] with the development of the ecological footprint (EF). Another index considered of importance in the debate on sustainability is the environmental sustainability index or ESI [54]. The scientific community considers these two indices (the EF and ESI) as of bigger impact in the evaluation of the sustainability of countries. [52] The ESI also includes a strong element of political factors, such as a nation's participation in international agreements to protect the environment and its ability to improve its environmental performance. Consequently, Morse has previously noted that the ESI is sensitive to the way in which the data are aggregated: "*If sustainability is viewed in terms of capacity and global stewardship, then the richer countries do well relative to the poorer ones, while if sustainability is seen in terms of the stress placed on the environment, then the richer countries come out worst*." [55] Ewers and Smith [56] have compared the results of using the ESI and EF in governance analyses to investigate the relationship between them. Although both the ESI and EF are designed to quantify the same concept, they were found to provide very different pictures of environmental sustainability at the global scale. The strong correlation ($r = 0.55$, $N = 89$, $P < 0.001$) that Ewers and Smith [56] found between the two indices indicated that the nations that are the most sustainable under the ESI are the least sustainable under the EF. Thus, these two measures of environmental sustainability contradict each other. Finally, the emergy performance indices known as renewability and emergy sustainability index [57] or EMPIs, which consider the economic system as an open thermodynamic system within the biosphere and account for all the flows in units of aggregate energy. These indices are based on the emergy theory proposed by Odum. [58] **Table 2** summarizes the essential characteristics of EF, ESI, and EMPIs.

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Table 2 Ecological footprint, environmental sustainability index, renewability, and emergy energy sustainability index as indicators of sustainability. Data compiled from Siche et al. [52]

Sustainability indicator	Concept involved	Measurement parameters	Strengths
Ecological footprint (EF)	Compares with the productive biological capacity of the available land and the sea to this population and measures the demand for natural resources	EF is a measure of the impact of the population expressed in terms of the appropriate area	Use of bioproductive area by EF as an aggregate unit is a powerful and resonant means of measuring and communicating environmental impact and sustainability
Environmental sustainability index (ESI)	According to ESI, environmental sustainability is a fundamentally multi dimensional concept. ESI for each country varies between 0 (most unsustainable) and 100 (most sustainable)	ESI considers five dimensions: environmental systems, human vulnerability, social and institutional capacity, and global stewardship	ESI is an index applied in the evaluation of ations' sustainability. To assist in the comparisons across countries with similar profiles, a cluster analysis is used
Energy performance indices (EMPIs)	Based on energy analysis, which includes geophysics to value the amount of energy connected to the production and use of natural and anthropic resources	The aim is to obtain a thermodynamic measure of the energy used to produce a resource. The energy analysis consists of: (a) Identification of all the materials and energy flows (b) Aggregation of flows of the same kind; (c) calculation of emergy energy yield ratio, (d) calculation of emergy-energy sustainability index	EMPIs are able to provide more information about the sustainability in the use of local resources, and can also reveal something about the ecological sustainability of the actual local system due to the human activities

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9 Community Involvement and Sustainability Indicators

The highly aggregated indices that are most commonly used tend to fail in involving local communities actively in the process of assessing the effects of projects undertaken to improve sustainability. By ricochet, the linkage of donor, funding, and R&D agencies tends to weaken. In this line of thinking, the analysis of interrelations among the several sustainability indicators deserves priority attention. According to López-Ridaura et al. [59] and from our own interpretations of data published in the literature over the last decade, research efforts have been directed toward determining which indicators should be individually measured or optimized, without an in-depth examination of strategies that would increase the sustainability of the system as a whole. Notably, there is a need to analyze how indicator interrelations may lead to trade-offs or, on the other hand, to synergetic effects, so as to define a minimum set of robust nonredundant indicators. At this point, community participation as a way of selecting relevant indicators of sustainability is believed to provide a number of key benefits. [49,60] The formalization of such "bottom-up" community involvement in environmental management projects has been driven by past failings of "top-down" approaches [60] that embodied a lack of representativeness and comprehensiveness with regard to the actual state of things at grassroots level. As an example, the global discussions about the situation in China have been recently characterized by a unbalanced focus on the development of towns, and until now, circumstances have generally been neglected in the rural areas, where over 60% of the Chinese population is still living. [61] Within the five years of the SUCCESS project research, this set of actual problems has been considered and analyzed under the principle of sustainability. The core goals of the SUCCESS project were in finding responses to questions like "What to maintain?" and "What to change?" Several interconnected processes, such as the interdisciplinary research process between many areas of expertise, the transdisciplinary process between the researchers and the Chinese villagers, and a negotiation process that made the connection between these two processes, were employed to find the solutions to this project query. [61] Hence, the innovation of the SUCCESS project was mostly in the methodology that consisted in the interdisciplinary research cooperation related to practice and to involving the affected communities actively managing the significant and growing imbalances between urban and rural areas regarding their sustainability. [61]

Regular community input tends to ensure that the evolutionary nature of indicators is catered for in the assessment of a dynamic sustainability, since circumstances change over time. Second, preliminary research has shown that local engagement may help better build community capacity to address present and future problems, and that this may be more significant than the results of the actual development projects. Indeed, as rightly argued by Jollands and Harmsworth [62], there is a strong need for sustainability indicators and a compelling rationale for indigenous community participation, both from ecological economic theory and

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from international and national policies to improve the worldwide quality of sustainability indicators. Doody et al. [63] have proposed the use of *selected indicators* to reduce complexity and improve communication, while maintaining scientific objectivity when assessing sustainability by utilizing the standard Q-method for discourse analysis. In the Q-method, Doody et al. [63] combined public opinion with technical expertise to create a list of technically robust indicators that would be relevant to the public. The method comprises statement collection, statement analysis, Q-sorts, and Q-sort analysis. Doody et al. [63] concluded that the Q-method provided an effective framework for public participation in the selection of indicators, as it allowed the public to discuss sustainable development in familiar language and in the context of their daily lives. By combining this information with inputs from technical experts, a list of technically robust indicators that resonated with the public was developed. In their work on PAR in the rural areas of northeast Hungary, Bodorkós and Pataki [10] concluded that university–community partnership in research brings a positive contribution to sustainability, including the activation of local capabilities and networking across various local stakeholder groups through various small-scale projects.

10 Socio-Technical Considerations

All technologies rely on the natural world to provide raw materials, energy, and to assimilate wastes they produce. [64] Technologies help in monitoring and understanding anthropogenic effects on the natural world, and stimulate economic growth and the sustainable development of social structures, with consequences for socio-ecological resilience. Emerging theories and approaches in environmental management have advocated the essential role of assessing and strengthening resilience. [65] Two aspects of resilience are considered crucial at this level. [66] The first characteristic of resilience is the capacity to absorb shocks while maintaining system functions, and the second is related to the sustained capacity for renewal, reorganization, and development, should the prevalent system fail, and although this aspect has been less studied, it is essential for socio-ecological sustainability. [66]

Cleaner (or green) technologies that bear the connotation of "sustainable development" improve the efficiency of material exploitation. In turn, remediation technologies help improve the state of degraded environments. [67] In all these ways, technologies help constitute SESs. [68] Social processes shape the development and use of technology, but technologies then open up possibilities for new and dynamic social practice. However, new technologies seldom come ahead fully formed and in the most expected and realistic working order. They arise through active research and development, associations and linkages, and reconciliation of several heterogeneous, social, and technical driving forces. [64] (Figure 1)

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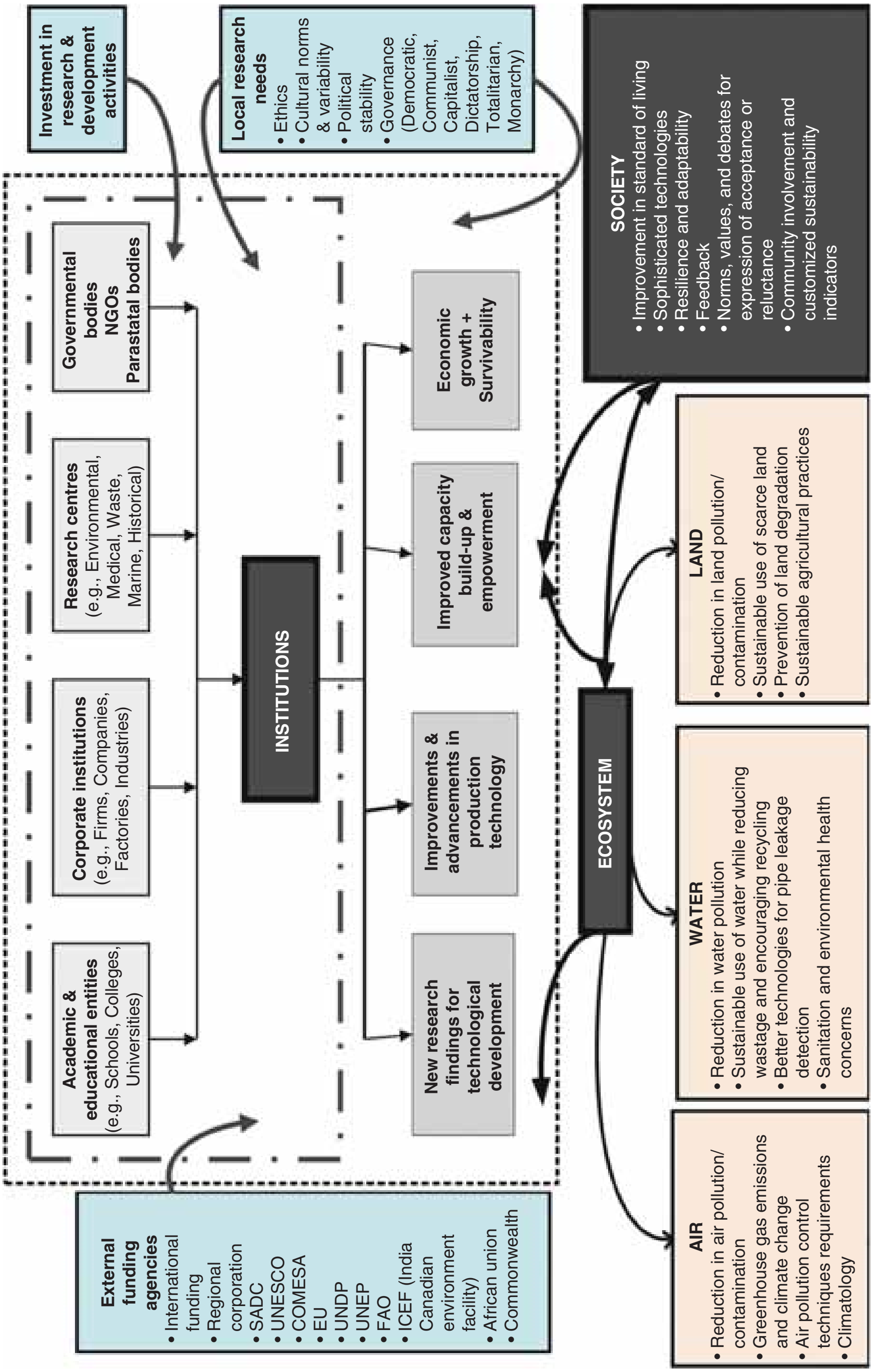

Figure 1 Simplified overview of social, institutional, and ecological interactions in technology development through research

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Work in technology-oriented research focuses on the coupled systems that link human and social values, behavior, relationships, and institutions to science and technology. [69] Like coupled human-natural systems or socio-ecological systems, socio-technical systems [70,71] are central to understanding the nature and dynamics of sustainability problems and their solutions through research. In our opinion, the key aspects to be considered when conducting applied research in view of technology development include the following:

(i) research planning in research groups or organizations has to be done with a view to match the structure and dynamics of socio-technical systems, which would finally contribute to sustainable outcomes for the actual developmental needs and problems,
(ii) research has to be conducted in a framework that underpins people's understandings of nature, environment, science, technology, and society as they relate to sustainability,
(iii) research has also to be engaged in multiple regional and international exchanges and collaborations, which will lead to the strengthening of the research sector as well as promote intensive capacity building in niche areas and technology development, intensification, adaptation, and transfer,
(iv) research has to be conducted as a response to infrastructure challenges and needs identified in the local/regional scenario under analysis for effectively contributing to broader research on sustainability, and work toward its correct implementation.

Should the latter four broad criteria be properly observed and practiced when planning and executing research plans, the following outcomes will progressively develop, mature, and become integral components of *sustainable scientific research and technology development*.

- Opportunities for networking and field-building
- Long-term, systematic, interdisciplinary research initiatives to adapt to the demands of a larger scale of research effort and support for systematic research efforts over a longer period of time than can currently be funded under existing grants from the funding agencies locally and externally too
- Support for international research, training, and collaboration
- Focal points for engagement and application of research such that the research needs have been identified by establishment of the institutional capacities for engaging with leaders in science and engineering, policy, business, and civil society

The recently launched Consortium for Advanced Research Training in Africa (CARTA), which brings together a network of nine academic and four research

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institutions from West, East, Central, and Southern Africa, and selected northern universities and training institutes, is a very good example of multidisciplinary research with strong elements of capacity building. Globally, Sub-Saharan Africa bears the greatest burden of disease. [72] Strengthened research capacity to understand the social determinants of health among different African populations is hence essential in addressing the drivers of poor health and developing interventions to improve health outcomes and health systems in the region. Yet, the continent clearly lacks centers of research excellence that can generate a strong evidence base to address the region's socioeconomic and health problems. [72] CARTA's program of activities comprises two primary, interrelated, and mutually reinforcing objectives: (i) to strengthen research infrastructure and capacity at African universities; and (ii) to support doctoral training through the creation of a collaborative doctoral training program in population and public health. The ultimate goal of CARTA is to build local research capacity to understand the determinants of population health and effectively intervene to improve health outcomes and health systems. [72]

11 Socioeconomic Aspects

Research in applied science and technology is also motivated by a strong element of economic sustainability and financial survivability. We believe that research and the application of it are hence to be geared in all possible fair and achievable means:

(i) by identifying, establishing, and securing the work/business-related exchange links that the findings and implementation of research projects will have on the public and private sectors (government bodies and institutions, private companies, NGOs, and the industry at large). There is a great deal of analysis on how social movement organizations and international NGOs interact with nation-states, intergovernmental entities, and other transnational NGOs in formulating and coordinating research plans. [73] While these relationships are both critical and relevant, it is equally essential to explore the nature and nuances of locally based, urban environmental stewardship organizations. Comprising both informal and formal organizations and networks, these groups interact at multiple scales, ranging from the household, to neighborhood, to urban area, to cross-regional scales, and tend to positively influence the target populations and bring them to cooperate as required in the implementation of developmental projects with possibilities of funding and then economic returns. Researchers and academics have only recently began to recognize the gap in understanding the structure, function, and relationship between these groups, and to question whether theories based on national organizations are applicable at the sub-national scale [74],

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(ii) by bringing maximum community participation so as to make the efforts deployed in implementing research projects economically viable, and
(iii) by attracting national and international funding through competition for national and international projects in applied research in areas of national and regional interest.

Addressing the latter two concerns has eventually made research a financial win–win situation, where funds and honoraria from consultancies and funded projects ultimately fuel research expenditures in the research organizations. Interpreting the existing economic contributions in view of the overall idea of sustainability, we argue that the emerging field of *sustainability economics* [75] can be defined by a growing concern for *economic efficiency* in research understood as non-wastefulness [76,77], in the allocation of natural goods and services [78] as well as their human-made substitutes and complements.

All humanly used resources are embedded in complex, social-ecological systems (SESs). SESs are composed of multiple subsystems and internal variables within these subsystems at multiple levels. [79] Scientific knowledge is needed to enhance efforts to sustain SESs, but the ecological and social sciences have developed independently, and do not combine easily. Furthermore, scholars have tended to develop simple theoretical models to analyze aspects of resource problems and to prescribe universal solutions. [79] Considerations of efficiency in the allocation of scarce resources would then much tend to refer to using these scarce resources in alternative ways to achieve the goals of *sustainability economics*. As there may surely be trade-offs and opportunity costs [78,80], "*efficiency*" means that no scarce resources should be wasted in this respect. It also then becomes almost obligatory to fully understand the socio-ecological and socioeconomic dynamics of a complex whole by shortlisting the specific variables and determining how their components are related. The material, energy, and information flows that actually make up the system and carry variable economic costs will then be more readily identified. Thus, instead of oversimplifying systems [81,82] to the point of eliminating the very essential aspects of socioeconomic, microeconomic, and macroeconomic interactions, sustainability-oriented research must scrutinize and harness such complexities [83], rather than eliminating them from such systems. To this end, Pretty [19] has identified five types of asset that make up the complexities in SESs and can be tapped. These are:

- *Natural capital* produces environmental goods and services (source of food, wood, and fiber; water supply and regulation; treatment, assimilation, and decomposition of wastes; nutrient cycling and fixation; climate regulation; wildlife habitats; flood control; carbon sequestration; recreation and leisure).
- *Social capital* yields a flow of mutually beneficial collective action, contributing to the cohesiveness of people in their societies. The social assets comprising social capital include norms, values, and attitudes that influence

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people to cooperate; relations of trust, reciprocity, and obligations; and common rules and sanctions mutually agreed or handed down. [84,85]

- *Human capital* is the total capability embodied in individuals, based on their stock of knowledge skills, health, and nutrition [86] normally enhanced by motivation brought by financial rewards and recognition. People's productivity is further increased by their capacity to interact with productive technologies and other people.
- *Physical capital* is the store of human-made material resources and comprises buildings, and energy, and transportation systems.
- *Financial capital* is more of an accounting concept. It serves as a facilitator rather than as a source of productivity in and of itself. It represents accumulated claims on goods and services, built up through sound financial systems that gather savings and issue credit such as pensions, remittances, grants, and subsidies.

12 Concluding Notes

Progress in understanding and addressing both global environmental change and sustainable development requires better integration of social science in research planning. For each research group(s), the definition of sustainability has to be translated to the institutional level by assessing the sustainability performance of technological developments, and by developing and ranking suitable sustainability indicators and indices. These then need to be clearly communicated to all the research institutions and stakeholders for a faster adaptation to and progress in common research directions. A dynamic process for redefining, reassessing, and re-ranking specific sustainability indicators should be set up through annual management reviews. Social and economic policies and institutions are rarely designed for abrupt nonlinear social and environmental change brought by technological development. Hence, understanding the underlying nonlinear dynamics will require integration of environmental and complexity sciences. Modern systems of governance are much more effective in addressing national and local problems over timescales of years to decades than in addressing global problems that will affect future generations more strongly than current generations. Addressing problems of global change will therefore require a bold change in research on fundamental questions of governance, economic systems, and the assumptions, beliefs, cultural norms, and values underlying human behavior and interaction. This must again involve close integration of social and biophysical sciences. These challenges solicit a research framework to mobilize the international scientific community around a focused decade (or more) of research to support sustainable development in the context of global environmental change. This will require new research capacity, including efforts to attract young minds, particularly in the developing countries. Research dominated so far by the natural sciences must transition toward research involving the full range of sciences and humanities.

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