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Sustainable agri-food investments require multi-sector co-development of decision tools

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ABSTRACT

Global targets, such as the UN Sustainable Development Goals, and private sector commitments, such as deforestation-free supply chains, are stimulating growing demand for sustainable investment opportunities in the food and agriculture sector. Yet, the supply of such opportunities has been slow to materialize despite a proliferation of impact funds and other sustainability-focused funders seeking to direct global capital flows into the sector. This can be explained, in part, by the heterogeneous, multi-layered, and fragmented nature of agricultural production systems and food value chains and the poorly developed knowledge systems available to inform new types of investment. The volume of sustainability-oriented investment in the food and agriculture sector is likely to be hampered by the absence of a robust scientific evidence base and well-designed tools (e.g. indices and other benchmarking mechanisms) for harnessing knowledge to investment decision processes. At present, indicator-based tools for incorporating sustainability into agricultural value chains are being developed without adequate engagement by scientists. Collaborative co-development of decision tools by researchers and corporate and financial actors, that draws upon their distinct needs and knowledge sets, can improve the utility of these tools for real-world application (e.g. assessing non-financial returns; mitigating reputational risk). This paper proposes new requirements and strategies for the scientific community to contribute to co-development of science-based indicators and other decision tools that better enable agri-sector companies and investors to integrate food system sustainability considerations into management and capital allocation. It will present early lessons from multi-sector engagement in construction of indices, such as the Agrobiodiversity Index (ABDI), and review new modes for research institutions to engage with private sector partners.

1. Introduction

1.1. Food systems out of (planetary) bounds

Recent scientific work has illustrated that food sits at the heart of several sustainability dilemmas at once, from human to environmental health and from social to economic inequalities (DeClerck et al., 2016; Rockström et al., 2017). Agriculture affects much of our land and freshwater ecosystems, covering 37% of global land area (World Bank, 2019) and accounting for 70% of global freshwater use (World Bank, 2017). The food and agriculture sector forms a central part of our global and national economies, with agricultural output representing trillions of dollars every year (Alston and Pardey, 2014). Local to global trends, such as urbanization, industrialization, digitalization, and other cultural and demographic shifts, shape and are shaped by how we produce, transform, trade, and consume food. At the same time, climate change is impacting agricultural yields (Scheffers et al., 2017).

Our global food system is failing in terms of both human and environmental health (GBD 2017 Diet Collaborators, 2019; Global Panel, 2017; Haddad et al., 2016; Poore and Nemecek, 2018; Willett et al., 2019). One-third of the people on our planet is malnourished – either hungry, micronutrient-deficient, overweight, or obese (Development Initiatives, 2017; HLPE, 2017). Poor diets are the most important cause of global ill health and chronic non-infectious diseases (Global Burden of Disease, 2017). Collectively, food systems are the greatest cause of biodiversity loss (Dudley and Alexander, 2017) and contribute nearly

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one-third of global greenhouse gas emissions (Niles et al., 2017). Agriculture is a significant factor in driving several planetary boundaries (e.g. phosphorus, nitrogen, genetic diversity) beyond a safe operating space (Campbell et al., 2017; Steffen et al., 2015).

1.2. Investments in sustainable food and agriculture systems

The importance of sustainability is being recognized throughout political, economic, and financial systems (Hart and Milstein, 2003; Rubin and Esty, 2010; WEF, 2019). The urgent need – and globally agreed mandate – to revolutionize our food systems is embedded in many of the UN Sustainable Developments Goals (SDGs), particularly calls to end hunger (SDG 2), to ensure healthy lives (SDG 3), to achieve sustainable consumption and production (SDG 12), to combat climate change and its impacts (SDG 13), and to conserve life on land (SDG 15).

To increase transparency about production conditions and enable financial investors to distinguish among agri-food producers, the European Union's High-Level Expert Group on Sustainable Finance has recommended revision of the EU's Non-Financial Reporting Directive "to improve disclosures in the agri-food sector and help to re-orient investments towards sustainable agricultural practices (HLEG, 2018)." They specify knowledge needs such as biodiversity levels on farmland and use of agri-chemicals. As one of three non-financial sectors likely to experience the greatest effect from climate change, the Task Force on Climate-related Financial Disclosures has called on asset owners and organizations with public debt or equity in the agriculture and food sector to publicly report GHG- and water-related policy and market risks as well as opportunities for carbon sequestration, increased food and fiber production, and waste reduction (TCFD, 2017).

At the same time, food companies are responding to a growing number of consumers in search of healthier, more sustainable diets. A global review of 449 public companies that produce food, textile, and wood-materials found that over half of these companies practice some form of sustainable sourcing (Thorlakson et al., 2018). The World Business Council on Sustainable Development (WBCSD), set up to drive business-led progress towards achieving global sustainability, includes 18 multi-national companies from the food and agriculture sector (WBCSD, 2018). The Sedex platform facilitates access to responsible sourcing data for over 50,000 member companies. This promising evidence of corporate engagement with the sustainability agenda would be strengthened by third-party monitoring systems that used science-based indicators to verify that sustainability commitments have been implemented and have met specified goals and targets.

Demand for sustainable investments in the food and agriculture sector is rising even though it is a relatively small piece of the global capital markets allocation (Mudaliar et al., 2018a). Impact investing is growing in terms of both the number of investing entities and assets under management (PRI, 2018). For example, in 2018, 415 investors representing over USD 32 trillion in assets signed a Global Investor Statement to Governments on Climate Change calling for improved climate-related financial reporting (GISGCC, 2018). However, there are persistent challenges in securing an adequate 'pipeline' of high-quality sustainable investment opportunities, in mobilizing research and data, and in building agreement on sustainability indicators (Mudaliar et al., 2018a).

1.3. Need for navigational aids

As environmental threats to agricultural production and supply chains magnify, the need for public and private investment in sustainability will increase. However, outdated and fragmented knowledge systems inhibit action as they cannot serve as the basis for decision support tools needed to navigate toward new cross-sectoral objectives. In the food and agricultural sector, current knowledge systems (e.g. scientific data and analysis; decision tools) are effective at diagnosing problems and offering high-level or conceptual solutions (for example, those generated through the important work of the Intergovernmental Panel on Climate Change, IPCC), but they are not yet capable of shifting business-as-usual behavior among companies and financial institutions.

Sustainability-focused investment has grown more rapidly in the energy sector than in food and agriculture. Science and engineering have enabled the capital markets to invest in clean energy by effectively contributing decision-relevant knowledge to support sustainable investments, for example, by modeling greenhouse gas emissions, climate-related risk exposure, and expected environmental impact of new technologies. This is reflected in the rapidly growing green bond markets where only about 1% of sustainability-labeled bonds are in the agriculture, forest, and land use domains, while better quantified renewable energy initiatives constitute 19% (CBI, 2017). As a technology-heavy, capital-intensive sector, clean energy lends itself more readily to investment than the complex, heterogeneous, and fragmented food and agriculture sector. Catalyzing sustainable investment in the food and agriculture sector, at scale, will require a shift in knowledge systems to simplify measurement and produce sustainability indicators that better inform investment decision making.

Global investments in agricultural research and development increased by an average of 2.4% per year between 1981 and 2008 (Beintema et al., 2012). Yet less than 10% of public agricultural research expenditure in the US funds research focused on sustainable agriculture (DeLonge et al., 2016). This figure is estimated to be less than 2% globally (Carlisle and Miles, 2013). The increasing, but still limited funding for sustainable food systems research exacerbates the gap between the need for and the capacity to deliver scientific knowledge that supports sustainable investment decision making.

The CGIAR and other research institutions are mandated to convert scientific knowledge into real-world outcomes through impact and scaling pathways and there is a body of conceptual, high-level work in this arena. The number of publications on food in relation to sustainability has boomed over the last decade, with 1711 papers published in 2017 compared to 324 in 2007 (retrieved using the search term '"food" AND "sustainability"' in Scopus). Yet it is not clear how to integrate this growing pool of scientific knowledge with investor and policymaker agendas to achieve sustainable food systems in specific decision contexts.

1.4. Knowledge in multiple sectors

Embedding sustainability into the food system requires greatly increased coordination among researchers, governments, consumer-facing companies, traders, funders, and other food system stakeholders (e.g. consumer and producer associations; retailers; labor and community organizations). Coordination entails developing mechanisms for appropriately integrating heterogeneous data produced through scientific research, environmental monitoring, and governmental statistics as well as data gathered by private sector actors. Companies commonly compile data on production areas, practices, and volumes in their supply chain. Agricultural lenders have information on the geographies, crop types, and use of financing by their borrowers. Similarly, insurance providers host a wealth of risk-related knowledge for their service regions and policy holders.

Scientific findings do not move freely across poorly connected sectors, inhibiting their use in public and private decision making. For example, water, energy, and food systems are typically studied within different boundaries, such as hydrological catchments, energy grids, and food value chains, each of which have their own sub-units. This can make it difficult for researchers to pinpoint interactions and leverage points at the water-energy-food nexus or to provide decision makers with clear information on how to improve system-level sustainability (Liu et al., 2017a). Structural and cultural features reinforce weak connectivity among researchers, governments, agri-sector companies, and investors in food and agriculture-related businesses (e.g. institutional investors, asset managers, banks).

There is limited experience globally with collaborative public-private sustainability research in the agriculture and food sector. Research, government, corporate, and investor communities each have essential knowledge to contribute. The challenge is to bridge different world views, priorities, and work modes to align knowledge and information systems.

In this paper, we articulate the need for multi-sector co-development of finance-relevant sustainability indicators and other decision tools (Section 2) and offer recommendations for how the scientific community can better enable agri-sector companies and investors to integrate food system sustainability considerations into management and capital allocation strategies (Section 3). These recommendations are complemented by examples of recent multi-sector collaboration to develop indices, standards, and benchmarks in the agri-food sector as well as discussion of data dimensions (Section 4).

2. Accelerating integration of sustainability knowledge into decision making

2.1. Assessing sustainability related risks

Increasing vulnerability to climate change and environmental degradation is leading to higher operational and reputational risks for companies and investors in the food and agriculture sector (WEF, 2017). These entities also seek to seize opportunities and adjust their business models in the context of changing food systems, population dynamics, and environmental and socio-economic pressures (e.g. investors screen their investments; companies shift their commodity sourcing strategies).

Quantitative indicators of agro-ecological risk provides a critical entry point for sustainability into public and private sector decision making. Uncertainty, the ability to assess actual risk (as opposed to perceived risk), and the availability of risk mitigation tools are core elements of investment decisions, regardless of the type of funder (e.g. impact investor, pension fund, development finance institution) or funding (e.g. equity, debt, aid).

Improved information (e.g. increased reliability and accessibility) to support risk assessment reduces uncertainty, facilitates risk mitigation, and expedites financial flows. This is most obvious for the insurance sector, which is increasingly integrating climate-related risks into product design and pricing. Market efficiency is lower when risk-related information is inaccurate or unavailable. For example, better scientific understanding of sources of resilience, such as soil quality, can enable better agro-ecological risk assessment and, therefore, greater efficiency in agricultural insurance and land pricing.

When the sustainability outcomes of farm and landscape management, food supply, and consumption options are difficult to identify or time-consuming to compare manually, indicators and other decision support tools (such as those presented in Table 2) can be used to monitor progress and assess trade-offs (Ness et al., 2007; Notarnicola et al., 2017; Soussana, 2014). Decision support tools enable faster access to information on sustainability performance trends in the food and agricultural sector, providing corporate and product marketing opportunities (Podnar and Golob, 2007). Such tools also help in identifying actual and potential environmental or social risks of agricultural interventions (Schindler et al., 2015) and enabling businesses to contribute to a global transition towards more sustainable markets (Oosterveer et al., 2014).

Sustainability assessment can help promote positive behavior change among food consumers, governments, and the food industry. For example, certification schemes based on sustainability assessments (e.g. Organic, Rainforest Alliance, Fair Trade) are increasingly used by agri-food businesses to label products as environmentally or socially friendly (OECD, 2016; Oosterveer et al., 2014). While some labels risk over-selling products' sustainability attributes (Hahnel et al., 2015), labels can help increase uptake of more sustainable food products by consumers, such as organic foods (Liu et al., 2017b; Zanoli et al., 2013).

2.2. Supporting key performance indicators and sustainability indices

Decisions within companies and financial institutions are often guided by key performance indicator (KPIs) targets that result from a complex set of considerations aimed at promoting the organization's priorities. Under pressure for greater transparency and accountability, these entities are increasingly called upon to report an expanding list of operational KPIs, including non-financial KPIs that reflect sustainability commitments, actions, and desired status changes.

To foster adoption of suitable KPIs, companies and financial institutions need widely accepted sustainability metrics and tools based on reputable research (Vörösmarty et al., 2018). However, early experimentation with sustainability KPIs has produced a proliferation of bespoke and standardized indicator systems and variable methods for securing suitable data (Mudaliar et al., 2018b). The Global Reporting Initiative (GRI) and other programs promote coherence and consistency across such disclosure reports. As these efforts mature, standardized reporting can enable development of new financial products and sustainability indices, which can unlock sustainable investments in the food and agriculture sector at scale.

Sustainability indices based on credible scientific evidence and populated with relevant data can provide comparable baselines and benchmarks for investments in the food and agriculture sector across countries and companies. Indices can support development of products for which sustainability is the central attribute, attracting investment and enabling lower cost of capital for sustainability-focused companies and funds, as well as popularizing such criteria into all classes of assets.

2.3. Building co-investment models for decision tools and data systems

While private sector actors seek information asymmetry that confers market advantage, there are many ways in which companies and financial institutions rely on financial and risk-related data and indicators provided by governments, or through neutral or pre-competitive platforms. As understanding of the links between sustainability and material business risk grows, so will demand for robust decision tools and data systems that support reporting on sustainability KPIs.

However, capacity for co-funding indicator development and data systems is insufficient. For example, of the estimated USD 274 million required to develop four global biodiversity datasets important to maintaining the International Finance Corporation's Performance Standard (IFC, 2012), only USD 160 million has been supplied, with most support coming from the philanthropic and public sectors (Juffe-Bignoli et al., 2016). Given that the IFC Performance Standards are referenced for billions of dollars of private lending, including by all banks that subscribe to the Equator Principles, private sector contribution to maintaining these data resources is warranted.

Multi-sector co-development of decision tools can enable companies and investors to integrate food system sustainability considerations into management and capital allocation (through non-financial KPIs), thereby mitigating risks and increasing capital flow into sustainable agri-food investments (see Fig. 1).

3. A changing mandate for the scientific community

Scientists are increasingly aware that the world looks to them to provide the necessary evidence basis for cost-effective, impactful investment in sustainable agriculture and food systems (Beddington et al., 2012). While communications departments at research institutes have expanded outreach efforts, individual scientists receive little guidance and experience few direct incentives to go beyond publishing 'policy-relevant' research findings in peer-reviewed journals. Yet, much more is needed if the scientific community is to make the critical contributions needed to mobilize investment in sustainable production, markets, and

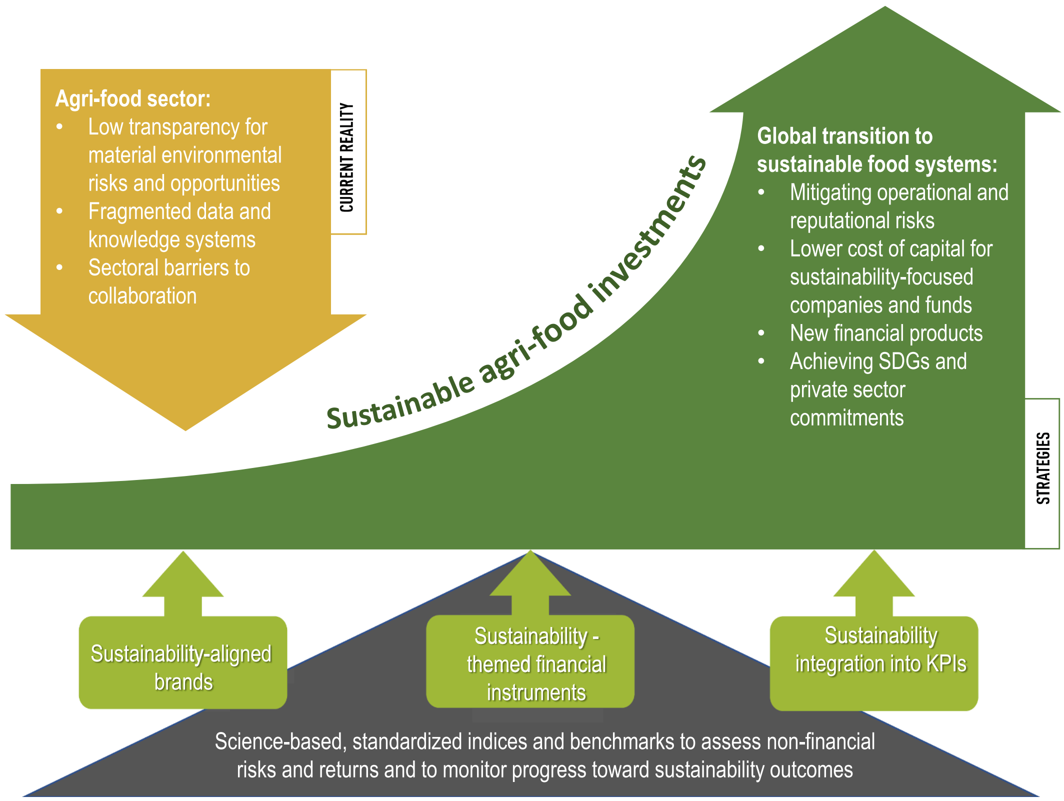

Fig. 1. Increasing sustainable agri-food investments requires science-based indices and benchmarks (adapted from Bioversity International, 2017).

Table 1
The research, corporate, and finance sectors have different objectives and capacities for facilitating sustainability investments in food and agriculture. Decision tools such as the Agrobiodiversity Index can help to bridge these differences.

Sectors	Objectives	Capacities	Example: Agrobiodiversity Index
Researchers	■ Document drivers of human and environmental health in agriculture and food systems. ■ Promote adoption of evidence-based recommendations by public and private sector.	■ Use rigorous methodologies to understand systems and test sustainability solutions. ■ Publish findings in peer-reviewed journals (which are read infrequently beyond the research sector).	■ Use to promote diversified breeding and seed systems, multi-objective agricultural management, valorizing of traditional or underutilized species, etc.
Agri-sector companies	■ Acquire market advantage and avoid costs through knowledge of supply chain risks and opportunities. ■ Demonstrate commitment to and progress toward sustainability aims. ■ Meet expectations for risk disclosure.	■ Diversify food brands/engage consumers. ■ Re-allocate internal capital (e.g. producer support). ■ Shift procurement policies. ■ Re-shape supply chains (e.g. peer leadership; traceability).	■ Use to detect / respond to agrobiodiversity-related opportunities (e.g. diversified production) and risks (pest outbreaks). ■ Supports issuance of agrobiodiversity-themed green bonds.
Investors (including donor agencies)	■ Pipeline of replicable investments with attractive risk-adjusted return and low transaction costs. ■ Improved risk management[+] and funding allocation process. ■ Clarity on sustainability metrics and claims. ■ Reduced reputational risk and potential liabilities.	■ Apply screening criteria and allocation targets to 'green' portfolios. ■ Design product labels, risk disclosure, and compliance based on science-based metrics and certification schemes.	■ Use to filter low-agrobiodiversity investments (initiatives) and actively drive capital to high-agrobiodiversity opportunities and programs (e.g. loans to projects based on positive agrobiodiversity impact; grants to implement policies that promote sustainable practices).

[+] Risk management is the overall term for identification, analysis, evaluation, mitigation, and monitoring.

diets. This includes quantifying vulnerabilities and forecasting outcomes of alternative practices and technologies at geographic and temporal scales that enable informed decisions by food system stakeholders such as farmers, input suppliers, traders, consumer-facing companies, funders, and policy makers.

Incentives for scientists and other researchers reinforce the primacy of publishing in high-tier journals, where information is presented in ways that are not readily accessible to companies and funders in the food and agriculture sector. The communities engaged around scientific journals, conferences, and professional societies rarely include members of the private sector, decreasing the likelihood that research objectives will consider their information needs. The gap between published research findings and the potential use of this information is sometimes bridged through gray literature publications (which commonly do not undergo peer review) produced by non-governmental organizations (NGOs) and others. But this uni-directional exercise does

Table 2
Examples of agri-food system sustainability decision support tools developed or applied through multi-sector engagement.

Example	Description	Multi-sector engagement
Sustainability indicators and indices – Simple quantitative indicators that may be aggregated into an index		
Access To Nutrition Index (ATNI)	Index for benchmarking food and beverage company performance on nutrition. Encourages adherence to international standards and best practices to enable improved diets and to reduce global obesity and undernutrition. https://www.accesstonutrition.org/	ATNI engages with businesses, nutritionists, and civil society to develop the ATNI methodology and to compile data on company contributions to improving access to nutritious foods. Company and investor engagement in nutrition is increasing as the index gains recognition.
Access To Seeds Index (ATSI)	Index for benchmarking world's leading seed companies to enhance the productivity of smallholder farmers. The Index seeks primarily to identify leadership and good practices, providing an evidence base for discussion of where and how the seed industry can step up its efforts. https://www.accesstoseeds.org/	ATSI engages with businesses, farmers, and civil society to develop the ATSI methodology. It compiles industry data feeding into the index.
Holistic Ecosystem Health Indicator (HEHI)	Tool for measuring ecosystem health in rangeland systems; comprises ecological and social indicators and interactive components of ecosystem health. https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryID=88077	Public and private sector stakeholders refine indicators through facilitated meetings and test measurement protocols on the ground.
Product-related sustainability assessment – Measures of resource use and impacts along a production chain or product life cycle		
Life cycle assessment (LCA), e.g. of food produced in organic versus non-organic agriculture	Used to analyze environmental impacts of raw material extraction, transport, processing, use and disposal, to inform product development and consumer choices (Notarnicola et al. 2017).	LCA has been interpreted, applied and refined by multiple users over the past four decades. The Life Cycle Initiative launched a global process in 2013 to provide global guidance on indicators and methods for the assessment of biodiversity impacts from land use in Life Cycle Impact Assessment (LCIA) https://www.lifecycleinitiative.org/
Integrated sustainability assessment – Assessment of local to global systems or integrated nature-society interactions		
Healthy ecosystem metric	A composite metric (with sub-components of biodiversity, soil and water) designed to measure the impact of a company on ecosystem health (Di Fonzo and Cranston, 2017).	Developed through collaboration between Cambridge Institute for Sustainability Leadership (CISL), the Natural Capital Impact Group (NCIG), the Investment Leaders Group, and researchers, corporate representatives, and conservationists. Included financing and pilot testing by leading companies.
Co$ting Nature	Modeling tool designed to quantify impacts on biodiversity and ecosystem services (at country or watershed level) of different land use and management scenarios (Mulligan et al. 2015). http://www.policysupport.org/costingnature	Survey with policymakers to determine enablers and barriers to use of scientific decision support tools which informed development (e.g. low user technical skills required, output data readily downloadable). Training on tool use delivered in multiple countries with ministry, NGO, academic, and private actors. Updates to the tool made iteratively based on user feedback.
Investor guides – Mechanisms to help sustainability-seeking investors identify relevant opportunities		
Climate Bonds Standard	Sectoral certification eligibility criteria developed by mobilizing scientists to inform 'rules of the road' for sustainability finance. http://climatebonds.net/	Criteria developed through iterative engagement between technical working groups (populated by scientists) and industry working groups (composed of investors and bond issuers).
Coalition for Private Investment in Conservation	Investment blueprints for agriculture, fisheries, forestry, and other sectors. http://cpicfinance.com/	Multi-sector working groups develop blueprints, using a common template, based on successful cases of private or blended finance for conservation activities.

(See above-mentioned references for further information.)

not resolve the mismatch between the scales at which research is conducted and at which findings would be applied (by private sector actors). Nor does it address the temporal mismatch between research process and implementation needs and the potential conflict of interest for scientists working together with the private sector. A shift is needed from the current model in which publication of 'policy-relevant' research is considered sufficient.

4. Strategies for multi-sector co-development of science-based decision tools

4.1. Aligning world views and work modes

Science-informed investment decisions in agriculture and food systems require deliberate efforts. Given the different paradigms and (career) reward structures within research, corporate, and finance sectors, strategies are needed to move from theoretical alignment of interests to actionable alignment. Transparent science-business dialogues, co-development of open access decision tools, and other methods for cross-sectoral, solutions-focused engagement can increase connectivity and capacity for collaboration.

Research-corporate-finance partnerships can be built collaboratively with attention to different needs and capacities (see Table 1) and explicit communication about expectations and potential conflicts of interest. Scientific teams can be assembled that mimic the diverse expertise needed to support company strategies and deployed through challenge-focused networks. Efficiencies can be captured through multi-region research projects (e.g. linked to corporate areas of interest) that are adapted to region-specific challenges and opportunities in production, nutrition, health, markets, and supply chains. Inclusive multi-sector processes can be adopted across all stages of research including co-investment, co-design, and joint implementation (e.g. conceptualize, prototype, test, and refine tools and data systems). Global knowledge centers can be established to deliver specific information streams that meet private and public sector needs (e.g. using indicators to assess progress toward commitments and targets; informing environmental regulation and dietary guidelines; foresight; scenario analysis).

4.2. Challenges of multi-sector partnership

Private sector actors tend toward a narrower set of decision-making criteria than public sector actors. For sustainability indices, they are more likely to prefer flexibility regarding types of data included and customization of aggregated indices in order to exclude sustainability dimensions that they do not consider as materially relevant or are not yet ready to factor into their investment decisions.

While they are more likely to be fit-for-purpose, sustainability indictors developed through multi-sector collaboration may be vulnerable to perceived or actual bias toward contributing companies and financial institutions (e.g. self-interested choices regarding data sources or interpretation). Establishing transparent protocols that reveal design choices embedded in indices is essential for attracting private sector partners that are committed to producing credible tools. Research partners will need to develop clear guidelines that ensure scientific integrity.

Broadly agreed principles for handling research data have emerged over time within the scientific community. In the private sector, data have traditionally been considered proprietary and closely held and the digital revolution has triggered a dramatic escalation in the commercial value of data resources. Public-private collaboration on sustainability decision tools will require carefully negotiated agreements and robust protections for handling confidential data. Such agreements can, over time, forge trust-based relationships across sectoral divides.

4.3. Examples of multi-sector co-development of sustainability-focused decision support tools

Many sustainability indicators, indices, and other assessment tools have been developed for use in the food and agriculture sector. However, adoption of decision support tools by intended users is generally low relative to the number of tools available (Grêt-Regamey et al., 2017; Rose et al., 2016). The likelihood that a tool will be used in the agri-food sector increases with its proven effectiveness at improving outcomes, its accessibility and ease of use, and its alignment with user needs and capabilities (Rose et al., 2016). Tool adoption is also likely to be greater when requirements for technical mastery or novel data collection by tool users are low as well as when tool design seeks to support, rather than replace, decision makers (Rossi et al., 2014).

The decision support tools showcased in Table 2 integrated multi-sector stakeholder engagement during their development or application and illustrate some of the factors that encourage tool adoption.

4.4. Multi-sector co-development of the Agrobiodiversity Index

Building on lessons from other decision support tools, the Agrobiodiversity Index (ABDI) is a recent example of deliberate engagement of private sector end users in development of a sustainability-focused decision tool. Developed by Bioversity International, the ABDI is a tool for synthesizing and scoring data on multiple elements of agricultural biodiversity, focusing on the domains of (i) healthy diets, (ii) sustainable production, and (iii) genetic resource use and conservation. The ABDI uses global, national, and company level databases and data sources to measure the status of agricultural biodiversity and progress towards managing this sustainably.

A central premise of the ABDI is that loss of agrobiodiversity creates material risks for food and agricultural supply chains (Zimmerer and Hahn, 2017). By detecting material agrobiodiversity-related risks and opportunities, the ABDI is intended to motivate companies and public and private investors to mainstream agrobiodiversity in supply chains (e.g. diversified sourcing strategies) and financial instruments (e.g. positive or negative screening).

A core innovation of the ABDI derives from its capacity for aggregating, interpreting, and supplementing ‘secondary’ data in the public domain in a scientifically rigorous way as well as from gathering data and building up use cases through co-development with partners. From early in its development process, design of the ABDI has included strategic engagement of governments (e.g. to inform policy and potential green bond issuance), food and agriculture companies (e.g. to explore application in their supply chains), and financial institutions (e.g. to understand how they might use such a tool). These partnerships are essential to designing a tool that accurately represents the different scales and dimensions of agrobiodiversity in corporate footprints and that produces information that can be integrated into investment decisions in concert with financial metrics for liquidity, volatility, and performance relative to market benchmarks.

4.5. Evolving models for research activities

Research funding is increasingly tied to evidence of real world impact. In that context, some research systems have begun broadening the set of ‘KPIs’ applied to their scientists beyond delivery of research projects and publications. For example, CGIAR research centers have developed real-time monitoring and evaluation systems that link project-level activities and outcomes to impact on reducing poverty, improving food and nutrition security, and improving natural resources and ecosystem services.

As new partnership models are tested with the private sector, industry associations and global alliances can be a lower risk entry point for research institutions. By working with a set of industry partners, rather than through bilateral partnerships, research groups can better maintain their independence (e.g. avoid becoming or appearing to be an R&D arm of a private company) and broaden their impact. Such new modes of engagement are emerging. For example, the Food Reform for Sustainability and Health (FReSH) initiative (https://eatforum.org/initiatives/fresh/) is a global business partnership that applies a consumption lens and systemic approach to the food system to drive industry change. Jointly launched in January 2017 by the EAT Foundation (EAT), the World Business Council for Sustainable Development (WBCSD), and 25 founding member companies, FReSH has since grown to include almost 40 companies. The Global Alliance for Improving Nutrition, GAIN (www.gainhealth.org), is mobilizing public and private actors of the food systems to increase consumption of nutritious, safe food by 1 billion people by 2022.

Partnerships focused on co-development of decision tools may be more effective if researchers engage with multiple units in a company to expand their reach beyond sustainability officers to R&D departments, procurement and manufacturing units, and corporate management. Research institutions can initiate private sector partnerships by setting out tangible collaboration opportunities (e.g. development of data and indices) anchored in broader impact pathways (e.g. SDG alignment; sustainable sourcing). For example, the Cambridge Institute for Sustainability Leadership (CISL) engaged ten companies (Anglian Water, Asda, Interserve, Kering, Mars, Mondi, Nestlé, Olam International, and Volac) in development and testing of a composite healthy ecosystem metric. With sponsorship from Dupont, the Economist Intelligence Unit has developed the Global Food Security Index, a modeled benchmarking tool for drivers of food security, based on 28 indicators of food affordability, availability, and quality. Transparent processes with independent review are critical elements of these and other international public-private initiatives.

5. Conclusion: A call for multi-sector co-development of science-based decision tools

The sustainability aspirations of companies and financial institutions are opening the door to new types of collaboration with the research community. This places new requirements on the scientific community to actively translate research-based knowledge into decision support, while also creating new opportunities for public-private co-investment in underlying data systems.

Multi-sector co-development of sustainability decision tools is necessary to enable companies and finance institutions to contribute to transformation of the food and agriculture sector. Better assimilation of multi-disciplinary science into private sector decision making can enable integration of sustainability considerations into supply chain management and capital allocation strategies. Promising entry points include quantitative indicators of agro-ecological risk and resilience as well as science-based benchmarking of agriculture sector products, companies, and investments. Consistent use of collaboratively developed, evidence-based indicators and other decision tools across the food and agriculture sector can unlock sustainable investments in the food and agriculture sector at scale.

Project- and network-based collaboration among scientists, government partners, industry players, and financial institutions is essential to addressing global challenges. This requires overcoming structural and cultural barriers and developing new incentives and protocols within research institutions and private sector organizations. By understanding where sustainability risks and opportunities of different food system actors align, we can determine the actions and investments that can optimize across these groups' interests.

Declaration of Competing Interest

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

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References

Alston, J.M., Pardey, P.G., 2014. Agriculture in the global economy. J. Econ. Perspectives 28 (1), 121–146.
Beddington, J.R., Asaduzzaman, M., Clark, M.E., Fernández Bremauntz, A., Guillou, M.D., Howlett, D.J.B., Jahn, M.M., Lin, E., Mamo, T., Nobre, C.A., Scholes, R.J., Sharma, R., Van Bo, N., Wakhungu, J., 2012. The role for scientists in tackling food insecurity and climate change. Agric. Food Security 1, 10.
Beintema, N., Stads, G.J., Fuglie, K., Heisey, P., 2012. ASTI Global Assessment of Agricultural R&D Spending. IFPRI, Washington DC. https://www.asti.cgiar.org/pdf/ASTI_global_assessment.pdf.
Dudley, N., Alexander, S., 2017. Agriculture and biodiversity: a review. Biodiversity 18 (2–3), 45–49.
Bioversity International, 2017. Reducing Risks and Seizing Opportunities: Integrating Biodiversity into Food and Agriculture Investments. Bioversity International, Rome, Italy.
Campbell, B.M., Beare, D.J., Bennett, E.M., Hall-Spencer, J.M., Ingram, J.S.I., Jaramillo, F., Ortiz, R., Ramankutty, N., Sayer, J.A., Shindell, D., 2017. Agriculture production as a major driver of the Earth system exceeding planetary boundaries. Ecol. Soc. 22 (4), 8.
Carlisle, L., Miles, A., 2013. Closing the knowledge gap: how the USDA could tap the potential of biologically diversified farming systems. J. Agric. Food Sys. Community Dev. 1–7.
CBI, 2017. Bonds and Climate Change: State of the Market 2017. Climate Bonds Initiative and HSBC, London, UK.
DeClerck, F.A., Jones, S.K., Attwood, S., Bossio, D., Girvetz, E., Chaplin-Kramer, B., Enfors, E., Fremier, A.K., Gordon, L.J., Kizito, F., Lopez Noriega, I., Matthews, I., McCartney, M., Meacham, M., Noble, A., Quintero, M., Remans, R., Soppe, R., Willemen, L., Wood, S.L.R., Zhang, W., 2016. Agricultural ecosystems and their services: the vanguard of sustainability? Curr. Opin. Environ. Sustainability 23, 92–99.
DeLonge, M.S., Miles, A., Carlisle, L., 2016. Investing in the transition to sustainable agriculture. Environ. Sci. Policy 55 (1), 266–273.
Di Fonzo, M., Cranston, G., 2017. Healthy Ecosystem metric framework: Biodiversity impact. University of Cambridge Institute for Sustainability Leadership (CISL), Working Paper 02/2017.
Development Initiatives, 2017. Global Nutrition Report 2017: Nourishing the SDGs. Development Initiatives, Bristol, UK.
GBD 2017 Diet Collaborators. 2019. Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. The Lancet; accessed 2 April 2019.
GISGCC, 2018. Briefing Paper on the 2018 Global Investor Statement to Governments on Climate Change. https://theinvestoragenda.org/wp-content/uploads/2018/05/GISGCC-briefing-paper-FINAL.pdf; accessed 18 April 2019.
Global Panel, 2017. Improving nutrition through enhanced food environments. Policy Brief No. 7. London, UK: Global Panel on Agriculture and Food Systems for Nutrition.
Grêt-Regamey, A., Sirén, E., Brunner, S.H., Weibel, B., 2017. Review of decision support tools to operationalize the ecosystem services concept. Ecosyst. Serv. 26, 306–315.
Haddad, L., Hawkes, C., Webb, P., Thomas, S., Beddington, J., Waage, J., Flynn, D., 2016. A new global research agenda for food. Nature 540, 30–32.
Hahnel, U.J.J., Arnold, O., Waschto, M., Korcaj, L., Hillmann, K., Roser, D., Spada, H., 2015. The power of putting a label on it: green labels weigh heavier than contradicting product information for consumers' purchase decisions and post-purchase behavior. Front. Psychol. 6, 1392.
Hart, Milstein, 2003. Creating Sustainable Value. Academy of Management Executive, 17(2).
HLEG, 2018. Financing a Sustainable European Economy: Final Report by the High-Level Expert Group on Sustainable Finance. European Commission.
HLPE, 2017. Nutrition and food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.
IFC, 2012. Guidance Note 6. Biodiversity Conservation and Sustainable Management of Living Natural Resources. Washington, DC: International Finance Corporation.
Juffe-Bignoli, D., Brooks, T.M., Butchart, S.H.M., Jenkins, R.B., Boe, K., Hoffmann, M., et al., 2016. Assessing the cost of global biodiversity and conservation knowledge. PLoS ONE 11 (8), e0160640.
Liu, J., Yang, H., Cudennec, C., Gain, A.K., Hoff, H., Lawford, J., Qui, L., de Strasser, P.T., Zheng, C., 2017a. Challenges in operationalising the water-energy-food nexus. Hydrol. Sci. J. 62 (11).
Liu, Q., Yan, Z., Zhou, J., 2017b. Consumer choices and motives for eco-labeled products in China: an empirical analysis based on the choice experiment. Sustainability 9, 331 https://www.tandfonline.com/doi/full/10.1080/02626667.2017.1353695.
Mudaliar, A.H., Bass, R., Dithrich, H., 2018a. 2018 Annual Impact Investor Survey. Global Impact Investing Network (GIIN). https://thegiin.org/assets/2018_GIIN_Annual_Impact_Investor_Survey_webfile.pdf.
Mudaliar, A., Pineiro, A., Bass, R., Dithrich, H., 2018b. The state of impact measurement and management practice. Global Impact Investing Network (GIIN).
Mulligan, M., 2015. Trading off agriculture with nature's other benefits, spatially. In: Zolin, C.A., Rodrigues, R. de A.R., (Eds.), Impact of climate change on water resources in agriculture. CRC Press, ISBN 9781498706148.
Ness, B., Urben-Piirsalu, E., Anderberg, S., Olsson, L., 2007. Categorising tools for sustainability assessment. Ecol. Econ. 60, 498–508 https://pdfs.semanticscholar.org/714b/390916dc178664f6d8c092a268fe389658b9.pdf.
Niles, M.T., Ahuja, R., Esquivel, M.J., Mango, N., Duncan, M., Heller, M., Tirado, C., 2017. Climate Change and Food Systems: Assessing Impacts and Opportunities. Meridian Institute, Washington, DC.
Notarnicola, B., Sala, S., Anton, A., McLaren, S.J., Saouter, E., Sonesson, U., 2017. The role of life cycle assessment in supporting sustainable agri-food systems: a review of the challenges. J. Cleaner Prod. 140 (2), 399–409.
OECD, 2016. Environmental labelling and information schemes. Available at: https://www.oecd.org/env/policy-persectives-environmental-labelling-and-information-schemes.pdf (accessed 24 August 2018).
Oosterveer, P., Rossing, G., Hendriksen, A., Voerman, K., 2014. Mainstreaming fair trade: the role of retailers. Sustainability: Sci. Pract. Policy 10 (2), 41–50.
Podnar, K., Golob, U., 2007. CSR expectations: the focus of corporate marketing. Corporate Commun. Int. J. 12 (4), 326–340.
Poore, J., Nemecek, T., 2018. Reducing food's environmental impacts through producers and consumers. Science 360 (6392), 987–992.
PRI, 2018. Impact Investing Market Map. Principles for Responsible Investment. https://www.unpri.org/thematic-and-impact-investing/impact-investing-market-map/3537.article; accessed 10 April 2019.
Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., Wetterstrand, H., DeClerck, F., Shah, M., Steduto, P., de Fraiture, C., Hatibu, N., Unver, O., Bird, J., Sibanda, L., Smith, J., 2017. Sustainable intensification of agriculture for human prosperity and global sustainability. Ambio 46, 1.
Rose, D.C., Sutherland, W.R., Parker, C.G., Lobley, M., Winter, M., Morris, C., Twining, S., Ffoulkes, C., Amano, T., Dicks, L.V., 2016. Decision support tools for agriculture: towards effective design and delivery. Agri. Systems 149, 165–174.
Rossi, V., Salinari, F., Poni, F., Caffi, T., Bettati, T., 2014. Addressing the implementation problem in agricultural decision support systems: the example of vite.net. Comput. Electron. Agric. 100, 88–99.
Rubin, D.A., Esty, D.C., 2010. The Sustainability Imperative. Harvard Business Review. Case Study. Boston. Harvard Business Publishing. May 2010. https://hbr.org/2010/05/the-sustainability-imperative?autocomplete=true.
Scheffers, B.R., et al., 2017. The broad footprint of climate change from genes to biomes to people. Science 354 (6313), 1–10 aaf7671.
Schindler, J., Graef, F., König, H.J., 2015. Methods to assess farming sustainability in developing countries. A review. Agron. Sustain. Dev. 35, 1043–1057.
Soussana, J., 2014. Research priorities for sustainable agri-food systems and life cycle assessment. J. Cleaner Prod. 73 (15), 19–23.
Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs,

R., Carpenter, S.R., De Vries, W., de Wit, C.A., Folke, C., 2015. Planetary boundaries: guiding human development on a changing planet. Science 347 (6223), 1259855.
TCFD, 2017. Final recommendations from the Task Force on Climate-related Financial Disclosures. Financial Stability Board. https://www.fsb-tcfd.org/publications/final-recommendations-report/.
Thorlakson, T., de Zegher, J.F., Lambin, E.F., 2018. Sustainability in global supply chains. Proc. Natl. Acad. Sci. doi: 10.1073/pnas.1716695115.
Vörösmarty, C.J., et al., 2018. Scientifically assess impacts of sustainable investments. Science 359 (6375), 523–525.
Willett, W., Rockstrom, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., et al., 2019. Food in the Anthropocene: The EAT-Lancet Commission on healthy diets from sustainable food systems. The Lancet Commissions 393 (10170), 447–492.
World Bank, 2019. Agricultural land (% of land area). World Development Indicators. The World Bank Group. https://data.worldbank.org/indicator/ag.lnd.agri.zs; accessed 10 April 2019.
World Bank, 2017. The Data Blog: Chart: Globally, 70% of Freshwater is Used for Agriculture. https://blogs.worldbank.org/opendata/chart-globally-70-freshwater-used-agriculture; accessed 18 April 2019.
WBCSD; Our members; https://www.wbcsd.org/Overview/Our-members; accessed 20 July 2018.
WEF, 2019. The Global Risks Report 2018, 14th ed. World Economic Forum, Geneva, Switzerland.
WEF, 2017. Shaping the Future of Global Food Systems: A Scenarios Analysis. World Economic Forum, Geneva, Switzerland.
Zanoli, R., et al., 2013. Organic label as an identifier of environmentally related quality: A consumer choice experiment on beef in Italy. Renew. Agr. Food Syst. 28 (1), 70–79.
Zimmerer, K., Hahn, S., 2017. Agrobiodiversity and a sustainable food future. Nat. Plants 3 (17047), 1–3.