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Future directions for early career researchers in planetary health equity

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ABSTRACT

Achieving social and health equity on a healthy planet requires attending to the structural drivers of intersecting crises of global environmental change, social inequities, and health inequities. A diverse group of early career researchers have formed a new network aligned in advancing work that promotes planetary health equity. This Perspective articulates proposed future research directions emerging from shared understandings of intersecting governance and policy challenges, including sections on transdisciplinary and co-productive knowledge paradigms; political economy and governance; policy integration; and opportunities to advance planetary health equity. We present this agenda with reference to a range of substantive environmental- and health-related domains, including food systems governance, trade policy, energy policy, urban planning, and education. As early career researchers in the emerging field of planetary health equity, these future directions for research are intended to offer novel avenues towards the goals of social and health equity in a stable Earth system.

1. Introduction

The effects of accelerating global environmental change and increasing social and economic inequity pose a fundamental challenge to human wellbeing in a sustainable Earth system (IPCC et al., 2023; Romanello et al., 2023). Achieving social and health equity on a healthy planet – referred to as planetary health equity (PHE) (Friel et al., 2022) – requires attending to the structural drivers of intersecting crises and how

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marginalised populations disproportionately experience the adverse effects of current systems on human health and the environment (Friel, 2019). PHE, as an objective, can therefore be seen as an outcome of systemic processes that encompass cross-cutting governance and policymaking activities within environmental, social, and health domains.

These systemic challenges, and potential pathways forward to address them, were explored in a two-week program that brought together a diverse group of 19 early career researchers through structured workshops and masterclasses aimed at mobilising the budding field of PHE. This *Future Leaders Program* of the Planetary Health Equity Hothouse, convened in September 2023 by ARC Laureate Fellow Professor Sharon Friel, forged a network of researchers from varying geographic, disciplinary, and lived experience backgrounds, aligned in advancing work that promotes PHE. Building on collective learnings and discussions during workshops, each author drafted a brief outline of core issues and necessary research directions, grounded in their disciplinary and substantive areas of expertise. These were grouped into overarching themes and refined to identify important areas for future research in a range of fields to advance PHE, from the perspective of this diverse group. This Perspective therefore interrogates PHE through various disciplinary and topical lenses to demonstrate the diverse research and practice opportunities that we envision. In the sub-sections below, we discuss these in terms of transdisciplinary methodological approaches drawing from diverse knowledges, political economy and governance, cross-sectoral policy integration, and windows of opportunity for solutions-based approaches to PHE.

2. Purposeful research across disciplines and knowledges

One of the first elements of directions for future research is setting out the *how* – articulating research paradigm(s) commensurate with the scale and complexity of the challenges at hand, and with the evolution of scholarly work on complex global problems (Darian-Smith and McCarty, 2016). In the context of intersecting crises, it is crucial to transcend conventional disciplinary and sector-based silos to develop interdisciplinary and transdisciplinary approaches that examine our complex realities and how to leverage change. Knowledge co-production and transdisciplinary approaches highlight the need for inclusively integrating diverse knowledge systems, including Western scientific paradigms, Indigenous Knowledges, and insights based on lived experience, among others (Bandola-Gill et al., 2023). By incorporating and valuing these perspectives, transdisciplinary work can achieve a richer and more nuanced understanding of the interconnectedness between human health, the ecosystems that underpin our wellbeing, and the complex political, economic, social, cultural, technological, and environmental relationships that determine PHE.

2.1. Indigenous Knowledges from the Torres Strait Islands

Indigenous Knowledges and lived experiences of First Nations Peoples have historically been marginalised and excluded from climate change discussions (Jones et al., 2022; Lansbury et al., 2022a; Matthews et al., 2021; Ratima et al., 2019) and other environmental and health governance spaces. Only as of 2022 was climate data from First Nations Peoples' Knowledges included in the *Sixth Intergovernmental Panel on Climate Change Assessment Report* (IPCC AR6) at the global level, and in the *State of the Environment* report in Australia (Lansbury et al., 2022a). In Australia, as elsewhere, it is essential to ensure that the resilience and knowledges of Torres Strait Islander and Aboriginal peoples are recognised, and that their voices are heard within the broader conversation of PHE. The peoples of the Torres Strait Islands, as other Indigenous peoples in Australia and globally (Matthews et al., 2021; Sahu et al., 2022), face inequitable direct and indirect impacts from climate change, shaped by the structural drivers of planetary health inequity. With current climate impacts causing irreversible damage to the people, region, culture, and health of the Torres Strait, it is vital that the decision-makers and influencers of structural drivers working from afar (who are creating damage they cannot see) are called to action to work directly with Torres Strait Islanders to address these problems more effectively. It is important to bring an Indigenist and decolonising approach to exploring and advocating for self-determination of the Torres Strait Islanders and other First Nations peoples in navigating the complexities of climate change and impacts on health (Lansbury et al., 2022b; Redvers et al., 2022). Indigenous researchers' ancestral connection to Country provides crucial knowledge, which can be mobilised into wider research and policy conversations to empower them and their people (Lansbury et al., 2022a), as well as benefit wider planetary health (Redvers et al., 2022). Planetary health research must centre existing decolonising work and the diversity of Indigenous knowledges and stewardship (Hoogeveen et al., 2023), as well as values and worldviews (Jones, 2019; Jones et al., 2020; Jones et al., 2022; Ratima et al., 2019; Redvers et al., 2022; Tu'itahi et al., 2021). This 'epistemological pluralism' is necessary to include multiple valuable ways of knowing, and an 'Earth-centred worldview', into research, policy, and law (Redvers et al., 2022). In particular, a strengths-based, community-focused lens is necessary to foreground Indigenous Peoples' existing leadership, and how this can be empowered and included through models such as co-design in policymaking processes. Grounded in the work of Indigenous leaders and scholars, this requires collective advocacy for policy change; addressing existing power asymmetries in policy and law; and co-governance of land, sea, and water for health and wellbeing benefits (Matthews et al., 2021).

2.2. Transcending natural and social scientific research divides

Another element in bringing together knowledges for PHE involves consideration of scientific and technological dimensions as inseparable from the social. This inseparability is increasingly recognised, as exemplified by the decision to add justice and equity to the Planetary Boundaries Framework (Gupta et al., 2024; Rockström et al., 2023). Science and technology play a critical role in supporting transformative shifts towards more sustainable systems and ways of being. However, the application of science and technology for systemic transformation is contingent on the context in which these innovations are developed. Innovations designed using purely biophysical or techno-economic criteria risk failure if they do not sufficiently engage with the complex, multifaceted social factors that influence successful adoption and translation, such as culture, policy, and political-economic structures (Geels and Schot, 2007). Developing innovations solely through a technocratic lens can limit the uptake of models promising paradigm shifts, such as the bioeconomy, circular economy, other types of "green" economies, or de-growth (MacArthur, 2013; Muscat et al., 2021; Wohlfahrt et al., 2019). These models and the innovations arising from them have been criticised as providing incremental shifts that perpetuate the current system, rather than disruptive solutions (Vogelpohl and Töller, 2021; Hermann et al., 2022). PHE provides a socio-technical lens to help identify transition pathways to reorient and align existing and emerging innovations towards transformational outcomes (Friel et al., 2022).

2.3. Solution-oriented knowledge production

Transdisciplinarity extends beyond institutionalised research spaces to foster the co-production of solutions that build on diverse knowledges, skills, and value positions. The Earth4All initiative provides an example of evolution from the 1972 interdisciplinary report *The Limits to Growth* (Meadows et al., 1972), to a cross-sectoral research and policy initiative fifty years later arguing for economic transformation to achieve wellbeing for all people within planetary boundaries (Dixson-Declève et al., 2022). Solution-oriented evidence can be generated and mobilised through cross-sectoral collaboration between policymakers, civil society, journalists and communication experts, and

business actors who seek to authentically institutionalise sustainable and socially just business practices. Embracing collaborative strategies is pivotal for generating culturally relevant solutions that recognise how context (i.e. time, space, culture) influences health, equity, and environmental outcomes. However, doing so requires critically navigating the power dynamics and potential conflicts of interest inherent to cross-sectoral collaboration, including with hybrid actors such as academic institutions and philanthropies (Littoz-Monnet and Osorio Garate, 2023). Moreover, to fully benefit from the strategic and substantive expertise of practitioners and advocates in diverse policy domains, governance mechanisms must redress power imbalances, including through First Nations-developed protocols and Indigenous Data Sovereignty (Lansbury et al., 2022b; Kukutai, 2023), and also through governance to avoid 'corporate capture' of these spaces (Gilmore et al., 2023).

Breaking disciplinary and sectoral silos is pivotal for tackling complex issues such as climate change and health inequities. While knowledge co-production paradigms like transdisciplinarity can provide an overarching orientation across the wide-ranging research topics described in this Perspective, within this ethos we recognise and celebrate the diversity of approaches that we adopt from our respective scholarly, professional, and experiential perspectives.

3. Political economy and global governance lenses for planetary health equity

While domestic institutional design, interests, and norms play a key role in conditioning PHE outcomes, so too do international governance arrangements. A PHE framework aligns with the evolving international relations scholarship, shifting from the study of individual institutions and their dyadic interactions to that of interplay among autonomous but interrelated institutions in overarching systems of global governance (Frank et al., 2024; Biermann and Kim, 2020; Gómez-Mera, 2020). This structural turn, developed in the study of international regime complexity and Earth systems governance, emphasises how institutions interact with one another and their environment to constitute a complex system with properties such as self-organisation, emergence, and adaptation (Alter and Meunier, 2009; Orsini et al., 2020; Raustiala and Victor, 2004).

In the absence of a central global authority to address systemic inequities, global governance looks beyond state-centric instruments, emphasising instead the constitution of power, knowledge, and norms for global governance through multi-level and multi-sectoral actors and institutions (Biermann and Pattberg, 2012; Zürn, 2012). It highlights the contributions of public and private agents at subnational, national, regional, and international levels, the collective actions of which constitute governance (The Commission on Global Governance, 1995). Understanding these interactions and operations of complex systems is critical to enabling policy actors to effect interventions that support the achievement of PHE objectives.

At a domestic level, lowering emissions and restructuring economies to promote PHE will require an expanded and novel role for the state in shaping the economy. The feasibility of interventions on the required scale, as well as their distributional impacts, will be influenced by domestic values and norms, state capacity and institutions, and economic interests (Lamb and Minx, 2020; Lewis et al., 2019; Meckling and Nahm, 2021). In turn, these factors are shaped by national growth models and their associated macroeconomic architectures (Baccaro and Pontusson, 2022; Hopkin and Voss, 2021). Variation across growth models – whether they are export-oriented, consumption-driven, or balanced – generates divergent politics of climate change and PHE (Frank et al., 2023; Nahm, 2021). Deepening our understanding of the interaction between growth models and domestic and international politics will help to identify the actors, strategies, and processes that will shape the success or failure of a transition to an economic system that protects the planet and people.

In this light, urgently needed improvements in PHE are only possible with a shift from the currently dominant political-economic paradigm where economic growth is seen as an end in itself to an approach that puts societal wellbeing and planetary health at the centre (Trebeck and Williams, 2019). While this would entail greater state intervention, governments must nevertheless be careful when regulating their domestic political economy to maintain economic competitiveness in the current era of hyperglobalisation (Rodrik, 2011). The *varieties of capitalism* literature shows that the liberal and financialised capitalism that is prevalent in the Anglosphere is not the only way to ensure economic growth in a globalised world (Hall and Soskice, 2001; Amable, 2003). Other advanced economies like Germany and Sweden have been able to generate economic growth without relying on market liberalisation and financialisation, while still intervening in the economy for the wellbeing of workers and the planet (Baccaro and Pontusson, 2016). Whether the Anglosphere can follow similar institutional paths towards greater PHE is a research question that needs immediate attention.

3.1. Example: the political economy of food systems under a planetary health equity lens

Exploring the shift from growth-oriented political-economic paradigms to those prioritising PHE is relevant in the context of food systems. Food systems serve as a nexus where health, the natural environment, and the wellbeing of humans and non-human animals converge, intersecting with culture, identity, and as an important source of everyday enjoyment. While ensuring secure and accessible food for some, global industrial systems – primarily controlled by a small number of industrial agribusinesses – pose challenges for PHE (Clapp, 2021). The dominance of multinational corporations in food production perpetuates resource-intensive and environmentally and socially harmful practices, contributing to ecological degradation, diet-related illnesses, and unjust conditions for workers and animals (Fuchs et al., 2009; Hendrickson et al., 2020). Highly profitable foods such as ultra-processed foods and intensively produced meat and dairy share analogous corporate and financial operational structures (Baker et al., 2020; Sievert et al., 2022), emphasising the need to confront and reshape corporate control and institutional arrangements beyond the food system itself (Sievert et al., 2021). Achieving PHE in food systems requires challenging ingrained cultural, commercial, and political norms that tend to deprioritise planetary health equity -(Friel, 2023a). Recognising the potential of social movements and the intrinsic regulatory capacity of nature itself may comprise part of this agenda (Parker and Johnson, 2019). In Mexico, community-led initiatives have shaped local policies to shift priorities from corporate-controlled industrial agriculture to agroecological practices that support small-scale farmers (Toledo and Barrera-Bassols, 2017). These policies have reduced dependence on resource-intensive monocultures, which are typically dominated by large agribusinesses (Altieri and Toledo, 2011). This shift has redirected focus toward, *inter alia,* enhancing biodiversity, supporting local food systems, and ensuring food security at the community level, integrating planetary health equity outcomes in food systems.

4. Policy integration for planetary health equity

To enhance justice for health equity at a planetary level, public policymaking must move beyond siloed thinking and meaningfully embed PHE as a cross-cutting objective across policy areas. Doing so, however, is a political process that requires navigating the various power dynamics that determine policy design (Tosun and Lang, 2017; Cejudo and Trein, 2023). In the following sub-sections, we provide snapshots of three policy areas that could better integrate PHE: international trade, energy, and urban planning. While these examples were chosen to provide concrete illustrations based on the expertise of the authors, the relevance of policy integration, by definition, extends beyond (transcends, even) those policy areas.

4.1. Trade policy

International trade defines consumption and production patterns and has powerful impacts on PHE. Although trade holds potential to increase global wellbeing, the current global trade system is characterised by growing distances between production and consumption, which is not only unsustainable, but also inequitable (Sharmina et al., 2021; Wiedmann and Lenzen, 2018). Unfair international trade agreements have undermined local capacity to design policies for sustainable development, especially in low- and middle-income countries (Ruse-Khan, 2009). For example, scholars have underscored the impacts of trade regulation in areas directly linked to public health, such as access to medicines (Sell, 2007) and sustainable food production (Friel et al., 2020). There are, however, possibilities to embed social and environmental justice principles in the global trade regime. Research has shown how Geographic Indication[3] regulation has the potential to preserve traditional agricultural knowledge and protect biodiversity and agroecological farming practices (San Martim Portes et al., 2021). Geographic Indication is one regulatory mechanism that can positively contribute to socio-environmental sustainability – even though this is not its primary objective. As such, it is an interesting avenue for PHE integration in trade policy.

4.2. Energy policy

As governments and communities around the world transition their energy systems away from fossil fuel energy sources, it is critical to place PHE and the values it embodies – including social and environmental justice, equity, and sustainability – at the core of a just energy transition (Rockström et al., 2023). Social impacts of the energy transition, including health outcomes beyond occupational health and safety obligations, are an essential consideration to avoid entrenching or exacerbating negative externalities, co-harms, and trade-offs that have prevailed under fossil fuel energy systems (Sovacool et al., 2019a, 2021). Negative externalities associated with renewable energy technologies have been identified by communities (von Möllendorff and Welsch, 2017). Some externalities, such as localised environmental degradation, excessive water consumption, and the use of child labour for critical mineral extraction, embody planetary health *in*equity, by harming the health of at-risk populations least able to protect themselves (Sovacool et al., 2019b). Effective climate change mitigation interventions should proactively seek to reduce, not exacerbate, existing inequities (Cissé et al., 2022). In the literature to date, there appears to be limited consideration of health outcomes across the life cycle of renewable energy systems (Tham et al., 2020). Such a blind spot points to the need for a transdisciplinary and holistic understanding of the energy system (Friel, 2023b). Further, the goals of the transition should themselves include delivering energy systems that meet the needs of populations to address underlying inequities driven by past and current systems. Applying a PHE lens to the development of renewable energy policies, programs, and interventions can reveal and help counter the perpetuation of 'green extractivism' (Bruna, 2022) as we decarbonise our energy systems.

4.3. Urban planning

Urbanisation trends present sustainability solutions and challenges, which impact the availability of basic services, housing, education, health, land tenure, jobs, and safety (United Nations, 2017, 2022). Growing urban populations globally can facilitate access to goods, services, and opportunities to deliver improved wellbeing, encompassing education, employment, healthcare, a healthy built environment, and food security. Effective urban public policies, therefore, can shape urbanisation dynamics with the potential to improve PHE outcomes through public investment in infrastructure and services (Turok and Parnell, 2009; Kinyanjui, 2020). Regulatory measures such as land value capture, zoning, and taxation must aim to deliver equitable distribution of these investments and ensure that industries are taxed for negative externalities, generating revenues for equitable distribution of climate and health interventions (Samantela and Maquiling, 2024). These instruments are important to harness the potential of cities as key players in climate change mitigation, adaptation, and social inequity reduction. However, weak and/or fragmented institutions, lack of political capacity, differentiated self-interests coupled with political conflicts, and the influence of powerful landowners and corporations hinder the achievement of those outcomes. This results in the inequitable distribution of both public goods and environmental hazards, entrenching health disparities (Farazmand et al., 2022; Jacobs, 2011; Samantela and Maquiling, 2024; Turok, 2014).

4.4. Moving forward: understanding policy change and continuity

Each of the policy areas explored above has the potential to contribute to PHE. As demonstrated in the case of trade policy, there are regulatory avenues for integrating PHE goals. However, generating *systemic* change faces challenges that are institutional and political in nature. This suggests that providing evidence of policy impacts is necessary but not sufficient to achieve change (Boswell and Smith, 2017). There is a perennial mismatch between research evidence highlighting the structural, political-economic root causes of the planetary health crisis, and policies framing the solutions around individual responsibility (Carey et al., 2017; Sell and Williams, 2020). Individualising poor health outcomes obscures negative externalities and perpetuates (health) inequities, as shown in the energy policy case. Furthermore, policymaking occurs in a multilevel governance context characterised by increasingly blurred boundaries between the governing and the governed (Hooghe and Marks, 2002). As highlighted in the urban policy example, this has resulted in institutionalising the most powerful corporate interests as influential norm-setters and indispensable governing partners, which undermines PHE integration.

To understand how (flawed) modes of governance become seen as natural and self-evident, PHE research on policy integration needs to engage with critical theories of power and public policy (Mykhalovskiy et al., 2019; Smith, 2013). Studying institutional change and continuity can offer valuable 'mid-level' insights in policymaking and governance dynamics, moving beyond the structure-agency impasse that either overestimates strategic agency of individual actors or falls victim to overly deterministic accounts of macrostructural power (Ralston et al., 2023). Such transdisciplinarity could foster new theoretical perspectives on policy integration and policy recommendations for effective PHE policy design.

5. Windows of opportunity for solutions-based approaches to planetary health equity

There are multitudes of opportunities to work toward PHE. Select avenues are highlighted in this section. Growing concern about climate change provides momentum to address social and health inequities, and provides increasing opportunities for early career researchers to engage in research addressing these issues as we realise the urgency with which we must uncover and implement solutions to these complex and interconnected challenges.

5.1. Seizing win-win opportunities

Governments at all levels, facing a need to secure 'green legitimacy'

[3] Geographical indications are place names used to identify the origin and quality, reputation or other characteristics of products. Examples of geographical indications include 'Champagne', 'Tequila', and 'Roquefort'. (bib_world_trade_organization_2024World Trade Organization, 2024).

(Eckersley, 2021), are investing in structures and policies that facilitate lower carbon ways of moving around, eating, and powering homes (see, for example, Kuss and Nicholas, 2022). Depending on how transitions occur, there is potential for these structural shifts to improve health and decrease energy, transport, and food poverty (Martiskainen et al., 2021; Riley et al., 2023). Windows of political will provide opportunities to implement transformative solutions as they arise, ensuring that they enhance state capacity to respond to diverse interests in building systems for the future (Eckersley, 2021). Political will can be leveraged for changes that demonstrate co-benefits, such as concurrently reducing pollution, supporting economic development, and improving health, as these are more likely to be supported than changes that address climate change alone (Bain et al., 2016). Instances of poor design, such as some low carbon zones or solar subsidies, have entrenched inequity (Dwarkasing, 2023; Player et al., 2023; Tidemann et al., 2019). Attention and priority must be given to ensure that climate policy outcomes include reduced, rather than increased (or unchanged), health and social inequity. Early career researchers can contribute to maximising windows of political will by engaging in political consultation processes such as giving feedback on draft policies or submitting relevant evidence from their research to parliamentary inquiries, emphasising co-benefits in doing so.

5.2. Recognising privilege

Positioning social and health equity as a focal point in policymaking is not a new idea. In 2008, the World Health Organization's Commission on the Social Determinants of Health identified that to improve health equity, urgent action must be taken regarding the unjust distribution of resources, money, and power (Commission on Social Determinants of Health, 2008). Over a decade since then, research and policy approaches continue to predominantly focus on marginalised or 'vulnerable' population groups, using downstream responses to address health and social problems once they have already manifested, instead of making structural changes (Baum and Fisher, 2014). Subsequently, we are yet to see a significant improvement in relative wellbeing and the gap in health outcomes between the most and least advantaged continues to increase (Flavel et al., 2022). Reorienting public and planetary health to foreground critical consideration of how public policies contribute to the distribution of power, privilege, and socioeconomic advantage—and how this distribution in turn influences the creation of public policy—is integral to ensuring that all people, within and across countries, experience PHE. This reorientation must involve, in part, those who are currently in positions of power and privilege, most notably high-emitting economies and wealthy elites. This cohort must confront the reality of their high-impact consumptive behaviours, which perpetuate states of insecurity, detachment, and apathy that only fuel further consumption and accumulation (Freudenberg, 2021; Oxfam International, 2023; Friel, 2023a). In the context of accelerated concentration of extreme advantage and privilege among fewer people, early career researchers can shift the problem narrative from one of disadvantage to one of advantage through research that highlights the nature of privilege; how public policy creates, maintains, or dismantles privilege; and feasible solutions to the undoing of privilege.

5.3. Cultivating compassion

While concurrent threats of climate change, biodiversity loss, and rising inequity understandably elicit apprehension and insecurity, and often result in cognitive dissonance (Haltinner et al., 2022; Australian Psychological Society, 2023), paralysis or avoidance of these uncomfortable realities are not viable options given the scale of challenges facing humanity. One way to navigate such challenges and further PHE in a constructive and resilient manner is to leverage affective states alongside cultivating greater social and emotional literacy (Brosch, 2021). Social and emotional literacy fosters self-awareness, self-management, social awareness, relationship skills, and responsible decision-making (Durlak et al., 2011). These vital human competencies offer a potent antidote to competition, exploitation, and degradation. As a new generation of researchers, recognising the need to divert from status quo perspectives, furthering our understanding of the association between social and emotional literacy and PHE through research may facilitate the development of strategies that aid in fostering a social and economic framework characterised by compassion and empathy, which are pivotal in building a more equitable and sustainable system (Trebeck, 2023).

5.4. Transforming education

Social and emotional literacy are qualities that can be cultivated through education, and it is important to re-focus curricula towards a praxis that combines compassion, knowledge, and reflection (Redvers et al., 2023). The multifaceted crises we face require multidisciplinary learning approaches to further understanding of planetary health, either as an independent field of study or through its integration across all disciplines (Faerron Guzman et al., 2021). Prior studies have identified universities as potentially ideal settings for raising awareness about planetary health among students of health professions given the training they receive in advocacy and managing complex situations (Walpole et al., 2019). Short courses by academic institutions and independent education centres can provide another avenue (Asaduzzaman et al., 2022). Research can support these developments by providing an evidence base for their effectiveness. However, one limitation of current education efforts is that most universities are focused on including planetary health education primarily in medical and nursing curricula, while its inclusion is needed in all disciplines (Faerron Guzman et al., 2021). As recognition of planetary health and its fundamentally transdisciplinary nature increases, early career researchers who also engage in teaching activities (e.g., lecturing, tutoring) can integrate planetary health-related content into their teaching. An important consideration regarding planetary health education is that this tertiary-level education is mostly offered in high-income countries, leaving out low- and middle-income countries, and primary and secondary education. Research is needed to build contextualised knowledge for the development and design of these educational interventions.

Exploring these windows of opportunity through research, including re-evaluating power dynamics, embracing social and emotional literacy, and restructuring education, can ensure a holistic approach that drives transformative policies to foster a more equitable and sustainable future for all.

6. Conclusion

A PHE approach cultivates critical perspectives across sectors, disciplines, and theoretical viewpoints. Through a PHE framework, critical approaches are essential for understanding how marginalised communities are made increasingly vulnerable to the compounding effects of climate change, rising inequity, and human morbidities.

This piece offers a variety of perspectives on future research needs, building on existing research to advance the goals of social and health equity on a healthy planet. This multiplicity of perspectives is intentional and reflects our commitment to epistemic inclusivity, which we see as a fundamental value and precondition for PHE. Future directions proposed include greater attention to knowledge co-production and transdisciplinarity, political economy and governance considerations, policy integration, and multiple windows of opportunity through which to mobilise political action, challenge power dynamics, build social and emotional literacy, and educate future generations. In light of the ongoing marginality of structural and systemic analyses, and of attention to the social and environmental determinants of health and health equity, we aim to elevate these perspectives in a wide range of substantive environmental- and health-related domains.

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Data availability

No data was used for the research described in the article.

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An early career researchers' perspective on inequality in ecosystem services research in Asia

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ABSTRACT

The ecosystem services (ES) approach has been widely applied for assessing nature's values and human-nature links. Over the past two decades, this research approach has experienced remarkable growth, exerting global influence on the sustainability policy agenda. Recent literature indicates that North America, Europe, East Asia, and Australia are major contributors to ES research, while other regions are progressing at a slower pace. Many countries in these regions remain under-represented due to various factors, including but not limited to knowledge transfer gaps, disparities in research capacities, as well as distinct needs and challenges among researchers in the Global North and South. Although the ES literature in Asia is growing in topics, methodologies, quality and quantity, many Asian researchers, especially Early Career Researchers (ECRs), still face problems typical of the Global South while conducting ES research. In this paper, we outline four major challenges from the perspective of ECRs. They include: 1) Inequality in career prospects and capacity-building, 2) Inequality and challenges in data access & knowledge transfer, 3) Circulation of research findings in global scientific publishing, 4) Challenges in funding. This perspective paper draws special attention to the challenges faced by ECRs in ES research in Asia. By presenting recommendations, we strongly advocate that the research community work together to make ES research a level playing field for ECRs like ourselves working in Asia and elsewhere.

1. Introduction

Global environmental challenges need truly global science to solve them. While assessments like the Millennium Ecosystem Assessment (2005), the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), the Intergovernmental Panel on Climate Change (IPCC) and Global Biodiversity Outlook (GBO) have been making calls for sustainable transformation, the concept and its operationalization still remain a conundrum for scientific and civil society alike (Salomaa and Juhola, 2020, Hulme, De Pryck, 2022). This makes it imperative to create and gain knowledge on how transformations happen, what research methodologies can be used to effectively assess and compare

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them across scales and how these transformations can be enabled in different environmental, socio-economic, and socio-cultural settings.

However, if we, as global teams of scientists, practitioners, and policymakers want effective collective solutions to global challenges, we need to aim for fairer knowledge production by tackling geopolitical and socioeconomic inequalities that are representative of global asymmetric power relations (Demeter, 2020; Mignolo, 2018; Sousa, de, 2018). With the persistence of a Global North-South divide in the form of the above inequalities to knowledge production and exchange in research relevant to biodiversity and climate change, we risk renouncing credible knowledge from the South that may be key to effective policies (Blicharska et al., 2017). Even though the specific challenges to making science more inclusive and diverse may differ across geographies and disciplines (Koch, 2020; Loureiro and Conceição, 2019), there are notable parallels in emerging environmental fields that impact young and early-career researchers (ECR). In this paper, we concur with the prevailing definition of ECRs as elucidated by Filyushkina et al. (2022). When we refer to "ECRs," we are addressing researchers who are degree- and position-contingent, implying that they should either be in the process of obtaining or have already obtained their doctorate (ibid.). In this sense, we as ECRs are in the early stages of our careers and need more guidance and mentorship than other established senior peers to navigate the challenges of our initial career trajectory.

The above concern about challenges we face holds true for the field of Ecosystem Services (ES), which has emerged as one of the many approaches to achieve sustainable transformation. The ES approach has been widely applied as an interdisciplinary lens for assessing nature's values and human-nature links (Haase et al., 2014; Scott et al., 2018). It has expanded tremendously since the early 2000 s (Collins et al., 2011; Dou et al., 2020; Millennium Ecosystem Assessment, 2005; Sagie et al., 2013; TEEB, 2010), globally influencing the sustainability policy agenda (Costanza et al., 2017; Pauna et al., 2018). Institutions at the science-policy interface between conservation, sustainable use of biodiversity and ES have made efforts for being more open to diverse participation and to facilitate the participation of ECRs (Filyushkina et al., 2022). However, the application of top-notch science and ES knowledge production still remains largely limited to institutions from the Global North (Gustafsson and Lidskog, 2018).

The literature indicates that the Global North is the major contributor to knowledge production on ES, while other regions are progressing at a slower pace (Chen et al., 2020). Particularly in Asia, China has been the most prominent contributor to ES publications in recent years (Kubiszewski et al., 2023), while authors from other countries of the region still remain under-represented, as evidenced by a systematic literature review on ES assessment and applications (Wang and Banzhaf, 2018). While Asian geographies are represented as case studies, we call attention to the fact that in many cases, publications in top-tier journals most often have authors from the Global North or are affiliated with universities based in the Global North as the leading authors (Kubiszewski et al., 2023). This practice may carry the risk of diminishing countries like Bangladesh, Indonesia, or Pakistan to mere case studies for researchers from the northern hemisphere, particularly when considering the long-term implications. This inequality in knowledge production and application can be attributed to many reasons, including geographic biases, knowledge transfer gaps, differing research capacities, and the diverse needs among researchers in the Global North and South. However, it is important to note that these factors are not exhaustive and there may be other contributing elements to this inequality (Báldi and Palotás, 2021; Blicharska et al., 2017). Although the ES literature in Asia is expanding in subject matter, methodologies, quality, and quantity (Dang et al., 2021; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2018), many Asian researchers, especially we ECRs, still face problems typical of the Global South while conducting ES research. These include the need for conducting extensive fieldwork to collect basic and primary data on ES-related issues that are not yet available, the availability of secondary data in the absence of primary data, the lack of stable long-term funding, and regional differences in the preferences of policymakers and funding agencies, which can drive or influence the direction of scientific research. We ECRs are also burdened by the pressure of the "publish or perish" model, which has created a ruthless environment in the scientific community (Sengupta et al., 2014; Rawat, Meena, 2014; Amutuhaire, 2022). These challenges are further aggravated by limited infrastructure, lack of mentoring capacity, shortage of standardised methodologies and categorizations in the concept, as well as very limited publication budgets. While employment positions remain limited and stagnant for us, their requirements are turning highly competitive and unrealistic for many ECRs like us to meet (Berenbaum, 2019; Evans and Cvitanovic, 2018; Smoliński et al., 2022).

Based on our experiences from conducting ES-related research in Asian countries this perspective article draws particular attention to four examples of the inherent and implicit inequality-based challenges faced by us ECRs in ES research in Asia, namely: career prospects and capacity-building, data access and knowledge transfer, circulation of findings, and funding. These four issues have been crystallised as central challenges in our ongoing discussions at conferences and in a series of regular meetings. While we are well aware that some similarities in challenges faced by ECRs exist across the globe, the magnitude of inequalities amplifies these concerns for the Global South for which we speak from an Asian perspective. As ECRs working in or focusing on Asia, we draw from our experiences and insights to highlight four specific challenges in the new and dynamic field of ES in Asia. The majority of ES research in the region tends to highlight the global significance of the issues being studied. While this is significant for understanding the issues at hand, it falls short in explaining how to deal with the problems. Recognizing the challenges of inequality, we attempt to propose some potential remedies. We strongly advocate that the interdisciplinary research community work together to make ES research a level playing field for ECRs like ourselves, who are working in Asia and elsewhere. This collaborative effort will contribute to fairer, more collective, and inclusive scientific and ultimately policy responses.

2. Four facets of inequality faced by early career researchers in Asia

2.1. Inequality in career prospects and capacity-building

In most Asian nations, economic disparity is prevalent and which is mirrored in academia (Hannum et al., 2019; Kanbur and Zhuang, 2013). ECRs in scientific research, not surprisingly, face inequity issues on many fronts. As is valid for young professionals in many other areas, the impact caused by disturbances like the Covid-19 pandemic have exacerbated the already vulnerable group of ECRs (Woolston, 2020). For instance, professional networking at the beginning of a career is essential and networking opportunities for ECRs from low and middle-income countries, like ourselves, have been widely obstructed. Despite the potential for virtual interactions to enable at least some scientific exchanges and facilitate communication in certain fields (Marx, 2022), it is significant to acknowledge the inherent limitations of those remote interactions as they are confined to certain digital platforms. Unfortunately, these digital platforms often amplify existing inequities in technology access and may also further contribute to gender disparities (López-Vergès et al., 2021), another significant underlying issue in Asian ES research. It manifests itself, e.g. in gender inequality in career prospects for women in science. The participation of women in science is still very low globally, yet particularly unfavourable for female ECRs in Asia because of traditional social and family structures (Ledin et al., 2007; Penner, 2015).

In a relatively recent field like ES, these factors intensified inequalities in career prospects for ECRs like us as there is limited availability of ES-specific perspectives in the job market, which is reflected in the scarcity of positions or opportunities for capacity-building during

the early stages of our careers. This inequality in capacity building, in turn, contributes significantly to the inequality in career prospects that we as ECRs in Asia face, particularly when competing with counterparts from the Global North. The lack of high-quality vocational training in many parts of Asia, brings down the employability of ECRs to compete for available positions outside of academia. Furthermore, it is worth mentioning that the guidance and support provided by supervisors and institutions have been extensively studied and proven to have a significant impact on the development and success of researchers in the ES field (Filyushkina et al., 2022). We have observed that ECRs working on ES in Asia often face significant challenges in keeping pace with the dynamic nature of the ES field and overcoming research barriers (e.g. impacting and disseminating the benefits of research and knowledge to wider community and society), and transitioning from education to employment (e.g. applying and translating knowledge and skills to practical contexts and challenges within and beyond ES studies). In most cases, ECRs are often forced to pursue other pathways that are only minimally similar (often even very distinct) in the fields of ecology, geography, or administration, to continue working on ES on the margins. This may not only affect the resilience of scientists in the field but also significantly influence the development of ES research in Asia and potentially slow down the pace of incorporating ES into policy and decision-making for sustainable development.

2.2. Inequality and challenges in data access and knowledge transfer

In the era of the increasing role of information and communications technology, data access and knowledge sharing play a key role in making available pertinent information based on which decisions are taken that target inequality and equity of resource access, while addressing the sustainable development goals of reduced inequalities in societies, building partnerships to reach these goals, and promoting just, peaceful and strong institutions. For ES research, a wide range of data is often employed and integrated to address social-environmental issues due to the field's interdisciplinary nature. Among them, crowd-sourced data (e.g., geolocated social media), and other secondary data sources (e.g., soil maps, hydrological maps, evapotranspiration data, temperature records) have become vital components (Dang et al., 2021; Havinga et al., 2020; Palomo et al., 2018).

As our experience in India has shown, secondary data on ecosystem services used as a proxy are more often obtained after going through numerous futile, strenuous, and door-to-door attempts by researchers with good networks and the necessary resources (e.g. time and budgets) for data collection. Existing datasets are commonly scattered across the region throughout individual institutions, written in various formats and languages, and are often even restricted internally. In most cases, access is mired by bureaucratic procedures and red-tapism, scale issues, and funds for procurement. This leads to unequal access to data, thereby creating artificial and real digital divides between those who can have digital access and those who cannot - despite theoretically being public or "open-access".

Among many existing platforms containing social, economic, and environmental datasets, we found that Open Development Mekong (https://opendevelopmentmekong.net/) is one of the most comprehensive portals facilitating updated data for Cambodia, Laos, Myanmar, Thailand, and Vietnam. On a larger scale, the Humanitarian Data Exchange (https://data.humdata.org) and the World Bank's Open Data portal (https://data.worldbank.org) play an important role in unifying and categorising secondary data from national to intergovernmental organisations and agencies for the Asia region and beyond. However, notwithstanding the diverse information hosted on these platforms, they are not specified to facilitate data for ES assessment.

In contrast to centralised database systems of Global North countries, such as EU Science Hub, European Environment Agency or the United States Environmental Protection Agency, secondary data of countries in Asia are rarely hosted under the same regional and institutional roof. Previous work by Lourdes et al. (2021) has shown that Asia's publicly accessible environmental, social, and ecological databases are marginal and still in their infancy. To date, there are only a few complete central data hubs facilitating ecological and environmental data for the Asia region. In most cases data is rather scattered in national and global database systems without adequate monitoring or updating protocols. We acknowledge that several Asian countries are trying to make their government data easier to access, through initiatives such as the Open Government Data Platform in India, Vietnam's National Data portal, the Biodiversity Center of Japan, or the International Ecological Information Bank from Korea. However, many are still in the beginning stages, written in local languages with limited information and outdated datasets for some themes, and lack data at finer scales. This is mainly rooted in the lack of precise transition mechanisms, human resources, and institutional capabilities to catch up with the open data movement (Thejesh, 2020; Yang et al., 2015) and open data maturity.

Working in India, Taiwan and Vietnam, we observe that without data repository systems or central online databases to facilitate ES research, we and our fellow ECRs are required to either a) spend a considerable amount of extra resources to acquire regional data or b) employ global datasets at much lower resolutions to overcome time and resource constraints, thus negatively affecting precision and research outcomes. Such data inaccessibility hinders not only studies within national borders but also cross-country comparisons and knowledge transfers. Efforts of public and private institutions that act as data storage repositories are needed towards decreasing restrictions on data, finding adequate solutions to privacy concerns, and improving data access would facilitate ES research for many ECRs with otherwise limited resources, and thereby promote diversity and inclusivity in scientific research (Nagaraj et al., 2020).

2.3. Circulation of research findings in global scientific publishing

As ECRs, we face many limitations in publishing our findings in international peer-reviewed journals. This is due to high publication costs, language barriers, and lengthy review processes. In our experience, researchers from Asian countries often opt for publishing in local journals, which limits the reach of their research to global audiences. In recent years, the popularity of open-access journals has increased the accessibility of research findings with broader public engagement and enabled multi-disciplinary and interdisciplinary collaboration with greater visibility and higher accessibility. However, the publishing charges for open access are usually very high. This adds substantial obstacles to publishing the results of our ES studies. Publishers like Elsevier provide specific support programs (e.g., Research4Life) for open-access publishing, covering most African countries but, to the best of our knowledge, very few Asian countries are part of these, despite facing similar challenges. We noticed that ECRs based at institutions in emerging Asian regions, unfortunately, suffer in between. Therefore, this limitation in scientific circulation and publishing, especially for ECRs who are building a scientific audience, should receive special attention.

2.4. Challenges in funding

Countries in Asia, as is the case for many other Global South countries, do not yet invest as much in ES, green infrastructure, or Nature-based Solutions (NbS), which might reflect their concern about major policies for sustainability transitions (Loc et al., 2018; Pham and Lin, 2023). In many Asian countries, insufficient funding for ES conservation and NbS impedes progress and the quality of research findings. Wealthier countries in the region, such as Japan, South Korea, China, and Singapore, are in the process of developing more research investments targeted at these topics, but even so, these budgets are small when compared to European ones. As a result, most ECRs from the Asian countries we represent here and who are willing to pursue research in the ES field do not receive the necessary monetary support. For this

reason, following available funds in the area of ES in Europe and North America, ECRs from newly emerging economies like India or China are contributing to patterns of brain drain in these areas, thereby further contributing to knowledge inequalities (Mouton et al., 2007).

Concerns about funding run through a wide range of issues, such as access to journals, publishing findings in reputable journals (where high article processing fees make this possible only for "rich" universities), doing expensive experiments with multiple tests and trials, collecting data through extensive primary surveys with a wide range of sample sizes, getting (easier) access to secondary data, etc. Furthermore, the impacts of being based at an institution with less available funds for an "innovative" research area like ES have on fundamental aspects like fieldwork, the ease of access to relevant conferences, engaging in career-enhancing training opportunities, and the choices of methods more often dependent on expensive infrastructure that is unavailable or limited to very specific cohorts of ECRs in Asia.

Taking the Young Ecosystem Services Specialists (YESS) network as an example, we have observed that among its Asian members, who form the second largest regional group (n=154, out of 948 members in total), there is a lower percentage of Master's and PhD students, but a higher number of practitioners and researchers. This can be mostly attributed to the challenges associated with funding postgraduate studies. Furthermore, a survey conducted among YESS members during the Stakeholder Day for Asia at the eighth plenary of the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (IPBES Secretariat, 2021; Pisa et al., 2021) showed that this group of ECRs perceived obtaining funding as their biggest challenge. Securing funding in densely populated Asian countries where the young population is the majority, also increases tensions in both ongoing ES research and in future job perspectives. Failure to obtain funding for many of the aforementioned aspects is frequently a serious issue influencing Asian ECRs' career development. In addition to the above, ECRs in Asia often have to compete for the already limited funding with more established senior researchers, not only from the ES field but from other related environmental fields because no specific ECR funding is available.

2.5. Synthesis

Social inequality and the all-encompassing effects of the North-South divide are regularly experienced first-hand by researchers from the Global South, especially at early career stages. While there are economic inequalities at the macro level in the region and even within individual countries, the wider influence of inequalities manifest themselves in a wide range of unfavourable conditions for young researchers that make the participation in international discussions like those related to the climate crisis an often insurmountable challenge.

The social and financial inequalities along with the challenges mentioned above are responsible for the research-related brain drain of ECRs to Western nations (Mouton et al., 2007), particularly from Asia. Although ECRs are compelled by restricted financing (Confraria et al., 2017) and associated top-down cumulative cascades of challenges to move out of their country of origin, an equitable and just environment of work along with lucrative pay offered by the Global North attracts the most competitive ECRs from Asia. Due to current inequalities, Asian countries need to stay at the forefront of social-environmental research (Wang et al., 2023; Yang et al., 2020) and must be acknowledged for their valuable contributions to the field of ES research.

Synthesising our argument, the existence of these multidimensional inequalities faced by ECRs in Asia needs to be more openly acknowledged before we can address and better understand them. By highlighting and elaborating on these issues, we want to ignite a conversation amongst the ES community at large and urge them not to overlook the challenges faced by ECRs but rather to put them up for discussions in global platforms including IPBES, the Ecosystem Services Partnership (ESP) conferences and among the scientific community at large.

We acknowledge that these inequalities are not exclusive to Asia, as other regions in the Global South share similar issues. However, historical, cultural, political, and social differences across the Global South lead to diverse impacts of these inequalities. Recognizing Asia's vast diversity is crucial for coordinated efforts to prevent disrupted and unequal knowledge production and uptake at the regional level.

Hence, we present some ideas that can be pondered upon and that can foster debate amongst the ES community for identifying potential solutions to tackle the major inequalities discussed above. Through the development of unified public databases on ecosystem services data in Asia, we can address some of the knowledge gaps as well as streamline many new scientific research questions. Data sharing can be fostered with bottom-up approaches through academic credit and incentives to contribute to the open-data movement. We advocate for promoting long-term, multilateral cooperation and collaboration on social-ecological data-sharing networks horizontally (across universities, research institutions, private sector) and vertically (local to national) across the global ES community. Journals can promote representation in the editorial board, waiving publication fees and creating more special schemes targeted at Asian ECRs, especially from low-income countries. This will allow for open-access publishing and increase our visibility. Oftentimes during the desk review process, as Asian ECRs, we are unfairly questioned about the relevance or internationality of our research and our work gets rejected, which often creates self-doubt and even impacts our mental well-being along with our research careers. Hence, we seek consideration to promote visibility of our local and regional Asian-based research in the global scientific community.

The perspectives presented in our commentary might lead to an opportune moment to work on creating an Asian vehicle for publishing ES research that gives value to the pioneerism of the local and regional studies that our Asian peers are conducting. We hope and urge for the establishment of a more unbiased foundation for the construction of bridges between ES researchers across the globe. If given the right chances, platforms, representation and resources, ECRs from Asia are able to bring novel research to the ES research community. Many already existing networks like YESS, the ESP (especially ESP-Asia), and boundary organisations like the Open-Ended Network of IPBES Stakeholders (Onet) can be utilised and upscaled for enabling transnational knowledge transfer and data sharing in transparency. Lastly, we advocate the need and importance of promoting diversity and inclusion among ECRs. It is crucial to foster a culture that values diversity, equality and inclusion in all its forms. This includes, but is not limited to, ensuring equal opportunities and representation for individuals from marginalized groups. By prioritizing diversity and inclusion at all levels, we can work towards transforming the landscape of ES research from one of inequality to one of inclusivity.

CRediT authorship contribution statement

Shivani Rai: Conceptualization, Formal analysis, Investigation, Project administration, Writing – original draft, Writing – review & editing. **Suvendu Das:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Jingxia Wang:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Yuehan Dou:** Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing. **Niklas Weins:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing. **Tanvi Gaur:** Funding acquisition, Investigation, Writing – original draft, Writing – review & editing. **Sakshi Rana:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Kien Pham:** Conceptualization, Formal

analysis, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Nita Shashidharan:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

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Data Availability

No data was used for the research described in the article.

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PROJECT REPORT

Enhancing early career professionals' representation and engagement at international conferences: WONCA "Rural Early Career Ambassador Integration" project

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ABSTRACT:

Introduction: International conferences offer an excellent opportunity for career development and are global academic opportunities with the potential to foster educational and professional growth. However, equitable access to participation and meaningful involvement in such events remains an issue. In this article we describe the novel Rural Early Career Ambassador Integration project and its implications for the 2022 World Rural Health Conference, held at the University of Limerick, Ireland.

Methods: The project offered vertical and cross-country collaborative opportunities to early career professionals with a passion for rural medicine. Three ambassadors of diverse nationalities, ethnicities and professional backgrounds were selected. They bore no personal cost for travel, transport or accommodation relating to the conference. Each ambassador was matched to and clinically shadowed an expert rural GP for a week preceding the conference, who provided mentorship. Mentors and ambassadors collaborated on goal-setting and work-planning throughout the conference, and were offered one-on-one career and networking support. The ambassadors were welcomed and integrated within a larger working party, the WONCA Working Party for Rural Health.

Results: The project was well received by conference delegates and organisers, and achieved its stated goal of enhancing conference equity through the representation and meaningful involvement of diverse early career professionals. Vertical and cross-country collaboration generated actionable policy implications as is evidenced by the ambassadors' co-authorship on the Limerick Declaration on Rural Healthcare.

Conclusion: Although sponsorship for these initiatives remains a challenge, this project highlights the importance of actively including early career professionals at international conferences.

Keywords:

conference equity, conference representation, early career professionals, health profession conference, medical conference, student ambassador, vertical integration.

FULL ARTICLE:

Introduction

International conferences offer an excellent opportunity for career development and have been conceptualized as globalized academic venues for educational and professional growth[1]. Emerging literature now recognizes that participation in such conferences results in social, emotional and intellectual expansion among attendees and argues for representation and inclusivity, especially that of early career professionals (ECPs), who have historically been underrepresented[1-3]. Given the pedagogical nature, potential for cultivating research interest, and opportunities for long-term mentorship, ECP engagement requires focused attention at such events. Limited accessibility to such opportunities has been identified as a key barrier to ECP participation. In particular, under-representation of delegates from low- and middle-income countries (LMICs) and other underserved regions has been critiqued as ongoing neocolonialism in our scientific community[4]. While online conference models have been proposed as a solution to financial and geographical constraints faced by ECPs, they remain limited in their ability to curate the human experience of networking and collaborating in person[5]. It is thus crucial for conference organizers to ask pertinent questions regarding equity and actively address them by creating avenues for finance, travel and global representation.

These efforts, however, must be informed by the nuances of the barriers to conference participation for historically underrepresented groups, of which ECPs are only one. Practical issues such as cost, visa restrictions, travel time and safety, along with overarching systemic issues such as political unrest, language barriers and discrimination in all its forms, have been identified as key barriers to conference participation for ECPs. This is especially true for those from LMICs and other underserved regions, and those who are racialized and/or female or gender diverse[4,6]. While many conference organisers have made efforts to allow ECPs to register at reduced rates, these rates are often far too high, and such efforts can at times be described as tokenistic, failing to demonstrate to ECPs that their participation is truly valued[4]. Hence, a lower fee for attendance does not suffice in mitigating the complexities of accessibility. Further, while scholarships and financial bursaries do facilitate attendance, they do not ensure effective integration of ECPs in the conference structure[7,8].

Proposed solutions must be examined for their inclusivity and should not halt at the arrival of delegates. Engagement projects that align with the interests and ambitions of ECPs and provide unique learning opportunities must be crafted into the conference design by organisers. Conference location has been identified as a key 'pull factor' owing to conference tourism, but inevitably acts as a barrier to ECP conference participation in many cases[4,6,9]. Thus, purposeful efforts to ensure ample time and support in planning

travel and accommodation, in addition to sufficient funding, are necessary to ensure access. Taken together, these actions have the potential to increase social accountability at international conferences.

It is important to note that aligning with the principles of equity adds diversity and richness to the academic exchange while encouraging social accountability within our profession. By providing a platform for the representation of diverse ECPs, including those from LMICs and other underserved regions, we encourage a true reciprocity whereby senior physicians learn from young leadership, gain innovative perspectives and ensure representatives of the future of the profession feel appropriately valued and included[4]. WONCA has developed one such initiative for conference equity through vertical and cross-country collaboration at the annual World Rural Health Conference. In this article we describe the novel Rural Early Career Ambassador Integration project and its implications for the 2022 World Rural Health Conference, held at the University of Limerick, Ireland.

Methods

The Rural Early Career Ambassador Integration project followed the vision to offer vertical and cross-country collaborative opportunities to ECPs with a shared passion for rural medicine and care of underserved populations through deliberate recruitment, integration and involvement. Rural health care continues to face a global workforce crisis[10-12], and the organisers wanted to ensure that a key outcome for this conference was credible and meaningful engagement with, and inclusion of, future rural healthcare practitioners and leaders in all conference activities. The call for global applications was opened in February 2022. Participants were required to submit a one-page curriculum vitae and a 3-minute video explaining the reason for their interest, their relevant experience and their motivation. Students enrolled in medicine, nursing or allied health professional degree programs and who were within 5 years of graduation were eligible to apply. Fourteen applications were received. Two independent judges scored the applications against a pre-established marking rubric (Table 1). The three most highly ranked applicants were offered the ambassadorship 2 months in advance of their expected arrival, with the option to defer or decline. Global scope and unconscious bias regarding gender, ethnicity and LMIC status were taken into consideration during the selection process to ensure equity.

The ambassadors represented diverse nationalities, ethnicities, educational and work backgrounds and possessed unique perspectives on and visions for rural medicine. All three ambassadors were female-identifying, first-generation physicians, who had recently graduated from medical schools in Brazil, Canada and India and were working and/or living in rural/remote areas. The ambassadors were at different career stages. At the time of the conference, one of the ambassadors was a final-year family medicine resident physician in Nunavut, Canada. The other ambassadors had not yet entered formal postgraduate training. One ambassador had completed medical school in India and was pursuing a graduate degree in Butaro, Rwanda. This ambassador required prompt visa support, which was provided by the conference organisers. The other ambassador had completed medical school in Brazil and had been working on rural health projects with an international rural health organisation, Rural Seeds, representing Ibero-America. The ambassadors bore no personal cost for travel, transport or accommodation for the conference. Medisec, a medical indemnity company and sponsor of the 2022 World Rural Health Conference, provided the majority of sponsorship funds.

In the weeks preceding the conference, the ambassadors, together with a representative of the conference student subcommittee, met weekly on Zoom to share their perspectives, and to develop their ideas and goals for their time in Ireland, the conference host country. Upon arrival, each ambassador was matched to and clinically shadowed an expert rural GP, who provided mentorship to the ambassadors for the duration of the conference and beyond. Mentors and ambassadors collaborated on goal-setting and work-planning throughout the conference, and mentors provided one-on-one career, research and networking advice to the ambassadors. The ambassadors were welcomed and integrated within a larger working party, the WONCA Working Party for Rural Health, through council meetings, and were encouraged to collaborate on The Limerick Declaration on Rural Healthcare, a significant policy article outlining the future of Irish rural health care[13]. The ambassadors engaged in conference promotion via social media in the lead-up to the conference, and this was continued throughout the conference. The ambassadors were also connected to peer mentors at the University of Limerick in advance of the conference, who provided additional networking and logistical support to the ambassadors during their stay. A formal introduction of the ambassadors was made during the opening session of the conference to facilitate networking. An invited plenary with no competing events was held at the end of the conference, which provided the ambassadors with a platform to share their education, work and conference experiences, in addition to a united vision for the future of rural medicine. The ambassadors actively participated and showcased their original research projects through oral and poster presentations while attending oral and poster presentations, keynote speeches and social events. Consistent feedback from the ambassadors was sought by conference organisers to enable a tailored and rich learning experience that catered to the unique interests and ambitions of the ambassadors.

Table 1: Application criteria, requirements and selection rubric for early career applicants to the 2022 World Rural Health Conference

Application criteria	Application requirements	Selection rubric
• Be a student of a healthcare profession (medicine, dentistry, nursing, physiotherapy, occupational therapy, social work) • Be less than 5 years postgraduation from degree • Be passionate about rural medicine	A one-page curriculum vitae and 3-minute video explaining: • who applicant was and where they come from • why applicant is passionate about rural medicine • why applicant should be considered to be a WONCA World Rural Health Conference 2022 student ambassador • what applicant hoped to gain from attending the conference.	Presentation (/10) Ideas proposed (/10) Overall enthusiasm (/10) Total (/30)

Results

The Rural Early Career Ambassador Integration project was well received by both the conference delegates and organisers, and was successful in introducing the global nuances of rural medicine to local experts. Most significantly, this cross-collaboration generated actionable policy implications as is evidenced by the co-authorship of the ambassadors in the Limerick Declaration on Rural Healthcare[13]. While this initiative is only a first step toward the equitable representation and meaningful involvement of ECPs at major international conferences, it also highlights the reciprocity of gain that results when obstacles to ECP participation are removed wherever possible. Further, the combination of formal interaction and unstructured personal relations with exemplary physician leaders encouraged learning in an effective way.

Although this initial cohort of ambassadors was small, a unique feature of this project was its encouragement of global representation and equity by design, including its reinforcement of the much-needed efforts required to reach gender parity in global delegations[14]. Prioritizing intersectionality in conference delegations is necessary to ensure transformative collaborations on policy, decision-making and system-strengthening outcomes[15,16]. It is important that these efforts be consolidated in the structure of conferences to ensure rather than hope for equity as a favourable outcome. The diversity in lived experiences of communities needs to be reflected at global academic congregations to truly enhance social accountability in research and its intended clinical impact. This process must hence be intentional and consistent.

Despite its week-long duration, the initiative fostered the creation of several mentorship loops that transcended well beyond the conference. The ambassadors have continued to maintain contact and mentorship relationships with the physicians with whom they were paired. Mentorship in rural health provides ECPs with powerful role models and has been associated with successful career outcomes[17]. The creation of mentorship opportunities is especially important to ECPs from countries where structured rural health training is not available. Our project is a testament to this, and highlights the importance of continuing medical education and mentorship in rural health in the development and promotion of a rural career pathway.

A deliberate effort to account for and support the unique interests and ambitions of the ECPs was also central to the success of this project. The elective week allowed for familiarity with the foreign context of general practice in rural Ireland and was encouraging for the ambassadors and mentors themselves. As a result of this effort, one ambassador was encouraged and supported to apply for a competitive research fellowship in rural health, which she is now undertaking. With the assistance and encouragement of her mentor, another ambassador has taken the initial steps toward establishing a locum practice in the region in which she was placed for the elective week. This example highlights the mutual benefit that can arise from meaningfully including ECPs in conference proceedings.

Conclusion

While the project had many positive outcomes, feasibility and sustainability of such initiatives in the context of limited funding will continue to remain a challenge. However, we believe that sponsorship for such opportunities should take precedence over other expenditures. The advantages of such a project lie in the vertical and horizontal concertation of ECPs, conference organisers, mentors and the expert delegation. Purposeful introduction of such opportunities as core components of international conferences has the potential to result in positive outcomes, including enhancing recruitment of ECPs in the context of rural healthcare workforce shortages. A lack of quantitative or qualitative project evaluation data is a limitation of this project, and is recommended for future projects. Going forward, formal data collection and analysis should be incorporated into such initiatives, in order to gauge the magnitude of impact and points of improvement. Given the experience of this initiative for the ambassadors, delegates and conference organisers, we recommend that all future international conferences ensure protected funding for the recruitment and meaningful involvement of a diverse group of ECPs by removing obstacles for a minimum of three ECPs who might otherwise not afford such opportunities. Moreover, conference organisers should ensure that students and ECPs are included in formal and informal ways, with clear intended outcomes, and the support requisite to achieve them. We therefore call upon WONCA and other representative member organisations to prioritize diversity, equity and reciprocal collaboration through ECP engagement as a policy and prerequisite for successful bids to hold international conferences in the future.

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Advancing sustainable development through planetary health – A holistic approach to global health: A systematic review

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ABSTRACT

In global health, three holistic and multidisciplinary approaches are typically mentioned: One Health, Ecohealth, and Planetary Health. The most recent concept, Planetary Health, has been spontaneously developed and promoted as a new science since 2015, with the establishment of the Sustainable Development Goals (SDGs). This coincidence marks a new era of interconnection between Global Health and Sustainable Development. However, this connection has rarely been examined, and a full-scale study covering the essential elements of Planetary Health is lacking. In this study, we aim to (a) provide an insightful understanding of the current research on Planetary Health, (b) address the interconnectedness between Planetary Health and SDGs and sustainability,s and (c) explore the determinants of Planetary Health in Sustainable Development context. The findings from diverse articles have revealed an increase in research interest among scholars in Planetary Health and Sustainable Development. However, regarding new contributions, most research deals with the topic in general terms rather than developing an analytical framework of concepts. Among the three pillars of sustainability, linkages have been strongly established between the economic and social impacts on Planetary Health while the environmental dimension has been slightly neglected. In terms of detailed SDG linkage, connections with SDG3 and SDG9 were found in all articles, whereas the linkages with SDG7 and SDG14 were absent. The determinants of Planetary Health in the context of sustainable development have also been explored in which climate change and the Sustainable Development Goals (SDGs) are the biggest contributors to the promotion of planetary health.

1. Introduction

The Anthropocene has significantly impacted natural systems that nurture human health and well-being. Simultaneously, the Industrial Revolution placed a premium on economic development as a measure of total prosperity, and the uncontrolled exploitation of natural resources became normal practice. The results of this approach are evident, as reflected by population growth, higher life expectancy, decreased infant mortality, and decreased ity ofsevere poverty (Whitmee et al., 2015). However, this growth pattern neglects the surrounding natural environment, and hence ignored major changes including pollution, loss of biodiversity, and climate change, with increased risks of extreme weather conditions (Pauly, 2009; Sánchez-Bayo and Wyckhuys, 2019; United Nation, 2020; Whitmee et al., 2015). These multilevel human consequences are now a part of our daily lives, with far-reaching effects on our economy and, more crucially, our capacity to maintain human well-being.

The Millennium Development Goals (MDGs) have been successful and have encouraged the United Nations and its member states to continue their causes. Global goals serve as potent policy tools within the realm of global governance because of their ability to establish uniform standards across nations, disregarding the intricacies of local settings. (Fukuda-Parr, 2014). Global goals also foster international agreements on shared objectives within the context of global diversity

Abbreviations: SDG, Sustainable Development Goals.

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and communicate complex challenges such as poverty eradication and educational equality (Hickmann et al., 2023). In addition to the success of the MDGs, multiple global challenges still exist throughout the year, such as worsening environmental catastrophes and increasing pressure from civil society, especially in the least developed countries (Cuenca-García et al., 2019). To address these obstacles, a multidimensional approach to sustainability that prioritizes cultural variety, solidarity with the earth, ethical principles, equality, rights, justice, and autonomy (Ventura et al., 2020) is needed. It comprises Agenda 2030, reinforced by 30-year efforts of the United Nations (UN) summits focusing on development elements to "prepare the world for the 21st century." Thus, the innovative prevalence of the "Sustainable Development" approach with new and more ambitious targets to be implemented by 2030 under the new Sustainable Development Goals (SDGs) has been established.

In 2016, the conference "Promoting Health in the SDGs" was held by the World Health Organization in Shanghai and set the foundation for health promotion on the SDGs agenda and embedded health promotion as a central framework of the 17 SDGs. In the conference, the concept of health, which arises from systems thinking and socio-ecological perspectives, extends beyond human well-being to include the well-being of natural ecosystems, healthy resource exchanges between people and nature, and resource flows that avoid vulnerabilities and inequities for people and other socio-ecological systems. Here, the term "Planetary Health" was coined and has recently been employed by scholars to indicate the dynamic and systemic relationships among global environmental changes, their effects on natural systems, and ultimately the changes in human health and well-being at multiple scales (Pongsiri et al., 2019).

Several holistic and interdisciplinary techniques have been proposed to protect human health. One Health, EcoHealth, and Planetary Health are the three most prevalent concepts (Lerner and Berg, 2017). One Health is a healthcare philosophy acknowledging the interdependence of human, animal, and environmental health. It encourages cooperation across different disciplines, including medicine, veterinary medicine, and environmental research, to solve health challenges that affect all three fields. On the other hand, EcoHealth similarly focuses on the connection between human health and the environment. This highlights the need to address the social, economic, and political issues that lead to health inequities and environmental degradation.

Although all strategies may seem interchangeable since they support the underlying premise that humans and other animals share the same planet and confront the same environmental concerns, the newly formed phrase "Planetary Health" has revolutionized the subject emphasis. This term approaches health subjects by emphasizing that human and planet health are closely intertwined. It considers the effects of human activities on natural systems that sustain life, as well as the effects of environmental change on human health (Prescott and Logan, 2019). Planetary Health is defined by the Planetary Health Alliance as "the health of human civilization and the condition of the natural systems upon which it relies.".

All three methods aim to improve the health and well-being of people and the earth by addressing interconnected variables that contribute to health and environmental concerns. Fig. 1 illustrates the development of the most widely accepted holistic concepts over the past two decades.

In 2015, a series of publications were released by the Rockefeller Foundation-Lancet Commission on Planetary Health, the most notable work being "Safeguarding human health in the Anthropocene period" (Whitmee et al., 2015). One widely accepted definition of Planetary Health is the attainability of the highest standards of global health, well-being, and equity thanks to human systems, including political, economic, and societal development, and the global sustainability of natural systems that nurture human development. Planetary health is a measure of human health and the natural systems on which it depends.

Although the term was dominant across the retrieved research articles, it has been argued that the definition of Planetary Health should also change in the context of a rapidly changing global health situation (Amuasi and Winkler, 2020; Ryan et al., 2019). For instance, there are human factors that should be considered such as consumption, population growth, technology and urbanisation that affect the development of Planetary Health (Hill-Cawthorne, 2019). The Lancet Global Health has already established a specialized journal, "The Lancet Planetary Health," since 2017 to promote Planetary Health through academic studies, capturing the attention of scholars towards the new concept. However, research that follows the movement of Planetary Health beyond concepts are urgently needed (Pham et al., n.d; The Royal Netherlands Academy of Arts and Sciences KNAW, 2023). A thorough knowledge on how human psychology perceives the natural environment and transitions to Planetary Health with more prosocial and pro-environmental behaviors is crucial for the realization of Planetary Health. Several scholars explored this concept: Anderson and Gough (2021) developed a framework that connects Planetary Health and Climate Change; Pérez-Escamilla (2017) found a relationship between humans and Planetary Health, focusing on food security issues; and Niankara et al., (2020) explored the role of digital media in educating

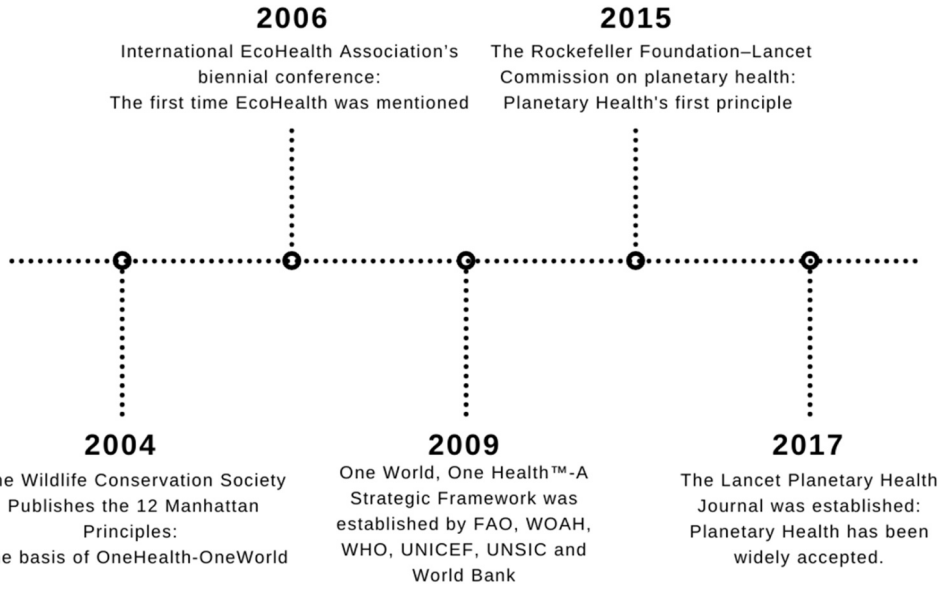

Fig. 1. The evolution of holistic concepts considered Global Health. Source: Author's elaboration.

and promoting Planetary Health interests. Although many aspects of this holistic approach have been discussed, a full-scale study that covers all the essential elements of Planetary Health has not been conducted because it is considered a novel holistic approach to global health (Rabinowitz, 2017). Hill-Cawthorne (2019) called these the "new kids on the block." Although several scholars mentioned that Planetary Health is only "a part of the One Health" approach, there are multiple overlapping principles and ideas with One Health and Ecohealth (Amuasi and Winkler, 2020; P. M. Rabinowitz et al., 2018). However, the majority of researchers who support Planetary Health have argued that it is a new, unique approach to achieving global health (McCarthy, 2022; Parsons, 2018; Rodin, 2015). Hence, it is important to reevaluate Planetary Health, which presents it as a separate entity and which researchers and policymakers can refer to.

Moreover, similar to Planetary Health, the SDGs call for global leadership, cross-sectoral collaboration, and explicit evaluation of numerous benefits and trade-offs for goals related to health, the environment, and sustainable development. All significant parties must immediately acknowledge and support Planetary Health (Gonzalez-Holguera et al., 2022). Planetary Health serves as a unifying theme to encourage states, the UN system, and other stakeholders to pursue integrated SDG actions, including a commitment to leave no one behind. The concept of Planetary health can be effectively implemented through the explicit recognition and analysis of the advantages and disadvantages associated with actions that impact environmental change, with a specific focus on their implications for both human health and natural systems (Pongsiri et al., 2019), which is necessary to achieve SDGs.

Acknowledging the importance of Planetary Health and the lack of comprehensive studies, this study attempts to fill the research gaps with a systematic review of scientific studies on Planetary Health and its connection to Sustainable Development. The purpose of this systematic review is to (a) delineate the evolution of the concept of Planetary Health among contemporary scientific disclosures, (b) highlight the interconnectedness between Planetary Health and SDGs or Sustainability, and (c) explore the determinants of Planetary Health in Sustainable Development context and examine and reevaluate the holistic nature of the current definition of Planetary Health.

The remainder of this paper is organized as follows. First, the methodology explains the process of retrieving and analyzing literature databases. This is followed by detailing the key findings in terms of the temporal distribution of the analyzed studies, the current research interest topics regarding Planetary Health, the target journals, and different approaches to understanding this term. Second, it describes a content analysis to reevaluate of Planetary Health in Sustainable Development context, considering its holistic concept. Third, a thematic analysis of the retrieved database was employed to determine the interchangeable linkage between Planetary Health and SDGs. Finally, it discusses the determinants of Planetary Health based on a full-paper review analysis to understand the current state of Planetary Health research and explore research gaps for future research contributions.

2. Approach and methodology

2.1. Systematic review process

This study produced a systematic literature review based on the Scopus database accessed on April 20, 2022, to collect existing research on Planetary Health and its relationship with Sustainable Development. In other words, we discuss references written before April 20, 2022. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed. The steps of the literature review are as follows:

In terms of search queries, the following Boolean strings were used: (TITLE (planetary AND health) AND TITLE-ABS-KEY (sustainable AND development)). There were no language limitations on the search query. However, non-English studies were excluded at the screening stage. Because Planetary Health is still considered a new holistic approach to global health, data were collected from 69 studies. During the screening process, 27 records were omitted at various steps: duplicate records (research notes that were published under one research series) (n=13), language selection (only articles written in English qualified) (n=2), inaccessibility (n=2), keyword screening (both the author's keywords and the indexing keywords were considered) (n=8), and abstract screening to filter papers that did not deal with Sustainable Development (n=2). Finally, 42 research articles were included in this systematic review.

2.2. Spider

"SPIDER" is a useful tool for analyzing qualitative articles in the context of systematic narrative reviews (Cooke et al.(2012); Methley et al., (2014). "SPIDER" representative important dimensions of research including S: Sample; PI: Phenomenon of Interest; D: Design; E: Evaluation, and R: Research Type. In this study, the retrieved articles were carefully categorized according to these five mentioned above aspects.

2.3. Content analysis

Content analysis is a widely used qualitative research technique. Scholars regard content analysis as a versatile tool for analyzing and assessing text data (Cavanagh, 1997). Content analysis is typically categorized as a qualitative or quantitative research approach. However, the careful application of a qualitative content analysis may shed light on important factors that researchers should consider when planning studies and their analytical techniques, to prevent a jumble in methodologies (Hsieh and Shannon, 2005).

The process underlying the content analysis provides text as the input and a theme as the output. In this process, the inputs were divided into basic units (units of analysis), which were then classified into categorical variables (categories of analysis). The enumeration method may be as straightforward as binary coding, which determines whether a category occurs in documents, or it may be as sophisticated as calculating how frequently the category appears in texts (frequency counts on specific keywords).

In this study, a content analysis was conducted to reveal the connection between Planetary Health and Sustainable Development. To illustrate this, two frameworks were established as proxies for Sustainable Development.

- The University of Auckland SDG Keywords Mapping Framework: All UN members reached a consensus on the 2030 Agenda for Sustainable Development, which sets the foundation for a sustainable world. SDGs are a call for action to protect the planet while not undermining social and economic prosperity. The University of Auckland SDG Keywords Dictionary Project aspires to build on the procedures provided by the United Nations and Times Higher Education to generate an enlarged list of keywords that may be utilized to identify SDG-relevant research to better understand scholars' contributions to SDGs (The University of Auckland, 2021). SDG Keywords Mapping provides a connection to separate SDGs solely by using a data mining technique to investigate research articles related to SDGs from Elsevier's Scopus database and returns a list of keywords that could represent a linkage between the research contents and an SDG. For example, the keyword "Poverty Alleviation" represents SDG1: No poverty. The purpose of this step is to ensure that the research content is connected to the relative SDGs if it contains a keyword on the list.
- Three pillars of sustainability: Although the term "sustainable development" is used frequently, there are many diverse interpretations of it, which leads to a wide range of reactions. Sustainable development may cover a range of environmental and

socioeconomic concerns. There are 17 goals and 169 targets set by the UN to identify global development priorities, effectively sketching sustainable development with three pillars (Stevens and Kanie, 2016). This paradigm suggests that achieving environmental, economic, and social objectives simultaneously is central to sustainable development (Wichaisri and Sopadang, 2017). Few studies have examined the connection between SDGs and the three pillars of sustainability. Kostoska and Kocarev (2019) clustered the SDGs into three pillars within an Information Communication Technology framework. To assess the regional performance of the SDGs in Italy, D'Adamo et al. (2022) categorized them into a subdivision of indicators. This study uses the categorization of the SDGs into three pillars of sustainability introduced by (Vinuesa et al., 2020) to address the connection between Planetary Health and Sustainable Development, as illustrated in Fig. 3.

.

SDGs are clustered into different dimensions, called "pillars": Environmental, Social, and Economic. SDG 17 is considered a combination of all SDGs and the collaboration and partnership to promote and fulfil the designated goals and targets; hence, it is not accounted for in the analysis.

2.4. Thematic analysis

Thematic analysis is often used in various academic subjects and disciplines to analyze qualitative data. This approach has been widely employed in social, behavioral, and other applied sciences (clinical, health, education, etc.).

"Thematic analysis" does not refer to a specific method, but rather encompasses a range of methodologies used to analyze qualitative data. These approaches share a common emphasis on identifying and developing themes—patterns of meaning derived from qualitative data. The goal of thematic analysis is to create conceptual patterns (or "themes") that respond to a research topic throughout a dataset. The researcher generates patterns through a meticulous process of data familiarization, coding, topic formulation, and theme revision. Numerous datasets, research concerns, and theoretical frameworks can all be addressed using this approach, which can also be utilized in a variety of other ways. Its advantages are its adaptability and simplicity.

We used thematic analysis in the full-text review process to scrutinize the retrieved articles and identify the themes behind these studies, aiming to elucidate the determinants of Planetary Health. Scriverner is utilized as the main tool to organize notes and concepts for easy access and reference.

2.5. NVivo

In systematic review research, the application of computer software is essential because a large amount of textual data must be dealt with by researchers. In this study, we applied NVivo to investigate word frequency to identify important keywords from the retrieved articles with

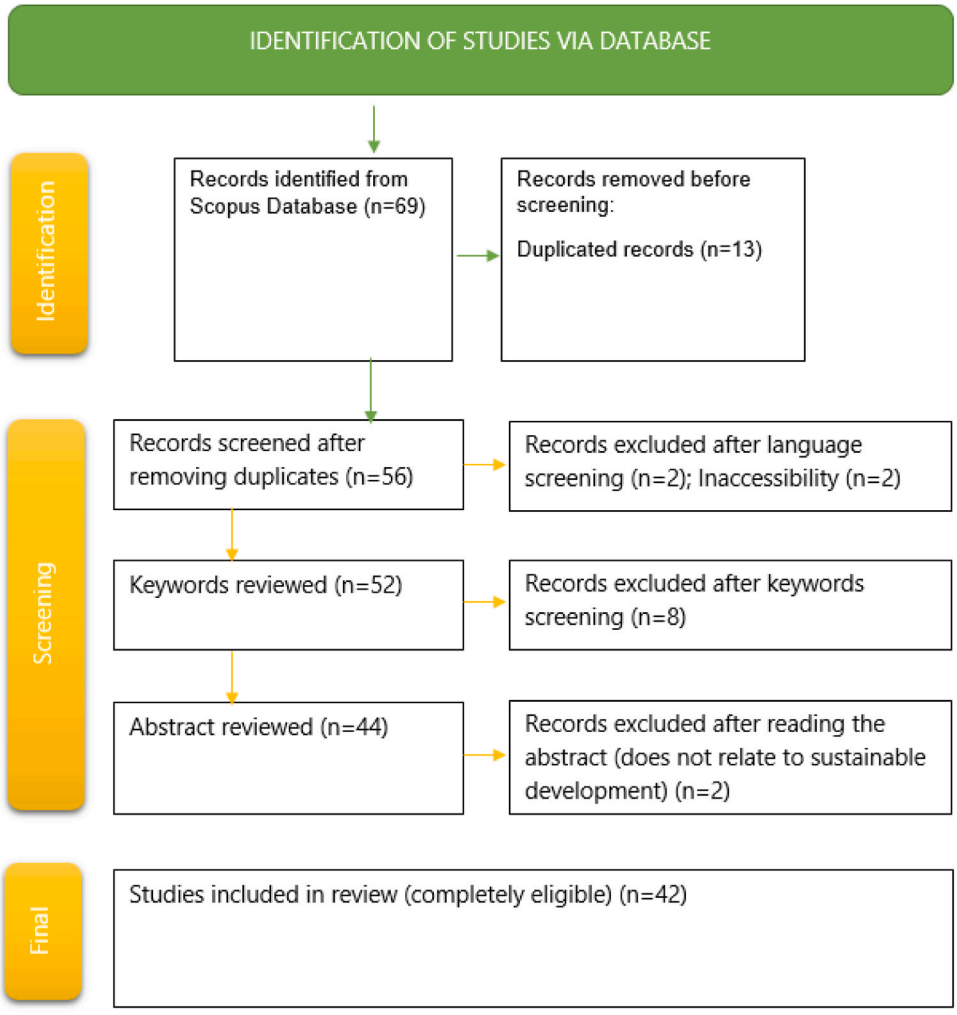

Fig. 2. PRISMA Systematic Review Flowchart.

Fig. 3. Categorization of the SDGs into the Society, Economy, and Environment groups (Vinuesa et al., 2020).

the aim of reevaluating the concept of Planetary Health since the first time the term was coined by Whitmee et al. (2015).

NVivo is one of the best qualitative analysis software packages and is widely used by scholars. From a holistic perspective, NVivo is important for analyzing data, especially in qualitative research (Triguer-os-Cervantes et al., 2018). Its interpretative techniques and the distinctive use of a variety of resources (such as observations, narratives, interviews, and the study of textual, digital, or audio-visual records) have helped in concept visualization. Moreover, research is set in natural contexts, allowing researchers to approach phenomena that are study subjects with an open mind, striving to decipher them from the words and actions of the individuals involved in the research process.

NVivo was used to review the retrieved articles by coding the contents (texts, sentences, and paragraphs) that contained keywords or key meanings that could generate a wider theme. The definition of a concept should fulfill three parts that answer the following three questions:

- Describe, explain and analyze the action/phenomenon (Why?).
- Address, investigate contexts, issues, and problems (What?).
- Generate responses or solutions (How?).

Based on the questions above, three large dimensions of Planetary Health were used as the main themes to apply the coding process: (1) Action, (2) Meaning, and (3) Roles. Planetary Health, the most recent term, hasowns distinct and complementary values compared to its predecessors (Amuasi and Winkler, 2020), thus it is important to determine what actions facilitated the evolution of previous approaches. Moreover, it is necessary to enumerate the evolutionary aspects and improve the concept compared to previous ones. Lastly, since Planetary Health has a strong connection to Sustainable Development, Hill-Cawthorne et al. (2017) stated that Planetary Health is a more integrated approach centralizing human health while simultaneously underlining and facilitating the UN's SDGs. Hence, it was decided to further denote the roles of Planetary Health in achieving Sustainable Development.

Fig. 4 illustrates the research flowchart applied for the data analysis in this study.

3. Findings and implications

3.1. Temporal distribution

Fig. 5 illustrates the temporal distribution of the articles reviewed in this study. The oldest article was published in 2006 when Planetary Health was first mentioned as the integration of ecological, social,

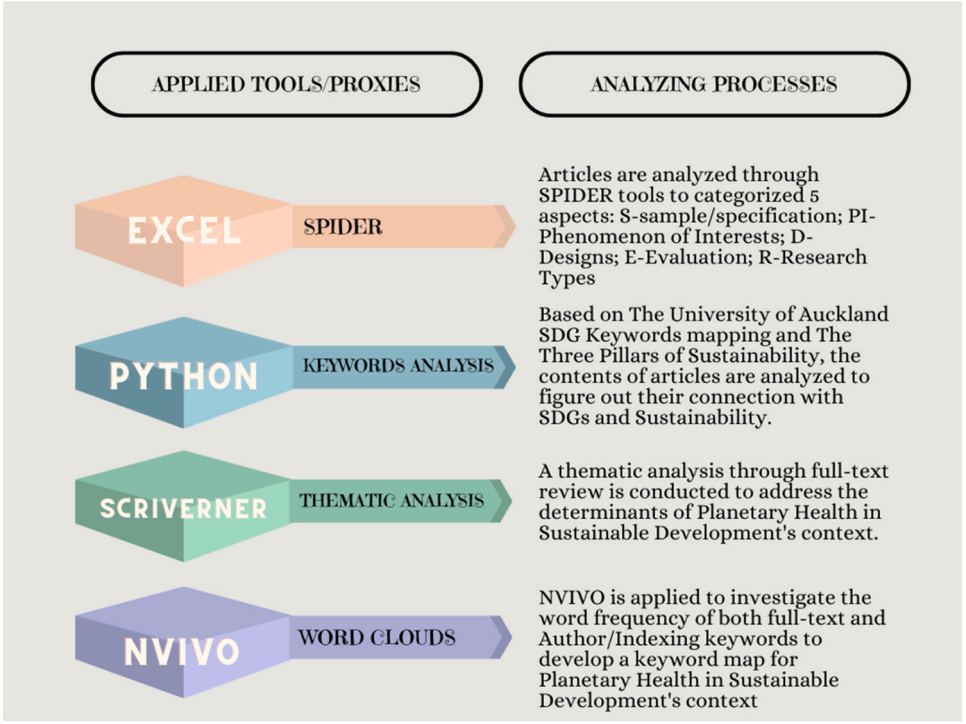

Fig. 4. Research process flowchart.

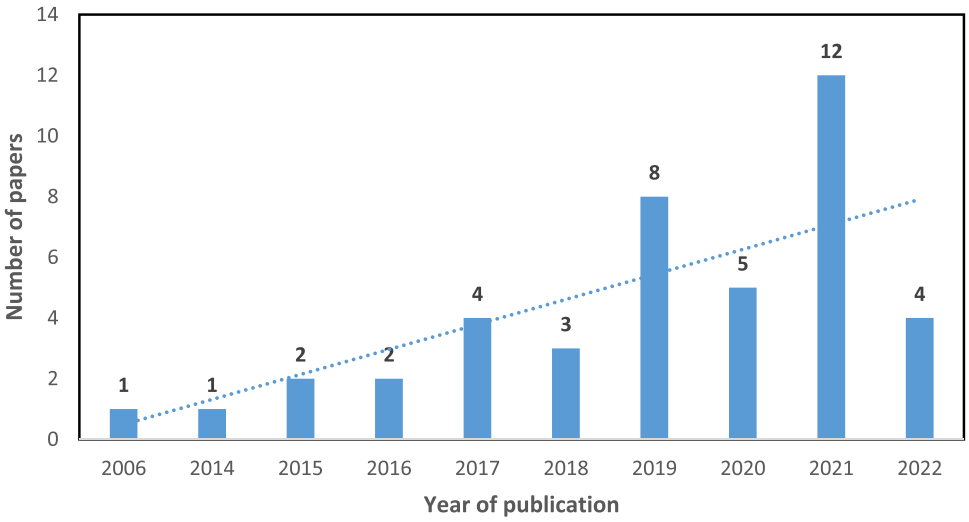

Fig. 5. Yearly distribution of research articles on Planetary Health and Sustainable Development.

cultural, economic, and psychological considerations into a flexible and responsive strategy to facilitate sustainable transition (Wahl, 2006). However, there was an eight-year gap between the first and second articles. This could be because, at that time, other holistic concepts like One Health and Ecohealth were preferred and facilitated by their own commissions. However, in 2014, the question of the Planetary Health movement was raised (Horton et al., 2014). He stated that "A powerful social movement based on collective action at every level of society will deliver planetary health and, at the same time, support sustainable human development." ". The year 2015 marked the first time that Planetary Health was clearly defined (Whitmee et al., 2015), and the SDGs were adopted by the United Nations General Assembly in the same year. The Millennium Development Goals were updated and evolved to the new term "Sustainable," which contributed to a slight increase in the number of papers that considered both the Planetary Health and Sustainable Development nexus shown in Fig. 4. In April 2017, The Lancet Planetary Health was established, a top-level academic journal among scholars, thanks to the reputation of the Lancet publication group. This

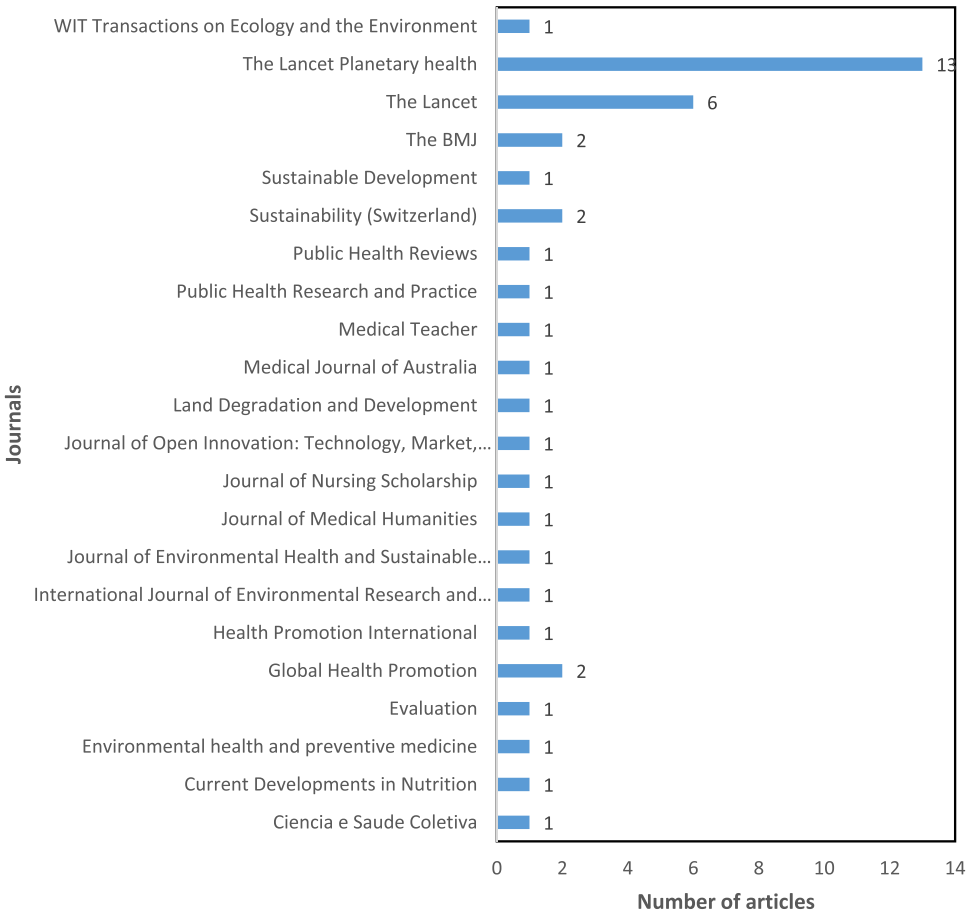

Fig. 6. Published journals distribution of research articles on Planetary Health and Sustainable Development.

doubled the number of research articles in 2017 and, in 2019, eight articles were published. The COVID-19 pandemic captured the attention of research scholars in 2020; therefore, the number of planetary-related studies decreased slightly to five. At the same time, COVID-19 also marked the need for a new holistic management approach that can lead to sustainable global health (Harper et al., 2020). This resulted in the reemergence of Planetary Health, which can replace older concepts with 12 articles focused on Planetary Health and Sustainable Development in 2021.

3.2. Main disciplines of target journals and journal distribution

Fig. 6 shows the 42 articles retrieved from 23 journals. This demonstrates the variety and diversity of approaches and fields. Further, it illustrates the dominance of The Lancet Planetary Health and The Lancet journal, with 13 and six articles, respectively. These journals outnumber the rest, with Sustainability (Switzerland), The British Medical Journal (BMJ), and Global Health Promotion contributing two articles each. The remaining articles are each published in a different journal. The modest number of publications implies that the concept of Planetary Health is still in its infancy among scientific communities and still has potential as an emerging field to be developed (The Royal Netherlands Academy of Arts and Sciences KNAW, 2023). Another reason for the spread of the articles could be the type of articles retrieved. Many of the collected records were research reviews or notes, which are often not allowed in many journals appearing on the list, except for The Lancet.

Fig. 7 shows the main disciplines in which articles were published. Approximately 50% of the collected articles were published in health journals, while another 28% came from medical journals, meaning that more than three-fourths of the total were published in health- and wellbeing-related journals. Another noteworthy proportion was that 8% of the articles were published in journals related to sustainability. Sustainable development and SDGs play pivotal roles in maintaining sustainability; hence, scholars usually publish studies in this field of research.

3.3. Categories of research papers

In the next stage, all the research articles were classified using the SPIDER framework, as shown in Fig. 8. First, more than half of the retrieved articles were classified under the category "Not Applicable," since most of the reviewed papers were not full research articles but research reviews, notes, and editorials. Therefore, they are unable to provide detailed research methodologies, frameworks, or analyses. They simply provide general information, views, or comments on Planetary Health issues/concepts/approaches. Besides, apart from the "Not Applicable" category, a total of nine research fields were classified. Nine

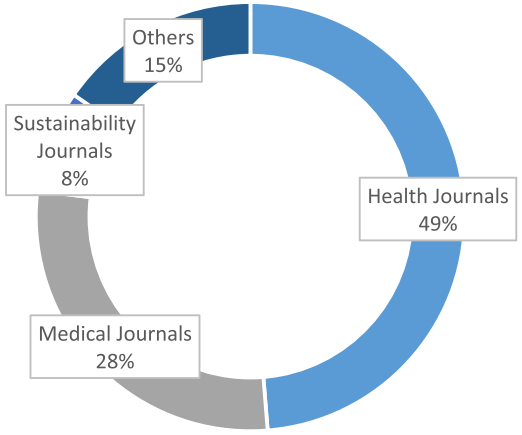

Fig. 7. Main disciplines of journals in which selected papers were published.

articles (21% of the total articles) focused on deciphering the connection between Human and Planetary Health. This implies that the distinct features of Planetary Health are comparable to those of health and ecosystem, which lies in the priority of humans over animals and ecosystems. This approach is considered extremely anthropocentric and human-health-centered (Lerner and Berg, 2017). The other research categories found in two of the articles were Sustainable Healthcare and Climate Change. Other records were defragmented with one article per category. This indicates that academic research on the connection between Sustainable Development and Planetary Health is still in an emerging stage. Therefore, to further explore and enhance the nexus, more efforts are required to collect scientific data on Planetary Health and Sustainable Development in various ecosystems or settings.

3.4. New contribution of selected research articles

Fig. 9 shows the research designs (D) of the collected studies after applying the SPIDER framework. Among the 42 retrieved studies, only 10 papers accounted for 24% of the total sample that proposed a new contribution in terms of a new framework, methodology, or approach to explain Planetary Health. To reiterate, this occurred because several of the collected documents were reviews, notes, or editorials. In fact, these studies only dtackle the general aspects of Planetary Health and Sustainable Development rather than developing a framework of analysis. These studies accounted for over three-fourths of the total sample (32 studies). Out of another 10 papers, five proposed either a conceptual framework for Planetary Health (Brousselle and McDavid, 2021; Ebi et al., 2020; Lewis, 2021) or a transdisciplinary model that connects Planetary Health to various sustainable dimensions (Shaw et al., 2021; Wardani et al., 2022). The remaining articles tackle different approaches such as the post-COVID-19 transition (de León et al., 2021), climate change (Anderson and Gough, 2021; Prior et al., 2018), food security (Pérez-Escamilla, 2017), and youth interest in Planetary Health (Niankara et al., 2020). In the assessment of Research Evaluation (E), only 10 of the above papers were considered because they developed a research question, framework, and methodology, producing results relevant to a research evaluation. In this matter, all 10 papers proposed research findings and conclusions that answer significant research questions via their new contributions through new frameworks or methodologies. This reflects that, although only a few studies have implemented a full-scale analysis, they ultimately succeeded in producing valuable analyses and contributions to establish a correlation between Planetary Health and Sustainable Development. This finding provides a premise for further studies and motivates researchers to continue exploring and identifying new research gaps.

3.5. Research methodology types

In the SPIDER framework, there are only three categories of research types (R)—quantitative, qualitative, and mixed methods. Fig. 10 shows the number of studies based on research type. Out of 42 selected articles, 24 records (57%) are categorized as "not applicable (N/A)" in terms of research type, because they do not provide any specific information about the research methodologies they use. Planetary Health has been scientifically identified as an intertwined concept of Health and Wellbeing. Owing to its intrinsic value, the dominance of qualitative research methodologies with theoretical knowledge is relatively recognizable. Only one study used a quantitative approach to evaluate planetary health. Niankara et al. (2020) analyzed the role of digital media in shaping youths' interest in Planetary Health. This study applies globalization as its context; hence, the authors apply a Random Utility-Based Conceptual Framework that is widely used in economic research. In conclusion, these findings open a research gap for scholars to apply more quantitative or mixed methodologies in future research, which could more precisely evaluate the interlinks between Planetary Health and Sustainable Development.

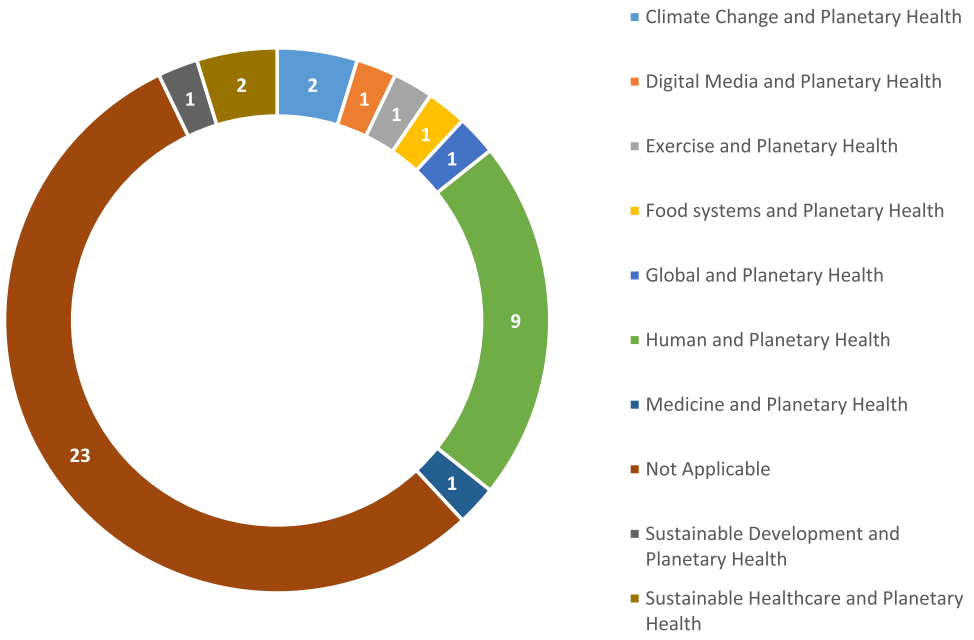

Fig. 8. Research concentration of selected articles.

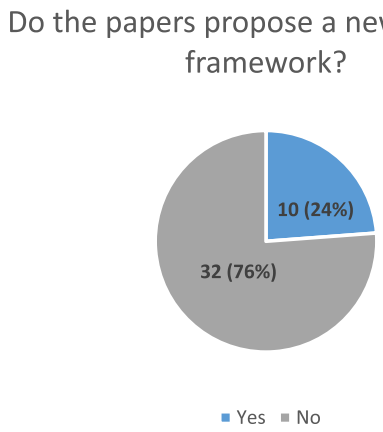

Fig. 9. New contribution of selected research articles.

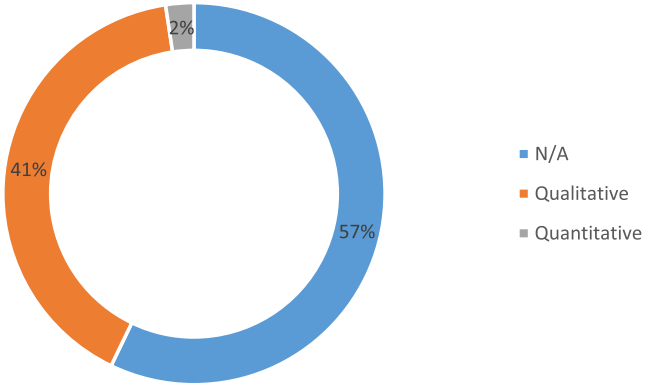

Fig. 10. Distribution of research types of selected articles.

3.6. The connection between planetary health and sustainable development

Fig. 11 illustrates the connection between Planetary Health and SDG by assessing the keywords contained in the 42 retrieved research articles. Generally, most research articles show a significant impact on the SDGs (if the number of papers exceeds half of the total, it is assessed that this SDG has a significant influence on Planetary Health). Besides SDG3 on "good health and well-being," the pivotal domain of Planetary Health, there are other dominant goals such as SDG9 on "industry, innovation, and infrastructure" (42/42 articles mentioned), and SDG12 on "responsible consumption and production" (41/42 articles mentioned). Innovation is required for the delivery, distribution, and consumption of energy, food, and water. Access to Information and Communication Technology is critical for improving access to electricity, transportation, and modern technologies to provide significant health benefits through innovative healthcare. Advancements in Innovation and Infrastructure can empower healthcare communities to deliver better care at lower costs (Chasek et al., 2017). Sustainable production and consumption play an important role in improving human and global health. Recently, governments have promoted the "Circular Economy" as a tool for a world without poverty or hunger (Sutherland and Kouloumpi, 2022). According to SDG Target 3.9, governments pledge to significantly reduce the number of fatalities and illnesses caused by hazardous chemicals and air, water, and soil pollution and contamination by 2030. A circular economy encourages the use of nontoxic organic products and methods that support and build ecosystems, safeguarding the quality of water, air, and soil. Agriculture is an excellent place to start, because our present global food systems emit emissions, rely on rising amounts of hazardous synthetic chemical additives, and degrade soil health and biodiversity.

On the other hand, SDG7 on "affordable and clean energy" and SDG14 on "life below water" are surprisingly considered to have less impact on Planetary Health than the other SDGs. Although it is believed that improving access to energy could better facilitate an effective healthcare system, adaptation to alternative clean energy can increase costs significantly, forming barriers to in improve the health and well-being of people living in poor or remote areas. For SDG14, protecting submarine life is undoubtedly necessary to preserve our ecosystem. However, the fact that Planetary Health is a holistic approach that prioritizes the standard of human beings rather than other living creatures could explain the neglect of SDG14 in Planetary Health among scholars.

Fig. 12 further describes the linkage between Planetary Health and sustainable development through the three pillars of sustainability. The

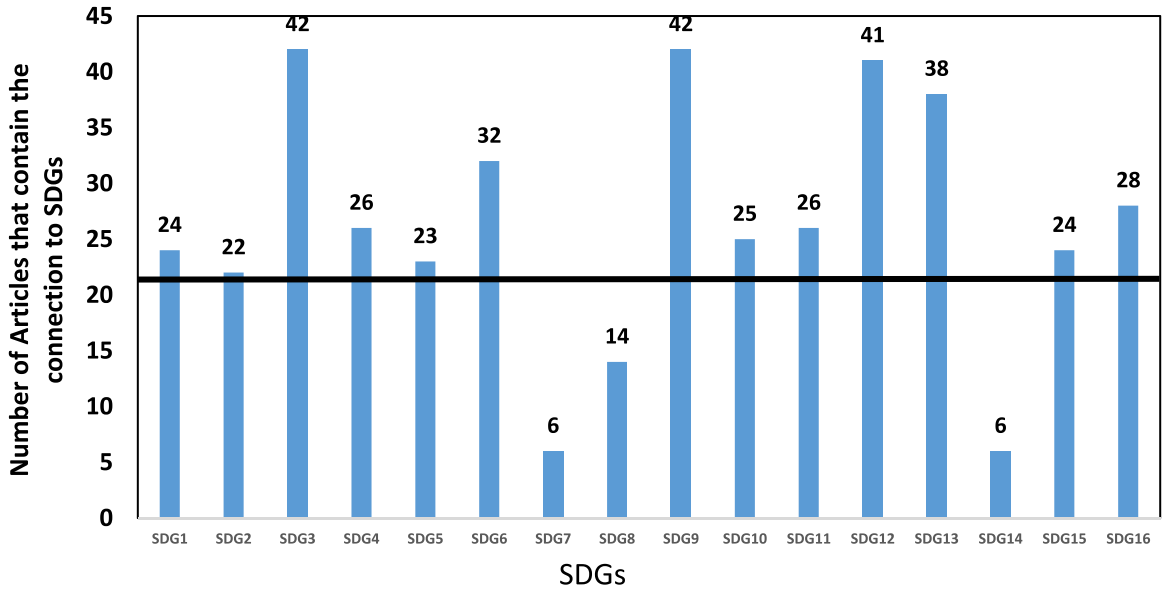

Fig. 11. Contents linkage to Sustainable Development by SDGs.

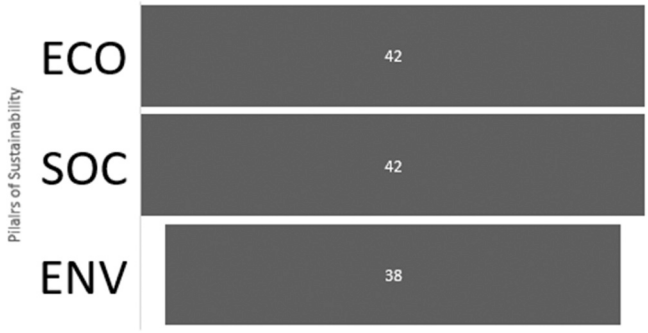

Fig. 12. Contents linkage to Sustainable Development by three pillars of sustainability.

name "Planetary Health" itself implies a clue about its focus or target areas. It is predicted that "Planetary", meaning things that are related to the planet, fall under the umbrella of the environmental pillar (Chang et al., 1988), while "Health" is directly connected to social well-being. Thus, scholars believe that Planetary Health is a concept that should focus more on the Environmental and Social pillars of sustainable development. However, the results of our review demonstrate a different picture. All 42 research articles have connections with the Economic and Social pillars, while only 38 out of 42 studies are categorized as relevant to the Environmental pillar. In terms of the Sustainable Development context, or SDGs in particular, the foundation of SDGs was a milestone for aligning not only developing countries but also developed ones on the path of sustainability (Pradhan et al., 2017). However, most of the goals are primarily focused on the improvement of living conditions in developing countries (Bain et al., 2019). In developing countries, both economic and social development are given priority over the protection of the environment (The World Bank, 1992). This could partly explain the scholars' tendency to prioritize the Economic and Social pillars rather than the Environmental pillar in terms of the nexus between Sustainable Development and Planetary Health.

3.7. The determinants of planetary health in sustainable development context

A summary of the reviewed studies to ascertain the determinants of Planetary Health in the Sustainable Development context is presented in Fig. 13. Climate change is an important factor in protecting Planetary and Human health. Most of the retrieved studies (64%) indicated a significant association among climate change, Planetary Health, and Sustainable Development. A study in the field of education for Planetary Health (Moore, 2021) suggested that "students are now calling for action since they are the generation that will face the most severe health repercussions from climate change." Other studies (Talukder et al., 2021) stated that "climate change has been identified as the biggest threat to human health worldwide in the twenty-first century and is a major driver of altering Earth systems," while Ebi et al. (2020) concluded that extreme weather and climatic events, the spread of infectious illnesses, declining food yields, and ecosystem degradation are just a few of the ways that climate change significantly impacts human health and welfare. Prior et al. (2018) emphasized the importance of avoiding environmental intervention for Human and Planetary Health to integrate global health into climate change adaptation and mitigation.

More than 52% of the research articles reported the SDGs as determinants of Planetary Health in the era of Sustainable Development. This finding is consistent with the context of this study, in which SDGs are one of the most important aspects of Sustainable Development. Brousselle and McDavid (2021) proposed a Planetary Health Framework to provide each SDG solution from the perspective of Planetary Health and arranged this goal into a master plan. The UN's global agenda on the social and environmental determinants of health and well-being is now primarily organized around the SDGs. The SDGs demonstrate the interconnectedness of health and well-being on variables broader than that of a person, similar to the concept of planetary health (Lewis, 2021). Anderson and Gough (2021) supported the idea that the implementation of the SDGs could directly influence climate change, which has one of the most significant effects on the degradation of Planetary Health.

Other determinants that seemed to share the same influence on Planetary Health are Public Health (40% of the retrieved research articles), Sustainable Production and Consumption (36%), and Water Sanitation (33%). Public health, which is closely connected to Planetary Health, plays a significant role in creating and securing a sustainable future (de León et al., 2021; Ebi et al., 2020; Loureiro et al., 2021; Talukder et al., 2021; Wardani et al., 2022). The potential synergies and cost savings between sustainability and health have been widely researched and documented (The Lancet Public Health, 2022).

Sustainable Production and Consumption is one of the main drivers of environmental and health deterioration. Resource use, the biggest

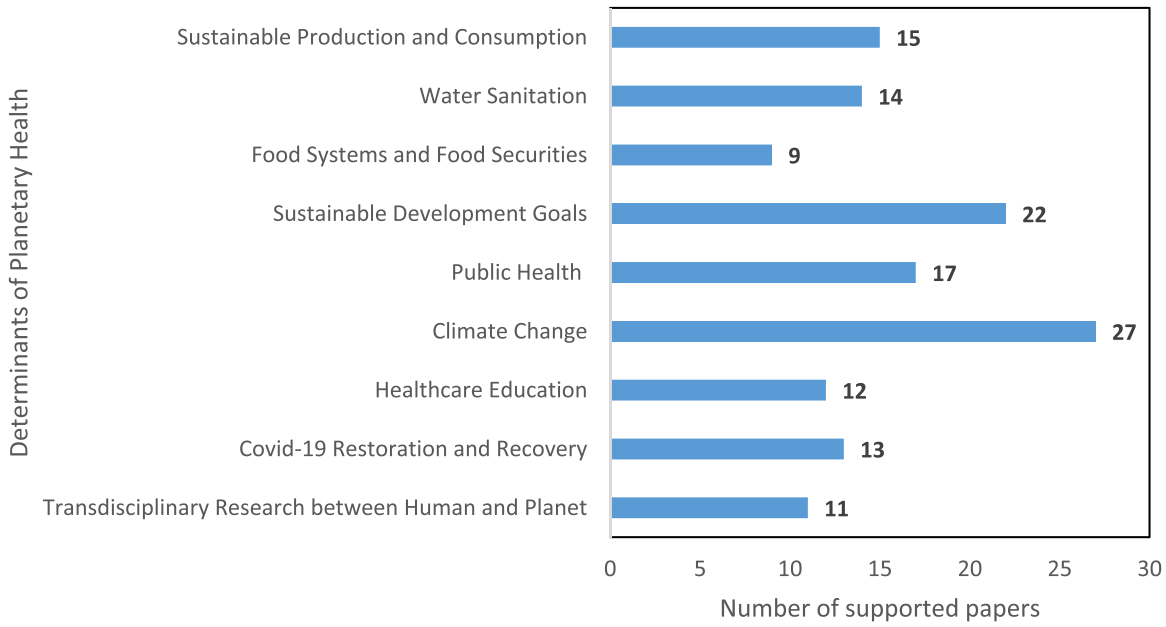

Fig. 13. The determinants of Planetary Health in Sustainable Development context by several supported papers.

contributor to the rising absolute environmental effect and the main culprit of Planetary Health damage, is predominantly driven by "growing absolute income" (Giulio et al., 2021; Lewis, 2021; Niankara et al., 2020).

Approximately, 1.5 percent of GDP is thought to have been lost because of insufficient sanitation and water provision worldwide. Less than half of the world's population has access to secure sanitation and water services, and for nations with poor sanitation, such as India, a loss of more than 6% of their GDP can be attributed to the above (Cole, 2018). Sanitation may be managed securely while being viable from economic and political standpoints. Lowering healthcare expenses linked to disease burden and boosting indirect economic advantages linked to better health outcomes can produce direct economic gains (Anderson and Gough, 2021; Ebi et al., 2020; Talukder et al., 2021).

3.8. Evolution of planetary health in the era of sustainable development goals

Fig. 14 illustrates the word cloud generated from the retrieved articles; the content was coded into three categories using NVIVO. Keywords highlighted in red and bold indicate significant impacts. Except for the keywords "Planetary" and "Health," which obviously appear,

Fig. 14. Word cloud results from three components of Planetary Health in the SDG era.

there are differences in terms of impact among the components. For example, in the word cloud for actions, it is conveyed that the actions that led to the evolution of Planetary Health were "International activities" with the aim of "prosperity" and contain a variety of "attributions." In the word cloud for meanings, Planetary Health is considered as a "condition" that ensures the "state" of both "planetary health" and "human health," aligned with the limitations of the systems. Finally, for the word cloud for "roles," it seems that Planetary Health offers a mediation role to balance "human health" in line with "planetary health" in "international systems.".

Fig. 15 shows the keyword map results for the entire context using three components based on keyword frequency analysis. A keyword map provides a powerful way to visually represent and understand a general idea or theme within a text. By focusing on keyword frequency, the map offers both quantitative and qualitative views of content, allowing for various applications. The more frequently a keyword appears, the more significantly it contributes to the main components. The keywords were divided into two tiers, where the significance of a keyword was demonstrated by the size of the space it occupied. The top five most common keywords are listed in tier 1, followed by the eight second-most-appearing keywords.

Based on this keyword map, scholars can generate ideas that they can exploit further for future research. By examining the keyword map, viewers can quickly grasp the main ideas, topics, and themes of the text. In addition to highlighting key ideas, a map can uncover hidden insights or patterns such as emerging trends or connections between seemingly unrelated concepts. For example, the keyword map presents a change in the trend of global health, which leads to a concentration on the human being and directly generates outcomes that an international health system has developed to protect the human condition. This statement is supported by the tier 2 keyword layer; for example, if there is a question raised regarding which aspect the international health system focuses on, one can refer to the mentioned aspects: communal, social, cultural, and sustainable, according to the tier 2 keyword layer. From different perspectives, scholars can amend many improvisations.

4. Conclusion

This systematic review aims to establish a nexus between Planetary Health and Sustainable Development. The results suggest an increase in the number of academic research papers, indicates the rising awareness of scholars towards this emerging concept. The Planetary Health issue is widely known and there are established promotion measures, although only a few of the retrieved articles provided a new contribution in terms of research frameworks or approaches. These findings reflect the dominance of qualitative over quantitative research methodologies. In terms of Planetary Health and its connection to sustainability, there is a clear connection between SDGs and Planetary Health, where the majority of goals have a great impact on Planetary Health, except for the lack of research studies focusing on SDG7 and SDG14. Based on the cluster analysis of Planetary Health, it is believed that there has been environmental compensation for economic and social improvement, and scholars have neglected the existence of environmental pillars in their studies. Finally, SDGs and climate change were found to be the most significant determinants of Planetary Health in the context of Sustainable Development.

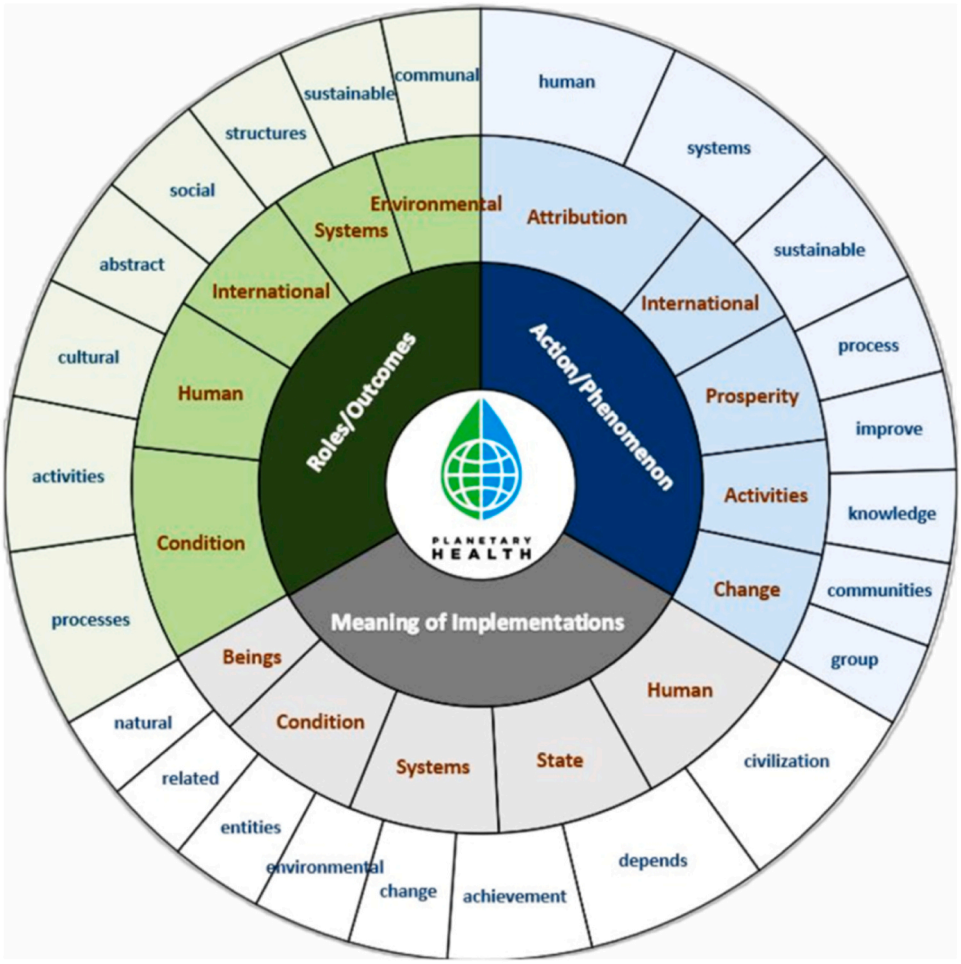

Fig. 15. Keyword map by three components of Planetary Health in Sustainable Development's era.

Based on the remaining gaps identified in this systematic review, the following ideas must be considered for further research.

- Building comprehensive research using quantitative techniques as the primary approach is essential to obtain better knowledge of the connections between Planetary Health and Sustainable Development. This will help diversify approaches to this rising challenge.
- Even though Planetary Health is primarily concerned with matters pertaining to this planet, research to define planetary boundaries related to Planetary Health is currently lacking and should be considered in future work to precisely evaluate the interrelationships between Planetary Health and Sustainable Development.
- Because there is a gap in the attention of Planetary Health towards several SDGs, it is important to understand the connection between Planetary Health and SDG7 and SDG14.
- Further research that addresses the importance of environmental impacts on Planetary Health in a Sustainable Development context is also needed.

CRediT authorship contribution statement

Long Tam Pham: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Pankaj Kumar:** Conceptualization, Formal analysis, Methodology, Supervision, Validation, Writing – review & editing. **Wirawan Dony Dahana:** Methodology, Resources, Supervision, Validation, Writing – review & editing. **Hong Duc Nguyen:** Methodology, Resources, Software, Writing – review & editing.

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.

Data Availability

Data will be made available on request.

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From complexity to integration: Insights for process design from an empirical case study of transdisciplinary planetary health collaboration in Indonesia

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ABSTRACT

Transdisciplinary research has been increasingly advocated as necessary to address complex planetary health challenges spanning environmental and human health in different socio-economic contexts. Recognising global interdependence, such research must engage in equitable co-production for lasting, meaningful impact. Existing transdisciplinarity frameworks and practices from the environment, health, and development fields primarily focus on research processes and outcomes, generically mentioning 'collaboration' without sufficiently expanding how the process can be designed to facilitate equitable and sustained outcomes. This case study undertakes an empirical deep-dive into a planetary health research in Indonesia to better understand transdisciplinary collaboration from participants' experiences. Deductive and inductive analyses of the enabling and constraining factors offer novel insights into the collaborative process of stakeholder engagement, interaction, and integration. Rich examples from the case study were then synthesised into process design strategies to overcome structural constraints through boundary spanning, adaptive project management, and creating spaces for social learning and reflexivity. (150 words).

1. Introduction

Transdisciplinarity has been increasingly advocated in recent decades as an important way research contributes to solving global challenges and accelerating action towards the 2030 Sustainable Development Goals (SDGs). Despite some notable advancements, transdisciplinary research practices remain bounded within the scope of distinct fields and geographies.[a] The emerging field of planetary health proposes substantial expansion of transdisciplinary research to address knowledge failures to recognise interconnections between human and natural systems (Whitmee et al., 2015). Planetary health scholars have recently identified a research agenda centred around transdisciplinary collaboration that is inclusive and equitable (Ebi et al., 2020), furthering human and environmental health and intergenerational equity. Coherence across academic and policy sectors and learning across geographies has also been argued as a key benefit (Pongsiri and Bassi, 2021), while others emphasise the "Leave No One Behind (LNOB)" imperative, recognising global interdependence for meaningful and lasting impact (Zeinali et al., 2020; Browne et al., 2023).

Furthermore, global inequalities mean that HIC-LMIC collaborations are more necessary than ever, yet potentially more complex with underlying political, cultural, and resource differences (OECD, 2018; Oxfam, 2019). Empirical examples of transdisciplinary research in Low- and Middle-Income Countries (LMIC) contexts remain poorly understood, potentially exacerbating historical inequalities in research and education and inadvertently erasing Indigenous knowledges (Jenkins et al., 2018; Reed et al., 2023). Transdisciplinary research frameworks and principles continue to disproportionately reflect High-Income Countries (HIC) academic perspectives, e.g., Lang et al. (2012) and Luederitz et al. (2017). Building on existing scholarship on the necessity of transdisciplinarity towards credibility, relevance, and legitimacy (Clark et al., 2016a), it is pertinent to explore how transdisciplinary research in LMIC contexts also advance global research equity.

However, substantial expansion of the breadth and scale of

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[a] e.g. built environment encompassing architecture, urban planning, and engineering; public health including epidemiology, nutrition, nursing, and social work; and natural resource management comprising ecology, biology, economics, and sociology.

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collaboration across potentially distant disciplines, sectors, and development contexts can intensify challenges well-documented in the transdisciplinarity literature. Efforts to integrate disparate disciplines can increase transaction costs (Brown et al., 2015), while widely different values and ways of thinking, knowing, and doing increase the likelihood of friction and tensions among stakeholders (Horcea-Milcu et al., 2019). Historical scarcity in transdisciplinary funding, practice, and theoretical development is widely recognised (Whitmee et al., 2015; Klein, 1990; Lang et al., 2012; Brown et al., 2019), with additional potential complications arising from cultural, political, and resource scarcity disparities (Toomey, 2016; Shackleton et al., 2023). A plethora of frameworks, guides, and toolkits exist, e.g. Lang et al. (2012) and Pohl et al. (2017), and despite recent progress in implementation models, gaps in understanding exist around attention to context (Schneider et al., 2022; Sheikh et al., 2020) and the value of collaborative, process-oriented approaches (Wittmayer and Schäpke, 2014; Pohl et al., 2021), and their interplay with complexity (Kerkhoff, 2014).

Nevertheless, expanding the breadth and scale of collaboration is necessary for solving complex societal challenges, and more could be drawn from the literature on collaborative governance, which has matured over the past decades around "wicked problems" in the field of urban and regional planning (Rittel and Webber, 1973). Wicked problems, with their multiple interrelated dimensions and uncertain and contested definitions, causes, and outcomes, are not amenable to technical solutions from a single discipline or sector. Instead, diverse stakeholders are needed to bring the requisite knowledge, skills, and experiences. Collaborative governance scholarship (e.g. Innes and Booher, 2018) could thus offer valuable insights applicable to understanding the collaborative process in transdisciplinary research, as they both seek to address complex societal challenges (Pohl et al., 2020; Kaiser and Gluckman, 2023). Action research, a type of transdisciplinary research, is considered by collaborative planning scholars as a form of collaborative governance practice (Forester et al., 2019).

Transdisciplinarity scholars have begun to establish conceptual foundations for integration as a multidimensional, interactive, and open-ended learning process between participants' previously unrelated thought styles and knowledges (Pohl et al., 2021) and as a 'litmus test' and defining feature of inter- and transdisciplinarity (Klein, 2017). However, how such a process could be designed or undertaken to achieve integration has not been clarified and further elaboration is needed on the *collaborative* process as a precondition to achieving integration (Boon et al., 2009). The process of transdisciplinary collaboration thus remains a 'black box,' with research stakeholders finding it 'elusive' and lacking a standard reference for its practice (Goebel et al., 2010; Klein, 2014; Roy et al., 2013). Existing transdisciplinary frameworks describe the ideal-typical research process (Lang et al., 2012; Luederitz et al., 2017) but provide insufficient detail on stakeholder engagement and how the collaborative process itself might unfold. More recent frameworks suggest potential similarities and complementary insights that can be drawn from the collaborative governance literature to inform transdisciplinary collaboration (Pineo et al., 2021), specifically the Diverse, Interdependent, Authentic Dialogue (DIAD) network dynamics of collaborative rationality (Innes and Booher, 2018).

However, further conceptual and empirical exploration is needed to determine whether and how collaborative governance concepts may be applicable to transdisciplinarity. Differences and similarities in understanding around related collaborative concepts suggest there is potential for applicability. For example, a key difference between collaborative governance and transdisciplinarity is the role of academic researchers. In the former, researchers tend to provide technical assistance in joint fact-finding amongst decision-makers (Innes and Booher, 2018); while in the latter, researchers lead the process and engage with societal stakeholders in applying or developing a joint solution to the challenge. Nevertheless, transdisciplinary sustainability scholars have alluded to different researcher roles, including mediating joint fact-finding to support decision-making and stakeholder negotiations (Clark et al., 2016a). Below, we identify relevant concepts of potential applicability for further exploration, preceding our empirical exploration of a case study in transdisciplinary collaboration in planetary health in LMIC contexts.

A central concept worth exploring from the DIAD network dynamics theory is the process of collaboration towards the attainment of authentic dialogue and communicative rationality. Designing collaborative processes requires the creation of ideal speech conditions for stakeholders to express their respective interests, their understanding of the problem, and their approaches to problem-solving (Innes and Booher, 2018). While critiques of collaborative rationality shun the over-reliance on consensus building (Rydin, 2007), the theory focuses more on authenticity of dialogue rather than agreement and consensus. These challenges in communication echo those in the transdisciplinarity literature, e.g. Marzano et al. (2006) and Stokols et al. (2008), while the potential for various communication and interaction in encouraging integration was highlighted in Klein (2017) and Hoffmann et al. (2022). Likewise, boundary spanning and communication were highlighted in a recent literature review of transdisciplinarity as a significant enabler of collaboration (Wardani et al., 2022). These include nurturing constructive dialogue through skilled facilitation (Brown et al., 2019), establishing relationships of trust and reciprocity (Datta, 2018), and negotiations through joint fact-finding (Clark et al., 2016a). Wardani et al. (2022) also highlighted the potential for a project to span the structural, relational, and individual factors in a collaboration; hence, we argue that process design at the project level could provide structure around engagement, interactions, and integration of stakeholders' diverse perspectives, attitudes, and ways of working. Moreover, the project level holds significant potential for transformational social learning (Bos et al., 2013), and thus improving how transdisciplinary research is designed, practised, and evaluated to ensure power equity, integration and impact (Schneider et al., 2019).

The concept of power is another way the collaborative governance literature could provide relevant complementary insight. Collaboration among HICs and LMICs brings an added dimension of equity due to the legacy of colonialism manifested in power and resource disparities, including in education and research training. In collaborative governance, *tacit* structural power conditions interplay in complex ways with the *explicit* power of individual actors through their decision-making. A third form of power is held by intermediaries in facilitating the co-construction of knowledge and decisions (Innes and Booher, 2018; Westin, 2022). Issues of power are pertinent to understanding transdisciplinarity because unequal power dynamics among HIC and LMIC partners, and a lack of understanding of power dynamics within the LMIC context present significant structural constraints to transdisciplinary research (Wardani et al., 2022; Reed et al., 2023). Examples of projects across environmental and health fields support and illustrate the value of roles such as facilitators, connectors, and coordinators in overcoming these constraints (Black et al., 2018; Cundill et al., 2018; Wallace et al., 2019).

Subsequently, sustainability science scholars have attempted to further unpack tacit, or hidden power dynamics, recognising the important influence of power relations on research processes and outcomes. Fritz and Binder (2020) posit that addressing power asymmetries require attention to the roles of and interactions amongst researchers and other actors, and (self-)reflexivity on the instrumental, structural, and discursive power that researchers wield over actor selection, agenda, and procedures of research. Sources of power including material (i.e. time and money) and ideational (i.e. authority, legitimacy, norms, values, and knowledge) are deeply embedded in context. Furthermore, Schneider et al. (2019) suggest that to generate impact towards sustainability transformations, transdisciplinary research not only needs to produce new knowledge but also foster social learning and build competences towards collective agency and joint action to effectively change practices, institutions, and power relationships in multi-stakeholder and North-South partnerships.

Beyond the conceptual, these dynamics need to be explored empirically in power-diverse contexts for more in-depth understanding on process design. The importance of the LMIC research context has been acknowledged in both health and environmental fields, and another area of potential contribution from collaborative governance. For example, sustainability science has explored notions of contextualisation and transferability (Luederitz et al., 2017; van Breda and Swilling, 2018), the need to incorporate diverse epistemologies (Hopkins et al., 2020) and the hegemonic knowledge production systems within which less powerful voices tend to be marginalised (Fazey et al., 2020). Likewise, collaborative governance and urban planning scholars have highlighted the crucial role of local knowledge (Corburn and Gottlieb, 2005; Innes and Booher, 2018) and cautioned against universalising HIC theories in LMIC settings (Roy, 2016; Chakrabarty, 2000). In public health, attention to local LMIC contexts is advocated in implementation science (Sheikh et al., 2020; Peters et al., 2013), while deep inclusion and shared governance are emphasised in ethical transnational global health consortium (Pratt and Hyder, 2017). Anthropology scholars have called for greater collaboration and integration of local knowledge (Sillitoe, 2018), while Indigenous scholars go further urging for decolonising methodologies and research sovereignty (Smith, 2021; Chilisa, 2017).

Against this background, this paper aims to deepen empirical understanding of the collaborative process in transdisciplinary research by examining how the factors enabling and constraining collaboration were experienced in a case study. This provides an opportunity to learn from participants' reflections on their experiences of a large-scale planetary health collaboration in an LMIC context. The following research questions guide the study: What are the factors enabling and constraining the collaborative process, and what insights and strategies could inform the design of such processes to enhance the effectiveness and equitability of outcomes? The potential for transdisciplinary research to accelerate progress towards the SDGs is reflected in the proposed mission-oriented science for sustainability (ISC, 2021). As the global science community advances to emphasise pluralist perspectives in the praxis of transdisciplinarity (Kaiser and Gluckman, 2023), this study contributes to the development of a broadly accepted reference for process design and implementation that reflect greater integration of science, Indigenous knowledge and diverse epistemological foundations.

Thus far, we have outlined the current understanding of transdisciplinary praxis and how the planetary health lens further highlights how the collaborative governance lens could offer a complementary perspective. Section 2 below describes the case study approach, participant sampling, data collection, and analytical framework. Sections 3 and 4 present the study findings, including new understandings of the enabling and constraining factors emerging from the empirical case. Sections 5 and 6 provide practice recommendations, research limitations, and areas for further research.

2. Methodology: case study design, context, and methods

Underpinned by a transformative research worldview (Creswell and Poth, 2018, p. 25), the case study approach was selected to inform future design and practice of transdisciplinary research. A single, holistic case design is suited to gaining in-depth empirical understanding of the collaborative process, answering "how" and "why" questions, and documenting events unfolding within a real-world, contemporary planetary health collaboration (Creswell and Poth, 2018, p. 97; Yin, 2018, p. 9). Typically, in a case study, multiple data sources are triangulated to form an understanding of less well-defined phenomena from different perspectives of participants (Yin, 2018, p. 16).

2.1. Case study context

This paper draws on a rich case study of Revitalising Informal Settlements and their Environments (RISE, www.rise-program.org), a large-scale transdisciplinary research project funded by Wellcome Trust's One Planet, One Healthprogram. The RISE project aims to assess the environmental, human health, and economic benefits of nature-based green infrastructure solutions to water and sanitation in informal settlements in two LMICs, Indonesia and Fiji (Brown et al., 2018). As part of a Randomised Controlled Trial (RCT), 24 informal settlements in each country were divided into 'intervention' and 'control' groups. The RISE project may be considered a "unique case" due to the breadth of disciplines i.e. across HASS, STEM, and the Built Environment; sectors including academia, government, and communities; and countries and contexts (Australia, Malaysia, US, UK, Fiji, and Indonesia). This study covers RISE globally, focusing on Indonesia as an early implementation site. The initial phases of any project are often the most intense due to uncertainties, yet crucial in defining future possibilities. This paper captures lessons learned from those phases to inform the design and implementation of future transdisciplinary research.

The economic and political context in Indonesia during this study has important bearing on research collaborations. While Indonesia has been, up to 2021, classified by the World Bank as a lower middle-income country based on Gross National Income (GNI) per capita, it is an emerging and strongly growing economy that has made strides in poverty reduction. Following reformations post-1997 economic crisis, Indonesia has been a stable electorate democracy with 18 political parties seated in the House of Representative and 82% voter turnout at the 2024 general election. State corruption may still exist, albeit much reduced upon introduction of presidential term limits and the subsequent establishment of the Corruption Eradication Commission (KPK) in 2003 (Slater, 2018, 2024). Relative political stability and economic growth in recent decades have encouraged greater international cooperation in research, especially with HICs such as neighbouring Australia, as exemplified by the signature of the Indonesian-Australian Cooperative Economic Partnership Agreement (IA-CEPA) in March 2019. In turn, increasing research partnerships have cast a light on the importance of knowledge production by local actors with stricter regulations of foreign researchers to address recent concerns around illegal transfer of biological materials in research authored by HIC scholars (Rochmyaningsih, 2018, 2019). This study seeks to reveal insights into such research collaborations, in order to contribute to more equitable research processes and outcomes.

2.2. Data collection and sampling strategy

Semi-structured interviews were the primary method to elicit participants' reflections, perceptions, and meanings (Arsel, 2017). Interviews were conducted online using Zoom from November 2020 to October 2021 due to COVID-19 travel restrictions. Secondary methods comprised individual reflections, focus group discussions, and document reviews to increase internal validity (Carter et al., 2014; Yin, 2018). Individual reflections allowed participants to express their views in an alternative, less structured format. Focus group discussions were conducted in December 2021 with the Indonesian project teams to validate preliminary themes emerging from interviews. While an even spread of stakeholders were interviewed following maximum variety sampling, due to the COVID-19 pandemic, travel to the case study site in Indonesia was restricted. Hence, end-users such as government and stakeholders were not as accessible and FGDs were conducted with the project team with relatively easier access to reliable internet. Individual reflections were solicited by the researcher, and participants voluntarily submitted their reflections for inclusion. Interviews were conducted in English or Bahasa Indonesia based on participants' preferences, by the first author with full proficiency in both languages. Audio recordings and texts were fully transcribed in English.

This study opted for a maximum variation sampling strategy to capture perspectives from the breadth of disciplines, objectives, career stages, roles, sectors, and development contexts (Creswell and Poth, 2018, p. 158). Participants were purposively sampled from individuals involved in RISE in various capacities during the study period

(2017–2019), while individual reflections were voluntarily submitted for inclusion. The FGDs validated preliminary themes and enriched the data with abundant details that enlivened the themes as noted in Sections 3-5. All participants provided prior informed consent. Data saturation was determined to have been reached when no new information or categories were identified in subsequent transcripts. Table 1 characterises the study participants. All data reported herein are de-identified and aggregated to protect participants' privacy and confidentiality.

Maximum variation sampling may be limited in terms of population representation and overall generalisability of findings (Bryman, 2016). However, this strategy was selected to provide a nuanced, in-depth understanding of the practical experiences and meanings of collaboration from multiple perspectives. The value of the case study approach has been acknowledged to be in the variety of context-dependent knowledge for practice and learning purposes rather than in attaining generalisability (Flyvbjerg, 2006). The study aims to illustrate the inner workings of a transdisciplinary collaboration during early operationalisation from participants' experiences, which were then analysed to shed light on the essence and features of collaboration in large-scale transdisciplinary research.

2.3. Analytical framework

The analytical framework developed for this study is based on a literature review of transdisciplinary research practices at the EHD nexus (Wardani et al., 2022). This review of 36 publications reported that structural constraints presented the most significant challenges to collaboration if poorly understood and considered in project design. **Structural constraints** were rigid and difficult to change, particularly the deeply entrenched disciplinary structures of academia (OECD, 2020; Shackleton et al., 2023) and the local socio-cultural, political, economic, and historical contexts of the LMIC research setting (Schneider et al., 2022). On the other hand, **relational factors,** i.e., boundary-spanning and communication, were the most significant enablers of collaboration, allowing partners to bridge differences, build relationships and trust, and work towards a common goal. **Individual factors** were found to be both enabling and constraining and referred to individual stakeholders' attitudes, experiences, and training. Project level factors were found to span across structural, relational, and individual levels; as such, they presented a significant leverage point, along with funding structures that could influence project design and implementation. A summary of enabling and constraining factors from the literature review is presented in Table 2. These structural, relational, and individual level factors reflect a continuous relational interplay between structure and agency occurring in a collaboration (Sovacool and Brisbois, 2019; Innes and Booher, 2018).

Table 1
Overview of study participants.

Participant Groups	No. of participants		
	Interviews	Reflections	Focus Groups
Community leaders			
'Intervention' settlements	2		
'Control' settlements	2		
City actors			
University partners	2		
Government	2		
Indonesian team			
Cross-program	3	2	3
Built intervention	1	1	9
Health assessment comprising:			
Field team	3	1	4
Laboratory team	2		2
International research team			
Senior	5		
Mid- to early-career	11	1	
International actors			
Funders & advisors	4		
Total Participants	**37**	**5**	**18**

Table 2
Analytical framework of enabling and constraining factors, adapted from Wardani et al. (2022).

Constraining Factors	Enabling Factors
Structural Level Structural factors are derived from macro-level institutions, norms, rules and resources, which may enable or constrain individuals' actions and practices through structuration. In turn, over space and time, individuals' collective action and practices construct and reconstruct social structures (Giddens, 1984; Cajaiba-Santana, 2014).	
- Local socio-cultural historical contexts - Unequal power relations - Language and cultural factors	- Involving LMIC researchers in conceptualisation, analysis, and publications; strengthening capacity - Understanding local knowledge, histories, needs, interests, and relevance of solutions
- Disciplinary structures of academia - Epistemological differences - Lack of incentive for collaboration	- Incentives for interdisciplinary collaboration - Flexible seed funding for collaborative projects - Interdisciplinary co-authorship & journals
- Funding - Strict requirements and timelines - Disciplinary bias	- Funding incentives - Sustained funding with built-in flexibilities - Balanced funding assessment, including societal impact
- Project/organisational factors - Lack of common ground - Lack of support and clarity	- Inclusivity through shared leadership, vision alignment, and clear rules of engagement - Adaptive project management
Relational Level *Relational factors represent meso-level interactions between individuals within the structural contexts of collaboration, including communication and spanning boundaries between disciplines, sectors, and cultures to promote understanding, learning, relationships and trust among individuals* (McIntosh and Taylor, 2013).	
- Limited communication and transparency - Lack of time and effort	- Communication and boundary-spanning: - Building relationships and trust - Teamwide facilitation, coordination, and integration roles
Individual Level *Individual factors are micro-level actions and practices of collaborators that collectively reinforce or modify structures. In turn, these individual actions may be shaped by personal values and* attitudes, education and research training, and socio-cultural experiences (Walsh, 1998).	
- Defensiveness and negative response to difference - Lack of training & experience	- Individual openness & reflexivity - Experience and training for complexity, flexibility, and agility required in interdisciplinarity

Subsequently, deductive and inductive analysis was undertaken following the thematic analysis method (Braun and Clarke, 2006), using NVivo qualitative analysis software. Deductive analysis was conducted using established codes of "constraining factors" and "enabling factors" and sub-codes for "structural," "relational," and "individual" factors (Stokols, 2006; Wardani et al., 2022). Additional codes were identified inductively from the data, adding new themes through the following steps: 1) coding to identify emergent themes, 2) clustering of the codes, 3) mapping and identifying interlinkages between themes. The frequency of occurrence of texts pertaining to each theme were then counted and ranked from highest to lowest frequency. A list of themes emerging from the analysis are provided in Appendix 1.

3. Complexity of stakeholder engagement requiring consideration of mutual interdependence

Overall, the case study findings were mostly in line with the structural, relational, and individual classification of factors identified in Wardani et al. (2022), namely significant constraining factors around well-entrenched disciplinary academic structures, and the importance of understanding of socio-cultural, political, and historical contexts of the LMIC research setting and enabling factors around relational

communication and boundary-spanning (Table 2). In addition, this empirical deep-dive revealed new insights into understanding the collaborative process (Table 3). An emerging theme around constraining factors highlighted the complexities of engaging diverse stakeholders and meeting their interests, priorities, and requirements. Nevertheless, this diversity of stakeholders was necessary due to interdependence in implementing all project aspects, including 1) the nature-based, green infrastructure, 2) the health assessment comprising environmental, human, and economic indicators, and 3) scaling up of the infrastructure. This complexity, and other constraining factors, were areas requiring significant attention, time, energy, and resources at the project and individual levels.

The complexity of engaging with the broad and unique combination of stakeholders in RISE, including multiple funders, disciplines, sectors, and development contexts was highlighted in the 2019 annual report. The project was described as "*complex, demanding, and ambitious*" with the teams globally numbering 170 people across "*distinct but highly related disciplines*" tasked to implement the program in 26 informal settlements with 7055 residents in Indonesia and Fiji. By 2019, project funding increased by over 60%, from five core scientific, multilateral, and national funding sources. While HIC academic research teams provided specialist research and technical leadership across various disciplines, LMIC implementation teams were broad-based and multi-skilled, engaging with diverse academic, government, and community stakeholders. Table 4 lists the range of RISE stakeholders cited by participants.

On the other hand, the most highly enabling factor in the case study was developing mutual understanding and acceptance amongst stakeholders, above and beyond the relational level factors in Table 2. This case study found that boundary spanning and communication happened through formal and informal interactions, providing a setting for ice-breaking and initial forming and storming (Bonebright, 2010). Through repetition and over time, relationships and trust began to grow, leading to mutual understanding, which then became acquiescence and acceptance of each other's diverse interests, perspectives, and methods. For example, upon understanding the rigorous research requirements, and despite uncertainties of funding outcomes, stakeholders chose to remain in the collaboration due to alignment of longer-term vision and interdependence of each other's contributions and interests. Participants suggested that open communication, mutual understanding, and acceptance of differences were crucial in bringing about reciprocity, willingness for mutual support, and overall cohesion. Table 5 lists the boundary-spanning and communication strategies that enabled collaboration.

The underlying complexity of interdependence across multiple stakeholders quintessentially defines collaboration and requires intricate weaving, bridging, and spanning, suggested in collaborative governance as the messy, relational co-construction of knowledge (Healey, 2012). In the absence of safe spaces for interactions and clarity around expectations, a sense of vulnerability was experienced by individuals, arising from having to rely on each other to achieve a common goal while facing uncertainties and perceived risks, e.g. around funding, regulatory compliance, community acceptance, long waiting times, and the feasibility of the technology. From HIC stakeholders' perspectives, participants cited that initial project implementation was like "*building the plane while flying it*" and manifested in a lack of clarity around roles and responsibilities, rules and priorities of resource allocation, and other project decisions that caused worries, frustrations, and stresses. Sections 3 and 4 describe in more detail case study participants' experiences and examples of challenges arising from complexities engaging with multiple stakeholders and how boundary spanning and communication lead to mutual understanding amongst stakeholders.

Table 3
Emerging themes around constraining and enabling factors in the case study.

(Sub) section	Emerging Themes	Constraints	Enablers
3	Complexity of diverse stakeholder engagement requiring consideration of interdependence (Section 3)	High complexity due to engaging diverse stakeholders	Mutual understanding and acceptance of diversity and interdependence
3.1	- Interplay between diversity and interdependence: Participants' experiences (Subsection 3.1)	Experienced as vulnerability from reliance on others, uncertainties, perceived risks	Requires adequate time, space, and effort; adaptive, flexible management approach (*"building the plane while flying it"*)
3.2	- Engaging government and communities in LMIC context (Subsection 3.2)	Challenges in engaging government and community stakeholders - Bureaucratic and legal barriers - Changes in political dynamics	Maintaining meaningful engagement with the communities - Gaining trust and acceptance - Informality and social interactions
3.3	- Understanding the local LMIC research setting and context (Subsection 3.3)	Consequences of lack of understanding: - Less effective strategies - Lack of capacity for ongoing sustainability	Benefits of understanding local context: - Team cohesion and mutual support - Cultural propensity towards collaboration - Integration of local knowledge increase project relevance
4, 4.1	Structural constraints requiring project-level strategies (Section 4)	Disciplinary and academic structures: - Academic structures - Funding institutions	Project-level structures (Subsection 4.1): - Governance, culture and leadership - Encouraging spaces for boundary-spanning and facilitating stakeholders' input and contribution
4.2	- Communication and boundary spanning as integrative processes (Subsection 4.2)	Consequences of lack of boundary spanning and communication: - Lack of integration, clarity, heavy workload - (Mis) communication challenges - Reduced opportunity for some to contribute	Integrative benefits of boundary spanning - Building relationships, mutual understanding, and acceptance - Promoting trust, inclusivity, and cohesion - Facilitating project activities and goals
5	Implications for process design: Stakeholder engagement, interaction, and integration (Section 5) - Engagement: Mapping stakeholder diversity, interdependence, and power (Subsection 5.1) - Interaction: Project management and process design (Subsection 5.2) - Integration: Creating spaces for social learning and reflexivity (Subsection 5.3)		

Table caption: Through *deductive* analysis, this case study found enablers and constraints (as summarised in Table 3) which approximated the factors gleaned from the literature review that formed the analytical framework for this study (Table 2). Through *inductive* analysis, this case study also further augmented and deepened understanding of the interplay of factors in the collaborative process

as outlined in Sections 3 and 4. Finally, this case study generated insights for process design, as described in Section 5.

3.1. Interplay between diversity and interdependence: participants' experiences

The case study found that the experience of interdependence and diversity was challenging from both LMIC and HIC stakeholders' perspectives, often experienced as a sense of vulnerability due to reliance on other stakeholders. Those with substantial financial resources and power, such as funding institutions and government stakeholders, shaped project structures and design, including the RCT and health focus, locations of implementation, and mechanism of funding flow across government levels. Uncertainties around community acceptance also highlighted the need for the project to maintain engagement with community residents and leaders for ongoing sustainability. As research participants and infrastructure end-users, the community's needs and interests must be met and their support maintained. One community with higher levels of internal conflicts eventually chose to withdraw their participation

despite best efforts by project teams, fortunately with limited impact on the study. This is in line with the experience of other sustainability research collaborations, where funding bodies, government, and community stakeholders have structural and discursive power (Fritz and Binder, 2020).

Another source of uncertainty was the long waiting times and delays, especially when research and infrastructure design details had to be adapted. Participants recognised that research, learning, and applying technology in a new context involved unknown elements. Different communities may benefit differently in terms of health improvement, and scaling up the infrastructure could vary in effectiveness and viability in different locations (Reidpath et al., 2022). The cost of a decentralised, bespoke infrastructure approach might be perceived as relative higher than traditional rationalist centralised approaches to water and sanitation to which funding and government stakeholders were accustomed, and current cost-and-benefit frameworks may be too narrow to encompass the broad range of benefits potentially provided by such innovative, nature-based infrastructure. Participants raised these examples of uncertainties awaiting actual project outcomes and deliverables.

In the LMIC context, it was found in the case study that these vulnerabilities can intensify in the context of relative poverty, scarcity of opportunities, and further potential loss of land and other resources (Corburn and Sverdlik, 2019). People living in informal settlements in LMICs like Indonesia are constantly exposed to and live with inadequate access to basic infrastructure that may be taken for granted in HICs, including clean water, sanitation, and income security. Informal settlement residents may fear the loss of land or exclusion from development plans. They may commit personal resources and agree to have their children participate in the research for the much-needed infrastructure upgrades. Despite best intentions, the infrastructure upgrades may only partially meet the communities' needs, leaving them with relatively less power for refusal.

However, a significant insight from the case study is that engaging diverse stakeholders was valuable, as they contributed necessary knowledge, skills, and experiences to the project. This challenging yet necessary involvement of diverse stakeholders reflects insights from collaborative governance, where interdependence and diversity are necessary preconditions for collaboration (Innes and Booher, 2018). The following subsections present examples of how these diverse stakeholders were necessary to engage with and how challenges were addressed.

Table 4
Stakeholders engaged in the case study context.

- Funding institutions across health and international development
- University partners in HICs, including Australia, the US, and the UK
- University partners in LMICs, including Indonesia, Malaysia, and Fiji
- Mayor and city government
- Local community leaders
- Communities (as beneficiaries and as research participants)
- Provincial and national government
- Private sector (e.g. housing developers)

3.2. Engaging government and communities in LMIC context

The study revealed that involving government and community stakeholders is necessary for health research and international development projects. Navigating formal bureaucratic structures and cultural-political dynamics were essential to garnering stakeholder trust, support, and acceptance. Indonesia's government spans several levels that may not be immediately understood by non-Indonesians, from national, provincial, and municipal or regency (*kabupaten*) levels, down to district (*kecamantan*), sub-district (*kelurahan*), and neighbourhood (*RT/RW*) levels. Each administrative jurisdiction and department are represented by elected or appointed officials, and changes presented challenges in tracking and managing stakeholder expectations. Government regulations and requirements included obtaining ethics clearance, import and material transfer permits, and foreign researcher visas (Evans, 2019). Health research with human subjects may trigger a comprehensive review by national ethics committee(s), especially when drawing biological samples (e.g., blood, faeces, etc) involving children. LMIC governments are increasingly aware of the need for capacity building, such as training national researchers in specific techniques instead of simply shipping biological and environmental samples overseas for analysis (Rochmyaningsih, 2018, 2019). These structural requirements were a matter of legal compliance.

Beyond regulatory changes, political dynamics also presented challenges in engaging government stakeholders. In Makassar, Indonesia, the Mayor had shown tremendous support, encouraging buy-in across city departments, including regional development and planning (BAPPEDA), housing and infrastructure, public health, and sanitation. However, the mayoral seat was contested in a series of elections in the first two years of project implementation, requiring intensive time and efforts from the Indonesian team to conduct repeat briefings with multiple departments. Understanding government mechanisms was vital to making the monetary flows happen, including having the knowledge and relationships with stakeholders to coordinate activities and obtain approval and support. Specific rules and procedures sometimes meant siloed ways of working and a desire for credit and recognition, which participants cited as significant constraints. Different government stakeholders may support the project to different extents due to unfamiliarity and perception of additional burden.

Involving community members was also crucial in RISE as they were the research participants and the end-users of the infrastructure. Project success depended upon community members' participation in the environmental and health research and green infrastructure design, including responding to household surveys, providing faeces and blood samples from children, hosting environmental monitoring equipment, and allowing entry into the community. Communities' priorities and preferences for toilet, wetland, and road design were crucial for the

Table 5
Boundary-spanning and communication strategies mentioned in the case study (from highest to lowest frequency).

Strategies and examples	Contributes to	Purpose/Benefit
1. Exchange of ideas & information	Increasing mutual understanding and acceptance	Building relationships, mutual understanding, acceptance, trust
• Provide explanation • Present one's research • Articulate expectations & interests • Highlight local conditions or cultural issues • Listening with genuine interest and respect • Reflect on and share experiences		
2. Building and harnessing familiarity	Building interpersonal relationships and trust	
• Express appreciation for each other's contributions • Celebrate progress and successes • Request and offer of assistance • Doing as agreed • Using a trusted messenger • Being in informal settings, including food and drinks • Drawing on a network of interconnections		
3. Coordination of activities	Achieving project goals and team cohesion	Promote transparency, inclusivity, cohesion, and trust
• Provide timely updates • Facilitate teamwork • Troubleshoot and resolve problems		
4. Alignment of perspectives	Building common ground for mutual accountability	
• Clarify issues and decisions • Clear rules and procedures • Clear roles and responsibilities • Articulate shared vision and goals		
5. Adaptation to diverse audiences	Promoting inclusivity	
• Adjusting the degree of complexity • Using audio-visual tools (e.g., maps, photos) • Using a variety of media (e.g., phone/text/email/ in person) • Using shorter formats (e.g., flash talks)		
6. Creating safe, inclusive spaces	Facilitating reflexivity, social learning, and team cohesion	
• Making time to listen to diverse perspectives • Creating judgment-free spaces • Mediation across differences • Field visits in the LMIC context		
7. Capacity building	Addressing research inequity	
• Provide training and coaching in writing and research • Providing office and laboratory facilities • Providing equipment and funding		
8. Negotiation	Promoting equity among partners	
• Articulating intentions, compromises, trade-offs • Identifying alignment and complementarity • Reaching consensus		

Table caption: The above boundary spanning and communication strategies were found throughout all stages of the process of collaboration, facilitating stakeholder engagement, interactions, and integration. The examples above are mentioned within the vignettes of participants' experiences described in the following sections.

suitability of the build component; communities also contributed important information on the location of existing infrastructure, especially those underground and otherwise undocumented. These findings reflect the literature on the importance of incorporating local knowledge into solutions (Corburn and Gottlieb, 2005; Innes and Booher, 2018).

Involving communities necessitates navigating several highly complex situations. Cultural factors such as socio-ethnic heterogeneity, traditional mindsets, and distrust of foreigners due to a history of colonisation and extractive research had to be carefully navigated in negotiating mutually beneficial outcomes for various parties. A particularly sensitive issue was land use and ownership, where conflicting claims of ownership were relatively common due to regulatory ambiguities. Where land ownership was sufficiently clear, the project needed permission or donations from individual owners to build parts of the infrastructure, meeting local and national administrative regulations and international development standards for social and environmental safeguards. The rapid pace of development in most urban areas in Indonesia meant staying abreast of local land transactions and regional development changes (e.g. a new suburban ring road).

Case study participants suggested that authentic and meaningful engagement was essential in gaining and maintaining stakeholders' support, trust, and acceptance. Indicators of meaningful engagement were identified as meeting all parties' interests with genuine respect, e.g., through advance consultation. Having legitimate representation and being valued for their contributions and competencies were further indicators. Meaningfully engaged stakeholders are likely to be mutually invested and desire participation in joint decision-making in the collaboration. These indicators were evident in the engagement of community stakeholders in RISE, and significant time and effort were dedicated to two-way communication, developing and maintaining relationships, engaging relevant leadership, and establishing new community groups. The RISE Indonesia team took great care to communicate project information clearly, including the infrastructure design process and reporting research findings. In turn, community members testified that the RISE team showed dedication in trying to understand and value community perspectives and input.

Maintaining two-way communication required a degree of informality where RISE field teams and community members could get to know each other, spend time with the community, and get along with all community members. Informal settings, usually involving snacks and drinks, allowed for social interactions that built familiarity and invited communication and dialogue in a relaxed, inclusive space. Some familiar physical spaces for these interactions included the '*bale-bale*' (a shaded gathering platform) or under the big mango tree, where residents

gathered for roasted tapioca and sweet jasmine tea. Repeated interactions and consistent presence helped build trust and relationships, especially as communities perceived RISE field teams as genuine in their interest and follow-ups. Through the KePoLink, the community engagement groups formed, project information was conveyed through WhatsApp as the preferred messaging platform, in addition to official written bulletins and annual activity reports. As validated in the FGDs, large project events e.g. on World Water Day and the filming of project documentaries were instrumental in developing the community's confidence and increasing engagement.

Such community openness and enthusiasm in support of the research was evidenced by vibrant participation during the PANRITA community design sessions and high rates of participation in the research (e.g. above 80% even during COVID-19 with surveys conducted over the phone). Indicative of community trust was the willingness of leaders to open up their homes as a familiar venue for child sampling. The PANRITA sessions were cited in the FGDs as key milestones for community engagement, providing spaces for information exchange enabling the project to meet community needs and preferences. Residents in the Batua demonstration site also provided access to the water and sanitation infrastructure to be built on their land and inside their homes. There was a sense of relief and celebration when the infrastructure was completed in Batua, as community members could witness the relevance and benefits of the project bringing solutions and much-welcome attention from local and international institutions.

The above vignettes also demonstrate that adequate time, space, effort, and other resources are required to achieve mutual understanding and acceptance among stakeholders. Particularly, the role of the Indonesian RISE teams and their lived experience and understanding of the local socio-cultural context of the research sites were highlighted in the FGDs. The Indonesian teams contributed their local knowledge of government administration and cultural nuances to mediate between the project requirements and meeting end-users' needs and priorities to help ensure smooth project implementation. Creating adequate boundary spaces was found to be an inclusive approach to enabling collaboration and knowledge integration (Wardani et al., 2023), for example through communication and boundary-spanning (McIntosh and Taylor, 2013). In summary, this study expands this finding by highlighting how communication and boundary-spanning helped build relationships and trust, with stakeholders arriving at a mutual understanding through repeated interactions over time. This is also reflected in the challenges identified in collaborative governance of creating the ideal speech conditions for communicative rationality (Innes and Booher, 2018).

3.3. Understanding the local LMIC research setting and context

The above examples of engaging with government and community stakeholders in LMICs highlight the importance of having a deep and nuanced understanding of the socio-cultural and operational context, which was crucial in research design, stakeholder selection, and infrastructure development. As suggested by Schneider et al. (2022), essential elements of the local context identified in this case study affected project implementation. Local operational conditions, such as the wet and dry seasons, religious practices, and public holidays, affected the scheduling of construction activities, working schedules, and timing of events. Research design including types of indicators and choice of survey questions, must consider regulatory constraints, local and cultural sensitivities, training requirements, and logistical practicalities. A case study participant illustrates the complexities of data collection in Box 1. Stakeholder engagement considerations include the choice of research and infrastructure partners, cultural and communication strategies, awareness of local capacity, and the perception of benefits. The public university system in Indonesia is part of the government, albeit a separate bureaucracy with intricate ways of working. Finally, implementing nature-based infrastructure requires understanding local building practices, locally available materials and technology, and ample training and long-term technical support. FGD participants also cited that unconscious bias towards international over local knowledge could potentially deprioritise local traditional or indigenous knowledge, such as knowledge of building techniques and materials and traditional medicine.

In Indonesia and other LMICs, lower education and research training could mean lower technical capacity, in addition to governance, institutional, and financial capacities than in HICs. This disparity may be experienced as a lack of clarity, slower response, construction failures, and operational and maintenance problems. Case study participants highlighted the all-too-familiar occurrence in international development projects where equipment stops working, limited technical capacity is available for repairs, and spare parts need to be imported. The FGDs underlined that without adequate socialisation, training, and behaviour change, project benefits may be unsustainable and perpetuate dependence on international assistance. While some constraints can be addressed through capacity building, HIC stakeholders need to develop practical experience and skills in working within the limitations and strengths of LMIC partners, including knowing the language, culture, and lived experience in relevant LMICs (Streck, 2021; Schneider et al., 2022). Understanding stakeholders' backgrounds and experiences can prove helpful in discerning power dynamics and cultural nuances.

Certain cultural norms could also advance collaboration, with Indonesian participants self-identifying with a degree of openness to learning and collaboration. Through the cultural norms of sharing stories ("*cerita-cerita*") and "*gotong royong*" embedded in everyday social life, Indonesians tend to prioritise collectivism and mutual assistance, which requires adaptability and flexibility. An Indonesian participant suggested that exposure to plurality and diversity of cultures is a reality of everyday life, summing up mutual assistance towards a common goal (Box 2). Specific religious influences could also promote collectivist attitudes, such as being grateful ("*alhamdulillah")* and surrendering to God's will ("*insyallah"*) when things are beyond one's control. Among Indonesian participants, having language proficiencies in and being able to translate between English, Indonesian and regional South Sulawesi languages was important to bridge between the international researchers, government, and community stakeholders. Indeed, these cultural influences were reflected in the close-knit Indonesian team demonstrating high level of mutual support and trust regardless of discipline and roles. Their hard work, dedication, and creativity in seeking solutions led to a non-Indonesian participant's description of the team as the "*engine of interdisciplinary implementation*." If well understood, these cultural strengths can be leveraged in enabling collaboration.

Box 1
Complexity of local operational conditions

"When we get the data, we might not understand that the measurement has come from a child up in a village, that someone had to walk 2 h to collect, that then had to try and ship in a cooler to get to the laboratory. We might not understand the logistics and challenges contributing to measurement error if we do not physically see and appreciate why we need to make sure designs are feasible."

Box 2
LMIC cultural norms can be help enable collaboration

"Here [in Indonesia], we are used to playing in a team, where a player may kick the ball towards another player, who then scores a goal." (Indonesian case study participant).

4. Structural constraints requiring project-level strategies

As another example of complexity, multiple disciplines involved in RISE, such as architecture and medicine, were distant disciplines that may not have conventionally collaborated in the past. Well-established in the transdisciplinarity literature, academia's disciplinary structures could constrain collaboration and require bridging across epistemologies (OECD, 2020; Klein and Falk-Krzesinski, 2017; Klein, 1996; Becher, 2001). HIC academic disciplinary constraints were experienced as a lack of cohesion due to siloed ways of working, with funding and publication as narrow incentives that do not nurture collaboration. Hierarchies may be assigned to hard, applied, and social sciences; some participants self-identified as "RCT purists." Multiple funding sources meant that different requirements had to be negotiated in all implementation aspects. Each funding source prioritized different outcomes (e.g., Wellcome Trust the health research; multilateral banks and aid agencies the nature-based infrastructure) and imposed different timelines and structural and procedural requirements. These were summarised well by an Indonesian team member in Box 3. This interdependence between the built environment and health disciplines was perceived by participants as a significant challenge. The health research relies on the infrastructure to be successfully built to capture the pre- and post-implementation indicators; similarly, the nature-based infrastructure would benefit from the health evidence of its effectiveness. Both disciplines stand to gain from the global scaling up of nature-based water and sanitation infrastructure as the "transformative WaSH" solution (Cumming et al., 2019).

The novel project and research design added another layer of complexity: nature-based, water-sensitive infrastructure concepts were developed in recent decades in Australia, the US, and other HICs but have yet to be tested in informal LMIC settings. Some LMIC stakeholders articulated in the interviews that the holistic approach and highly technical concepts were difficult to comprehend, and some raised concerns over users' adoption. Land issues were also perceived as more complicated for the decentralised infrastructure, which needed numerous smaller individually owned parcels of land, compared to a conventional, centralised infrastructure (e.g., wastewater treatment plant) requiring larger land parcels with fewer owners. For the health research stakeholders, this was a "*high-risk, high-reward*" as such community-led, bespoke physical infrastructure is not the typical intervention assessed in an RCT and cannot be tested in a laboratory before on-ground implementation. The longitudinal research design meant that community participants had to be tracked over five or more years, a challenge in rapidly developing urban environments. Numerous changes along the way required agility and adaptation at all levels, from research and infrastructure design to implementation.

4.1. Project-level structures: challenges and opportunities

The next level of structural factors that can either hamper or enable collaboration are project-level factors. Project-level factors span structural, relational, and individual levels, translating much entrenched structural factors into organisational policies and procedures, governing spaces in which interactions and relational processes occur among individual stakeholders (Wardani et al., 2022). Project design, governance, and management can introduce formal constraints and enablers through specified rules and parameters of engagement or informal influences through organisational culture. This section outlines project-level structural constraints in the case study, followed by opportunities to address them.

One primary project-level constraints cited by participants was budgetary restrictions and uncertainties around allocation of funds. Implementing an ambitious transdisciplinary research involved high costs and uncertainties. The initial Wellcome Trust funding in 2017 was significantly reduced due to currency fluctuations following Brexit. The community co-design necessary for a bespoke solution was perceived to be higher than for conventional infrastructure. Further, some project components, such as the scaling-up component to broaden and proliferate implementation in other settings, were subsequently added, which required seeking additional funds and bearing uncertainty awaiting funding outcomes.

Case study participants reflected on whether the project's ambitiously large scale necessitated a top-down approach, impacting team integration. While some participants acknowledged facilitative leadership occurring at the highest level, others suggested that sometimes decisions were made without the expected level of transparency. It is not uncommon for such tension to affect work morale for project 'doers' when decisions seem beyond control (Bark et al., 2016). Some participants felt there could be a more inclusive space to gather ideas, facilitate dialogue, and promote shared understanding around major decisions. Some moments were experienced as lacking clarity and structure during early implementation, e.g., interface between core and additional project components, and data sharing and management. In addition to the above formal parameters, participants referred to informal factors that may have negatively impacted integration and morale. Differences in values and priorities were likely reasons for a lack of integration between the Build and Assessment components and between the HIC and LMIC stakeholders, which in turn impacted interpersonal trust and understanding.

Participants experienced heavy workloads and were under relentless pressure to deliver. Initial stages of implementation required intense preparation, from training the Indonesian team, building the laboratory, and procuring equipment in-country. Back-and-forth communication was required between the communities and the Indonesian and

Box 3
Project level complexity of meeting stakeholders' interests

"*It has been challenging to balance the research components of RISE with the actual delivery of infrastructure upgrades. It takes time to build consensus with stakeholders, balance plans with realities in the field, and [manage] donor expectations.*" (RISE, 2019 Annual Report).

international Build teams to develop the nature-based infrastructure in informal LMIC settings. Indonesian team members with multilingual capability did the hard work of translation and interpretation; some suggested professional translators could be hired, but the highly technical and complex ideas required in-house translation to convey accurately and appropriately to specific audiences. Despite the mental demands, some participants acknowledged the work as rewarding and meaningful.

Against the above challenges, participants highlighted practice strategies that could inform future collaborations including adaptive project management supported by clear rules of engagement and fair delegation of responsibilities. A dedicated project manager in a formal integrative role was crucial in coordinating activities across teams, facilitating shared leadership, and engaging with diverse perspectives. Some participants stated that strong leadership and well-defined core goals helped drive the collaboration and clarify benefits for stakeholders, who were motivated by "*different levels of outcomes*." Some flexibility was needed to allow time and space to listen to diverse perspectives, value diverse contributions, and meet diverse interests. Shared leadership was essential for equalising power dynamics and filling in disciplinary and cultural blind spots through periodic feedback across teams. Participants suggested that a relaxed, welcoming atmosphere would be conducive to listening to ideas, considering all options, and collective decision-making. Overcoming early challenges also required transparency, creative thinking and problem-solving (de-Graft Aikins et al., 2012). The Indonesian partners' existing connections and knowledge of the university system were highly instrumental in the various negotiations and navigation of systems for approvals, procurement, and construction.

4.2. Communication and boundary spanning as integrative processes

While the above section presented the case study participants' reflections around project-level structures enabling collaboration, the following section explores how communication and boundary-spanning could lead to team cohesion and integration. While participants highlighted the communication challenges in such a large and multi-sited collaboration, they also emphasised that communication played a vital role in building relationships of trust, mutual understanding, and acceptance, as summarised in Table 5. Below, we highlight some examples illustrating the relational and integrative benefits of communication and boundary-spanning.

Communication challenges can be expected in any collaboration involving diverse stakeholders (Marzano et al., 2006), whether related to communication styles, language and cultural barriers, or geographical distance, as found in the case study. Different preferences for direct or indirect verbal or written communication were potential sources of miscommunication and tension. A commonly cited example is when a lengthy email is intended to provide detailed explanation and instruction for clarity and transparency. However, the recipient may not be accustomed to using email or have the time to read, much less to respond with the same level of detail. Participants indicated that different situations required different intensities of communication; some felt the need to provide constant and detailed reports and updates, while others may not provide sufficient updates, creating a gap in understanding for effective coordination. A lack of cohesion among teams may also create communication blockages and uncertainty. Facilitation or mediation was identified as potentially helpful in negotiating different priorities, requirements, and methods.

Working across different cultures amongst both HICs and LMICs, language and cultural barriers can impede effective communication and mutual understanding among stakeholders (Wöhlert, 2020). These pertained not only to English, Indonesian, and regional languages but also to scientific or legal terminologies. Cultural differences and social nuances had to be attended to; for example, in Indonesia, sensitivities and hierarchies around age, gender, education, and ethnicity define rules of social engagement. Additionally, there may be different work cultures surrounding accountability, professional and personal boundaries, online and in-person communication, and overall enthusiasm and work ethic. For a multi-country collaboration, geographic distance could present challenges for participants due to time zones and internet availability. Some participants highlighted that partners' differences in perspectives would be less visible with geographic distance. Participants suggested that being in the same physical space or having researchers in-country would create proximity, ease communication, and further enable collaboration.

While the above exemplified the complexities and constraints, study participants also identified types of boundary-spanning and communication that help bridge differences and create an atmosphere that encourages openness and integration. While communication has been recognised as key to international research collaboration, micro-level interpersonal level communication remains open for further research (Wöhlert, 2020). This case study provides empirical evidence of how communication helped build relationships, mutual understanding, and acceptance and promote trust, inclusivity, and team cohesion. Boundary-spanning occurred across cultures between the HIC research team and the Indonesian team, between RISE and communities, government, and university stakeholders, and also across seniority levels (i.e., Leadership, CIs, and ECRs).

Case study participants identified at least eight communication strategies and their relational and integrative benefits (summarised in Table 5). One example is unidirectional or multidirectional exchanges of information and ideas that contribute to mutual understanding, e.g., when providing explanations or presenting one's research and highlighting local conditions and cultural issues. Another example is communication that contributes to building interpersonal relationships and trust, e.g., through expressions of respect and appreciation of others' perspectives and contributions and requests for support. Yet other communication strategies can contribute to inclusivity and equity, including adaptation to the audience's preferences and making time to listen to diverse perspectives in a judgment-free space, which in turn promotes reflexivity, social learning, and team cohesion.

Participants observed that openness of dialogue often occurred through social interactions in informal settings, e.g., during field visits, as mentioned elsewhere (Clark et al., 2016a,b). Through repeated social interactions, people get to know each other, friendships and relationships begin to form the basis of shared understanding and appreciation. Identifying thematic and social interconnections is another boundary-spanning that contributes to team cohesion. A particularly well-loved example among HIC academics is the monthly Integrators' Meeting, which participants noted provided space for early-career researchers (ECRs) to brainstorm, coordinate, and reflect together to create shared understanding. Such spaces facilitate reflexivity and flatten hierarchies, which helped the Integrators embrace ambiguity safely and appreciate different disciplinary perspectives through constructive dialogue and social learning. Participants cited the annual, whole-of-project workshop as where they experienced "*working as a whole team*," "*on the same issues*," facing common challenges and working towards shared outputs. Participants added that facilitation to speak across disciplines and breaking the silos could be helpful, formally and informally provided by those playing integrator roles (Hoffmann et al., 2022). Such spaces are valuable in building team cohesion; participants felt they gained a holistic project understanding and willingness to put aside self-interest towards a shared vision.

The articulation of a shared vision of improving human and environmental health through water and sanitation upgrading in informal settlements in LMICs effectively coalesced project stakeholders' perspectives and facilitated collaboration regardless of discipline, sector, and culture. Sharing a common vision hence is an example of how boundary-spanning created common space where members feel shared belonging and purpose. In RISE, case study participants readily credited the visionary leadership style in spurring the team forward through

challenges, validating the importance of interdisciplinary research and demonstrating keen commitment to collaboration. Instilling shared ownership was cited as a benefit of inclusive strategies, which is felt when participants could exercise their agency to contribute ideas and exercise judgement.

Further examples of how boundary-spanning promoted equity were through technical capacity building and close negotiation around sensitive issues. Through staff training for field implementation and occasional lectures on public health and built environment, visiting HIC academics helped increase technical understanding for the Indonesian team and university partners. Invitation to co-author or initiate academic papers, accompanied by training in research skills such as data analysis and writing, could contribute to equalising research inequities. Providing state-of-the-art equipment in a new laboratory built by Indonesian partners and negotiating to reduce the number of samples transferred overseas were hoped to increase capacity for scientific analysis in Indonesia. Community residents appreciated reporting back research findings during World Water Day and Science Day, and the opportunity to be involved in infrastructure construction and learn new skills and techniques.

Finally, the integrative benefits of communication and boundary-spanning contributed to project-level goals, both directly and indirectly. Communication and boundary-spanning play a direct role in coordinating activities through timely updates, facilitation of teamwork, troubleshooting and resolution of issues, and alignment of perspectives. At the project level, communication creates transparency, clarifies issues, and articulates common goals. Clear rules and procedures, roles and responsibilities, and communication of decisions, in turn, created common ground and transparency for mutual accountability. Indirectly, communication and boundary-spanning facilitate the collaborative process and enable project implementation through building mutual understanding, relationships of accountability and reciprocity, and trust and through creating inclusivity and cohesion (Reed et al., 2023).

5. Implications for process design: stakeholder engagement, interaction, and integration

This section synthesises the implications of the study findings for the practice of transdisciplinary research for sustainability. From our analysis of RISE as a transdisciplinary project aimed at bringing together diverse disciplines, sectors, and contexts to assess nature-based infrastructure as a potential transformative WASH solution in urban informal settlements, the case study revealed clarified the collaborative process. Drawing from elements in collaborative governance, the case study provided empirical insight into process design, from the complexity of stakeholder engagement, to project level structures facilitating stakeholder interaction, and creating spaces for social learning and integration.

5.1. Engagement: mapping stakeholder diversity, interdependence, and power

Considering the complexity of engaging multiple stakeholders due to their diversity and interdependence of interests, it is essential to reflect on relevant stakeholders to involve, the timing, degree, and intensity of involvement. These themes are supported by the literature on collaborative governance (Innes and Booher, 2018), co-design (Moser, 2016), and transdisciplinarity in sustainability research (Lang et al., 2012; Schneider and Buser, 2018). Stakeholder analysis should occur at the start and throughout the collaboration, with selection criteria that may be based on stakeholders' interests and contributions, topical and regional expertise and stakes, complementarity of contributions, and well-aligned and opposing values, norms, and goals (Moser, 2016). Innes and Booher (2018) posit that stakeholders' interests must be interdependent, or there would be insufficient motivation to engage. Frequency, length, and type of engagement should be considered, e.g., annual whole-of-project workshop in-person; monthly or quarterly technical group meeting; online or hybrid in-person, joint leadership, and having internal or external facilitation.

Stakeholder engagement should also consider dynamics of power and equity, especially when reflecting on which stakeholders are the primary decision-makers on project design, partner selection, and budget allocation (Reed et al., 2023; Fritz and Binder, 2020). Such considerations are elaborated in participatory engagement models, including Arnstein's "ladder of participation" (1969) Arnstein (1969) broadly accepted in diverse fields, including sustainability science (Mobjörk, 2010) and urban planning (Satterthwaite et al., 2020). Issues of power are neither new nor specific to transdisciplinarity; sustainability researchers have explored the role of power, theories of power dynamics, and implications on social change (Avelino, 2021). Power dynamics could be mapped by exploring a system's leverage points (Abson et al., 2017; Fischer and Riechers, 2019; Meadows, 1999; Newell and Proust, 2012). The present analysis suggests that power dynamics could also be mapped through understanding interdependence; non-academic stakeholders' contributions could be small but critical. Hence, process design should begin with reflection upon the dynamics, types, and sources of power – and interdependences – among stakeholders (Fritz and Binder, 2020).

Beyond stakeholder selection, our analysis also suggested some indicators of meaningful engagement and how this brings a sense of mutual ownership, understanding and acceptance, and team cohesion. The resulting trust and relationships, this analysis argues, are what underpins integration in the collaborative process. This analysis also highlights the necessity of considering early on the effort, time, and space required for boundary-spanning and communication. The following section outlines the project design and management strategies providing the structures for boundary-spanning and communication.

5.2. Interaction: project management and process design

This analysis could inform stakeholders seeking to initiate transdisciplinary research in developing project management and process design strategies. In terms of project management, ample space and flexible structures for boundary-spanning should be built into project timelines, activities, and budget. Stakeholders within and across teams need spaces to interact and get to know each other, engage in formal and informal conversations, and build relationships and trust. A clear set of core goals, a shared vision, clear rules and procedures for engagement, and active facilitation would encourage stakeholders to reach out to those with different backgrounds, knowledge, and experiences. An open and inclusive culture, transparency and engagement in decision-making, and adaptive project management would likely bring the necessary flexibility for stakeholders to contribute in unexpected ways and adapt to changing information and priorities (Streck, 2021). Literature in urban governance, sustainability science, and organisational culture all support the idea of creating spaces of psychological safety (Edmonson, 2019) around a 'safe-to-fail' rather than 'fail-safe' culture (Clark et al., 2016a,b) to encourage candour, reflexivity, and social learning (Bos et al., 2013; Schneider et al., 2019).

In terms of process design, this case study suggests that a dynamic, collaborative process brings stakeholders through phases of engagement, interaction, and integration. Researchers have considerable instrumental power in designing transdisciplinary research projects, supported by funders' structural and discursive power (Fritz and Binder, 2020). Some of the foundational considerations for stakeholder engagement outlined in a practice framework for transdisciplinary collaboration (Wardani et al., 2024), were supported by this analysis. These include local context, power dynamics, diversity and interdependence, boundary spanning, and an aligned vision. This analysis supports that collaboration requires early and ongoing reflection around stakeholder contexts, contributions, interactions, and integration, to bring about transformational change in the relevant societal challenge

and in stakeholders' capacities for individual and collective action (Schneider et al., 2019). With appropriate training and experience, stakeholders in transdisciplinary collaborations can help create a conducive culture for social learning and reflexivity, as described below.

5.3. Integration: creating spaces for social learning and reflexivity

The importance of reflexivity in questioning one's values, assumptions, tacit norms, and practices has been recognised to support social learning processes in transdisciplinary research (Reed et al., 2023). Sustainability science suggests a pragmatist approach to reflexivity (Popa et al., 2015; Jahn et al., 2012), while individual attitudes and training could present constraints but also enable collaboration (Wardani et al., 2022). Individual characteristics unconducive to collaboration include defensiveness and rigidity towards difference, which reflect a lack of openness to learning from, adapting to, and building relationships with stakeholders with different perspectives (Marzano et al., 2006). Some examples of this defensiveness observed by participants were passing judgment on the quality of others' work, anecdotal comments and negative presuppositions on others' behaviours and situations, blaming or expressing dissatisfaction towards others' shortcomings, and dismissing others' ideas. Professional hubris (seeking self and others' recognition as 'the expert') was not helpful and shedding disciplinary identities can feel confronting and vulnerable.

On the other hand, individual factors especially related to openness were vital enablers, including openness to learning from different perspectives, to collaboration with different disciplines, to meeting and listening to diverse people and ideas, to trying new things and failing in the process, and to requesting and receiving help. This openness requires humility, which does not imply downplaying one's strengths but recognising one's strengths and weaknesses in relation to others from an interdependent and relational perspective (Nielsen and Marrone, 2018; Reed et al., 2023). Openness also includes being flexible to adapt to others' contributions and styles, to multiple and unexpected changes, and perseverance through challenges. Participants cited having to reflect on their own attitude, the particularities of interdisciplinarity, and their own disciplines in relation to other disciplines. Generosity, patience, and the ability to embrace ambiguity are just as important as hard work and relevant experience. For HIC researchers, previous lived experience in LMIC helped participants recognise different perspectives and values and develop greater understanding of one's strengths and areas for improvement. Creating spaces for social learning and building individual competences have been suggested to change practices, institutions, and power relations, which are in turn necessary for impact generation (Schneider et al., 2019).

6. Conclusions

This empirical analysis sheds light on the factors enabling and constraining the collaborative process, validating and extending recent transdisciplinary research practices at the environment-health-development nexus. Structural, relational, and individual factors interact to facilitate or hinder collaboration, with boundary-spanning and communication playing critical roles in building understanding across differences and addressing structural constraints. Higher-order themes emerging from this analysis revealed the inner workings of collaboration, from the complexity of engaging with relevant stakeholders with diverse interests and perspectives, to weaving and bridging through communication, social interactions, building relationships, mutual understanding and acceptance, and reaching cohesion and integration. As seen in examples from the Indonesian context, the importance of understanding the LMIC research setting cannot be overstated. Deep and nuanced understanding through active listening, dialogue, and lived experience can go a long way in informing the collaborative process. Indonesia's cultural tendency towards collaboration, as embodied in '*gotong royong*,' represents cultural attributes that can be harnessed. Practice strategies were highlighted around mapping diversity and interdependence during stakeholder engagement, project management and process design to facilitate interactions, and reflexivity and social learning towards integration (Section 5). Hence, this study provides insights to initiators of transdisciplinary research projects, which could be academic researchers, although practitioners and end-users involved in such projects could also apply these insights. Funders hold structural and discursive power in framing relevance and legitimacy (Fritz and Binder, 2020), hence play a crucial role in ensuring equitable process design and outcomes (Wardani et al., 2022).

This study is not without its limitations, highlighting future research needs. One limitation is the study timing during early project implementation in the first 1–2 years (2017–2019). Many constraints would have been addressed at the project level and may no longer apply. The examples highlighted should not be perceived as critical evaluation of the project but as key learnings benefiting future projects. The limitation of conducting FGDs with the Indonesian teams to the omission of government and community stakeholders, whilst justified due to COVID-19 travel restrictions, could have put greater emphasis on the Indonesian teams' perspectives. Further, bounded by a single case, those seeking generalisability would suggest further empirical research to test, validate, and measure effectiveness of proposed strategies. While this study provided fresh insights into meaningful engagement, interaction, and integration as the stages in the collaborative process, more detailed qualitative inquiry could reveal a more nuanced understanding into each concept and their relationship. For example, if integration is indeed a 'litmus test' for transdisciplinarity, then how does meaningful engagement impact integration? Another line of inquiry could examine integration as both process and output of collaboration. Integration has been proposed as a process of developing relations among previously unrelated elements (Pohl et al., 2021; Hoffmann et al., 2022); this case study suggests that integration could be an output of social interactions among stakeholders in a collaboration.

This case study sought to understand collaboration in transdisciplinary research, drawing from longstanding collaborative governance, urban planning, and sustainability scholarship. Rarely discussed as a concept in its own right in the transdisciplinarity literature, the collaborative process risks remaining a black box thus limiting the degree the credible, legitimate, and 'socially robust' knowledge and impact which transdisciplinarity purports to produce (Nowotny et al., 2003; Schneider et al., 2019). We hope these findings contribute to deeper understanding of the factors constraining and enabling collaboration revealing glimpses into the process, towards greater transparency and equity in knowledge production for humankind (Streck, 2021).

CRediT authorship contribution statement

Jane Wardani: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Joannette J. (Annette) Bos:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Conceptualization. **Diego Ramirez-Lovering:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Anthony G. Capon:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esg.2024.100233.

Data availability

Thematic codes have been included as an Appendix.

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Commentary

Interdisciplinary insights on the future of food systems research: perspectives from the next generation of research leaders

Abstract

Our dominant food system is a primary driver of worsening human and planetary health. Held in March 2022, the Public Health Association of Australia's Food Futures Conference was an opportunity for people working across the food system to connect and advocate for a comprehensive, intersectoral, whole-of-society food and nutrition policy in Australia to attenuate these issues. Conference themes included food systems for local and global good; ecological nutrition; social mobilisation for planetary and public good; food sovereignty and food equity. Students and young professionals are integral in transforming food systems, yet they are under-represented in the academic workforce, across publishing, scientific societies and conference plenaries. A satellite event was held to platform initiatives from early career researchers (ECR) in areas integral for improving planetary and public good. The research topics discussed in this commentary reflect sub-themes of the conference under investigation by ECR: food systems governance and regulation; local food policies; commercial determinants of health; sustainable healthy diets; and food equity and sovereignty.

Keywords
Food systems
Food systems governance
Sustainable food systems
Sustainable healthy diets
Food sovereignty
Food equity
Early career researcher

Our current consumptogenic food system has exceeded planetary boundaries and is a primary driver of deteriorating human and planetary health[1]. Held in March 2022, the Public Health Association of Australia's Food Futures Conference was an opportunity for those working across the food system to connect, share their work and advocate for a sustainable, equitable and healthy food system. The conference theme, 'transforming food systems for the planetary and public good', consisted of five sub-themes: (1) food systems for local and global good, (2) ecological nutrition, (3) social mobilisation for planetary and public good, (4) food sovereignty and (5) food equity. Students and young professionals, as future leaders, are integral in transforming food systems. However, given the scarcity of funding available for research, academics early in their careers have reduced opportunities to contribute to research and thus are under-represented in grants, publishing, scientific societies and conference plenaries[2].

Thus, we developed the satellite event *The Future of Food Research: An Early Career Showcase* to platform initiatives from early career researchers (ECR) in areas integral for improving planetary and public good. The showcase presented valuable opportunities for capacity development, networking and reflections from ECR about how to navigate the challenges of building an engaged academic career. This commentary synthesises the valuable, internationally applicable work and perspectives of ten emerging food systems leaders to highlight their voice and opinions and to demonstrate the value of including ECR in all aspects of conducting and disseminating research. This includes fostering leadership, developing intersectoral partnerships and building workforce capacity. This work describes key food systems considerations and highlights implications for future research, policy and practice in this space.

Food systems governance and regulation

Healthy and equitable food systems transformation – wherein the systems of food production through to food consumption contribute to a safe, sustainable, affordable, accessible and nutritious food supply – requires widespread transformation in the policies and processes governing food systems[3]. ECR have been pioneering research into the impacts of international trade and investment agreements on national food environments – making a significant contribution to our understanding of the impact of public policy on nutrition and health. This work demonstrates that the current trade and investment system has produced (and reproduced) a global food system that preferences heavily processed products and increasing corporate concentration[4–7]. Intersections with contemporary issues such as calls for reduced animal products in the global food supply have also been highlighted. For example, trade and investment rules regarding non-discrimination may inhibit national policies which

attempt to obstruct the marketing of alternative plant-based proteins (e.g. restrictions on monikers such as 'sausage' or 'burger') at the request of domestic meat industries[7]. Greater engagement from public health nutritionists in this space is required to ensure that trade and investment agreements can be leveraged to deliver healthy and equitable food systems.

Breast-feeding is the optimal or 'first food system'[8] for infants. When a mother cannot provide her own milk, the WHO[9] recommends donor human milk, obtained from a milk bank or through safe informal arrangements in the community. Various milk-sharing practices and policies address concerns about risk[10] and ethics[11] but face commercial pressures from novel technologies and international trade[12], potentially distorting infant feeding systems. By drawing theories of 'multicentric governance'[13], empirical studies of legal structures and interviews of key actors (mothers, milk banks, health professionals and policy makers), research demonstrates that, in Australia, the regulation of milk sharing is fragmented, with conflicts between policy and social objectives and sources of authority. Policy focused on milk as a product and milk banking lacked integration with breast-feeding, while informal systems of milk sharing captured local social processes important to resilient infant feeding systems globally.

Local food policy

In research and public fora on food system governance, much attention is given to the role of state and federal governments, and the food industry. However, relatively little is known about how local governments and civil society organisations contribute to creating a healthy, sustainable and equitable food system. The Strengthening Local Food Systems Governance project included a policy mapping study that audited food system-related policies developed by all local governments in the Australian states of New South Wales and Victoria (n 207)[14]. To expand on these findings, focus groups with six local governments identified common enablers of and barriers to development and implementation of these policies (e.g. funding, collaboration, legislative mandate). Additionally, a survey of civil society organisations revealed a wide variety of organisations, activities and policy priorities, which were further explored through focus groups with nine organisations. To strengthen the role of local governments and civil society organisations in food systems, they require dedicated funding to undertake food systems work and better coordination across all levels of government, between government departments and across all sectors of society. This research provides evidence to support advocacy for food and nutrition-related legislation that protects and promotes health.

Complementary research has explored the policy response of local government authorities globally to contribute to the population-wide shift towards healthy and sustainable diets called for by the EAT-Lancet Commission[1]. Based on a review[15] of relevant United Nations' publications, a set of thirteen desirable diet-related practices were identified and presented to demonstrate how they can trigger a whole-of-system transformation, including (i) where food is sourced, (ii) what is eaten and (iii) how food is consumed. To explore and map policy options available to local government authorities to facilitate the population-wide uptake of these practices, a scoping review[16] of Milan Urban Food Policy Pact signatory cities was published, demonstrating bold leadership and innovation occurring by these urban cities. This review highlighted that while a holistic approach, considering health, equity and the wide scope of the food supply chain is being taken, opportunities exist to leverage the dual benefits to human and planetary health of policy actions, such as those which discourage the overconsumption of food, including animal-derived foods, and the regulation of ultra-processed foods.

Commercial determinants of health

National dietary guidelines are one important lever to promote healthy and sustainable food systems and diets, yet research suggests that few dietary guidelines present straight-forward advice regarding ultra-processed foods, instead reverting to euphemisms that can be exploited by food companies for marketing[17]. Understanding the gap between evidence and policy is a political question. Research has been undertaken to explore the intersection between corporations, politics and health – a field referred to as the Commercial Determinants of Health – and questions who has power, where power comes from, how power is exercised and how to challenge power[18]. Applying a Commercial Determinants of Health lens to food system governance questions the logic of public–private partnerships and the risks of conflicts of interest when powerful food companies have a seat at the table with nation states[19]. Ultimately, efforts to promote more sustainable, healthy and equitable food systems must contend with the vested interests that pull the financial strings and drive ever-growing corporate consolidation[20].

The food and beverage industry frequently acts to influence food and nutrition policies, preventing the introduction of barriers to the sale of their unhealthy products[21]. Research is underway to describe the commercial determinants of health in the Philippines, and how this disrupts policy development. The food and beverage industry in the Philippines builds its power and influence by occupying key positions, forming coalitions, operationalising its extensive resources and swaying constituents to support industry objectives. Industry engages in a range of tactics aimed at influencing policy development and implementation, including contacting policy makers directly, promoting 'substitute' policies, presenting evidence and

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data that they have generated themselves and offering gifts and financial incentives to government agencies and individuals[22,23]. Industry messaging commonly frames globally recommended policies as having unintended negative impacts and being ineffective at improving health. As a result, food and nutrition policies in the Philippines have been delayed, watered-down or abandoned. As such, ECR-led research is important for advocating for legislation to protect and promote health through food and nutrition policies.

Sustainable healthy diets

Measuring and monitoring characteristics of diets at global and national levels are needed to inform and assess the effectiveness of policy actions that promote sustainable healthy diets. In 2019, the FAO of the United Nations and the WHO reported sixteen guiding principles for sustainable healthy diets, but these principles have not yet been operationalised into a diet quality metric[24]. Novel research aimed to develop a multidimensional diet quality index based on recommendations for sustainable healthy diets through a scoping review of the literature on how principles of such diets are considered in metrics used to assess diet quality globally. No existing dietary metric captures all principles of sustainable healthy diets. Notably, the significance of ultra-processing, environmental and cultural aspects of diets is generally understated. This highlights the importance of revising current dietary recommendations, especially to include emerging topics.

Food systems monitoring has identified consumer behaviours as key drivers of the food system, which can be addressed to encourage more healthful, sustainable diets by individuals, communities or nations[25–29]. However, to date, there have been no reported measures for assessing food acquisition, preparation, meal practices and storage: all key components of food literacy[26,30]. The development of a measure to assess this component of the food system has been hindered by low agreement on a definition and conceptualisation of food literacy. However, a recent publication reported agreement on the Vidgen & Gallegos[31] model as the core conceptualisation of food literacy[32]. This allowed for the development of the International Food Literacy Questionnaire (IFLQ-19), a questionnaire which adheres to the four domains and eleven components of food literacy by Vidgen & Gallegos[31] using comprehensive validation techniques. The IFLQ-19 fills a substantial gap by allowing for consumer behaviour monitoring and surveillance within the food system.

Food equity and sovereignty

There is little literature in Australia that acknowledges the ingenuity and adaptability of Indigenous people to Western agriculture, with the conversation instead contending whether agriculture systems were evident before colonisation[33,34]. There are only a few instances which discuss the co-existence of Indigenous and non-Indigenous People[35], and even less acknowledgement that considers the cross learning of cultures on stations. The Australian perspective is approximately 40 years behind the discussion when acknowledging international perspectives[36], creating further tension and unease between non-Indigenous and Indigenous People. Emerging research aims to reform the current position in Australia by enabling Indigenous culture (and therefore Indigenous agriculture) to be seen as a fluid concept, rather than having a static demeanour. Ultimately, this work contends that an Aboriginal person farming today is as authentically Aboriginal as what this person would have been throughout time – we are the same people, but just a people in change.

With global food systems currently dominated by powerful actors, fair opportunities to participate in food and health decision-making have been compromised[37,38]. Indeed, the voices and values of those experiencing social and/or economic disadvantage, and the poorest diet-related health, remain under-represented in food system decision-making, policies, research and advocacy efforts[39,40]. To challenge similar exclusion practices, international movements by disability and First Nations advocates have long championed the phrase 'Nothing About Us Without Us'[41,42]. If we are to ensure that everyone has access to a healthy diet, especially in the wake of the global COVID-19 pandemic, we must start listening to and acting on the voices of communities who are facing the harshest impacts of our unhealthy, unfair and unsustainable food systems[38]. Irrespective of location, this is likely to necessitate the creation of safe spaces for people to share their stories (supported by culturally appropriate communication), shared ownership over public food system initiatives (compared with tokenistic involvement of the public) and ongoing investment in diversifying and empowering community leaders in our food systems[43].

Conclusion

ECR are integral in food systems transformation and advocacy. Improved representation and diversification of ECRs across food systems research is important; both because diversity in voice and opinion are essential for equitable practice, but also to foster leadership skills and innovation into the future. Indeed, recent reforms from the National Health and Medical Research Council have sought to lower the barriers for ECR to access competitive funding[44]. Overall, this commentary highlights the diverse, yet interconnected work guiding future research and practice related to food policies and systems governance at local, national and international levels; the influence of commercial factors and the need to maintain food sovereignty and equity as central foci. This work highlights how ECR are integral in upholding the legacy of leaders in this field through publication contributions and by

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building workforce capacity. These themes, and the inclusion of researchers across all career stages in publishing, scientific societies and conference plenaries, must be prioritised and acted upon if we are to ensure continuity in progression of food systems transformation for healthy and sustainable food systems for all.

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Case report

Boundaries as Spaces of Knowledge Integration: Learning from transdisciplinary collaboration on planetary health in Indonesia

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ABSTRACT

Introduction: Deepening global inequalities in the health impacts of climate change highlight the need for transformative solutions through international and transdisciplinary collaborations. While the emerging field of planetary health provides a unique lens for recognizing interlinkages across a broader range of knowledge systems, a deeper understanding is needed about the processes through which such knowledge systems can be developed and integrated. Existing transdisciplinarity scholarship offers useful concepts of integration across boundaries; however, such understanding predominantly reflects the perspectives of Global North academic stakeholders, conceivably due to systemic power imbalance as an enduring colonial legacy. This study aims to identify opportunities for learning from the experiences of Global South stakeholders in transdisciplinary collaboration.

Methods: We empirically explore the process of transdisciplinary collaboration in a case study of a large-scale planetary health research project. Through multi-method thematic analysis, this study seeks to understand Global South stakeholders' contributions, motivations, and interactions on transdisciplinary collaboration, through their experiences in the case study context.

Results & Discussion: The study found that Global South stakeholders contributed a plethora of disciplinary and non-disciplinary knowledge and other resources, guided by strong cultural inclinations for collaboration. The opening up of boundary spaces was key to multi-directional knowledge integration. Analysis revealed concepts of interdependence and complementarity towards a common vision, and provides insight into stakeholders' motivations for initial and continuing engagement.

Conclusion: Recognizing interdependence provides strong motivation for transdisciplinary collaboration and can help revalorize contributions from historically disadvantaged knowledge systems and stakeholders.

1. Introduction

The emerging field of planetary health calls for the expansion of transdisciplinary research, in order to address knowledge failures in recognizing the interlinkages across environmental sustainability, public health, and socioeconomic development [1]. While planetary health strives for transcendence and integration of a broader range of knowledge for systems transformation, a deeper understanding is needed of the processes through which transcendence and integration occur. Experiences in transdisciplinary research from public and global health perspectives, when considered together with those from environmental sustainability, have yielded new insights into the enablers of collaboration and integration of diverse disciplines and epistemologies [2].

In addition, urban poverty and inequality scholars highlight the importance of including traditionally disadvantaged perspectives in knowledge production [3]. This is especially pertinent considering the disproportionate degree of the health impacts of climate change in low- and Middle-Income Countries (LMICs) [4]. Informal settlements, in particular, are vulnerable to flooding, extreme weather events, and sea level rise induced by climate change [5,6], increasing their already disproportionate global burden of water- and vector-borne disease, mediated by social and environmental determinants such as poverty, polluted water sources, and inadequate sanitation [7].

Given LMICs' disproportionate burden of water-related disease, further exacerbated by climate change and inadequate water and sanitation, the field of Water, Sanitation, and Hygiene (WaSH) has become an important focus area for researching effective solutions in the context of LMICs and urban informal settlements. Global health researchers largely agree that a holistic, "transformative WaSH" solution is necessary [8,9], as recent large-scale randomized controlled

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trials (RCTs) have indicated the inefficacy of single-dimensional WaSH interventions, such as handwashing with soap or water disinfection when implemented alone, in reducing diarrhea, malnutrition, and other health outcomes [10,11]. Contextualized to the household and environmental exposure landscape [8], such transformative solutions require broader collaboration combining public health, built environment, and development disciplines. Planetary health perspectives suggest that global challenges require transformative systems change inclusive of and equally valuing diverse perspectives and knowledge perspectives for coherence and impact [12–14]. As such, understanding the process of collaboration across broader and more diverse perspectives could potentially yield novel insights.

Substantial understanding of transdisciplinary research has emerged from public health and environmental sustainability scholarship. Both fields offer similar definitions, focused on producing societally relevant solutions and integrating academic and non-academic knowledge (see **Glossary**). In conceptualizing transdisciplinary research, both fields draw from the Science of Team Science (SciTS), and their definitions are based on ideal-typical research processes [15,16] featuring integration as multidimensional interactions among stakeholders in knowledge co-production [17–19]. Definitions of multi-, inter-, and transdisciplinarity illuminate the different degrees of integration and types of interactions across disciplines and sectors [20]. The literature further suggests that knowledge integration occurs across disciplinary, sectoral, and cultural boundaries [21–26], requiring boundary-spanning skills such as understanding, organizing, and influencing [27]. However, challenges of transdisciplinarity remain, including rigid conceptual and institutional boundaries, and the high transaction costs of boundary-spanning [28,29].

Yet others propose that transformative knowledge integration requires more than spanning, but rather the blurring and fundamental breaking down of boundaries and recombination of different knowledge standpoints towards a common goal [30]. Indigenous perspectives in planetary health advocate for greater focus on holistic systems understanding, interconnections, and transcendence [31]. Urban and environmental governance provides an example of an expanded boundary space, with complex real-world problems necessitating interactions amongst a broad array of perspectives across intersecting boundaries [32,33]. The idea of boundary objects (e.g. maps, charts, or graphics), typically robust enough to maintain a common meaning, but flexible enough to be interpreted differently amongst stakeholders, suggests that integration brings together of different stakeholders into a common space [34]. These ideas imply that boundaries can be perceived as more than linear, definitive lines, but potentially as larger spaces of knowledge integration.

Rethinking boundaries as spaces merits empirical exploration into how knowledge integration occurs in such boundary spaces, stakeholders' motivations for coming together, and how their interactions unfold in these spaces. Further, much of the above insights into transdisciplinarity have been largely conceived through High-Income Countries (HIC) academic perspectives, notably silent on issues of power as a persistent legacy of colonialism [35]. In light of growing collaborative research and international development partnerships among HIC and LMICs [36], perspectives of LMIC stakeholders could be better represented in developing a shared global understanding of such collaboration, toward a more equal and inclusive ecosystem of knowledge production and international development [37]. Urban health and planning scholarship has emphasized the need to attend to local knowledge and community participation in producing solutions to complex issues [38,39]. This is echoed by calls within the field of planetary health to implement solutions reflecting unique contexts and geographies, histories, economies, and cultures [40].

This study thus aims to develop an in-depth understanding of the experiences and perspectives of LMIC stakeholders about the process of integrating a diversity of knowledges in the context of a large-scale transdisciplinary planetary health research collaboration. Questions guiding our inquiry include: *What are the knowledge and other contributions of LMIC stakeholders in such a collaboration? What were some motivations for initial and continuing engagement? How is collaboration defined and understood? How were interactions during early implementation experienced?* Building on these findings, the paper presents practical considerations to guide the future design of transdisciplinary research projects.

2. Methods

2.1. Research approach

The case study approach [41] was selected for its value in understanding a contemporary phenomenon unfolding over time, within its specific, real-world context, and through the perspectives of various participants. The case study design hence provides construct validity for studying an ongoing transdisciplinary collaboration where multiple perspectives come together. The Revitalising Informal Settlements and their Environments (RISE) Program (www.riseprogram.org) provides a unique setting as a planetary health research platform [42,43]. A large-scale, action-research program consisting of 25 institutional partners and 150+ academic researchers, practitioners, and societal stakeholders, it utilizes the RCT, a 'gold standard' health methodology, to assess the human and ecological health and wellbeing impacts of a physical, built environment intervention in informal settlements, comprising of nature-based, water-sensitive cities (WSC) solutions such as biofilters, constructed wetlands, and rainwater harvesting, also known as green infrastructure [44] (Fig. 1). These green interventions are co-designed with participating stakeholders to provide water and sanitation and environmental upgrading to each of the 24 urban informal settlements in Makassar, Indonesia, and Suva, Fiji.

The RISE program operates at the intersection of global health, the built environment, and international development, and is instructive as an empirical deep-dive into transdisciplinary collaboration across a broad diversity of disciplines, sectors, and development contexts. This present study focuses on Indonesia as a site of early RISE implementation between 2017 and 2019, hence a rich source for understanding the initial operationalization within an LMIC context. Indonesian staff was employed specifically for program implementation, including cross-program, built intervention, and health assessment teams. At the time of writing in 2022, the program had completed baseline assessment and infrastructure construction in the Makassar demonstration site, and infrastructure construction in the Phase I ("intervention") communities was imminent. Hence, this study reflects participants' sentiments prior to the full intervention within the communities. This study was approved by the Monash University Health Research Ethics Committee (MUHREC) and Universitas Hasanuddin Faculty of Medicine Health Research Ethics Committee (see Acknowledgements for details).

2.3. Data collection methods

Underpinned by a transformative research worldview [46], this case study is a qualitative exploration, seeking a co-construction of knowledge that could improve the design and practice of transdisciplinary research. Data has been collected through multiple methods (**Appendix 1**). The primary data collection method comprises semi-structured interviews designed to illicit reflections, perceptions, and meanings from participants [47]. Interviews were conducted during the period of November 2020 to October of 2021 using Zoom to circumvent COVID-19 travel restrictions. Secondary methods of data collection consisted of individual reflections, focus group discussions, and document review, intended to increase validity through triangulation across multiple methods [41,48]. Individual reflections provided an alternative format for participants to contribute their views

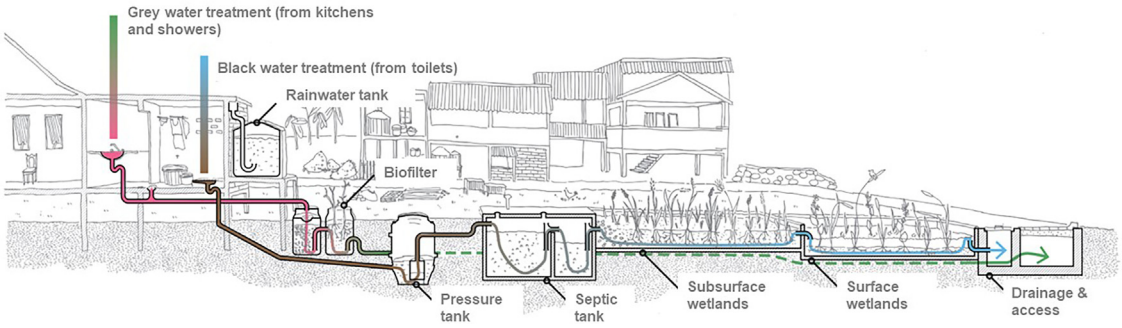

Fig. 1. The 'built intervention' comprising of nature-based, water-sensitive cities (WSC) wastewater treatment train in RISE[45]. The RISE built intervention consists of a series of nature-based, wastewater treatment infrastructure (also known as green infrastructure), using the power of nature to safely treat wastewater and reduce human exposure to fecal contamination. These water-sensitive cities (WSC) approaches complement conventional infrastructure to increase access to services, manage the water cycle holistically, and improve urban liveability. Graywater (from kitchens and showers) is treated using plant and gravel-based biofilters, while the flow of blackwater (from toilets) is managed through a pressure tank, septic tank and constructed wetlands before release into drainage. Rainwater is harvested from rooftops to supplement household water supply. A community and stakeholders co-design component ensures appropriate consideration of the biophysical conditions, user needs and priorities, and feasibility at each site.

in more complex, less structured ways [49]. Focus group discussions were conducted to validate preliminary findings from the interviews, in December 2021. Data was collected in the participants' preferred language (English or Bahasa Indonesia) by the first author, who has full proficiency in both languages. Audio recording and text in Bahasa Indonesia were then fully transcribed in English. Document review was conducted to provide contextual and complementary information.

2.4. Participant sampling

Participants for the semi-structured interviews were purposively sampled (Table 1) from those with understanding of the initial stages of research design and implementation, using a maximum variety sampling strategy [46] to capture the perspectives and experiences of LMIC stakeholders from different disciplines, career stages, roles, and sectors. All participants are individuals involved in RISE in various capacities during the study period (2017–2019). Individual reflections were voluntarily submitted for inclusion. All study participants voluntarily provided informed consent. A total of 26 interviews were conducted and 4 reflections submitted. Two focus group discussions were held separately with the Indonesian staff of the RISE program, the first with 9 members of the intervention team and the second with 6 members of the assessment team and 3 cross-program staff. International stakeholders were interviewed if they were located in an LMIC or if their previous experience focused largely on LMICs. From 30 interviews and individual reflection participants, 18 were Indonesian and the remaining were international participants whose work focused predominantly on LMICs across Africa, Latin America, South and South East Asia, and the Pacific. We refrain from naming specific countries to protect participants' identities. Data saturation was reached as no new information or categories were identified in later interviews and reflections.

In selecting a diversity of participants and perspectives, maximum variety sampling may be limited in terms of representation of overall population sampled and thus generalizability of findings [50]. However, this strategy was purposefully selected to provide in-depth, nuanced understanding from multiple perspectives of the practical experiences, meanings, and connections in a collaboration, rather than to attain generalizability. Maximum variety sampling is valuable in reflecting the diversity of multiple perspectives about the case [46], and the case study approach yields context-dependent knowledge contributing to and necessary for the learning process [51]. Hence, we do not generalize the results to the Global South, but utilize the experience of RISE program implementation in Indonesia to illustrate the inner workings of early operationalization from the perspectives of Indonesian and international LMIC-focused participants. Participants' experiences in turn are analyzed to shed light on the meaning of collaboration in a large transdisciplinary research collaboration.

Table 1
Overview of stakeholders interviewed and providing individual reflections.

Participant Groups	No. of participants		
	Interviews	Reflections	Focus Groups
Community leaders			
'Intervention' settlements	2		
'Control' settlements	2		
City & international actors			
University partners	2		
Government	2		
Funders & advisers	4		
International research team			
Senior	4		
Mid- to early-career	1		
Indonesia team			
Cross-program	3	2	3
Built intervention	1	1	9
Health assessment			
Field	3	1	4
Laboratory	2		2
Total participants	**26**	**4**	**18**

2.5. Data analysis

Data were analyzed inductively using NVivo qualitative analysis software. The following steps were taken during analysis: 1) Coding to identify emergent themes, 2) Clustering of the codes, 3) Mapping where the themes lie, and 4) Identifying interlinkages between themes [52]. These steps are congruent with the thematic analysis method outlined by Braun & Clarke (2006) [53], i.e. "identifying, analyzing, and reporting patterns within the data by applying codes to portions of texts into similar categories of meanings and themes relevant to the research question, hypotheses, or construct." Interviews and individual reflections were primary sources of coding themes and categories, while FGDs and document review provided a means to validate core themes and provide complementary details. A list of coding themes emerging from the analysis are provided in **Appendix 2**.

3. Results

Mapping stakeholders' knowledge contributions in the study case revealed a diversity of disciplinary and non-disciplinary knowledges contributed by international and Indonesian stakeholders during

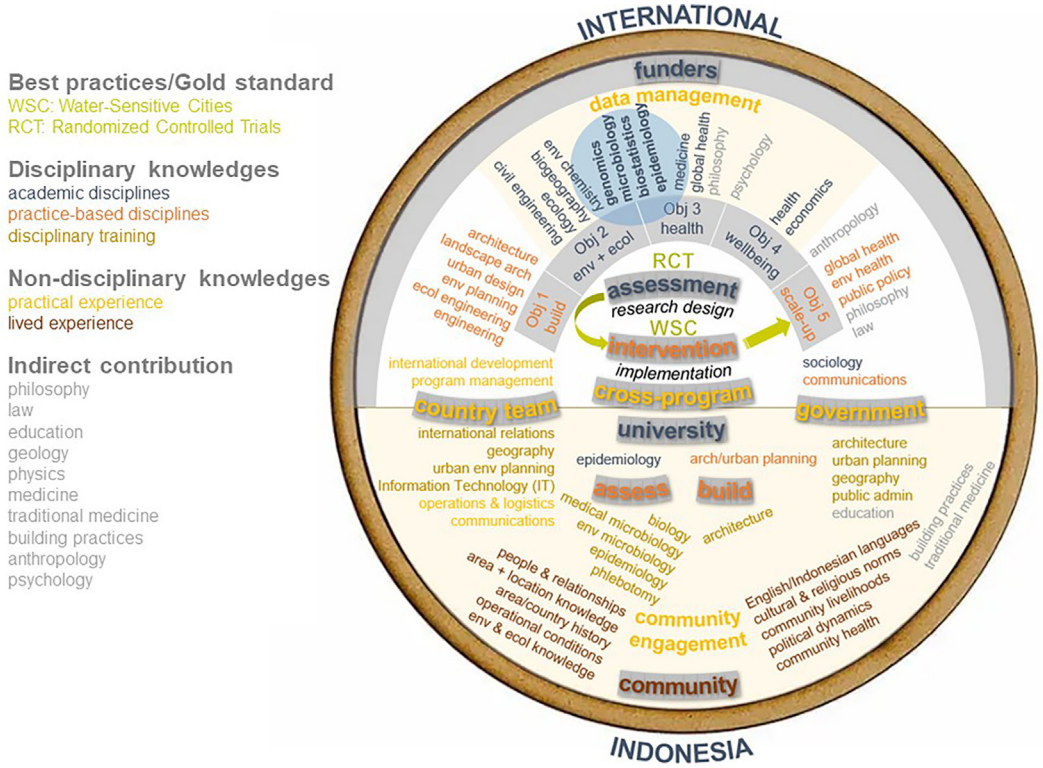

Fig. 2. Diversity of knowledges and stakeholders contributing to RISE. Mapping the knowledges and stakeholders in the study case revealed a diversity of disciplinary and non-disciplinary knowledges contributed by international and Indonesian stakeholders during research design and early implementation respectively. The unique program created a boundary space where interactions and degrees of integration amongst stakeholders could take place. International knowledge tended to be structured around academic disciplines (in blue, Objectives 2, 3 and 4) manifesting in complementary, *multidisciplinary* interactions, with more *transdisciplinary*, practice-based disciplines (in orange, Objectives 1 and 5). The *interdisciplinary* combination of water-sensitive cities (WSC) as a best practice in built environmental upgrading and the randomized controlled trial (RCT) as a gold standard in health methodology created an interdependence with practical implications. Indonesian stakeholders applied disciplinary training and practical experiences (in dark and light yellow) in implementing the research, as did the international cross-objective professional team. All Indonesian stakeholders constantly applied local knowledge gained through lived experience (in brown), while all efforts were underpinned by community engagement, bridging the program and the communities. Indirect contributions (in gray) indicates flexibility in stakeholders' contributions and, in some cases, knowledges that were less well-incorporated into the program.

research design and early implementation. The unique program facilitated the opening up of boundary spaces, thereby supporting integration amongst stakeholders.

3.1. Diversity of knowledge and resource contributions of stakeholders

Research stakeholders in Indonesia contributed a broad range of knowledges through their respective academic, practitioner, government, and community roles. Some of these were in areas directly within the program scope, such as epidemiology and architecture and urban planning. Others were in areas complementary to the research, such as in Information Technology (IT), operations & logistics, and a variety of local context knowledge. These knowledges were gained from previous disciplinary training and practical and lived experiences (Fig. 2). Some participants revealed they were flexible in contributing to the program within and outside their disciplinary training. They valued the opportunity for 'learning-by-doing' beyond their disciplines or backgrounds. Participants were also willing to take on dual roles beyond their initial assignment, depending on program needs at different times. For example, a program officer had undergraduate training in science, but contributed practical experience in non-science. When doubled up as community fieldworker, they found their science education helped in understanding environmental sampling requirements. Another community fieldworker had a Master's degree from an Australian university. Their English language skills, combined with their Indonesian and regional dialect skills, greatly facilitated communication between the international and Indonesian teams, and between the program and community members. The breadth of the program goals and activities provided the space for individuals who were willing and flexible to contribute from multiple disciplines and professional fields, and to align with multiple program areas.

Stakeholders with extensive lived experience in Indonesia or other LMICs contributed to a rich plethora of local knowledge, irrespective of their academic, practitioner, government, or community roles or backgrounds. Some participants were born and raised in the study settlements, region, and country, while others gained lived experience as working professionals. Some accumulated knowledge through multiple generations of cultural practices, norms and beliefs, and ecological and environmental knowledge. Others reported valuable knowledge on government mechanisms, including laws and political dynamics. Cultural history, operational conditions, and other local context knowledge areas were emphasized by participants as crucial for program implementation in several ways.These include deeply understanding community needs, facilitating interactions with government and community stakeholders, soliciting community participation in intervention co-design processes and household health surveys, and customizing the design of the nature-based infrastructure itself. For example, local beliefs or '*pamali*' warned program architects and engineers against placing a road directly leading towards a particular house or building. At the same time, each toilet had to be checked to ensure none faced the direction of Mecca, an essential criterion for Muslim residents. The wealth of local knowledge does not easily lend itself to disciplinary categorization, yet it contributed significantly to several aspects of program implementation.

Inseparable from knowledge, Indonesian stakeholders, also contributed other resources towards program implementation (Table 2),

Table 2
LMIC stakeholders' contributions and their motivations/interests (not an exhaustive list).

Academic Stakeholders (Indonesia)		**Professionals/Practitioners (Indonesia)**	
Contributions	**Interests**	**Contributions**	**Interests**
Expertise	**Societal**	**Expertise**	**Societal**
Disciplinary knowledge	Improve informal settlements	Disciplinary knowledge	Improve informal settlements
Research experience	Address complex challenge	Practice experience/skills	**Professional**
Materials	**Professional**	Local knowledge	Paid employment
Funding	Paid engagement	Language skills	Career progress
Facilities	Career progress	**Roles**	Further education
Equipment	Prestige	Community engagement	International opportunity
Processes	International opportunity	Coordination	**Personal**
Partnerships		Facilitation	Learning opportunities
Procurement		Operations	Friendships & identity
Permitting			
Research ethics			
Roles			
Coordination			
Government & Community (Indonesia)		**Funders & Advisors (other LMIs)**	
Contributions	**Interests**	**Contributions**	**Interests**
Expertise	**Societal**	**Expertise**	**Societal**
Disciplinary knowledge	Improve informal settlements	Technical advice	Address complex challenge
Practice experience	Meet policy mandates	Disciplinary knowledge	Improve informal settlements
Local knowledge		Research experience	**Professional**
Materials		Practice experience	International opportunity
Facilities		**Material**	**Personal**
Funding		Funding	Learning opportunity
Roles			
Coordination			
Facilitation			
Bridging			
Operations & maintenance			
Non-material			
Time			
Consent			
Moral support			
Political support			

including expertise, materials, processes, moral support, and through the roles they played. University partners had health research expertise specific to Indonesia, provided office and laboratory facilities and equipment, and established institutional processes. Participants highlighted the important contribution of the partner university in funding the renovation of a low-use computer room into a new microbiology laboratory, complete with a suitable generator to support critical equipment in case of frequent electrical disruptions. The professional research support team hired by the program had not only English, Indonesian, and regional language proficiency but also knowledge of international relations, project management, community engagement, and operational conditions instrumental to program establishment. Government stakeholders, especially those familiar with inter-organizational coordination and community engagement, provided facilitation and institutional solutions supporting the program.

Community members, despite their relative poverty, generously offered their consent, time, and knowledge for participation in surveys; some donated land on which to build the infrastructure intervention; and community leaders provided their houses as sampling locations for child health assessments, including blood sampling, hemoglobin testing, and anthropometric measurement. Information about children's health and family wellbeing was contributed through household health surveys. These contributions may seem small relative to millions of dollars provided by international funders and universities; however, they are significant considering the limited availability of research funding, infrastructure, and other resources in Indonesia.

3.2. Diversity of motivations and interests of stakeholders

Considering their enthusiasm and important contributions, it is pertinent to understand the motivations and interests that spurred these LMIC stakeholders' initial and continued engagement with the program. Participants cited diverse and complex motivations, reflecting the societal, professional, and personal benefits perceived by the stakeholders through program engagement. The most important motivation, common across stakeholders, was to improve the lives and wellbeing of residents in informal settlements. However, participants identified different ways this could be achieved, whether by building an access road, improving water and sanitation, or improving human health. Most stakeholders interviewed valued the program's holistic approach to addressing complex challenges in urban informal settlements, such as the proposed nature-based infrastructure, bringing together multiple complementary perspectives and producing multiple benefits to meet users' needs. Interview participants realized the challenges of such an ambitious, transdisciplinary approach but felt motivated to contribute and empowered to be part of a solution with potential for impact ("*academic work that is going to be applied*"). Engagement with multiple disciplines was considered a valuable learning opportunity, "*expanding one's knowledge and horizon*" in "*a very rich learning environment*," and "*learning from the richness and diversity of the team*." Not least important for the stakeholders interviewed was the opportunity for professional and personal development. Interest in the research topic and development issues, prestige and international exposure, career advancement, and employment and income were also cited as motivators.

Some also stated new friendships and a sense of identity as highlights of their engagement.

While the above motivations were common across different stakeholders, interview participants suggested that different stakeholders would also hold different interests. For example, academic stakeholders would be focused on generating publications and further funding, while government and international development stakeholders seek innovative solutions to pressing societal issues. Stakeholders also welcomed the opportunity for capacity building in LMICs, for example, in establishing state-of-the-art laboratory equipment and research training. Some stakeholders interviewed were motivated to join the program if they previously knew the core team or were assigned by someone more senior as part of their existing work responsibilities. Government stakeholders were motivated if mandated by policy or senior officials in the hierarchical and political systems, highlighting the value of maintaining relationships as a motivation for engaging in collaboration. As one participant said, "*You're not going to waste your time negotiating with someone unless you get something out of it.*" Hence, while articulating a common vision or outcome is known to be an important enabler [22], the current study demonstrates that without concurrently meeting the diversity of stakeholders' interests, some would no longer maintain their engagement.

This understanding of collaboration as an exchange of knowledge and resources is reflected in the participants' views on collaboration itself. When asked to define collaboration, most participants agreed on "*working together*," but also highlighted the need to involve multiple stakeholders and meet their diverse interests, bringing together diverse knowledges to achieve common goals. Mutual respect and appreciation for differences, as well as mutual understanding and willingness to help each other, were seen as important elements for collaboration. Interdependence and complementarity of stakeholders' contributions and interests emerged as the core motivation for engagement in collaboration throughout the study case. These are experienced through different types of interactions, as further illustrated below.

3.3. Different types of interactions and knowledge exchange

In alignment with the current understanding of integration as a multidimensional process of stakeholder interactions [18,19], focus group participants were asked to describe the flow of and settings within which knowledge exchange and interactions occur. Participants suggested that HIC-to-LMIC knowledge flows tended to be technical, 'universal,' normative knowledge, recognizing that research funding, interests, and expertise also flow along these lines. These are conveyed to LMIC stakeholders through capacity building, training, and overall implementation of the research designed by HIC academic researchers. LMIC-to-HIC flows of knowledge were specific to the local context, through face-to-face meetings when HIC researchers traveled to the field, and increasingly virtually due to travel restrictions throughout the COVID-19 pandemic, and as the Indonesian team gained familiarity with research procedures. Participants from Indonesia mostly agreed that the transfer of local context knowledge took place during less formal discussions after visits to the research sites, in informal, relaxed social settings preferably involving food and drink. Knowledge of the local context modified the research design and provided critical input to the intervention design in different ways, as described below, with varying degrees of integration. Understanding how diverse stakeholders interacted with and complemented each other through different roles and contributions helped to shed light on the implications these interactions had on research design and implementation.

An example of highly integrated, transdisciplinary, multidirectional knowledge exchange is the co-design of the intervention (Fig. 1), conducted by the build team who are highly accustomed to working across architecture, landscape architecture, urban design, and engineering. The Indonesian team was specifically experienced in engaging government and community stakeholders. The Batua demonstration site, where the full range of water-sensitive technologies has been built to include rainwater harvesting, greywater biofiltration, and blackwater sanitation train comprising a pressure pump, septic tank, and surface and subsurface constructed wetlands, was a microcosm of the technical knowledge transfer described above [45]. The multi-day 'PANRITA' community co-design process provided spaces for extensive knowledge input by settlement residents through transect walks, interviews, and focus groups [54,55]. Government stakeholders had to be consulted and designs reconfirmed following changes external to the project, such as contested mayoral elections. The Indonesian team cited that knowledge of such political dynamics was necessary, as were follow-up field visits in order to ascertain locations of unmarked land boundaries and underground infrastructure with community residents, and to ensure design details met community needs. The build team used highly visual and interactive illustrations – inspired by their disciplinary training and experiences – to convey and solicit complex information from government and community stakeholders.

While the large-scale program is overall transdisciplinary, interactions among academic stakeholders can be multidisciplinary or interdisciplinary (see **Glossary**), as described below. These varying degrees of integration affected implementation by the Indonesian team. Research data collection protocols indicate that different assessment objectives required separate and parallel sampling procedures, indicating *multidisciplinary* interactions. Objective 2a, focusing on ecological indicators, had fieldworkers install equipment like sound meters, rat and mosquito traps, and temperature sensors, while Objective 2b, focusing on environmental microbiology, required samples of soil and water from various sources for laboratory analysis. Objective 3, focused on human health, collected data through surveys and child blood and anthropometry sampling, while Objective 4, focused on wellbeing, relied on surveys and provided questions alongside other objectives. Integration of these complementary, multidisciplinary objectives occurred in the finalization of the survey instrument with the Indonesian team, and during deployment of surveys and sampling equipment by fieldworkers in Indonesia requiring careful coordination and scheduling of manifold campaigns (further details below).

The research design is anchored on an *interdisciplinary* methodological framework, subjecting a built environment intervention to the rigors of an RCT in order to assess their public health benefits. Interview participants noted that this methodological framework of applying a health methodology to a built intervention could help validate the effectiveness of nature-based WSC solutions and facilitate its scaling up and adoption in global health policy frameworks. Conversely, the health assessment objectives very much depend on the successful construction of these solutions to be able to assess its benefits. When the built environment and public health researchers first met to develop the funding proposal, finding common ground amidst the dissonance was challenging: "*The very first meeting was a shock, like a war with everyone saying something totally different. Through time and a process of negotiation, stakeholders started to open up to different schools of thought to get the job done.*" Creativity was needed in finding a "design criteria" drawing on the medical expertise of the health assessment team that engineers could work towards. The rigor of an RCT requiring standardization of the intervention in order to measure its effectiveness was a challenge given the different exposure contexts of communities and bespoke co-design of each site's infrastructure with the community and government stakeholders.

The challenges of bridging the epistemological divide between built environment and public health research required the recognition of interdependence between these seemingly non-cognate fields. One challenge voiced by the Indonesian team as a result of this

interdependence was the ongoing management required of staff and community expectations. On the one hand, the program resembled an international development program, similar to other informal settlement upgrading programs in the region. On the other hand, the program's community engagement strategy suggested describing the program as a health research program, which would take longer than other upgrading programs. Staff members with experience in community development had to adjust their expectations of what was within their creativity to implement and what needed confirmation and approval from the international research team. The community, perceiving a long waiting time, asks, "*Why is this taking so long? Just to decide one thing they have to go back and forth?*" These sentiments also reflect the complexity of satisfying both built and research requirements of different levels of government and those of different funders.

Indonesian participants voiced another challenge due to interdependence in terms of the capacity building and continued community engagement required for long-term operations and maintenance. Participants asserted that program success relies not only on government and community input on the intervention and the collection of community data but also on the long-term operations and maintenance of the infrastructure by local government and residents. At the time of writing, some introductory training has taken place on the infrastructure, specifically the pressure pump technology, and residents from other communities have visited the Batua demonstration site for an overview of the completed system. However, during the focus groups, the Indonesian team asserted that substantially, more training and awareness raising is needed to bridge the gap. One participant suggested that it would be a considerable task to operate and maintain the 100+ installed pressure tanks after the research has been completed without long-term guidance, especially if the program cannot be scaled up.

Once ready for operationalization, the assessment arm of the research was deployed through highly transdisciplinary interactions. The Indonesian team constantly applied local knowledge about the community and political dynamics to generate support for the program, coordinating field activities according to the residents' day-to-day schedules based on their livelihood activities to increase chances of successful contact. The Indonesian team was aware of cultural norms of informality, spending some idle time and sharing stories with residents in pre-existing gathering spaces, e.g. around the mango tree, to build relationships and gain trust and acceptance by the community. Another example of transdisciplinary knowledge integration was the deployment of the household health surveys that required consistent delivery across Bahasa Indonesia and Makassarese and Buginese dialects. Through hours of practice and role play, the academic researchers and Indonesian teams co-produced a standardized procedure consisting of posing the question in Indonesian, then using a standard glossary to explain specific terms if queried by survey participants. Such preparation was necessary to ensure accurate interpretation of questions pertaining to unfamiliar or sensitive concepts around water and sanitation practices, asset ownership, and mental health.

In other instances of transdisciplinary integration, Indonesian stakeholders displayed cohesion and 'all hands on deck' teamwork towards milestones such as establishing the microbiology laboratory. Regardless of disciplinary training, assessment and cross-program staff worked closely seamlessly with international researchers and local suppliers to procure equipment according to precise technical specifications and successfully navigated university processes to import research equipment exempt from approximately AUD50,000 of customs duties. University partners negotiated for the physical space to be renovated, and the build team worked with the assessment team and international researchers to translate electrical and structural specifications into the required standard of physical laboratory design and layout. The arrival of some of the larger equipment required dozens of manual laborers provided by suppliers and the university to haul up to the laboratory on the third floor.

Another milestone of the collaboration cited by focus group participants was during a highly intensive child health sampling campaign. Participants recounted having to put aside their differences and trust each other in conducting blood sampling and anthropometric measurements. Community leaders provided not only the location for sampling but also a bridging role in conveying program information to fellow community members. The phlebotomists reported feeling supported by the community fieldworkers trained in conducting on-site hemoglobin testing, entering survey data, transporting samples to the lab, and entertaining children in the waiting room. The international research team stood by on site for technical troubleshooting. Everyone played a part in making the campaign a success with high sampling rates and broad community acceptance.

4. Discussion

4.1. Boundaries as spaces of knowledge integration

From the above vignettes of study participants' experiences, transdisciplinary collaboration can be understood as the opening up of spaces of learning and knowledge exchange at the boundaries of multiple disciplines and knowledge systems. These boundaries are no longer lines, but spaces of knowledge production and integration of diverse perspectives. Examining the degrees and types of integration in stakeholder interactions in such spaces can help understand the inner workings of a collaboration, while exploring stakeholders' motivations can inform future engagement strategies. Understanding the diversity of stakeholders' interests beyond the common aim – in this case, to improve informal settlements – also helps in understanding what stakeholders expect to benefit from the collaboration. While boundary spaces have been discussed elsewhere as a shared space of knowledge production where stakeholders' knowledge, interests, and perspectives become explicit [33], the focus had been on activities and boundary objects rather than the roles and interactions among stakeholders.

In particular, this case study highlights the important role played by the Indonesian team and stakeholders in providing "holding spaces" for mobilizing a rich array of local knowledge, from languages to cultural norms and practices, people, government and universities, to communities' interests and needs, livelihoods, traditional beliefs, as well as environmental knowledge to be used and applied as and when needed for both the build and assessment components of the program in interactions with the international team. While technical knowledge was transferred in more structured ways through trainings and under the auspices of capacity building, local knowledge tended to be conveyed in more informal ways, and required international team members to be cognizant and open to understanding local context and conditions. Especially during the research design phase, such openness could help identify mutual or complementary research interests and outcomes that a collaboration could fulfill. Without such openness, the inherent power inequalities due to knowledge and resource differences could inadvertently ignore or erase local knowledge held by LMIC stakeholders [56] or result in failure of implementation due to lack of capacity to maintain and operate the installed systems.

In the case of Indonesia, the strong willingness to collaborate could be attributed to cultural factors. A vast and diverse country, the national motto of *Bhineka Tunggal Ika*, or "unity in diversity" underpins a cultural inclination towards collectivism, harmony and teamwork amidst plurality. Indeed, this study highlighted that word "knowledge" in Bahasa Indonesia translates to "ilmu" which is commonly used in its plural form, "ilmu-ilmu," or knowledge**s** or expertise**s**, which is less common in English. Collective efforts and mutual assistance towards a common goal, also known as "gotong royong"

Table 3
Considerations for future transdisciplinary collaborations.

RESEARCH STAKEHOLDERS	CONSIDERATIONS
HIC funders & networks	• Require that academics, practitioners, and societal stakeholders in both HICs and LMICs be engaged early on in formulating research priority and design as well as in publications • Allow for a more flexible timeline and budget for meaningful engagement especially for integrating historically undervalued LMIC perspectives
HIC researchers & practitioners	• Approach all potential partners with openness and listen to all parties' interests and capacities to maximize contributions through sustained engagement • Structure in time and spaces for deeply understanding local histories and cultures, in a format determined by LMIC partners • Create time and spaces for LMIC partners to co-lead based on their interests and knowledge and adapt the research to local context and operational conditions • Identify interdependent and complementary relationships among stakeholders and potential challenges in interactions
LMIC researchers & practitioners	• Recognize the knowledge, skills, and other contributions and expectations of benefit from the engagement • Request that authorship be inclusive of LMIC partners and time allocated for publication led by LMIC partners' research interests • Leverage funding and resources from national and regional government and research agencies for greater ownership and rights
LMIC governments & communities	• Support and facilitate research and international development that engage in participatory processes in order to meet national research priorities and communities' needs • Recognize the ways in which HIC-LMIC partnerships depend on your engagement and whether alternative arrangements can be pursued

[57], are often undertaken where all parties are welcome to pitch in their hard work and enthusiasm. Social harmony and personal relationships are highly valued, taking care to avoid criticism or offending others by saying no, but instead remaining open and curious to learning from one another. Such willingness to seek and receive help from one's network of relationships contribute to a "can do" attitude and flexibility in adapting to broader social needs and transcending disciplinary and other boundaries. Fluidity in boundaries and identities could increase complexity at times, but largely helps to create more relaxed and informal interactions, where people get to know each other as people with lives outside of work, which lead to greater mutual understanding and mutual support.[1] While some of these cultural tendencies may introduce ambiguity, they are overall enablers of collaboration.

These examples of interactions also illustrate the uniqueness of the project in bringing together diverse knowledges and perspectives, which each on their own may not be new or unique, but in this case combining at a large, international scale, a broad array of environment, health, and development disciplines across academic, government, and community sectors, and spanning multiple countries. As such, there may be limitations and multifaceted understandings of fields and categories as gleaned from the data. For example, Humanities, Art, and Social Sciences (HASS) and Science, Technology, Engineering, and Mathematics (STEM) categories are limited to within academia, while built environment disciplines have evolved to transcend HASS and STEM, and academia and practice. Architecture may be in the art and design faculty of one university, or the engineering faculty in another. One participant completed their Bachelor's degree in geography in the science faculty of their undergraduate institution, but noted that geography was located in the engineering faculty in their graduate institution. Such differences in understanding presented challenges in implementation as discussed below.

4.2. Challenges in the implementation process, lessons for research design

Some of the challenges in implementation point to the limited inclusion of certain knowledge stakeholders at the early stages of the project, such as in the research design phase. It is common for HIC partners to meet with LMIC partners at the conception phase of a project, and request a letter of support. However, LMIC partners may not be involved to the same extent as HIC partners in identifying research priorities and co-designing the research. LMIC participants reported that they did not always feel empowered to voice their own research interests and perspectives, and insufficient time and space were built into the program to explore their interests, thus limiting their contribution to academic knowledge. Study data suggests that meaningful engagement of certain LMIC partners early on could facilitate later processes, whether academic partners with more experience in international partnerships, or government or community stakeholders that could influence the process at different levels. Some practical advantages could be a more comprehensive, resonant and expedient development of survey questions and response choices to include options familiar to traditional perspectives of health and formal and semi-formal health service providers. Examples of the latter given by participants in the focus group were midwifery and herbal therapies by experienced elders with the intergenerational knowledge on such therapies [58].

At the research design phase, it may be useful to consider which stakeholders' perspectives and inputs are *interdependent,* and which would be *complementary*, to achieve desired outcomes. Incorporating such a vast array of knowledges manifested into high intensity and frequency of interactions requiring space, time, and resources. Different languages used by stakeholders require consistent translation and interpretation to help equalize participation dynamics, on one hand contributing to collaborative rationality [38], on the other increasing transaction costs that could be built into project design and budgeting. Getting diverse stakeholders on the same page require skillful facilitation, multiple meetings, trainings, and back-and-forth communication which can affect initial research design and require adjustments from all parties. Orchestration of diverse stakeholders and knowledges also requires coordination and an open-endedness [59] to be able to adapt the research design to changing operational conditions and diverse stakeholders' requirements. On one hand, a transdisciplinary collaboration should embrace "building the plane while flying it," but on the other, allow contingencies for additional contributing stakeholders to jump on board and tweak the design of the plane. As the built intervention is just entering construction phase during the time of writing this manuscript, the classic downfall of international development projects can be avoided by continuing intensive community engagement and capacity building to ensure the longevity of the infrastructure. Participants described a familiar scenario of previous water and sanitation infrastructure breaking down, with no technical assistance available to repair the system, and no spare parts available in the country. Some of the infrastructure may have been built on donated land; without clear administration of land and asset ownership, such infrastructure may be subject to private appropriation.

Structuring such a program requires a recognition of interdependence and complementarity, as posited by scholarship on collaborative governance [38] and co-production in public administration

[1] https://culturalatlas.sbs.com.au/indonesian-culture, accessed 7 September 2022

[60]. As the data suggest, stakeholders may contribute diverse resources, coming together in different types of interactions and creating opportunities for mutual learning at the boundary spaces. This requires a culture of openness and valuing of different knowledge sources, especially historically disadvantaged LMIC perspectives. Such culture could enhance understanding of problems and produce innovative, exuberant solutions. While a common vision allowed for action towards a common direction, stakeholder interdependence necessitates meeting diverse interests through mutually advantageous arrangements. Inclination towards mutual support among the Indonesian team and their transcendence of boundaries towards mutual learning offer useful lessons for enabling transdisciplinary collaboration among HIC-LMIC partners. Beyond the core team, the program also depends on the knowledge and other resource contributions of Indonesian government and community stakeholders, and these interdependencies need to be acknowledged.

5. Conclusion

Further exploration and incorporation of the perspectives of LMIC stakeholders can contribute towards a more inclusive, global understanding of transdisciplinary knowledge integration. One participant's poignant reflection, titled "Weaving Togetherness," highlights the potential of harnessing local context knowledge and cultural values towards global impact in improving our collective environment. Indeed, decolonizing research scholars have long advocated for the recognition of interlinkages and interdependencies among humans and the environment, calling for the interweaving of knowledges through story-telling methodologies [61,62]. This study aimed to explore diverse LMIC perspectives, and to acknowledge the value of their stories and voices. Without them, valuable learnings on integration, interdependence, and cultural concepts relating to collaboration would have remained undercover. We acknowledge the immense privilege in conducting this study from an HIC institution, and aim to further leverage our findings by proposing some practical considerations for the design of future transdisciplinary collaborations (Table 3).

Glossary

Collaboration

In urban planning, a process that gathers and engages stakeholders in making decisions in a way that considers all interests and positions to produce innovative solutions to societal challenges with the contribution of all stakeholders' knowledge, skills, and resources. Such processes generate individual and collective learning, system adaptations, and increased resilience in the face of future uncertainties. [38]

Integration

In sustainability science, 'a key process in transdisciplinary research and knowledge co-production. . . a multidimensional interactive, open-ended learning process relating perspectives, knowledge, and practices [and] involving cognitive, emotional, and social-interactional dimensions [17,18]. Different definitions converge around the site of integration being *interactions* among actors, stakeholders, or team members [19,63].

Knowledge co-production

In Science & Technology Studies, a model of production of knowledge that recognises the inseparable evolution and interdependence of science and social order. Scientific knowledge depends on how it is produced, hence mediated by power, social practices, material resources, and institutions. [39,59]

In sustainability transformations, 'iterative, collaborative process involving diverse types of expertise, knowledge, and actors to produce context-specific knowledge and pathways towards a sustainable future.' [64]

Multidisciplinarity, interdisciplinarity, transdisciplinarity

Though frequently used interchangeably, the three terms are generally distinguishable by the degree of integration among disciplines as a litmus test or primary criterion. [20]

In health, multidisciplinarity is *additive*, 'draws on knowledge from different disciplines but stays within the boundaries of those fields.' Interdisciplinarity is *interactive*, 'analyses, synthesizes and harmonizes links between disciplines into a coordinated and coherent whole.' Transdisciplinarity is *holistic*, 'integrates the natural, social and health sciences. . ., and in doing so transcends each of their traditional boundaries. [65]

Planetary health

Planetary health is the highest attainable standard of human health, wellbeing, and equity globally and the natural systems on which human civilization depends. It recognizes the interconnections between human health and the health of the environment, and the impact of human activities on natural systems supporting life. Planetary health hence aims to promote policies and practices that protect the health of the planet while ensuring sustainable development and safeguarding human wellbeing. [1]

Transdisciplinary research

In health, 'an *integrative* process whereby scholars and practitioners from both *academic disciplines and non-academic fields* work jointly to develop and use novel conceptual and methodological approaches that synthesize and extend discipline-specific perspectives, theories, methods, and translational strategies to yield *innovative solutions* to particular scientific and *societal problems*.' [16]

In environment, 'a reflexive, *integrative*, method-driven scientific principle aiming at the *solution or transition of societal problems* and concurrently of related scientific problems by differentiating and integrating knowledge from various *scientific and societal bodies of knowledge*.'[15]

Transdisciplinary research is also considered equivalent to knowledge co-production in the sense of different disciplines coming together in a collaborative process among researchers, practitioners, and private and public sectors including civil society.

CRediT authors' statement

Jane Wardani: Conceptualisation, Methodology, Investigation, Data curation, Formal analysis, visualization, Writing - original draft, review & editing; **Joannette J. (Annette) Bos**: Supervision, Conceptualisation, Methodology, Writing - review & editing; **Diego Ramirez-Lovering**: Funding acquisition, Supervision, Conceptualisation, Writing - review & editing; **Anthony G. Capon**: Supervision, Conceptualisation, Writing - review & editing

Declaration of Competing Interest

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

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Supplementary materials

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Bridging disciplines-key to success when implementing planetary health in medical training curricula

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Planetary health is being or should be added to medical training curricula in accordance with association consensus. Several articles published in recent years have addressed concern on the implementation, and the challenges that can occur if not addressed properly. This scoping narrative literature review focuses on planetary health as a concept, as well as challenges and suggested solutions to address these challenges. Planetary health is an important concept and needs to be addressed in all medical training. We found that one main challenge is implementation without ensuring the right competences and resources. Medically trained teachers set out to understand and teach complex natural and social systems. At some institutions the time allocated to teach planetary health is limited or non-existent. Case studies and student led teaching are solutions suggested, while other argue that true interdisciplinarity by inviting experts are more in line with what we expect from other subjects. In conclusion, the roots of planetary health, the enormous health risks at stake and nature of the subject requires medical training to adopt a true inter/trans-disciplinary approach to succeed. It might not be expected for all students to become planetary health experts, but all need a general understanding of the most important aspects and values.

KEYWORDS

planetary health, one health, medical training, medical curriculum, climate change

1 Introduction

Planetary health is increasingly added to the medical training curricula in accordance with the international medical training association consensus. This is very promising, but several articles have raised challenges if the topic is not addressed properly.

1.1 What is the planetary health concept and where did it come from?

This little blue planet, perfectly formed for human life, has been our home for thousands of years. Earth systems enabled human life under the best conditions, a state that lasted for around 10,000 years, referred to as Geological period "Holocene." The anthropogenic (human-made) impacts on the planet's natural systems have led to civilizational successes of the past decades (e.g., increasing life expectancy and reducing poverty) coupled with negative global developments (e.g., loss of biodiversity, pollution and climate change). These trends are in an historical perspective

quite new, and often coupled with industrialization toward the end of the 19th century with an increase particularly from the 1950s onwards (1).

The alarm bell started in the early 1960s with Rachel Carson's book Silent Spring on man-made chemicals leading to a decline in birds (2). In 1972, Dr. Sargent wrote about the connection between the 'planetary life-support systems' and health and well-being (3). At about the same time, Gennady Tsaregorodtsev called for a new integrative hub of science called 'planetary public health' to better understand the evidence on the human health impact of environmental degradation (4). In 1980, Friends of the Earth expanded the World Health Organization definition of health, stating: "*health is a state of complete physical, mental, social and ecological well-being and not merely the absence of disease – personal health involves planetary health*" (5).

Some scholars highlighted that the idea that planetary health wasn't a new concept; rather, these ideas have been deeply embedded within Indigenous cultures for centuries (6). The first Navajo woman surgeon said "*human health is dependent upon planetary health and everything must exist in a delicate web of balanced relationships*" (7). We should thus be humble when we present planetary health as a novelty topic or 'new discipline'.

Planetary health can be seen as a concept that affects all healthcare providers and understood by our ancestors. This relates to indigenous knowledge, but also western ancient roots had a medical interest in the environment. The Hippocratic text *On Airs, Waters, Places* advised physicians to attend to all aspects of the environment. It took some decades for the planetary health term to become a term in mainstream modern medicine since its reintroduction in the 1980's. The success and widespread notion of the concept came with the highly-cited 2015 keystone report by the Rockefeller-Lancet Commission on Planetary Health (1). The report defined planetary health as "*the health of human civilization and the state of the natural systems on which it depends*," with its stated goal to find '*solutions to health risks posed by our poor stewardship of our planet*' (1), the term planetary health (and what it represents) had finally entered the lexicon of mainstream medicine. The *Commission* report calls for the application of interdisciplinary knowledge, as well as input from healthcare professionals to play important its roles by supporting environmental and social sustainability (1).

1.2 Planetary health in medical training curriculum

Medical schools are now being called to develop physicians with the skills necessary to navigate the planetary health crisis, including the natural science and policy transformation necessary. It has been argued that a physician's place is at the individual patient's bedside, but now also to preventatively advocating for public health beyond the bedside. Numerous medical societies and organizations have called climate change the single greatest threat to human health (8, 9). Medical students have been pushing for integration of climate health content in curricula to equip them to adequately care for patients in a rapidly changing environment (10).

Still the medical schools have failed to adapt fast enough. The International Federation of Medical Students' Associations conducted a survey in 2019 and 2020 in 2817 medical schools in 112 countries. Only 15% of medical schools had incorporated climate change and health and only 11% added air pollution and health into the curriculum (11). Another study covering 45% of the UK medical schools found a large disparity in the education that medical students receive on planetary health and sustainability topics, with many schools not prioritizing the field. The extent of teaching varied considerably among courses with a mean estimate teaching time of only just over two hours (12). Another study found that faculty often lack the knowledge to teach this emerging subject (13). In a US study using in-depth interviews found personal expertise as a barrier in applying climate change aspects in their teaching material or knowledge often bound to a specific person (14).

1.3 Aim

This narrative review article aims to give the reader a deeper understanding of planetary health as a concept and to explore challenges and solutions related to the interdisciplinary aspects of planetary health in medical curricula.

2 Method

This mini review used a narrative review approach which is considered appropriate when in relation to a collection of quantitative studies that have used diverse methodologies or theoretical frameworks. Narrative reviews are a useful way of linking together studies on different topics related to a new concept or to understand the historical perspective of a new concept (15). We conducted a search on PubMed on the term `planetary health' and ´education´, ´medical curricula´ or `interdisciplinary` and ´transdisciplinary´. We also expanded the references in the articles we had found by so-called citation searching, and snowball searching. As it is a narrative mini-review we had to make limitations if similar statements had already been included.

3 Results

3.1 Inter/transdisciplinary approach vital to planetary health

In the result section we will first highlight key finding on importance of inter/trans/multi-disciplinary in medical training of planetary health. In the next chapters we will take a deeper look into some disciplines that have been addressed in the literature.

Several frameworks to address planetary health into medical curricula has been suggested (16). This includes the Planetary Health Report Card, a student developed metric tool for evaluating and improving the planetary health content (17). Sustainable Healthcare Education network has developed methods of including planetary health literacy in clinical training, such as deeper understanding on how the environment is degraded, how this impact our health and what actions can lead to improvement (18). Along with learning the science behind environmental health, students need to develop skills to lead and advocate for community change according to the Association for Medical Education in Europe consensus (19). One suggested way to get students involved is working with case studies (20). Building students' commitment to planetary health approaches requires engaging students

in interdisciplinary active learning of a transformative systems-based paradigm (21). Other concepts suggest expanding interdisciplinarity to indigenous reciprocal stewardship of our natural surroundings (22, 23). Planetary Health Education Framework also highlights the importance of transdisciplinary knowledge (including epistemological diversity) (24). Climate Crisis and Clinical Practice initiative also highlights the need for medical training to include a multidisciplinary approach (9).

The One Health and Planetary Health approaches are increasingly influencing the field of medicine way of thinking in everyday clinical practice and research (25). Both approaches represent the integrative consideration of health topics against the background of other sciences. Particularly characteristic of planetary health are, among other things, the aspects of a transdisciplinary approach (26), and this was also the findings of the methods/frameworks we identified above. Another narrative review also had similar results of the need to work interdisciplinary when including planetary health in medical training. They also highlighted the importance to work across sectors to reach a better understanding of the interactions between humans and its surrounding environment (27). Based on the seemingly importance of inter/trans-interdisciplinary curricula we will highlight some important disciplines we found in the literature and how they could be addressed. This should not be seen a complete list of an ever-expanding field.

3.1.1 Natural sciences

With global health burdens shifting from infectious to non-communicable diseases (NCDs), we need greater emphasis on the health-mediating role of lifestyle and the human-manufactured threats to life within the biosphere (28). Irreversible changes to our environment have already occurred that are affecting the health of the world's population, also known as triple crisis. Environmental pollution can be detected in the most remote areas of the earth (29), and the consequences of climate change are measurable and visible (30). The natural areas are diminishing at high speed caused by anthropogenic (human made) environmental changes to the land (31).

The concept of Planetary health in the Rockefeller report was influenced by (32, 33) models of planetary stress limits. The boundaries represent components of Earth system critically affected by anthropogenic activities and relevant to Earth's overall state. For each of the boundaries, control variables are chosen to capture the most important anthropogenic influence at the planetary level of the boundary in focus. So-called tipping points were quantified, the exceedance of which results in the relatively abrupt and irreversible changes for the Earth system. These changes can challenge the socio-ecological resilience of societies and be catastrophic for societies and individuals alike (32).

For planetary health action to happen Anthony McMichael, one of the first epidemiologists to study the links between climate change and human health says: "*The health sector*," McMichael demanded, "*must lift its gaze to bigger, ecological horizons. This will require […] an ability to collaborate with unfamiliar disciplines*" (34).

The future leaders in medicine need to understand the basis of our natural life-supporting systems and their boundaries. This includes a profound knowledge of natural laws on which our life support systems depend (22, 23).

3.1.2 Political and economy sciences

A central characteristic of planetary health are also the terms of the urgency of transformative measures (35). It was physicians and the nascent public health movement of the 19th century that demanded the reforms in urban sanitation (36), workplace hazards (37), and battled the tobacco industry and often indifferent governments for tobacco controls (38). But never have the stakes been higher, or the scale greater, than what ecological crises now entail. The survival of our societies as we know them depends on medically informed political responses to the disruption of our planet's human life–support systems. This will require augmented skills in health promotion principles, and deeper knowledge for health professionals to politically mobilize through social, economic and environmental advocacy for urgent and major reforms (39). The World Health Organization ask for health actors that can identify and accelerate those climate change mitigation actions that brings the greatest health gains, including the promotion of healthy urban transport systems and diets (40).

The Association for Medical Education in Europe (AMEE) has made a consensus statement *Planetary health and education for sustainable healthcare* intended to inform national and global accreditation standards, planning and action at the institutional level as well as the role of individuals in transforming health professions education. They state: "*health professions education must equip undergraduates, and those already qualified, with the knowledge, skills, values, competence, and confidence they need to sustainably promote the health, human rights, and well-being of current and future generations, while protecting the health of the planet.*" As an example they mention the skills to model co-benefits to people and planet of socio-ecological informed health programs (19). Changes that are implemented in the spirit of climate protection usually contain an additional benefit (co-benefit) for health and vice versa as exemplified by environmentally friendly forms of transport and other lifestyle factors (41). Skills to understand these co-benefits and to quantify them also in economic terms puts planetary health on par with other agendas in political and economic discussions.

3.1.3 Social sciences

The consequences of human interaction with the earth's natural systems are diverse, interconnected, and global because of globalization and the sheer scale of human resource use and consumption. The fact that impact can be both local and global, and often unevenly distributed, makes environmental justice central in planetary health. Rich nations in the global north are primarily responsible for the transgression of planetary boundaries, such as causing significantly higher CO_2 emissions. But the effects of which are felt most acutely by poorer countries in the global south (30). Social determinants of health can either improve or exacerbate vulnerability to poor health outcomes associated with climate change, pollution, and access to green areas. Knowledge of vulnerable groups by age, culture and socio-economy and other determinants are important to consider when setting health recommendations (42). This makes it important to get a deeper understanding of inequality and justice perspectives of planetary health.

3.1.4 Medical science

Resident physicians need to be equipped to care for patients affected by climate-mediated disease and advocate for solutions to the climate crisis. One approach is to organize evidence-based topics in climate and health by medical subspecialty and integrated them into pre-existing lectures in the longitudinal, outpatient lecture series (43). This will still require that students have some background knowledge on ecosystem services and planetary boundaries. Humans are inter-linked with the necessary life-support systems of this planet. In total

about one quarter of all global preventable premature death is due to environmental risk factors (44).

Future physicians must be aware of, for example changes in infectious disease patterns due to lack of clean air and changing weather patterns affected by flooding and temperatures. The planetary boundary *novel entities* relate to released unsafe chemicals which are directly linked to health. Novel entities can be exemplified by the release of Per-and polyfluoroalkyl substances (PFAS) which can be present in municipal drinking water and reduce antibody levels in response to vaccination (45). Another planetary boundary is the aerosols which relates to air pollution of combustion particles that can penetrate the alveolar blood-gas exchange and causes about 7 million premature deaths a year (44). The planetary boundary, nitrogen excess, impacts ecosystems by eutrophication and more directly humans by drinking water quality. The health impacts is early in life the blue baby syndrome and later in life an increased risk of cancer (46). Planetary health is also not only about global changes but to understand local exposures. Future physicians need to develop a system thinking of these complex interrelationships with patients in their entire environment and how social determinants can impact health effects.

4 Discussion

Gaining support from medical school faculty can be a major challenge. In a study of eleven medical schools in UK, one educator said that sustainable healthcare '*was at first seen as one of my pet extra projects*' (47). It was suggested that with time as more residency programs incorporate environmental-related content into their curricula, faculty will become more familiar with these important topics and allocate time and resources (43). Moreover, an overarching paradigm of higher education often upholds ideologies of individualism and meritocracy and a shift toward skills in compassion-knowledge-reflection are highly needed (22). The need of planetary stewards was put forward by 126 Nobel prize laureates in their 2021 statement *Our planet, our future*. One suggested way of getting an increased understanding of our interlinkage with our planet and thus the importance of biodiversity is getting the subject near the heart of the students. One example is the understanding of biomimetics for curing diseases as one third of medications used in healthcare originate from nature, the development of future cures depends on preserved diversity (48). For others it can be beneficial with the introduction of the ecosystem framework which categorize the benefits of healthy functioning ecosystems that regulate (climate), support (water, food, medicine, air) and provide services for human health and wellbeing (49). Even though this concept still has an aspect of anthropocentric (human-centered) thinking seeing nature purely as goods, it can be a steppingstone for those furthest from a more eco-centric planetary health thinking.

Teaching planetary health to students presents unique challenges, especially when some students may deny the human impact on climate change. This mirrors societal skepticism, where vocal climate change deniers exist despite overwhelming scientific consensus. It is crucial for lecturers to be exceptionally knowledgeable, capable of engaging in informed discussions with students who question the human role in climate change and planetary health. Most students have on the other hand grown up aware of insufficient actions against climate change, mass species extinctions, and pervasive pollution. This background can lead to feelings of hopelessness for some students, making the topic particularly heavy during their early clinical training years. Therefore, it is imperative that educators in planetary health maintain a high level of expertise. They must be equipped to address the skepticism of some students while also supporting those who may feel overwhelmed by the gravity of environmental issues (50). Balancing these perspectives with scientific rigor and empathy is essential for fostering a constructive and educational environment.

Using only medically trained faculty is deemed to fail in teaching a subject such as planetary health. Management of "wicked problems," messy real-world problems that defy resolution, requires thinkers who can transcend disciplinary boundaries, work collaboratively, and handle complexity and obstacles (51). Medical training would benefit from including faculty researchers from a range of disciplines across the natural, social and health sciences (52, 53). An in-depth study of one medical school on successes and pitfalls in introducing climate change into the medical curricula recognized the importance of climate and health literacy on all levels, also those with the power to make curricular decisions (54).

We acknowledge that this article is a narrative report and should not be seen as a systematic review covering all relevant studies in the field. The selection and interpretation of studies rely on our perspective, potentially introducing bias, neither was the study quality assessed systematically. Despite these limitations, our study can provide an overview of the emerging fields of planetary health and identify some challenges and suggested solutions.

5 Conclusion

In conclusion, the roots of planetary health, the enormous health risks at stake and nature of the subject requires medical training to adopt a true inter/trans-disciplinary approach to succeed. It might not be expected for all students to become planetary health experts, but all need a general understanding of the most important aspects and values.

Author contributions

EM: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AO: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Pedagogical strategies for supporting learning and student well-being in environmentally sustainable healthcare

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Planetary health education needs fresh approaches to engage learners and educators in positive visions and future planning to navigate the societal challenges of climate change. The human health impacts of the climate crisis, environmental degradation and pollution are far-reaching and compounding in nature. International leaders in healthcare are recognizing the time-pressured opportunity to mobilize and motivate colleagues to optimize health outcomes by addressing these issues. Healthcare systems across the globe contribute significantly to ecological footprints through greenhouse gas emissions and consumption of various polluting materials. Therefore, the necessity to prepare future health professionals to identify and manage environmental health conditions in their patients, as well as foster their future role as leaders and advocates in sustainable healthcare is acute. Health education organizations have begun to appreciate this need and have developed learning objectives to guide curricula. In the development and implementation of content on environmentally sustainable healthcare, an important consideration is the affective and moral distress from the confronting and often overwhelming nature of the topic. The main objective in teaching planetary health is to equip learners with the tools and skills to address the relevant health issues in their professional role whilst providing the support necessary for them to accept these harsh realities. The University of Newcastle and University of New England Joint Medical Program's, four-week course in Sustainable Healthcare aims to meet this objective. In this article we discuss how our curriculum utilizes Self-Determination Theory (SDT) and other psychological strategies to support learners' well-being and motivation. SDT explains the need for supporting autonomy, relatedness and competence in the learning environment. Strategies employed to address these include providing students with the opportunity to select discussion topics that they contribute to, maximizing choice of focus for the assessment task, utilizing personal reflections, case-based learning scenarios and incorporating presentations from relatable industry leaders.

KEYWORDS

planetary health, health professional education, sustainable healthcare, educational theory, student well-being

1 Introduction

As medical students are at risk of emotional distress when they learn about the effects of climate change on individual and population health, their well-being must be seen as a priority in order for them to maintain their motivation to engage with the subject. This is also critical for their understanding that their future professional involvement needs to be guided by moral values. Human health has long been recognized to be dependent on healthy and intact ecosystems, but the environmental determinants of health are now changing in unprecedent ways and rates. Planetary health has emerged in the wake of global events and encompasses climate change, biodiversity loss, pollution and the need for humans to live, work and to maintain their health in ways that do not compromise the ability of future generations to do the same (1).

In order to be fit for purpose as future doctors, medical students need to learn about the changing environmental determinants of health, understand the health impacts of planetary degradation and how to mitigate risk to their patients, practice in a sustainable way and advocate for reducing the environmental impact of the health care system (2). The addition of curricula to prepare medical students for managing the impacts of climate change or how to practice in an environmentally sustainable way is relatively recent. In 2019 an international survey of medical students identified that only 15% of medical schools had begun to include climate change and health into their curriculum (3). In recent years health professional education stakeholders have proposed learning objectives (4) and recommendations to assist in developing planetary health curricula (2, 5, 6). Whilst a number of programs have begun to implement and evaluate curricular interventions in this area (7–17), there has been little consideration as to which educational approaches support student well-being. Climate change is now causing widespread illness, injury and death from direct effects such as extreme weather events and sea level rise, and indirect causes such as crop failure, civil unrest and population displacement (18, 19). Further worsening impacts from climate change are unavoidable, and the likelihood of societal collapse and widespread suffering is increasingly described in the literature (20). The scale of the challenge of working to ensure that humanity lives within the capacity of the planet is such that students can feel overburdened. Uncomfortable feelings in learners can arise as they grapple with complex real-world problems entrenched in politics, exploitation, social disadvantage, and power imbalances (2).

Eco-anxiety, climate change distress and solastalgia are terms to describe negative emotions that relate to concern about the future, the loss that has already occurred, and the adverse consequences of human impact on the environment (21, 22). The psychological response to environmental degradation encompasses a wide range of emotions, especially in the younger generations. In their international study that surveyed young people from ten different countries on climate change distress, Hickman et al. found that of the 10,000 participants, over 50% reported feeling anxious, angry, sad, afraid, powerless, helpless and guilty (21). Furthermore, over 45% of participants felt that their feelings negatively impacted their daily life (21). These emotions originate not only from the concerns of the devastating impacts of environmental degradation, but also from the perceived lack of influence to tackle the enormous task ahead. The majority of power, when it comes to preventing and mitigating the impacts of threats to the planet, is held by governments, dominant industries and large corporations. Not only do individuals perceive they have little influence over these bodies, but there is also a sense that these entities are not adequately addressing the issues at hand. The Hickman et al. study also found that only 30% felt that their governments were taking their concerns about climate change seriously and 58% they felt their governments were betraying them and/or future generations (21). While this international study is the largest quantitative study contributing data to our understanding of emotional distress in young people related to environmental degradation, surveys of young people in Australia and the UK have demonstrated that significant proportions, 89% and 74%, respectively, of young people are worried about the effects of climate change (23, 24). A recent study of over 15,000 young people in the US demonstrated that 85% of participants were at least moderately worried about climate change and it's potential impacts (25). There is also significant concern raised by academics and health professionals regarding the direct and indirect effects on the psychological well-being of young people (26–31). Furthermore, the significant increase in youth led climate activism globally demonstrates the level of concern for the future amongst our youth (29). While the psychological impact of learning about sustainable healthcare on medical students has not been specifically investigated, students within studies evaluating a sustainable healthcare curricula intervention have described learning about climate degradation and the effects on patients as "scary", highlighting the importance of curricular to create a sense of empowerment to balance the potential distress and reduce the chance of becoming "disillusioned" or "disengaged" (10, 32). Educational stakeholders have recognized that we have a responsibility to consider student well-being and cultivate resilience for learning about this potentially confronting and "sobering" topic (33) and dealing with planetary health related uncertainty (2).

There is much to be gained by educators utilizing psychological theories that optimize human motivation for planetary health education. Implementing learning strategies underpinned by psychology enables knowledge acquisition, while supporting students to develop adaptive coping strategies and capacity to enact change in the face of uncertainty.

2 Pedagogical frameworks

Compared to when many of today's educators may have learned about motivation in the last decades of the previous century, we now better understand the basic psychological needs of people which if catered to, can provide conditions for optimal performance, creative problem-solving and conceptual learning (34). Faced with current and future planetary health challenges, professionals need to be optimally motivated and engaged. Self-determination theory, as developed by Deci and Ryan, explains that better outcomes result when a person is autonomously motivated, rather than controlled or incentivized contingent on performance. In other words, there are different types of motivation, and when people are intrinsically interested in an

activity, or personally identify the value of doing it, then they will be more energized and effective than if they feel or are forced into doing something, whether due to obtaining rewards and approval or to avoid shame or punishment (35). Social contexts, including educational settings, can support these natural tendencies or thwart them. The provision of the deep needs of people for autonomy, competence, and relatedness allows optimal human flourishing. Autonomy is the need to self-regulate one's experiences; a sense of voluntariness as distinct from independence. A hallmark of autonomy is that one's behaviors are self-endorsed. Competence refers to the need to feel effective and feel mastery when completing tasks. Relatedness is to feel socially connected, feel cared for by others, and contribute to others.

If these needs are satisfied, people are more likely to develop and function effectively and experience wellness. If these needs are thwarted, people will more likely evidence ill-being and non-optimal functioning. Classroom studies have shown that provision of autonomy to students by both teachers and parents has helped students maintain intrinsic motivation (36). Autonomously motivated learning has been found to lead to better educational outcomes, and medical students who have had autonomy-supportive learning have been shown to provide patient care that is more autonomy supportive (37).

Optimizing motivation is part of what is required in delivering planetary health education, but equipping learners with the emotional tools to manage the knowledge that they acquire is just as important. Climate change distress may be eased with judicious use of adaptive coping. Seth and colleagues have helpfully explained that such strategies comprise:

- Emotion-focused coping which addresses the feelings associated with climate change.
- Problem-focused coping which leads to behavioral responses.
- Meaning-focused coping that builds on hope and one's values (38).

The Australian Psychological Society outlines examples of adaptive coping strategies in their "Coping with change distress" resource. These include: taking a break from the 24/7 news cycle, taking specific action that is within one's own control to reduce their own carbon footprint, and prioritizing issues that are the most important, recognizing that no-one can do everything (39).

A third theoretical framework that is applicable to this area concerns taking action that is based on what is important to us. Acceptance and Commitment Therapy (ACT) has been identified as particularly suited to climate change distress with confronting concepts that cannot be refuted, highlighting the benefits of values-guided action. ACT provides guidance on how to reduce the impact and consequences of uncomfortable feelings and thoughts while planning actions to build a rich and meaningful life (40). While ACT is designed for clinical application, educators can apply some of these principles in guiding students to consider what is important and meaningful to them, and then to use these values to develop plans for actions that will enrich and enhance their lives and the world around them.

3 Learning environment

To demonstrate how principles of adaptive coping, self-determination theory and values-based action can be applied in planetary health curricula, we will describe the development of the sustainable healthcare course of the Joint Medical Program of the University of Newcastle and the University of New England (JMP). This course has been based upon the learning objectives of the Medical Deans Australia and New Zealand (MDANZ) Working Group on climate change and health. In 2017, a group of educators came together to develop learning objectives which were distributed to all medical programs in Australia and New Zealand as a resource that could be used to incorporate planetary health learning objectives in their curricula (41). The learning objectives were also published in the Medical Journal of Australia (4). The specific learning objects for the JMP course can be found in Table 1.

The four-week sustainable healthcare course commenced in 2021 as core learning for Year 3 of the JMP. The JMP is a 5-year program, of which the first two years are primarily classroom based and include a brief two-day General Practice (GP) placement. Year 3 of the program includes GP, hospital and classroom-based rotations. The sustainable healthcare course is conducted several times per academic year, with approximately one eighth of the student cohort completing their course at any one point. Therefore, students' prior exposure to clinical placements varies depending on when in the year their sustainable healthcare course occurs. A breakdown of JMP Cohort Demographics can be found in Table 2.

In developing the content, we were cognizant of balancing the emotional load for students whilst equipping them with knowledge and skills in this field. The course comprises three modules, each completed over one week. The module's content aligns with both the MDANZ Working Group learning objectives, and three of the four Australian Medical Council (AMC) domains for graduate outcomes; Science and Scholarship, Clinical Practice and Health and Society (42, 43). Throughout the program, we present a range of resources from different sectors, aimed at a variety of audiences for students to reflect upon how best to communicate about climate change and planetary health. Each module centers around carefully curated shared resources which lead to tasks for students to complete. These relate to real-world problem solving within Australian and international healthcare settings, with an emphasis on the Australian healthcare setting. Each task incorporates opportunities for student reflection. Once per week, learners and their academic facilitator engage in a small group tutorial, where they discuss their reflections and engage in case-based learning. The final week of the four-week course is set aside for preparing and delivering their final assessment presentations.

3.1 Module 1 relates to science and scholarship

This Module begins with the tenet that human health is fundamentally dependent on healthy ecosystems. As part of this module, students are tasked with watching an introductory presentation about planetary health and making a note of what

TABLE 1 Learning objects JMP sustainable healthcare course.

Week 1—module 1: science and scholarship
Outline the dependence of human health on global and local ecological systems which supply clean air, clean water and nutritious food and the Earth systems that provide a stable climate.
Discuss the contribution of human activity to global and local environmental changes such as climate change, and biodiversity loss and resource depletion in land and marine environments.
Describe the mechanisms by which human health is affected by environmental change, e.g. exposure to extreme weather, change in disease vectors, migration and decreasing food and water security.
Explain how the health impacts of environmental change are distributed unequally within and between populations and the disparity between those most responsible and those most affected by change.
Week 2—module 2: clinical practice
Prevent, diagnose and treat the adverse health effects attributed to climate change and environmental causes.
Propose ways to practice medicine sustainably by considering what models of care could reduce the environmental impact of best practice care and service delivery to patients.
Propose ways to practice medicine sustainably by considering the environmental impact of medications and other treatments in prescribing decisions.
Identify the vulnerabilities of health services and health facilities to climate change and extreme weather events and how these risks can be minimized and prepared for.
Explain the concept of 'health co-benefits' by considering how lifestyle choices can promote both patient well-being and a healthy environment.
Week 3 and 4—module 3: health and society, professionalism and leadership
Identify the role of health care professionals in advocating for policies and infrastructure that promote the availability, accessibility and uptake of healthy and environmentally sustainable behaviors.
Describe features of a health-promoting local environment, in community and healthcare settings, to include access to green spaces, clean air, and an active travel infrastructure.
Explain how trends in climate change may affect capacity to provide healthcare in the future.
Explain the contribution of the Sustainable Development Goals to addressing the socio-economic and environmental determinants of health.
Identify ways to improve the environmental sustainability of healthcare systems by reducing the carbon footprint through individual practice, health service management and the design of care systems.

Learning objectives derived from the MDANZ Working Group on climate change and health (4).

TABLE 2 Cohort Demographics of three year groups of Joint Medical Program Students who had completed the Sustainable Healthcare course by 2024.

Age Range (years)	18–24	25–30	31–39	40–50
	352 (60%)	174 (30%)	41 (7%)	15 (3%)
Gender	**Male**	**Female**	**Non-binary**	
	281 (48.3%)	299 (51.4%)	2 (0.3%)	
Total 582				

made the greatest impression on them. This is when students introduced themselves to each other within the group.

Students consider the effects of climate change in Australia as depicted in a video by the Bureau of Meteorology. The task is to consider what climate change impacts have been most apparent where each of the students are living or regard as home. Two articles are presented that utilized air quality data to determine the burden of disease, mortality and economic impact of the 2019–2020 bushfires in Australia (44, 45). This presents a chance for students to consider how environmental health data and modeling can be used to highlight impact contemporaneously, as well as how socioeconomic and health impacts of environmental change are unevenly distributed within and between populations.

In recognition that reading and thinking about climate change and other large scale environmental threats can be confronting, and sometimes distressing, students are referred to a resource "Coping with Climate Change Distress" developed by The Australian Psychological Society (39). Students are directed to think about how these techniques could be useful to themselves and others, and discuss which of the "recommended activities" in the resource resonate with them.

3.2 Module 2 relates to clinical practice

Within this Module students explore the need to adapt clinical practice to manage the health impacts of climate change, the ecological footprint of the healthcare system and the concept of "health co-benefits".

Students learn that health services and facilities are vulnerable to climate change and extreme weather events. They are directed to the World Health Organization "WHO Guidance for Climate Resilient and Environmentally Sustainable Health Care Facilities" to consider how the outlined consequences of climate change for health care facilities could apply to their region or a community of practice (46). The task is to bring to the tutorial an idea for a way of safeguarding the health care facility and/or its staff from this consequence of climate change and whom they could approach to have this implemented.

The Module examines how healthcare itself has a large ecological footprint. Students are directed to read an article that argues that health professionals have a role in advocating for reducing the environmental footprint of healthcare (47). In their assigned task, students think of an example of how they became more aware of their personal environmental impact and how this led to behavioral change. Students watch a presentation by the Local Health District's Executive Director of Infrastructure and Planning on leading and managing change in healthcare, such as new models of care to reduce environmental impact and achieve carbon neutrality whist maintaining best practice care for patients.

Additionally, the idea of sustainable medical clinical decision-making is introduced. Sustainability in medication prescribing is now mainstream in the UK's NHS (48), and explained in an article from the UK National Institute for Health and Care Excellence (49, 50). Students reflect on how they can apply these principles in patient consultations about respiratory inhalers, considering factors of patient preference, compliance and medication safety. The final component of this module introduces students to "health

co-benefits", highlighting that lifestyle choices can promote both patient well-being and a healthy environment. Students interact with television media from Australia's national broadcaster that engages viewers in understanding the carbon footprint of different foods. Students also contemplate the best way for patients to receive information about the environmental impact of medicines, diet and lifestyle advice.

3.3 Module 3 relates to advocacy

In Module 3, students consider opportunities for doctors and other health professionals to advocate for improved health of patients and the environment. Examples given include:

- Patient education about healthy lifestyle choices (diet, exercise, transport options) that have environmental co-benefits,
- Writing and releasing reports, contributing to public and academic forums,
- Position statements from professional colleges,
- Submissions to government committees of enquiry and lobbying members of parliament, and
- Media comment, interviews and advertisements.

Students read the report produced by Doctors for the Environment, Australia entitled "Net zero carbon emissions: responsibilities, pathways and opportunities for Australia's healthcare sector" and are tasked with discussing how effectively this report conveys its message and ways that it could be improved (51).

Students watch two interviews with one student and one clinician leader in the field of environmental advocacy and sustainable healthcare practice, and a TED talk by a representative of Doctors for the Environment. The task is for students to share perspectives on leadership qualities that they observe in watching these advocates. Students engage with a multi-media comedic article and reflect on how humor has a place in communication about planetary health issues (52).

Lastly, the Module highlights how planetary health relates to the United Nations' Sustainable Development Goals (SDGs). Multiple nations, including Australia, have signed up to the SDGs as a way of addressing socio-economic and environmental determinants of health, and these are pertinent to planetary health on an international scale. 'Health equity' is considered using resources of the World Health Organization and a presentation by Professor Michael Marmot on the socioeconomic determinants of health inequity (53). The task is to reflect on one of these SDGs and consider how health professional advocacy and action could enable progress toward this SDG in a particular community. This activity brings together a range of sustainability challenges, allowing students to consider a multidisciplinary lens for problem solving and to explore an interest area in more depth.

3.4 Tutorial case-based discussions

Throughout the course, small groups of 8–12 students meet weekly with a tutor for 90-minutes to review the learning from each module. The assigned reflective tasks form the basis of student led discussions, providing structure to the tutorials. Each week we give students the opportunity to write their name next to the two or three tasks for which they would like to lead the discussion and contribute what they have learned. This provides a reliable way of starting the group discussion and avoids what can otherwise be awkward pauses or students feeling put on the spot.

In addition, for each module the group navigates through a clinical case that is related to planetary health. Each case discussion includes aspects of altered illness patterns from climate change, as well as key tenets of clinical practice, ethics and the social determinants of healthcare.

The case study for Module 1 is an older woman who presents with a bushfire related exacerbation of asthma. As well as the clinical diagnosis and management of her condition, students consider issues including shared decision-making about the patient returning to her home, the risks that this may pose to her health, and longer-term worries about the prospect of fires becoming more frequent with climate change.

The case study for Module 2 is an older man who has a syncopal episode in his backyard during a heatwave. Students need to consider how to assess syncope, how to classify heat related illnesses, and both the acute and longer-term management priorities.

In Module 3 students discuss a young student who presents with a history of fever, rash and joint pains. Her travel history requires consideration of zoonoses including Ross River virus and dengue fever. Students discuss how environmental factors influence vector population breeding habitats and patterns, and the subsequent impact on disease incidence and geographical spread of communicable disease outbreaks. They explore the role of the public health units in prevention and response to such changes.

3.5 Assessment

In the assessment for this course students are required to submit a pre-recorded ten-minute presentation in week four of the course. All presentations are viewed in a seminar, with questions and student-led discussion following each presentation. Students need to choose three learning objectives to address in their presentation - one of the learning objectives from Module 1, one from Module 2, and one from Module 3. Since these are quite general, students are able to focus their presentation on a particular topic that is of most interest to them.

4 Experience of course delivery

This program has now been delivered to over 700 medical students since 2021. As this was a new program with delivery being online and utilizing zoom tutorials due to the COVID-19 pandemic, we were keen to understand how students engaged with the material and whether they could achieve the learning outcomes in a remote format. Following overall positive feedback, we continued to deliver this material online and this provided students with more choice of how and where they spend this month-long course.

The modules gave students the opportunity to explore the diversity of resources in as much or little depth as they liked. Being able to choose their own assignment topic and research in depth gave them the freedom to explore what was of interest to them, and creating a video was an engaging way to learn. For example, students' presentations have addressed topics as varied as anesthetic gases, microplastics, air pollution and active transport (Table 3). Some students drew on their own experiences living in a particular location, and personal experiences of climate impacts such as bushfires, floods and droughts. We received early feedback that students needed more direction about how much to cover given the range of areas was broad. We responded by ensuring that students were comfortable with the expectations after each tutorial and clear about the idea being to break complex information down into teachable moments for the other group members.

The reflective tasks, and subsequent discussions, were observed to have provided an opportunity for students to connect over common experiences, challenges and goals. The case-based learning applied the concepts of planetary health into a clinically relevant context. Students had many opportunities to link the cases to recent climate events, and relate them to their personal experiences of local bushfires, major flooding events and outbreaks of zoonoses such as Japanese encephalitis in previously unreported regions.

Each year, students have been asked to complete an anonymous evaluation about the sustainable healthcare course. Since its commencement in 2021, 51.1%, 39.7%, and 8.3% of the 360 respondents have rated the quality of the learning experience as excellent, good and satisfactory, respectively (RR = 53.3%). We have regularly incorporated feedback from students about changes that could improve the course. This included giving them further guidance about their assessment task, use of additional pre-tutorial resources, and discussion of optional activities that students could be involved with including the Australian Medical Students' Association (AMSA) Code Green initiative and attending a local "green" operating theater that featured environmentally sustainable innovations. A number of students have taken advantage of this opportunity. Two publications spotlight an example of how our course inspired further scholarship and student advocacy in the area of environmental sustainability in anesthetic practice (54, 55).

TABLE 3 Examples of assessment topics.

Topic area	Specific examples
Climate event or environmental hazard related to location	Sea level rise in Pacific Islands, Bangladesh and Japan, Water security for remote Indigenous communities in Australia, tuberculosis in India, malaria in Papua New Guinea, dengue fever in Singapore, Flooding in Malaysia, bushfires in Australia, heat waves in Japan
Environmental issue	Micro-plastics, pharmaceutical manufacture and waste, funerary practices, sanitation in healthcare, green spaces in hospitals
Clinical specialty	Environmental footprint of radiology, renal health with emphasis on dialysis, telehealth, surgical waste, anesthetic gases, public health initiatives

5 Discussion

Medical school curricula need to feature the changing environmental determinants of health and how students and doctors can be agents of positive change. However, the principle of "first do no harm" applies to the learning environment as it does to healthcare. How do we care for our students as they learn about planetary health, when increased awareness of climate change and other ecosystem changes can lead to distress, poorer mental health and burnout especially amongst those who may already be involved in advocacy?

We have applied several principles from motivational psychology in how we have delivered our sustainable health course, but more can be done. Educators need to be mindful of the impacts of planetary health content and assist learners in coming to terms with the enormity of the challenge and showing a path toward progress. Acceptance and commitment therapy or training, offers the practice of avoiding being hooked by unhelpful thoughts and ruminations that can lead to despair and instead identifying productive ways of thinking about the opportunities for moving in desired directions. Committed action is best planned by first being in touch with one's values. Our students are invited to consider their values in thinking about how health professional advocacy could achieve progress toward a sustainable developmental goal in a particular group in one exercise. However, this principle could be further applied by incorporating subsequent projects or teamwork exercises.

Self -determination theory explains that people are more likely to maintain intrinsic motivation and enjoyment in learning if their environment promotes autonomy, competence and relatedness. In our course we have implemented a number of strategies to enhance the learner's autonomy. Students chose which discussion points to lead during the tutorials, and the direction in which they take these. Students also have autonomy over the areas of interest to research and present to the group. The self-paced modular content and tutorials on zoom also provide flexibility and convenience for students. There are however limitations on autonomy in that the course and assessment are compulsory. This is overcome by some programs in having environmental sustainability as an elective choice, however this limits the reach of this important area of curriculum development.

In terms of relatedness, students in our example learn in small groups with a dedicated tutor, and have the opportunity to consider each other's perspectives as they reflect on their own learning and personal experiences. The reflective task in module one which asks students to describe what climate change impacts they have observed where they live or within the location they call home, fosters connection within the group by recognition of common experiences and concerns. A sense of relating to their community of practice is fostered by incorporating presentations from medical leaders who display openness in sharing their own challenges, hopes and fears. Likewise, the host in the featured mainstream media production on the carbon footprint of foods, shows vulnerability by expressing his own concerns, knowledge gaps and personal mistakes (56). Finally, the assessment task is a time for students to learn from each other and provides the opportunity for shared learning and encouragement. Further

possibilities to strengthen a sense of relatedness could include increasing time allocated within the course for group activities and sustainability projects with their wider community of practice.

Students may develop a sense of competence by problem-solving clinical approaches to a variety of patient presentations that relate to climate change and environmental health impacts. The design of the assignment allows students to acquire depth of knowledge in their particular areas of interest, which they utilize to educate and facilitate discussion with their peers. A number of the reflective tasks also provide students with an opportunity to practice a new skill and receive group feedback. In module 2, for example, students reflect on the coaching model of balancing support and challenge, and describe how they could utilize this to make a change in their own lives. Students bring this to the tutorial to discuss and receive feedback. While these tasks support the development of competence, students are not formally assessed on levels of competence during the course. Ways of doing so could include embedding hands-on experiences within the course for students to practice and be assessed on their clinical or advocacy skills.

Our course draws on concepts of adaptive coping. Within the first week of our course we check in with students during the tutorial about their reactions to the content and provide them with resources that promote emotion focused coping (39). Students are invited to share particular adaptive coping strategies that resonate with them. Part of our strategy is to provide positive examples of progress in environmental sustainability, and provide a sense of hope for a better future. A benefit of this is that students learn about skills that could help their own future patients to deal with climate change distress.

Educators in all disciplines need to consider how best to engage learners. Planetary health has the potential to overwhelm learners with its scope, and to lead to distress about the concerning trajectory of climate change and environmental degradation. At the same time, there is the opportunity to inspire medical students to embrace the challenge of protecting the health of patients and communities from current impacts of extreme weather events and ecosystem damage, and to develop adaptive capacity for a changing world. Being mindful of relevant and helpful psychological theories and interventions can help to sustain learners and to assist in positive change and solutions that promote environmental sustainability and safeguard the future.

6 Acknowledgment of context

Introducing new curricula with considerable time allocation is typically challenging due to the existing content-dense medical curricula. In this case, the cancellation of an elective community placement in which many students traveled overseas, due to the COVID-19 pandemic provided an opportunity to introduce this content. Students now have the opportunity to learn about planetary health embedded into their medical education, while the overseas elective opportunities were shifted to later in the degree.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

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Towards a practice framework for transdisciplinary collaboration in planetary health

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Abstract

Non-Technical Summary. Despite growing recognition of the importance of transdisciplinary research in addressing complex sustainability challenges, in practice it has been much hampered by persistent inequities, power disparities, and epistemological disconnect. Planetary health as an emerging field offers a unique lens highlighting the need for knowledge integration across the environment, health, and development (EHD) nexus. Drawing upon extensive analyses, including a meta-analysis of existing transdisciplinary frameworks, a literature review of practices in these fields, and a case study of a planetary health action research project in Indonesia and Fiji, we propose a framework to guide the design and implementation of transdisciplinary research.

Technical Summary. The proposed framework was iteratively designed, starting with existing frameworks, complemented by findings and practice recommendations from a literature review of 36 publications of recent transdisciplinary practices in the EHD fields and an in-depth case study of a planetary health research from Indonesian perspectives. The practice framework focuses on the stakeholder collaboration process, and emphasizes reflexivity and co-learning throughout all research phases: initiation (co-design); implementation (adaptive co-management), and monitoring and refinement (co-monitoring). Foundational considerations for stakeholder engagement could inform process design by reflecting on stakeholder contributions, interactions, integration, and expected outcomes. As suggested by development studies, and implicitly agreed upon but insufficiently elaborated within environment and health, attention to the local context of the research, mapping of power dynamics, and the values of equity and inclusivity are pertinent if research is to produce credible, relevant, and legitimate knowledge and outcomes. A renewed focus on addressing power equities can help ensure stakeholders' perspectives and interests are equally valued and potential solutions are not inadvertently excluded as a legacy of systemic power imbalance. The practice framework is most effectively applied in the initial process co-design, by process initiators and funders assessing proposals for international transdisciplinary research in power-diverse settings or resource-poor contexts.

Social Media Summary. How can researchers across diverse fields collaborate with renewed focus on power inequities to accelerate progress towards the Sustainable Development Goals?

1. Background and context

Transdisciplinary research approaches have been increasingly promoted and practiced in order to co-produce knowledge and urgent action towards the 2030 Sustainable Development Goals (SDGs). In particular, the emerging field of planetary health calls for the expansion of transdisciplinary (TD) knowledge integration and collaboration amongst scientific disciplines, policy, and societal stakeholders for more significant impact and coherence, as systemic disconnect among sectors could potentially delay meaningful and lasting impact (Pongsiri et al., 2017; Zeinali et al., 2020). Planetary health also offers a unique lens highlighting the interconnections amongst the health of natural systems, human health, and socio-economic development, as evidenced by the irreversible harm to human and environmental health caused by socio-economic development systems during the Anthropocene (Whitmee et al., 2015). Previously, such interconnections were conceptualized by human ecologists as biosensitivity (Boyden, 2016, 2004) and echoed by proponents of a broader eco-epidemiological understanding of health (McMichael, 2013). Boyden (2016) also extensively underscores the importance of reducing disparities among all sections of humanity towards intergenerational equity. With the Leave No One Behind (LNOB) imperative at significant risk, collaborative efforts with greater emphasis on addressing inequalities could provide a worthwhile boost towards the SDGs (Browne et al., 2023). Figure 1 shows the intersection of environmental

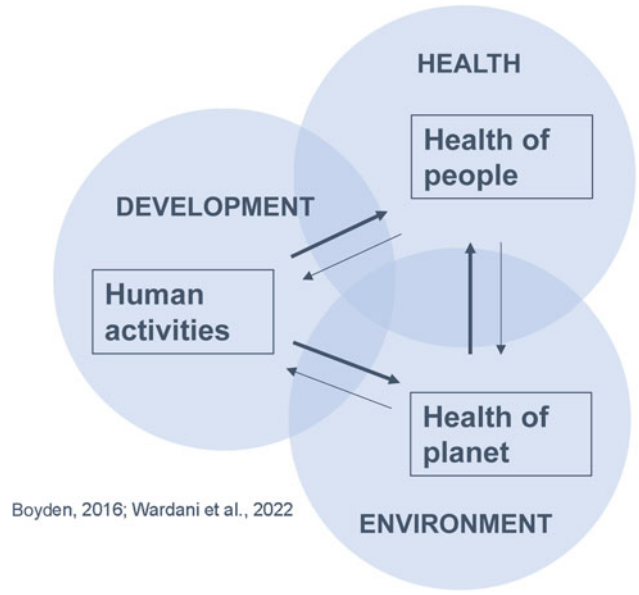

Figure 1. Biosensitivity and interconnections at the environment-health-development (EHD) nexus.

sustainability, public health, and development, previously operationalized as the environment-health-development (EHD) nexus (Wardani et al., 2022).

In recent years, TD research has grown in importance and practice in the respective EHD fields; however, its practice remains undertheorized, underfunded, and underdeveloped (Brown et al., 2015, 2019). Theories, principles, and frameworks for TD research exist, but a number of gaps exist that merit deeper exploration. First, there has been little comparison and synthesis across these diverse yet interrelated fields in search of common ground for collaboration. Meanwhile, increased breadth and scale of collaborations in planetary health could intensify challenges due to deep epistemological, methodological, and cultural differences among distant disciplines, sectors, and development contexts (Ely et al., 2020). Second, much TD research follows an ideal-typical, linear model of 'linking knowledge to action,' i.e. producing *then* applying knowledge, thereby compromising the immediacy and potential for transformative impact of an experimental approach to developing solutions (West et al., 2019). Third, the terms 'collaboration' and 'integration' have in many cases been used generically, but remain as black boxes without sufficient elaboration of how the process might unfold, especially in power-diverse contexts (Pohl et al., 2021). Finally, in light of widening global inequalities, TD collaboration between High-Income Countries (HIC) and Low- and Middle-Income Countries (LMIC) partners may not sufficiently consider disparities in higher education and research training and historical loss of indigenous knowledge (Jenkins et al., 2018). This is not surprising as most TD theories and frameworks have been conceived through HIC academic perspectives, e.g. Schneider and Buser (2018); Lang et al. (2012); Luederitz et al. (2017).

A brief review of transdisciplinarity across the EHD fields reveals some similarities and potential for complementarity, towards finding a common language which can help achieve common understanding and strategic alignment in addressing common risks and opportunities (Demaio & Rockström, 2015). TD scholarship in environment and health fields largely agree on the importance of local contexts and the value of local knowledge to ensure feasibility, relevance, and legitimacy (Luederitz et al., 2017; Peters et al., 2013). Likewise, planetary health scholars have emphasized the importance of local contexts and unique geographies, histories, economies, politics, and cultures (Capon, 2017). However, there has not been a thorough exploration into the perspectives of development studies and decolonizing and indigenous knowledge scholarship and how these may be useful in understanding diverse contexts and knowledge systems (Odora Hoppers, 2011). These fields have deeply established the fallacy of universalizing HIC theories without addressing the specificities and knowledge systems within LMIC contexts (Alsayyad & Roy, 2004; Chakrabarty, 2000; Roy, 2009, 2016). They have also drawn attention to differences in power and resource realities across HIC and LMIC research contexts (Littman et al., 2021). Indigenous scholars have similarly emphasized principles of holism, interconnectedness, self-determination and mutual respect, which are of major importance if indigenous and local knowledge were to contribute globally and locally relevant solutions (Archibald et al., 2019; Kimmerer, 2013; Kovach, 2009; Smith, 2021).

In bringing together diverse knowledge systems, the challenge remains how collaborations can transcend and equally value different disciplines, sectors, and cultures to produce credible, relevant, and legitimate knowledge (Clark et al., 2016b; Pineo et al., 2021). Planetary health scholars have articulated cross-cutting TD research priorities, involving diverse stakeholders in co-design and implementation, and striving for intergenerational equity (Ebi et al., 2020). However, the practice of TD research in planetary health needs more in-depth empirical exploration into recent practices, especially to understand how the process of integration and collaboration among disciplines and sectors may unfold in HIC-LMIC partnerships. As such, the literature on collaborative urban environmental governance may yield important insights, based on four decades of research and observation of collaborative practices (e.g. Innes & Booher, 2018). In addition, while some understanding of cross-disciplinary, team-based research have developed within public health (Hall et al., 2017), a more explicit theoretical and empirical synthesis of existing frameworks and practices among diverse fields at the EHD nexus is needed to understand the collaborative process itself, including the factors that may enable or constrain collaboration (Stokols, 2006), especially in LMIC settings.

In summary, this research seeks to address the abovementioned theoretical and practical gaps in the state of TD research, specifically the need for (1) explicit synthesis of recent TD practices and theoretical frameworks at the EHD nexus; (2) exploration of the collaborative environmental governance literature which may shed light on the collaborative process; and (3) deeper empirical understanding of the implementation of planetary health TD collaboration, especially from LMIC perspectives. The remainder of this section outlines the eventual aim of this research to develop a practice framework, while Section 2 describes the empirical and theoretical analyses conducted to address the abovementioned gaps, and how their findings intertwine and contribute to the framework development process. The practice framework is presented in detail in Section 3, followed by a commentary on its application (Section 4) and some potential limitations of the framework in its infancy (Section 5).

1.1 Aim of the research

Against this background, this research draws upon extensive theoretical and empirical analyses to conceptualize a practice

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framework guiding the design and implementation of TD collaboration in planetary health conducted in LMIC settings. Typically, such collaboration would be initiated by HIC funders and researchers who then engage with LMIC academic, government, and community stakeholders. Empirical understanding of how such research is operationalized would provide rich insights into the process of collaboration and how diverse stakeholders and knowledges could come together in meaningful, relevant, and legitimate knowledge co-production.

1.1.1 Defining a practice framework

A practice framework, as drawn from the field of social work, commonly combines formal theoretical knowledge, and knowledge accumulated through repeated practice (Healy, 2014, pp. 226–332) In social work, a practice framework '**integrates empirical research, practice theories, ethical principles, and experiential knowledge in a compact and convenient format that helps practitioners use the knowledge and principles to inform their everyday work.'** A practice framework is a mapping out of the rationale for practice, and is often devised at a scale where values, theories, and practice are clearly linked. Its purpose is to provide schematic guidance for improving, analyzing, and reforming practice (Stanley, 2016). While most existing TD research frameworks describe the ideal-typical research process, a practice framework considers higher-level principles and institutional and cultural contexts driving action-oriented practice; conversely, it creates synergies in individuals' practices to be formalized into knowledge and institutionalize improvements in practice (Connolly, 2007; Healy, 2014). Another point of difference is explicit consideration of values, inclusion, and equity, as social work is a values-driven field serving disadvantaged communities.

1.1.2 Focus on stakeholder collaboration

The proposed framework aims to bridge theory and practice by focusing on the praxis of collaboration among stakeholders, providing guidance for practice and a tool for restructuring current institutional contexts of knowledge production (Giddens, 1984). As mentioned earlier, existing frameworks do not specifically elaborate on the stakeholder collaboration process e.g. Lang et al. (2012); Luederitz et al. (2017); Newell and Proust (2012); hence our framework aims to address this gap. The framework is intended to be inclusive, bringing together diverse stakeholders, serving as a 'boundary object' (Star & Griesemer, 1989) to enable collaboration. To encourage mutual exploration and understanding, the framework is developed through a bricolage of concepts broadly accepted in the EHD fields, an emergent construction fitted and combined with findings from the literature review of recent practice and planetary health priorities. In qualitative research, bricolage is an interpretive piecing together of concepts, methods, and representation fitted to the specifics of a complex situation in an emergent fashion (Denzin & Lincoln, 2011). While some may argue the fallacy of achieving consensus amidst stakeholder diversity (Nogueira et al., 2021), consensus is not expected in all situations but the process would be actively facilitated to orchestrate and navigate diverse contributions, interests, and power dynamics towards mutual respect and benefit (Touati et al., 2019).

1.1.3 Audience

The intended audience of the practice framework would be the stakeholders of research as a process of knowledge production. A broad definition of the term 'stakeholders' is used to signify actors with an interest in and are affected by the governance decisions and sustainability challenge being addressed, including those with relevant knowledge and other resources to contribute, and those who benefit from or are adversely impacted (Deverka et al., 2012). Such a diverse stakeholders setting is expected to be of considerable contestation and unequal power dynamics, requiring a high degree of stakeholder engagement (Schneider & Buser, 2018). Nevertheless, such diversity is crucial for the knowledge produced to pass the credibility, relevance, and legitimacy (CRL) criteria (Clark et al., 2016b), and reflects the breadth of stakeholders in planetary health or sustainable development. Ideally, the audience of the framework would be all research stakeholders, i.e. funders in the public and private sectors, academic institutions and researchers, government, civil society organizations, and communities. This inclusive definition adds a transparency and legitimacy towards a common vision by forming a picture of the whole process for all stakeholders to perceive their potential roles.

1.1.4 When and how to use the framework

We define transdisciplinarity as a research approach involving academic and non-academic stakeholders with a view towards societal application, including action research that simultaneously integrate policy, physical or health innovations. Application to solving societal challenges is needed to accelerate progress towards the SDGs, especially action research by iteratively adapting the intervention through experimentation and reflexivity (Wiek et al., 2017). Application of the research could involve developing a novel community infrastructure, or a cross-cutting environment, health, and equity policy (Ebi et al., 2020; ISC, 2023; West et al., 2019).

Hence, the practice framework could be used by stakeholders to provide guidance for reflexivity and co-learning: (1) during the design and inception stage, (2) at multiple points during the process as a continuous monitoring tool, and (3) as a post-mortem evaluation tool to identify refinements and lessons for future TD collaborations, especially in LMICs. Lessons learned could include elements that have worked better than others, and potential reasons for unrealized or unintended outcomes. However, as elaborated in Section 4, the framework would be most effectively applied at the pre-development and co-design phase by process initiators and funders assessing TD research proposals for potential funding.

2. Methodology and framework development approach

The practice framework development took place from 2019 to 2023 and incorporated three areas of extensive analyses, namely a literature review, an empirical case study, and a meta-analysis of frameworks. The findings and practice recommendations from these previous analyses are described in detail in Table 1, which also provides examples of how they were translated into the framework. In summary, the literature review of practice (Section 2.1) identified a leverage point for transformative change in knowledge production systems, in which funding institutions play a pivotal role in influencing project design. Funding institutions are hence identified as one of the primary audiences of the framework. The empirical case study (Section 2.2) yielded two publications: the first (Wardani et al., 2023) highlighted the essential elements of collaboration as experienced from LMIC perspectives, which were included as Foundational Considerations (Section 3.2.1) around stakeholder engagement in the practice framework; while the second (Wardani et al., forthcoming)

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Table 1. Summary of findings and practice strategies from previous publications

Publications	Findings	Practice strategies	Examples of translation into practice framework
Wardani et al. (2022). 'Enabling transdisciplinary research collaboration for planetary health: Insights from practice at the environment-health-development nexus.' *A literature review of 36 publications of recent transdisciplinary research practice, synthesizing insights and lessons learned through qualitative thematic analysis across the EHD fields*	• Funding institutions were at the fulcrum of transformative shift, with knowledge and financial resources as leverage	• Balanced inter- and transdisciplinary evaluation process for funding • Flexible timelines allowing open-endedness of outcomes	• Funders identified as providing structure shaping the design of a collaboration (Sec 3.2.2) and primary audience of framework (Sec 1.1, Sec 4) • Building in learning and reflexivity into TD collaboration (Sec 3.3) and in co-monitoring of outputs and outcomes (Sec 3.2.4 and 3.2.5)
	• Project and organization structures were also enabling as it spans structural, relational, and individual levels, especially in supporting boundary-spanning efforts • Relational factors such as communication and boundary-spanning were the most enabling, but requires much effort and resources by individuals	• Complexity-aware, adaptive project management allowing time for boundary-spanning • Institutional support for collaborative research	• Project design should budget time for the collaborative process to allow for adequate social interactions and multi-way and repeated communications (Sec 3.2.4) • Stakeholders' institutional context can provide structure and support (Sec 3.2.2)
	• Structural factors were the most constraining, incl. lack of understanding of local socio-cultural and historical contexts and inherently unequal power dynamics; and disciplinary structure of academia • Individual personal characteristics could either constrain or enable collaboration, but experience and training can increase researchers' capacity	• Engage and support LMIC partners in research design and priority- and agenda-setting and build LMIC capacity for research design, data analysis, and publications • Build HIC researcher capacity for inter- and transdisciplinary research, cross-cultural learning e.g. anthropological approaches, sensitivity to underlying power relations	• Flexibility in project design to allow for equally valuing all stakeholders' priorities and interests (Fig 2, Sec 3.1) • Local context, values and ethics, and power dynamics as foundational considerations (Sec 3.2.1)
Wardani et al. (2023). 'Boundaries as spaces of knowledge integration: Learning from transdisciplinary collaboration on planetary health in Indonesia.' *Findings from empirical case study on understanding the essence of collaboration through Indonesian perspectives.*	• Indonesian stakeholders contributed a plethora of disciplinary and non-disciplinary knowledge and other resources, highlighting a web of interdependence of stakeholders' diverse interests and contributions • Opening up of boundary spaces was key to multi-directional knowledge integration, with varying types of interactions observed among stakeholders • Important roles of Indonesian stakeholders as providing 'holding space' for local and indigenous knowledge and cultural predisposition towards plurality, collaboration and mutual assistance • Pertinent themes identified include diversity and interdependence, complementarity, reciprocity, recognizing interlinkages, mutual learning, and innovation	For HIC funders and researchers: • Require all (HICs and LMICs) stakeholders to be engaged in research priority-setting and design • Allow more flexible timeline and budget for meaningful engagement and integrating historically undervalued LMIC perspectives and contributions • Create time and space for LMIC partners to co-lead based on their interests and knowledge • Identify interdependent and complementary relationships and potential interaction challengesFor LMIC researchers and practitioners: • Recognize the knowledge, skills and other contributions as well as expectations of benefits & outcomes • Request that authorship include LMIC partners and time and space for LMIC-led publications • Support co-design processes to meet national and community priorities • Recognize that collaboration depends on meaningful engagement of all stakeholders (HICs and LMICs)	• Stakeholders' diverse contributions (Sec 3.2.3) need to be equally valued • Creation of safe spaces for stakeholder interactions through facilitative co-leadership, culture of openness and inclusivity, and social learning (Sec 3.2.4) • Importance of local context and operational conditions as foundational consideration (Sec 3.2.1) • Diversity and interdependence are part of Foundational Considerations (Sec 3.2.1) • LMIC stakeholders' involvement in identifying local priorities in research co-design (Phase 1, Sec 3.1) and in producing research publications as a litmus test for stakeholder integration (Sec 3.2.4) and Leave No One Behind • Boundary spanning requires considerable effort and resources and should be a foundational consideration in project design and budgeting (Sec 3.2.1)

Wardani et al. (forthcoming). 'From complexity to mutual understanding and acceptance: Participants' experiences of a transdisciplinary planetary health collaboration in Indonesia' (draft title) *Findings from empirical case study on understanding the enabling and constraining factors of collaboration based on participants' experiences*	• Engaging multiple stakeholders with diverse and interdependent interests takes a long time to ensure communication and alignment of perspectives and expectations due to high complexity of structural, political, land-related uncertainties and differences • Developing mutual understanding and acceptance takes a long time through meaningful engagement and repeated formal and informal interactions to build familiarity and trust	• Highlights the importance of considering stakeholders' diverse and interdependence of interests early on • Attend to local LMIC context specificities (challenges and opportunities) • Meaningful engagement includes meeting all parties' interests/needs, genuine respect, shared leadership, and equally valuing contributions • Clear roles and responsibilities, strong facilitative leadership, and developing a common vision enabled mutual understanding	• Diversity and interdependence are part of Foundational Considerations (Sec 3.2.1) • Importance of local socio-cultural, political, economic and historical context as foundational consideration (Sec 3.2.1) • Process of stakeholder interaction (Sec 3.2.4) is dependent on valuing stakeholder contributions (Sec 3.2.3), contexts (3.2.2), and foundational considerations (3.2.1) • Boundary spanning as foundational consideration (Sec 3.2.1) and key to mutual understanding (Sec 3.2.4)

Findings and practice strategies from previous analyses were incorporated into the development of the practice framework, supplementing the theoretical meta-analysis of existing TD frameworks in the EHD fields. In summary, these previous analyses identified the leverage point for transformative change of knowledge production (i.e. funding institutions), revealed severe constraints relating to understanding local contexts and power dynamics, provided strategic guidance for process design and management, and highlighted pertinent foundational themes of interdependence and diversity of stakeholders' interests. These findings inform our practice frameworks, specifically in formulating the Foundational Considerations, Structure, Input, and Process Factors, and in identifying the primary audience of the framework (i.e. funding institutions and initiators of collaborations).

illuminated the factors and key stakeholder processes occurring at different stages of the collaboration outlined in the framework, e.g. Stakeholder Contexts corresponding with Structural Factors, Stakeholder Contributions with Input Factors, etc. The meta-analysis of frameworks (Section 2.3) identified the research phases (Section 3.1), and Foundational Considerations gleaned from development studies around Local Context, Values & Ethics, and Power Dynamics; while TD research frameworks in environment and health enabled the construction of the stages of collaboration (Structure, Input, Process, Output, Outcomes) (Sections 3.2.2 to 3.2.5) and the crucial role of Reflexivity and Co-Learning (Section 3.3).

2.1 Literature review of recent TD practice

A literature review of 36 publications was conducted to draw insights on lessons learned from recent transdisciplinary research practice in the respective EHD fields. These lessons learned were qualitatively analyzed to obtain second-order understanding of the factors enabling and constraining collaboration. These factors were then inductively clustered into structural, relational, and individual factors enabling and constraining collaboration. These findings have been published (Wardani et al., 2022), and described the interplay between factors that enhanced understanding of the collaborative process. Recommendations for practice were identified, emphasizing leverage points for change at the structural level through funding requirements and the project design of such research.

2.2 Empirical case study of TD research in LMIC setting

A unique case study of a contemporary large-scale planetary health research collaboration allowed for an empirical deep-dive. The case study site was the Revitalizing Informal Settlements and their Environments (RISE) program, a planetary health collaboration aiming to implement and assess the environmental, health, and socio-economic benefits of decentralized green infrastructure upgrades of integrative water and sanitation services in a total of 26 informal settlements in Makassar, Indonesia and Suva, Fiji (Brown et al., 2018). Data collection in the case study consisted of 47 semi-structured interviews and six individual reflections in English and Indonesian languages, and two focus groups in Indonesian. Indonesian interviews and reflections were translated into English, and thematic analysis was conducted using NVivo software following an inductive, grounded theory approach (Braun & Clarke, 2006; Charmaz, 2015). The case study yielded two publications; the first on the meaning of collaboration from the perspectives and experiences of Indonesian and LMIC stakeholders (Wardani et al., 2023) and the second on the enabling and constraining factors found in the case study based on experiences of all participants (Wardani et al., forthcoming). Findings from both publications yielded practice strategies that intertwined with and informed the framework development process as elaborated below.

2.3 Meta-analysis of existing TD frameworks

A theoretical meta-analysis was conducted of existing TD frameworks commonly used in the EHD fields. Seeking commonalities and complementary perspectives across the EHD nexus was intended to result in a more comprehensive framework that is more readily accepted in these fields. Throughout the framework

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analysis and development, ongoing feedback was sought from an academic panel representing the EHD fields, which served as validation within an expanded community of academic practice (Cundill et al., 2015). The rationale for selection of included frameworks are detailed in Table 2 and further elaborated below as part of the iterative framework development process. Table 2 also highlights how these were incorporated into the framework.

2.4 Practice framework development process

The framework development followed an iterative design process adapted from Romme and Meijer (2020), starting with (1) selection and compilation of frameworks, (2) comparative assessment interweaving inductive theorization from previous analyses; and (3) theoretical validation. Findings from previous studies provided empirical validation of the frameworks, as they were compared and triangulated with the meta-analysis to inform the practice framework development. The iterative framework development process, including the interplays among previous analyses, is detailed below.

(1) Compilation and assessment: comparative analysis of frameworks

The framework development process started with the selection of existing TD frameworks from the EHD fields for comparative analysis. Three selection criteria were used: (1) the existing framework is broadly used and accepted in their respective fields; (2) the existing framework is relevant to and aligns with planetary health priorities and imperatives (Ebi et al., 2020); and (3) the frameworks show some similarities and differences complementing each other. Exclusion criteria are frameworks outside the EHD fields, as they are beyond the scope of comparison for this research. Table 2 lists the frameworks selected and detailed justification for their inclusion.

The most significant planetary health imperatives that were not explicitly mentioned in existing environmental sustainability frameworks is that TD collaborations must be inclusive, intergenerationally equitable across HICs and LMICs, and embedded within local contexts and geographies. These led to the inclusion of public health, development studies and Participatory Action Research (PAR) frameworks which emphasize attending to power dynamics to address values of equity, inclusivity, and local context and knowledge (Corburn & Gottlieb, 2005; Littman et al., 2021). Indigenous knowledge and decolonizing methodologies scholarship were also included as they align with these values. Other frameworks that did not mention these values explicitly were not excluded, as they contribute useful complementary understanding about the research process.

From this compilation of frameworks emerged similarities in components, serving as initial building blocks for our framework. The Structure-Process-Outcome format commonly used in public health service delivery (Donabedian, 2003), in particular, resonates with a number of other frameworks in environmental sustainability (Djenontin & Meadow, 2018; Luederitz et al., 2017) and collaborative governance (Innes & Booher, 2018). Hence, our practice framework retains the Structure-Process-Outcome format to enhance familiarity and acceptability across fields. Input and output components were added drawing from the abovementioned environmental sustainability frameworks.

While similarities provided useful starting points for collaboration, differences among frameworks suggested areas of complementarity and tension for further exploration. For example, the TD research framework widely used in sustainability science (Lang et al., 2012), provides a useful ideal-typical model and design principles for a TD research process. The authors identified challenges around lack of integration across knowledge types, organizational structures, and technical and communicative aspects. These challenges reflect structural factors which were not explicitly addressed in that framework, e.g. disciplinary and institutional contexts that predetermine stakeholders' epistemologies, organizational priorities, and communication styles. Therefore, the Structure component was added to our framework, also depicted as Context factors in the co-production framework in environmental management (Djenontin & Meadow, 2018). Advance consideration and improving understanding of these rigid structural factors and how they may shape the process can help facilitate collaboration and address constraints.

Another common element across frameworks in the EHD fields is the time-sequential phases of the research, with one key difference. While some frameworks depict the research process as more linear (Djenontin & Meadow, 2018), most frameworks agree that different phases are interdependent and iterative, e.g. Lang et al. (2012); Luederitz et al. (2017); Stokols et al. (2013); Cornish et al. (2023). Different terms may be used in different frameworks; however, we focus on the overall intentions of each phase which were more alike than different. For example, TD initiatives in public health are described as occurring in four phases, Development, Conceptualization, Implementation, and Translation (Stokols et al., 2013), and we considered additional phases from a more recent iteration to include Reflection & Refinement, and Co-Learning (Pineo et al., 2021). The iterative PAR phases are Observe reality; Reflect on gaps; Plan improvements; Act to test improvements; and Observe outcomes (Crane & Richardson, 2000). Although these reflect a more integrated action-research approach, the phases are similar to those in the public health TD model, for example in encouraging reflection, refinement, and research and observation. A synthesis of these phases, and the collaborative process alongside them, are described in more detail in Section 3.

(2) Assessment and inductive theorization: empirical research

Previous studies provided empirical validation for the importance of attention to structural factors. Wardani et al. (2022) found structural factors, including the disciplinary traditions and structures of academia (Becher, 2001), to be the greatest constraints in a collaboration. Beyond academic structures, in LMIC research settings, a lack of understanding of the local socio-cultural, political, economic, geographic and historical context also caused constraints, challenges, and inequitable division of labor due to nuanced communication and cultural differences (Sillitoe, 2018) and power imbalance (Gunasekara, 2020). The importance of local context and knowledge contributed by LMIC stakeholders were also highlighted in Wardani et al. (2023).

Beyond structural factors, the collaborative governance framework suggests underlying preconditions to be considered prior and throughout the collaboration, specifically, notions of interdependence and complementarity among a diversity of stakeholders' interests (Innes & Booher, 2018). These notions are echoed in co-production models in public administration (Ostrom, 1996) and Science and Technology Studies (STS) (Jasanoff, 2004). In public administration, involving the general public as end-users is deemed necessary as the latter contributes

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Table 2. List of existing TD frameworks in planetary health and EHD fields compiled in the meta-analysis

Fields	TD framework and brief description	Rationale for selection	Examples of translation into practice framework
Planetary health	TD research approaches and priorities (Ebi et al., 2020) – Principles of TD research focusing on multiple scales, inclusivity and equality, and broad communication and outreach	• Espouses values of inclusivity in co-design and implementation • Responsive to intersectionality and intergenerational equity encouraging diverse partnerships and representation in research projects	• Values & ethics as foundational considerations (Sec 3.1) • Power dynamics and diversity & interdependence as foundational consideration (Sec 3.1)
	Collaborative Conceptual Modeling (Newell & Proust, 2012) – Practical way for stakeholders to map out different understandings of interactions within a system-of-interest	• Focus on respect and value for diversity of knowledge and perspectives through listening and social learning • Employs complex systems thinking as embedded in specific local context including history, system behavior, and leverage points	• Diversity as a foundational consideration (Sec 3.1), and key to social learning during stakeholder interactions (Sec 3.2.4) • Local context as foundational consideration (Sec 3.1) and leverage point identified for transformative shift at the funding level (Sec 3.2.2)
Environmental sustainability	TD research in sustainability science (Lang et al., 2012) – Conceptual model of ideal-typical TD research process adapted from several models outlining similar phases Ten reflective steps for TD research (Pohl et al., 2017) – Aims to provide systematic procedure for producing socially relevant knowledge linking science and society Conceptualizing TD integration as a multidimensional interactive process (Pohl et al., 2021) – Integration defined as a process, and its characteristics and features elaborated further	• Main framework selected for review from environmental sustainability, with below frameworks as supplementary. • Widely used and accepted as indicated by high citation value (> 3,000 as of Aug 2023). • Provided useful design principles including phases of research, integrating scientific and societal practice, and challenges for further research. • Practitioner feedback as evidence of usefulness of the ten steps, interlinked with a four-stage policy process as an interplay of actors in the public, private, civil, and academic sectors. • Explicit attempt to elaborate on the process of integration.	• Research phases adopted in practice framework (Sec 3.1) • Identified challenges around knowledge integration, organizational structures, and communicative aspects to be complemented by other frameworks in Compilation of frameworks (Sec 2.1) • Stakeholder integration (Sec 3.2.4) proposed in practice framework to be an output of the collaborative process, as a result of stakeholder interactions (Sec 3.2.3)
	Sustainability transition (Luederitz et al., 2017) – Tentative scheme for evaluating the design and effectiveness of sustainability transition experiments which aims to be generic, comprehensive, operational, and formative. Environmental management (Djenontin & Meadow, 2018) – The art of co-production of knowledge in environmental sciences and management: lessons from international practice Natural resource management (Hakkarainen et al., 2022) – Integrative understanding of co-concepts (co-creation, co-design, co-production, adaptive co-management, and co-learning) in understanding collaborative resource governance	• Builds on Lang et al., 2012 and other frameworks (e.g. Ostrom, 2009) to evaluate sustainability experiments integrating research and action. • Features and iterative Input-Process-Output-Outcomes format which clarifies categories of factors to be considered or expected in each phase. • Input-Process-Output-Outcomes format similar yet complements Donebedian model in public health featuring Structure-Process-Outcomes, with Context and Impacts added in Djenontin and Meadow (2018). This similarity in format is hoped to broaden acceptability. It also resonates with collaborative governance model based on network dynamics (Innes & Booher 2018). • Recognize importance of local context and international perspectives in adapting and implementing the research and experiments.	• Structure-Input-Process-Output-Outcomes format similar to public health model, adopted in framework (Sec 3.2) • Local context and stakeholder contexts as foundational consideration and structure, adopted in framework (Sec 3.2.1 and 3.2.2) • As it represents current integrative understanding of the co-concepts as research phases (Sec 3.1)
	Collaborative governance (Innes & Booher, 2018) – Diversity, Interdependence, Authentic Dialog (DIAD) network dynamics theory of collaborative environmental planning and governance, developed from 40 years of research	• Extensive elaboration on the process and actor network dynamics of collaboration for complex systems change, complementing other frameworks which rarely detail but refer generically to collaboration • Validates empirical case study and literature review of practice on the importance of boundary spanning, i.e. authentic dialog and its preconditions of diversity and interdependence	• Diversity & interdependence identified as foundational consideration (Sec 3.2.1) • Authentic dialog as key in boundary spanning, a foundational consideration in the framework (Sec 3.2.1) • Contributes detailed, evidence-based understanding of collaborative process and its many features (throughout the framework)

(*Continued*)

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Table 2. (*Continued.*)

Fields	TD framework and brief description	Rationale for selection	Examples of translation into practice framework
Public health	Transdisciplinary public health model (Stokols et al., 2013) – Shared definitions, characteristics, and strategies for transdisciplinary health initiatives bridging research and practice to solve public health problems using a team-based approach and working collaboratively with diverse communities	• Developed jointly and bridging between academic and practice perspectives • Identified four phases in a transdisciplinary public health initiative (Development, Conceptualization, Implementation, and Translation) • Provided basis for iteration by planetary health scholars spanning built environment and public health (e.g. Pineo et al., 2021) indicating acceptability and relevance	• Research phases complemented that in environmental sustainability, recent iteration included in the framework (Sec 3.1)
	A new transdisciplinary research model (Pineo et al., 2021) – Built upon Stokols et al. (2013) to include two additional phases to address complex health challenges including climate crisis and global inequalities	• Includes scholars in environment and health with ongoing consultation with community of practice. • Expanded to include two ongoing phases: Co-Learning, and Reflection and Refinement recognizing distributed knowledge generation and mutual learning, and emergent priorities.	• Co-Learning and Reflection adopted as integral to this practice framework (Sec 3.3) • Refinement adopted in framework as part of research Phase 3: Monitoring & Refinement (Co-Monitoring) (Sec 3.1)
	Implementation science (Peters et al., 2013) – Bridging multiple disciplines and practice in global health, offers principles for inquiry into implementation strategies and outcomes of policies, programs, or practices (interventions) in the real world	• Highlights importance of local context and users' concerns • Implementation outcomes reflect the practical usefulness of research, including acceptability, adoption, appropriateness, feasibility, fidelity, implementation cost, coverage, and sustainability, echoing the Credibility, Relevance, Legitimacy, and Equity (CRLE) criteria	• Local context as foundational consideration (Sec 3.2.1) • Importance of user involvement in determining adoption, acceptability, appropriateness, highlights concept of diversity & interdependence as foundational consideration (Sec 3.2.1)
Development studies/ Decolonizing methodologies	Participatory action research (Cornish et al., 2023) – Values-based research approach for conducting integrated research and action, led by and for the user communities themselves	• Widely used across environment and health fields, promotes emancipatory values of social change and epistemic equity aligned with planetary health • Collaborative, iterative, experimental and open-ended, appropriate for engaging broad range of stakeholders, with local experiential knowledge valued in all stages • Offers four stages of cycle (problem definition, action, observe, and reflect), emphasizing relationality of knowledge production	• Values & ethics as foundational consideration (Sec 3.2.1) • Adaptive, open-ended project design during initial phase (Sec 3.1) reflected in lighter shade of blue in Figure 2 • Cyclical, iterative research phases adopted in framework (round shape of Figure 2), with observe and reflect incorporated into Phase 3: Monitoring & Refinement (Co-Monitoring) and Co-Learning & Reflection (Sec 3.3)
	Decolonizing methodologies for research with indigenous peoples (Smith, 2021) – Foundations in decolonization of knowledge production and methodological guidance, rooted in Aotearoa/New Zealand indigenous thought Indigenous research methodologies (Chilisa, 2019) – Outlines epistemological and methodological grounding in postcolonial Indigenous knowledge production rooted in African knowledge systems	• Widely used across environment and health fields, seeks to address pervasive power dynamics in Western, colonial research traditions of erasure and marginalization of Indigenous knowledge • Offers principles of respect, responsibility, reciprocity, holism, interrelatedness and synergy towards authentic, relational, and situated knowledge production	• Values of equity, diversity & interdependence, and addressing power dynamics as foundational considerations (Sec 3.2.1) • Indigenous knowledge as important foundational consideration in Local Contexts (Sec 3.2.1)

Starting with values and approaches proposed by planetary health scholarship, existing frameworks in EHD fields were selected and analyzed to inform the practice framework development. Based on comparative analysis and a bricolage of useful concepts and frameworks, we compiled common elements and explored differences to seek resolution, aiming for broad applicability and common ground across disparate yet interrelated EHD fields. Our practice framework highlights the importance of local context, values of equity and inclusivity, and power dynamics, and focuses on the process of stakeholder collaboration, against the background of research phases and co-concepts found in existing frameworks (Section 3.1).

relevant knowledge and skills in co-producing public services (Loeffler & Bovaird, 2021). In STS, knowledge is understood to be interdependent and co-evolving jointly with its social and political context (Jasanoff, 2004). Likewise, planetary health scholarship aims to highlight systemic interlinkages (Whitmee et al., 2015), while transnational studies and globalization scholars emphasize interdependence across global development contexts (Sassen, 2016, 2019). Understanding interdependence among diverse stakeholders goes a long way in enabling collaboration, as validated in the empirical case study (Wardani et al., 2023). Section 3 below details further interdependence and other foundational considerations related to stakeholder engagement.

Another significant foundational consideration drawn from the literature review of practice was that of boundary spanning, or communication and relational factors, which were found to be the most enabling (Clark et al., 2016a; Norström et al., 2020; Pohl et al., 2017). Suggested practice strategies include accounting for transaction costs of boundary spanning in project design and management, and researcher training to build individual capacity (Wardani et al., 2022). The empirical case study further cemented that communication and repeated social interactions were required to build trust and relationships, and eventually mutual understanding and acceptance of differences among stakeholders (Wardani et al, forthcoming). Boundaries were found to be the spaces of knowledge integration, therefore creating these spaces were key to bringing together and bridging across different knowledge systems and stakeholders (Wardani et al., 2023). These findings echo the collaborative governance literature, indicating that 'communicative rationality' was an ideal condition that could take extensive effort (Innes & Booher, 2018).

(3) Theorization & validation

Regardless of the field, existing TD frameworks often mention 'collaboration' and 'integration' as a generic process, without detailing how the collaborative process might unfold. This practice framework aims to complement this gap using the collaborative governance framework (Innes & Booher, 2018); hence, the cornerstone and focus of this practice framework is on the stakeholder collaboration process. The Structure, Input, Process, Output, and Outcomes Factors relate respectively to stakeholders' contexts, contributions, interactions, integration, and collective benefits. The Foundational Considerations in Section 3.2.1 relate to stakeholder engagement, which include factors that process initiators might reflect on when building the team, designing the collaboration, and during continuous monitoring. Finally, we draw from natural resource management scholarship on an integrative understanding of 'co-concepts,' intended to support and enable TD collaboration (Hakkarainen et al., 2022). Each co-concept is aligned with the stakeholder collaboration process and research phases in our practice framework, as elaborated below in Section 3.

3. Towards a practice framework for transdisciplinary collaboration

While our framework selection and assessment drew from the broader EHD fields, the 'co-concepts' (co-creation, co-production, co-design, co-learning, and adaptive co-management) were a useful starting point as they represent a contemporary and integrated understanding of 'collaborative modes of knowledge production and the engagement of non-academic participants' intended to support TD collaboration. This practice framework refers to collaboration as a transformative co-production process, where 'a group of actors engage in developing shared understandings and novel ideas of how to intervene in social-ecological systems, requiring deep and protracted stakeholder engagement' (Galafassi et al., 2018; in Hakkarainen et al., 2022; Shackleton et al., 2019). This is aligned with co-production in highly contested socio-ecological and knowledge systems in sustainability science (Clark et al., 2016a; Norström et al., 2020; Schneider & Buser, 2018). The factors to be considered are provided in the Foundational Considerations, and in the Structure-Input-Process-Output-Outcomes format, which serves as guide posts in developing a TD collaboration.

The practice framework consists of a graphic diagram (Figure 2) and a matrix of reflexive practice questions (Table 3) designed to guide the initial development of and throughout the collaborative process. Figure 2 illustrates how the different elements of the collaboration are integrated, including the research phases, foundational considerations, and collaborative process components and the factors to be considered under each one, as explained in the next section. Table 3 reinforces the framework's focus on stakeholder engagement, with the Foundational Considerations outlined in the left-most column and suggested questions corresponding to each component in the collaborative process. The suggested questions in Table 3 are intended to clarify the points under each component in Figure 2 but relate to broader interpretation centered upon the Foundational Considerations as they correspond to each collaborative component.

3.1 Research phases in the practice framework

The practice framework offers a conceptualization of TD research phases aligned with their respective co-concepts (Hakkarainen et al., 2022), namely *Phase 1: Predevelopment & Initiation (Co-Design)*; *Phase 2: Implementation (Adaptive Co-Management)*; and *Phase 3: Monitoring & Refinement (Co-Monitoring)*. These stages of the research process are depicted in blue in Figure 2, arranged in order from the most open-ended (in lighter shades of blue) to more certain (in darker shades of blue). Specifically, the research design should initially be open-ended and adaptable alongside evolving stakeholder priorities, and gain more certainty during implementation and monitoring.

Each phase will be described further below, however it is worth mentioning that *Phase 2: Implementation (Adaptive Co-Management)* could simultaneously integrate research and action, following an iterative, emergent, experimental approach as practiced in sustainability transitions (van Breda & Swilling, 2018; Wiek et al., 2017). While some argue that transdisciplinarity aims towards usable or actionable knowledge (Clark et al., 2016b) this implies production of knowledge (research) *then* implementation of intervention (action). Some suggest integrated action research would achieve more immediate impact (West et al., 2019), trialing at a smaller scale initially to reduce risks of unintended negative impact. Lessons learned can inform subsequent iterations of the intervention (van Breda & Swilling, 2018), consistent with experiential, 'learning-by-doing' approaches in built environment (Raymond et al., 2017) and PAR in urban health (Barke et al., 2020). Development studies and implementation science in public health further agree on locally embedding, developing, implementing, and refining interventions iteratively, as feasibility, effectiveness, and adoption may not be as expected when moving across HIC-LMIC or LMIC contexts (Reidpath et al., 2022; Roy, 2009).

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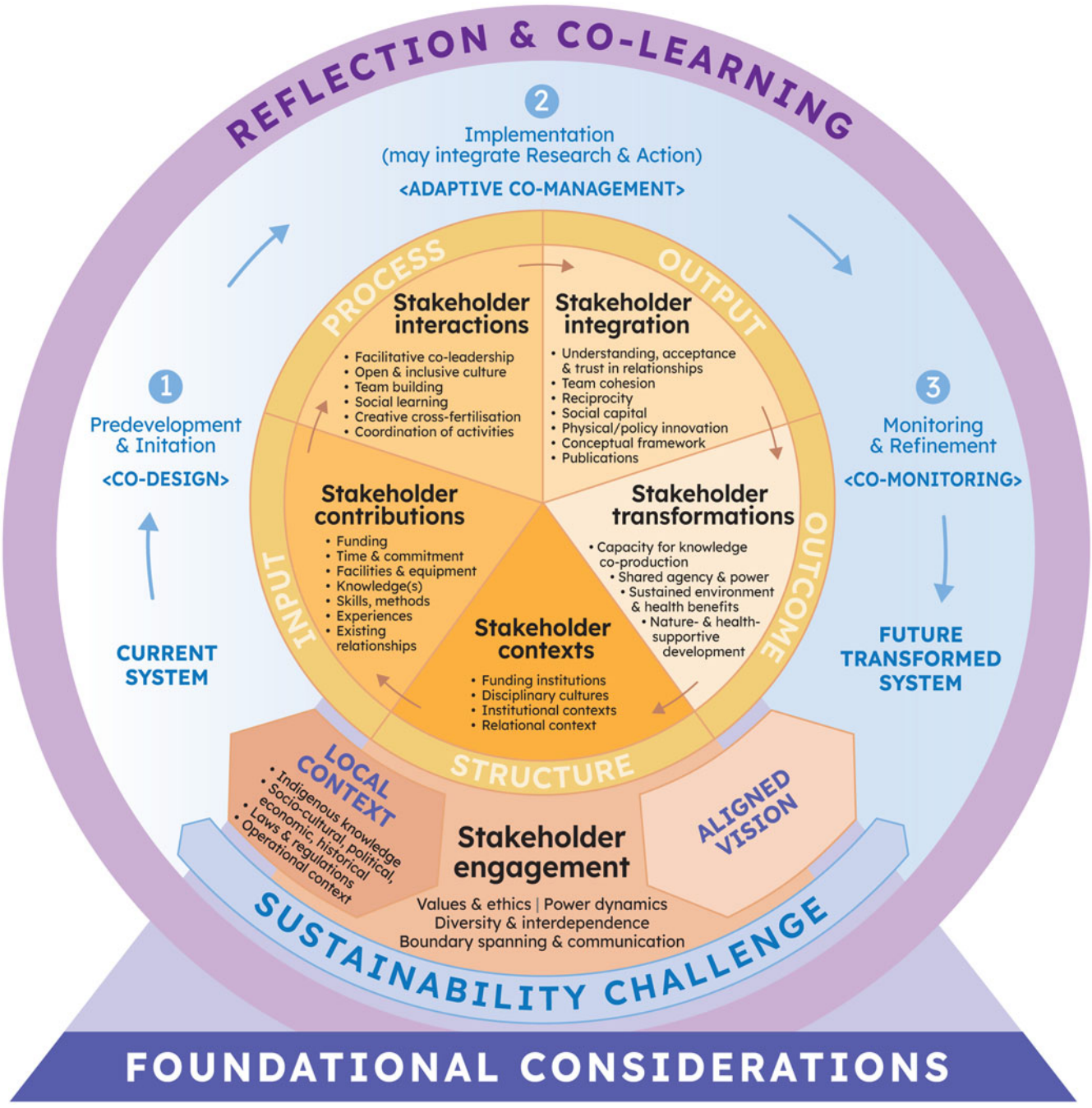

Figure 2. A practice framework for transdisciplinary collaboration in planetary health.

However, academic research globally remains bounded in discovery research separate from direct application or translation. Efforts to transcend disciplines and involving non-academic stakeholders would be necessary to address constraints due to academic disciplinary structures (OECD, 2020). Conducting research with a view towards application to a real-world problem, whether in physical, policy, or other forms, would be the transformative shift required if our knowledge systems were to accelerate progress towards the SDGs. Regardless of approach, research implementation would occur in *Phase 2: Implementation (Adaptive Co-Management)*, followed by *Phase 3: Monitoring & Refinement (Co-Monitoring)*.

3.1.1 Phase 1: Pre-development & Initiation (Co-design)

Reflections on the Foundational Considerations (Section 3.2.1), Structural Factors (Section 3.2.2), and Input Factors (Section 3.2.3) should ideally take place during Phase 1, to inform an analysis of stakeholders to be engaged in setting the agenda and priorities for the research, their institutional and other contexts, and potential contributions. Through meaningful stakeholder engagement and analysis using the reflexive practice questions in Table 3, this phase should also result in a shared understanding of the local context within which the research should be firmly embedded, the current system and sustainability challenge to be addressed, and a broad, inclusive vision of the future transformed system (see Figure 2).

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Table 3. Matrix of reflexive practice questions

Reflection & Co-learning					
Foundational considerations Stakeholder engagement	Structure Stakeholder contexts	Input Stakeholder contributions	Process Stakeholder interactions	Output Stakeholder integration	Outcomes Stakeholder & systems transformations
Predevelopment, Initiation, and agenda setting (Co-design)					
		Implementation (Adaptive co-management)			
			Monitoring & refinement (Co-monitoring)		
Local context	Which individuals, groups and institutions in the academic, government, community, and private sectors in the LMIC have an interest in the sustainability challenge? What existing indigenous knowledge can contribute to addressing this challenge? What are similarities and differences in LMIC & HIC stakeholders' perceptions of the sustainability challenge? Do HIC stakeholders have a good understanding of the local context including language, culture, and power dynamics? What laws and regulations and operational conditions pertain to human resources, taxation, data management, research, transport of equipment, samples, etc that require compliance?	Are LMIC stakeholders' interests and priorities reflected in the research agenda, as well as HIC stakeholders' interests and priorities? What disciplinary and non-disciplinary knowledge, skills, and methods do LMIC stakeholders contribute and have an interest to gain? What professional and personal lived experiences do LMIC stakeholders bring to the collaboration? What facilities and equipment do LMIC stakeholders contribute, and stand to benefit? What other non-material contributions (e.g. time, political support) do LMIC stakeholders contribute and how are these valued?	What co-governance processes are in place to encourage meaningful engagement and interactions among HIC-LMIC stakeholders? Are there LMIC stakeholders represented in project co-leadership? What powers and decision-making authority do LMIC stakeholders hold? How does the collaboration demonstrate commitment to transparency and building an open and inclusive culture across geographical divides?	What boundary-spanning and communication efforts are required to ensure meaningful integration of LMIC stakeholders and interests? What is the extent of cross-fertilization, understanding, acceptance, and trust among stakeholders? Is there cohesion perceived through mutual assistance and support within teams, between teams, and across sectoral, cultural, and geographical differences? How have LMIC & HIC stakeholders benefited from the social capital generated by the collaboration?	How have LMIC stakeholders gained capacity for collaborative research and locally relevant problem solving? Have LMIC & HIC stakeholders benefited equally from the collaboration? Are there sustained benefits to the environment, health, and socio-economic development in the LMIC? Does the knowledge and innovation produced satisfy credibility and relevance criteria in the LMIC context, i.e. solutions are accepted and used by intended stakeholders?
Values & ethics	What values are being emphasized in the collaboration and how do those reflect LMIC & HIC stakeholders' values, priorities, and concerns? What is the possible impact of including or excluding certain stakeholders on equity and innovation outcomes?	Are LMIC & HIC stakeholders' contributions equally and inclusively valued, e.g. in budget allocation, division of roles, other benefits?	Is the collaboration being facilitated to allow equal and inclusive engagement and meeting of diverse interests? What values alignment can be used as a compass to guide decision-making?	Which stakeholders benefit the most from the social and political capital and other outputs generated and which stakeholders the least? What innovation can we achieve by including diverse stakeholders that may not be typically engaged?	Have LMIC & HIC stakeholders gained equally in capacity for collaborative research and problem solving? Do LMIC stakeholders have the know-how and capacity to sustain the intervention and its benefits? Do outcomes reflect equal valuing of LMIC & HIC stakeholders' interests and perspectives?

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Power dynamics	What power, knowledge, and financial resources do HIC stakeholders derive through their institutions, disciplines, and positionalities? What are the power dynamics among LMIC stakeholders based on institution, social status, abilities, and identities?	Which stakeholders' contributions are explicitly and implicitly valued over others? Which stakeholders contribute crucial input but are inadvertently excluded? What challenges in generating legitimacy and relevance can we expect through inadvertent exclusion?	Is the collaboration facilitated to allow cross-fertilization, social learning to occur in multiple ways and directions, e.g. through social interactions, team building and other venues that 'level the field'? What important differences in knowledge and perspectives exist and how can they be mutually learned and understood?	How are power dynamics facilitated and navigated in the collaboration to allow for equal distribution of benefits and opportunities for engagement? How can understanding and trust be facilitated amidst stakeholders with power diversity and conflicting values, interests, and identities?	To what extent has there been a yielding and wielding of power among HIC and LMIC stakeholders towards a more balanced and shared power dynamics? Does the knowledge and innovation produced satisfy legitimacy and equity criteria?
Diversity & interdependence	Does the collaboration have the required individual and institutional diversity to implement the research or address the sustainability challenge? What do stakeholders perceive to benefit from engagement in the collaboration over doing it alone?	Does the collaboration have the diversity of contributions relevant to addressing the sustainability challenge? Who decides what contributions are relevant, legitimate, and valuable? How are stakeholders' interests and contributions interdependent?	How does the collaboration provide spaces that respect diversity of perspectives and contributions? How can interdependence be highlighted through knowledge exchange and team building? What creative cross-fertilization can take place among diverse stakeholders?	How can interdependence be leveraged to generate understanding, trust and acceptance amidst diversity? Are there signs of reciprocity observed among stakeholders, including personal or professional?	Did the knowledge or innovation benefit a diversity of stakeholders including disadvantaged groups (gender, disability, race & ethnicity, etc)? How were a diversity of user needs considered in implementing the research and innovation?
Boundary spanning & communication	What communication and boundary-spanning efforts are required to bridge institutional level differences? To what extent are TD and collaborative efforts financially and institutionally supported?	Which individual and institutional stakeholders have the experience and ability to create boundary spaces, e.g. boundary organizations, intermediaries, bridging and facilitating across disciplines, institutions, sectors, and cultures? What training and mentorship can be provided to individuals to develop collaborative capacity?	What specific events and venues create a boundary space for diverse stakeholders to come together? Are there language and cultural barriers that need support to overcome? What formal and informal mechanisms of boundary spanning and communication exist?	What boundary-spanning efforts are required to encourage mutual understanding, acceptance, and trust in relationships? Has there been multi-directional flows in knowledge including through language, social, and cultural interactions?	How have stakeholders increased their capacity for boundary spanning through the collaborative experience? How have the environment, health, and development benefits of the collaboration perceived across differences in perspectives and backgrounds?
Aligned vision	What do stakeholders envision the collaboration will achieve in the medium to long term? What short- and medium-term outcomes are expected to support this vision? To what extent is there vision alignment among stakeholders?	What do stakeholders expect to contribute towards the aligned vision in the short, medium, and long terms? What are stakeholders' motivations and interests for engagement in the collaboration?	How are different voices listened to and have power to influence the long-term vision of the collaboration? How much flexibility and adaptation are there to broaden the vision and include complementary or conflicting voices and interests? Who decides which vision is relevant and which is not?	What knowledge outputs and innovative solutions have been produced? To what extent are these outputs aligned with the medium- and long-term vision? Are there conflicting interests remaining and if so, how can they be resolved? To what extent has team cohesion, reciprocity, and social capital been generated towards achieving the vision?	To what extent do the realized vision and outcomes reflect all stakeholders' expectations? Have there been certain stakeholders excluded or marginalized due to perceived and irreconcilable vision misalignment? Have there been certain stakeholders that were inadvertently excluded despite vision alignment?

The above matrix of reflexive practice questions is an integral part of the framework and is to be used together with the framework diagram in Figure 2. The questions are centered upon the Foundational Considerations in the left-most column, reinforcing the framework's focus on stakeholder engagement. The header rows here correspond in color with the framework diagram, with reflexivity and co-learning as important throughout in both. The stakeholder collaboration stages (in orange) are aligned with the research phases (in blue). The practice questions are intended to be used for individual and collective reflection both at the beginning and as subsequent stakeholders join in the collaboration.

3.1.2 Phase 2: Implementation (Adaptive Co-Management)

As previously mentioned, this practice framework encourages integrated action and research to accelerate impact through direct intervention and experiential learning, as commonly practiced in 'Living Labs' (Wiek et al., 2017). An adaptive, emergent approach is recommended in LMIC or other highly fluid and complex contexts (van Breda & Swilling, 2018), which requires high degree of flexibility and adaptability while maintaining vision alignment (Bos et al., 2013). Open-endedness is also important for innovation (Norström et al., 2020). An integrated approach can allow iterative and incremental reflection on stakeholders' perspectives, interests and contributions through the foundational considerations, and reveal other structural issues that could present challenges later.

In conditions of contested values, a high degree of stakeholder engagement is necessary (Schneider & Buser, 2018). Intensity of stakeholder engagement was found to be a heavy burden due to steep learning curves in developing new relationships and repeated back-and-forth communication required (Wardani et al., forthcoming). However, creating the conditions, space, and time for authentic dialog and mutual understanding is critical to ensure meaningful engagement and equity in agenda- and priority-setting, especially in a power-diverse collaborative process (Littman et al., 2021; Pratt et al., 2016). Integrating research and action stakeholders from the start can influence *Phase 1: Predevelopment & Initiation (Co-Design)* and *Phase 2: Implementation (Adaptive Co-Management)*, by creating spaces for all contributions to be equally valued through a shared learning agenda exploring perspectives and mutual interdependence (Bos et al., 2013; Pineo et al., 2021). These would likely have an effect on the Process Factors around Stakeholder Integration, as described in Section 3.2.4 below.

3.1.3 Phase 3: Monitoring & Refinement (Co-Monitoring)

During this phase, a monitoring of outputs and outcomes could take place, along with ongoing reflection on previously identified priorities and objectives, to identify possible reasons for unmet or unintended outcomes. Stakeholder outputs and outcomes (Sections 3.2.5 and 3.2.6) could be distinguished from but are no less important than research outputs, such as a conceptual framework, publications, and the policy or practice solution. Although co-monitoring is not one of the co-concepts identified by Hakkarainen et al. (2022), it is included in the practice framework as an important element identified in PAR (Crane & Richardson, 2000) to ensure outcomes and changes in reality are observed and monitored, and the proposed improvement or solution is continually refined through ongoing translation as suggested TD frameworks in public health (Pineo et al., 2021; Stokols et al., 2013). Such a co-monitoring approach, when carried out involving diverse stakeholders, could be useful in combining different knowledge systems, including local ecological knowledge, indigenous knowledge, and scientific knowledge and lead to a more effective, equitable, and inclusive monitoring (Peacock et al., 2020).

3.2 Process of stakeholder collaboration

Against the background of these research phases and 'co-concepts,' this practice framework focuses and elaborates on stakeholders as active agents, mediating towards shifts in structural power and institutional change as drawn from the scholarship on collaborative praxis and sustainability transitions (Giddens, 1984; Innes & Booher, 2018; Sovacool & Brisbois, 2019). The factors that may influence the collaborative process, are arranged in order in Figure 2 and Table 3, from most foundational and difficult to change (in darker shades of orange), to most open and uncertain in the future (in lighter shades of orange).

3.2.1 Foundational considerations | stakeholder engagement

Following collaborative governance literature, preconditions underlying collaboration require reflection prior to *Phase 1: Predevelopment & Initiation (Co-Design)*, but these Foundational Considerations (Figure 2 in purple, including all elements therein) should be applied continuously throughout the process, e.g. when additional stakeholders are engaged. These Foundational Considerations provide a set of principles that guide process design on a philosophical level, which are necessary to reach in-depth value and power differences among stakeholders. Along with questions in Table 3, these are considerations for stakeholder engagement especially in relation to the Local Context and Vision Alignment, and can influence the framing of the Sustainability Challenge being addressed. Process initiators would need to maintain openness and flexibility in their vision of the transformed system to adapt particular research questions, methodology, and desired outputs to meet all stakeholders' interests. In LMIC and resource-poor contexts, these considerations are especially pertinent to safeguard against unintended consequences of asymmetrical power dynamics. The Foundational Considerations are: Local Context; Values & Ethics; Power Dynamics; Diversity & Interdependence; Boundary Spanning; and Aligned Vision.

- **Local context:** Depicted in darker peach in Figure 2, the sociocultural, political, economic, geographic and historical context of the research setting is of paramount importance to ensure relevance and legitimacy of the knowledge or solution produced (Capon, 2017). Lack of deep and nuanced understanding of the local context, including administrative and legal barriers and operational conditions could present severe structural constraints, such as risks of failure and increased costs due to uncertainties, ambiguities, and constant changes (Cundill et al., 2018; Pineo et al., 2020; White et al., 2018). LMIC stakeholders also provide specific local and indigenous knowledge systems, research and societal priorities, and knowledge on political and power dynamics (Corburn & Gottlieb, 2005). Power and resource differences especially among HIC and LMIC partners need to be acknowledged so as to avoid marginalization of indigenous knowledge and stakeholders (Littman et al., 2021; van Breda & Swilling, 2018). Moreover, nuances in power dynamics and other complexities within and among LMICs which can influence outcomes (Pratt et al., 2016; Reidpath et al., 2022). LMIC stakeholders' priorities and interests need to be central in the co-design for equitable outcomes and to meet relevant needs (Pratt & Hyder, 2017); hence LMIC stakeholders need to be engaged in research agenda setting, leadership, and decision-making (Clark et al., 2016a; Littman et al., 2021; Peters et al., 2013).
- **Values & ethics:** Consistent with planetary health priorities for intergenerational justice and equity (Ebi et al., 2020; Zeinali et al., 2020), TD collaborations must equally value and include relevant actors, sectors, and scales (Pongsiri & Bassi, 2021) through open listening, dialog, and respect for different perspectives (Newell & Proust, 2012). These values of equity and inclusivity are compatible with indigenous and decolonizing principles and methodologies (Chilisa, 2011; Smith, 2021).

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These values are also central in social work and PAR approaches and in health which recognize the co-production of values and relations in collaborations (Corburn & Gottlieb, 2005; Filipe et al., 2017).

Intergenerational stewardship values are implicit in environmental sustainability frameworks (Lang et al., 2012; Luederitz et al., 2017), and in producing 'target knowledge' about the normatively desirable future (Schneider & Buser, 2018). Likewise, environmental sustainability explicitly recognize personal values as intertwined with authentic leadership (McIntosh & Taylor, 2013) and social learning and innovation processes (Bos et al., 2013; Bos & Brown, 2012). These latter processes are inherently value-laden, requiring higher order or 'double-loop' and 'triple-loop' learning (Tosey et al., 2012) asking the questions *'are we doing the right things' and 'how do we decide what is right?'*, in contrast to single-loop learning which focuses on efficiency and maintaining the status quo by asking *'are we doing things right'*. Social learning, through opening up perceptions of diverse possibilities, thus facilitates a fundamental questioning of the status quo with the potential to transform power relations, ways of knowing, and underlying values.

It is important to note that sustainability challenges would require collaboration among stakeholders with diverse values; however, as suggested by collaborative governance scholars, values alignment is not always necessary (Forester, 2006). Nonetheless, it may be a challenge to reconcile deep-seated differences, as reflected in epistemological differences among HASS and STEM, quantitative and qualitative methodologies, and disciplinary cultures and values (Becher, 2001). For example, Randomized Controlled Trials (RCTs) as a public health 'gold standard' methodology stem from positivist epistemology which views knowledge as objective and value-free (Bryman, 2016, p. 24). Such ontology and axiology contrast with social constructivism or critical epistemologies where individual and collective values are made explicit in the co-construction of knowledge, e.g. in addressing social justice among marginalized groups (Creswell & Poth, 2018, pp. 34–35). In natural resource management, opposing environmental values among conservationist and economic use stakeholders are both necessary for longevity of the solution (Zietsma & Lawrence, 2010). Sustainability science scholars have proposed four perspectives to address differences in values, to enable moving beyond general importance-of-values discussions; reflect on the positionality of one's values; and the contextual operationalization of values (Horcea-Milcu et al., 2019).

- **Power dynamics:** Consistent with values of intergenerational equity and commitment to 'Leave No One Behind', TD collaborations in LMIC settings need to be cognizant of power dynamics for the proactive avoidance of potential negative impacts including inadvertent erasure of existing knowledge systems (Littman et al., 2021; Reidpath & Allotey, 2019). Mapping and making sense of power dynamics has been suggested to increase the transformative potential of TD research as suggested in natural resource management (Hakkarainen et al., 2022), in sustainability transitions (de Geus et al., 2023), in global health consortia (Pratt & Hyder, 2017), and in PAR approaches (Littman et al., 2021). As posited in collaborative governance and other fields, knowledge is emancipatory in uncovering reified power relations and unacknowledged assumptions (Innes & Booher, 2018), which are critical for shifting power dynamics (Avelino & Wittmayer, 2016). Unequal power dynamics may also arise from persistent hierarchies among academic disciplines, and among HIC academic and local or indigenous knowledge (MacMynowski, 2007; Moser, 2016). Critical self-reflection and collective power reflexivity are important in encouraging equal valuing of diverse epistemologies and knowledge systems (Forester, 2013; Pineo et al., 2021) while offering greater variety of knowledge produced (Hopkins et al., 2020).

  Power is not simply a force one holds over others, but intersubjectively co-constructed within social and relational contexts, as demonstrated in the intersectionalities of power, privilege and disadvantage (Avelino, 2021; Crenshaw, 1989; Severs et al., 2016). Considering intersectionality is one way of mapping power dynamics and inequalities related to personal, professional, and social identities and the myriad discrimination that individuals and groups may face (Hankivsky et al., 2010; Larson et al., 2016). Internal factors, e.g. agency, knowledge and skills, and access to and control over resources and opportunities; and external factors, e.g. laws and policies, and social norms and exclusionary practices mediate stakeholders' ability to shift structural power through everyday practices (Avelino & Wittmayer, 2016; Sovacool & Brisbois, 2019). Explicitly acknowledging stakeholders' values, positionality, and contributions can help ensure meaningful engagement and equal valuing of all interests and contributions.

  Conducting research in LMIC settings is subject to a different set of power and resource conditions than in HICs. Most TD frameworks have emerged from well-resourced, HIC academic institutions in largely formal and legitimized contexts where societal and academic stakeholders can engage on equal footing, e.g. van Breda & Swilling (2018). Transnational and development studies scholars argue such resource and power differences are manifest in deeply uneven geographies of knowledge production, with HIC theories often universalized and flowing unidirectionally towards LMIC settings (Roy, 2009; 2016; Sassen, 2014; 2019; Sillitoe, 2018). These views are echoed in public and global health and justice research (e.g. PAR approaches), which question notions of expertise and thus usually conducted by and for communities (Corburn & Gottlieb, 2005; Littman et al., 2021), and in health where principles of equality of partners and primacy of end-user could safeguard against exploitation and 'trickle down science' (Heaton et al., 2016; Reidpath & Allotey, 2019). Our literature review of practice also revealed such unevenness in division of labor, with HIC partners involved in high-level agenda setting and research design, while LMIC partners tend to be involved in data collection (Gunasekara, 2020; Pryor et al., 2009).
- **Diversity and interdependence:** Following collaborative and environmental governance scholarship, collaboration necessarily serves diverse and interdependent stakeholders who contribute relevant and complementary knowledge and resources, but also rely on other stakeholders to achieve common and respective interests (Innes & Booher, 2018; Moser, 2016). Diversity and inclusion help ensure relevance and legitimacy, including those who benefit and those potentially harmed, stronger and weaker interests, deal makers and deal breakers, and contrarian and disadvantaged stakeholders (Forester, 2006). Collective reflexivity can feed the potential for creativity and innovation, reciprocity, and discovery of mutual benefits (Wittmayer & Schäpke, 2014).

  Recognizing interdependence was identified as a way to equally value LMIC stakeholders' knowledge and contributions, who generously supported the research despite relative lack of resources (Wardani et al., 2023). Research field workers, community, and government stakeholders contributed local contextual

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knowledge and resources crucial to intervention design, and facilities, time, and moral support for household surveys and data and sample collection. Interdependence was also found to be a key ingredient underlying stakeholders' motivation to engage. Case study participants' responses to the meaning of collaboration, such as '*you can't do it alone*,' '*all stakeholders need each other*' and '*they won't engage if they don't perceive to get something out of it*' underlined such interdependence, where diverse participants must rely on each other to achieve a common goal (quotes from Wardani et al., 2023). Likewise, interdependence is reflected in the collaborative governance and co-production of public services literature (Innes & Booher, 2018; Ostrom, 1996).

- **Boundary spanning and communication:** Upon reflection of diversity in values, power dynamics, epistemologies, and local contexts, the collaboration must consider the resources needed for boundary spanning. Used in the sustainability transitions field and drawn from institutional theory (Zietsma & Lawrence, 2010), boundary spanning include 'strategies that connect different worlds,' such as facilitating dialog, negotiation of interests, and reconciliation of potential tensions (Smink et al., 2015). Water sustainability scholars have also proposed the T-shaped concept highlighting three core group of skills to be developed by boundary spanners, including technical and functional understanding of one's own and collaborators' disciplines; organizing and management; and influence leadership (McIntosh & Taylor, 2013). Such efforts can be a time- and resource-intensive endeavor and individuals acting as boundary-spanners tend to be underappreciated, but are necessary to build mutual understanding, acceptance, and trust in relationships (Brown et al., 2019; Clark et al., 2016b; Harris & Lyon, 2013; Innes & Booher, 2018; Moser, 2016; Schneider & Buser, 2018). Deep and meaningful engagement and respect for diverse stakeholders' perspectives and interests, are essential to collaborations (Hakkarainen et al., 2022), and should not be avoided at the expense of efficiency (Littman et al., 2021). These represent transaction costs of facilitating a process from complexity towards mutual understanding, which need to be built into budgets and timelines, especially when working across multiple scales and diverse geographies (Brown et al., 2019; Moser, 2016; Wardani et al., 2023).

  In power-diverse settings, individual and collective reflexivity, itself a form of boundary spanning, is required to encourage mutual learning and accountability, yielding and wielding of power, and using values and vision alignment as a guide (Brown et al., 2019; Hakkarainen et al., 2022; Littman et al., 2021; Tawake et al., 2021). Integration of diverse knowledges require boundary spaces, conducive for social interactions, multi-way communication, relationship building knowledge exchange, and social learning (Bos et al., 2013; Marzano et al., 2006).
- **Aligned vision:** Another form of boundary spanning, an alignment of vision redraws an inclusive boundary and drives stakeholders towards a common direction and purpose (Brown et al., 2015; Brown et al., 2019). It is an essential part of collaboration bringing together diverse stakeholders towards '*a common aim*' alongside '*different classes of outcomes*' (Wardani et al., 2023). This is reflected in recent TD practice in EHD fields, which identified a shared vision, common ground, group safety and transparency as enabling factors (Black et al., 2018). Forging a shared mission requires visionary leadership in engaging stakeholders in *Phase 1: Predevelopment & Initiation (Co-Design)*, but also facilitative co-leadership in *Phase 2) Implementation (Adaptive Co-management)* phase to encourage transparent governance and for others lead and develop the process (Wardani et al., forthcoming).

3.2.2 Structural factors | stakeholder contexts

Structural factors may be difficult to change, but may also be assets to the collaboration. With stakeholders as the focus of collaboration, structural factors relate to stakeholders' disciplinary, institutional, and cultural contexts. Not least important are funding institutions at the fulcrum of change with financial and knowledge resources as leverage to institutionalize collaboration (Abson et al., 2017; Wardani et al., 2022). Funders play an important role in the evaluation, design and mechanisms of international TD collaborations; reflexivity is required to explicitly map values and power held by global funders vis-à-vis recipients of funding and communities benefiting from an intervention.

Disciplinary and institutional contexts of stakeholders can affect propensity towards collaboration, epistemological and axiological standpoints, and power dynamics within and across HIC and LMIC settings. Disciplines considered academic purists may view interdisciplinarity as risky, while those more applied and practical or formed at the boundary of two disciplines may be more encouraging of inter- and transdisciplinarity (Becher, 2001; Klein, 1996). Institutions that identify as 'boundary organizations' at the interface of science, policy and practice, such as policy think-tanks and applied research centers may be more experienced with facilitating interactions and mutual understanding among diverse epistemological and values perspectives (Gustafsson & Lidskog, 2018; Kivimaa et al., 2019). Within HIC academic settings, institutional ranking and traditional hierarchies (e.g. HASS *vs.* STEM) may create power dynamics that require reflexivity to identify and address proactively for balanced engagement (MacMynowski, 2007). LMIC settings are not homogenous, with geographical, resource and training disparities across countries and complex power dynamics within each context (Gunasekara, 2020).

Relational contexts can also predetermine power dynamics and value clusters among stakeholders. Process initiators may draw from existing networks and prior collaboration in identifying partners, as a preference over the steep learning curve required for establishing new relationships amidst managing funding uncertainties (Moser, 2016). Prior collaboration may mean sufficient mutual understanding and trust, while little prior knowledge and shared experience requires greater intensity and facilitation of interactions (Harris & Lyon, 2013; Schneider & Buser, 2018). Existing relationships may bear significant power and values clustering that may be a barrier for 'newer' partners, while complementarity and interdependence should be considered in balance, i.e. some stakeholders are critical, while others may add value but also complexity (Wardani et al., forthcoming).

3.2.3 Input factors | stakeholder contributions

Consideration of inputs is iterative with that of stakeholder engagement and structural contexts. Additional stakeholders may be required to provide relevant knowledge and as such prompt reflection on foundational considerations and structural contexts. Different stakeholders may also have different understanding of the societal challenge being addressed and different concepts depending on disciplinary and cultural backgrounds. Facilitating exploration of such differences and coming to a shared understanding is important in the initiation stage (Moser, 2016). Further, openness and ability to adapt to changes

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must be maintained throughout, as stakeholders may contribute differently than initially expected. In the framework diagram (Figure 2), this is reflected in the lighter shading of *Phase 1: Predevelopment & Initiation (Co-Design)* and in the need for an adaptive approach to co-management (Hakkarainen et al., 2022; Norström et al., 2020).

As found in the empirical case study, collaboration depended on a variety of stakeholder contributions, including tangible and intangible contributions (Wardani et al., 2023). Tangible contributions, such as funding and material resources, were typically contributed by HIC funders and researchers, while intangible ones, such as time, commitment, moral and political support, existing relationships and use of existing facilities for gatherings, sampling events, and laboratories were typically contributed by LMIC academic, government, and community stakeholders. Scientific and technical knowledge and skills tend to come from HIC stakeholders, while LMIC stakeholders contribute locally relevant applications, and contextual knowledge that may not be easily identified, described, and valued. Nonetheless, due to interdependence, without LMIC stakeholders' contributions, by completing surveys, providing biological and environmental samples, and providing community land tenure information, the research could risk implementation failure. Highlighting such interdependence could help equalize power dynamics (Wardani et al., 2023).

3.2.4 Process factors | stakeholder interactions

Strategically incorporating foundational considerations into process design and management can help enable collaboration, as the project level can span structural, relational, and individual factors and offer multi-level opportunities (Wardani et al., 2022). Organizational conditions, for example, can be established to encourage follow-on effects in stakeholder interactions (Process Factors), for example by forging common vision, values, and identity which also develops commitment and ownership (Brown et al., 2019). Likewise, creating a culture of openness and transparency in decision-making, listening and respect for diverse perspectives, and group psychological safety which help ensure equity in negotiating power dynamics (Black et al., 2018; Edmonson, 2019; Littman et al., 2021).

Another example of a structural Process factor that can be established include clear and equitable division of roles and responsibilities, institutional support for dedicated staffing and a base for a Project Management Unit (PMU), clear rules and policies, and information and communication technology (ICT) (Bark et al., 2016). Clear roles and responsibilities were highly cited as enabling, an absence of which creates ambiguity and confusion leading to misunderstanding, tension and conflict (Nix et al., 2018). Equitable division of roles means LMIC stakeholders' involvement is not limited to data collection, but should include representation in governance, agenda -setting, co-design, data analysis and authorship (Gunasekara, 2020; Pratt et al., 2016).

Strong facilitative leadership is likely to enable collaboration (Wardani et al., forthcoming), along with power-reflexive co-governance structure including sectoral and HIC-LMIC representation (Littman et al., 2021). Co-governance helps ensure relevance and legitimacy and lack of engagement of societal stakeholders could compromise dissemination and impact (Heaton et al., 2016). Processes of governance, team building, learning, and innovation must be established, to effectively orchestrate stakeholder interactions. These processes are pivotal in creating the conditions, space and time for authentic dialog, boundary spanning, and build trust, understanding and relationships (Hakkarainen et al., 2022; Harris & Lyon, 2013). Facilitative leadership helps encourage the sharing of power with leaders showing willingness to step back and yield to emerging leaders, allowing them to take greater ownership (Tawake et al., 2021). Facilitation can help with developing consensual theoretical, methodological, and evaluation frameworks, establishing common language for shared understanding (e.g. evolving text for negotiation) (Innes & Booher, 2018).

Facilitation can help build team cohesion by providing semi-formal spaces for social interactions, social learning, and creative cross-fertilization. This helps build trust through familiarity and repetition (Wardani et al., forthcoming), which helps achieve the conditions for authentic dialog where stakeholder interactions are mutually comprehensible, accurate, sincere, and inclusive (Bracken & Oughton, 2006). Social learning can be facilitated by encouraging reflexivity, listening, openness, and valuing of different perspectives (McIntosh & Taylor, 2013) to achieve triple-loop learning and systemic change (Bos et al., 2013). Creative cross-fertilization is necessary for innovation, producing knowledge and solutions through bricolage, borrowing of concepts, and looking at problems through complementary lenses (Klein, 1996).

In addition, facilitation can help stakeholders have equal access to knowledge, and that their knowledge and interests are being equally valued. High complexity, as proxied by degree of contestation and diversity requires careful design, planning and facilitation, and sound knowledge of power dynamics and stakeholder interests for knowledge exchange and production to happen (Schneider & Buser, 2018). Sustaining engagement through shared understanding, trust, and relationships is important due to the inherent uncertainties and ambiguities (Harris & Lyon, 2013). Collaborative governance scholarship note stakeholders may engage initially for instrumental reasons, but over time sustain their motivation for learning complementary viewpoints and personal friendships (Innes & Booher, 2018).

3.2.5 Output factors | stakeholder integration

Through facilitated interactions, the collaboration may start to see intermediate outputs within *Phase 2: Implementation (Adaptive Co-Management)* and into *Phase 3: Monitoring & Refinement (Co-Monitoring)*. Occurring in conducive boundary spaces, social learning and creative cross-fertilization can bring stakeholders to discover reciprocity and interdependence amongst their interests, and innovative problem-solving beyond initial expectation, which may snowball into greater motivation and cohesion for mutual support and accountability (Innes & Booher, 2018). Repeated social interactions build familiarity, mutual understanding, trust and acceptance, which eventually develop into team cohesion, and social and political capital (Putnam, 2000; Sabatier, 2005). Experiencing the initial uncertainties of the collaborative process together may build stakeholders' adaptive capacity to solve future problems, a sign of transformative triple-loop learning whereby stakeholders recalibrate their perspectives through collective decision-making.

These Output Factors are expected in parallel with specific knowledge outputs which may be the formal 'deliverables' of the project, including physical and policy innovation for the societal challenge at hand, a jointly developed conceptual framework, and academic co-publications. Innovative solutions and heuristics serve as boundary objects relevant and legitimate to all stakeholders, held together by 'communicative rationality' (Innes & Booher, 2018). For research equity, LMIC stakeholders should

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be involved in governance, leadership, coordination, and analysis activities, including co-authorship of research outputs (Gunasekara, 2020; Pryor et al., 2009). Building trust and shared heuristics, like achieving conditions for authentic dialog, requires formidable effort, time and resources (Innes & Booher, 2018). However, diversity should not be foregone in the interest of efficiency (Littman et al., 2021), and excluding certain stakeholders may create obstacles later on in the process (Wardani et al., 2023).

3.2.6 Outcomes | stakeholder & system transformations

As TD action research seeks to address a societal challenge, a litmus test for success is sustained improvements in human health, the environment, and social equity – a whole system transformation (Abson et al., 2017) or systems adaptation through innovation (Innes & Booher, 2018; Luederitz et al., 2017). Co-creation of solution-oriented knowledge (Lang et al., 2012) towards nature- and health-supportive development involves a shift in the power dynamics in decision making. A systematic shift in power dynamics is crucial in upending deeply entrenched legacies of colonialism and reification and imposition of 'universalized' HIC values, knowledge and cultures to LMIC contexts (Odora Hoppers, 2011; Tawake et al., 2021). Sustainability scholarship and PAR approaches emphasize the reflexive role of HIC researchers and stakeholders in not only recognizing the different thought styles and power dynamics (Christian Pohl et al., 2010), but also in yielding power and centering LMIC interests in such collaborations (Littman et al., 2021). Power reflexivity can help avoid inadvertent exclusion of certain stakeholders' interests and subsequently, the knowledge or resource they contribute. Socio-economic wellbeing and intra- and intergenerational equity are expected (Luederitz et al., 2017).

Sustained benefits in health and environment include socio-ecological integrity, resource maintenance and stewardship (Luederitz et al., 2017; Sabatier, 2005), and a more integrative appreciation of the interdependence between nature and health for all stakeholders (Boyden, 2016). Examples of development mechanism meeting health, environmental, and social objectives include the Green New Deal, prioritizing renewable energy, with positive health impact through improved air quality, reduced carbon emissions, and investments in inclusive upskilling centered on traditionally disadvantaged communities (Calhoun & Fong, 2022).

Knowledge produced collaboratively is hoped to meet the CRL criteria the notion of 'socially robust knowledge' (Clark et al., 2016a; Nowotny et al., 2003) – or knowledge transformation. Adoption and sustainability of the intervention are important outcomes to monitor, as suggested by implementation science (Peters et al., 2013) and attests to knowledge CRL. Legitimacy implies that all stakeholders' interests are satisfactorily communicated, listened to and addressed, even if they were not fully met; otherwise, long-term sustainability is compromised. Transformation of the current system towards the desired state needs to abide by the CRL and equity (CRL + E) criteria if we are to avoid decision making by a powerful elite at the disadvantage of certain groups; and such decision making rely on a transformation of praxis described below.

With increased collective capacity for problem solving and social learning, collaborative experience is hoped to bring about transformation of praxis, a change in the system and practices of knowledge production. Following Giddens' structuration theory (1984), our practice framework centers upon stakeholders as agents of change, and knowledge production and innovation practices conceived and embedded within its socio-political context, are more likely to yield transformative solutions and lead to the institutionalization of new norms for sustained systemic transformation. Power reflexivity, and centering historically marginalized and LMIC interests, need to be core to praxis to reverse and avoid further harm caused by colonialism and neoliberalism with enduring negative systemic effects (Littman et al., 2021; Pratt & Hyder, 2017).

3.3 Reflexivity & co-learning

Continuous and iterative reflexivity and co-learning is important in *Phase 1: Predevelopment & Initiation (Co-Design)* and at multiple touchpoints throughout. This is depicted in a purple band encircling the entire process in Figure 2. Initially during stakeholder engagement, explicitly mapping out values clusters and power dynamics in a stakeholder analysis (Littman et al., 2021), and spending time understanding the local socio-cultural, geographical, political, economic, and historical contexts through lived experience and/or learning the LMIC language, can lead to deeper understanding of potential opportunities and constraints (Gunasekara, 2020; Sillitoe, 2018). In environmental sustainability, reflexivity is a type of social learning supporting TD collaboration through self-positioning, acknowledgement of values and epistemic worldviews, and increasing mutual understanding of a complex natural system (Hakkarainen et al., 2022).

Engaging a diversity of stakeholders at various stages would likely bring some differences that must be reconciled, and values and vision alignment can be useful mitigation strategies (Littman et al., 2021). Due to mismatched institutional logics, stakeholders do not always agree on reasons, goals, and values; but importantly need a shared understanding of the problem to be addressed and direction to be taken, and trust that their shared and interdependent interests can be met through collaboration (Harris & Lyon, 2013; Innes & Booher, 2018; Smink et al., 2015). Developing shared understanding is another form of co-learning; here, academic researchers can provide mutually credible, high-quality systems, target, and transformative knowledge (Schneider & Buser, 2018). Joint agenda setting is important to reach common ground and ensure diverse stakeholders' interests are met, especially LMIC priorities that may not always be central in international research consortia (Pratt & Hyder, 2017). Discussions around target knowledge can help determine the common vision, through mapping out power dynamics and practicing reflexivity for more equitable outcomes (Littman et al., 2021).

During all phases, skilled facilitation is highly recommended across EHD, in planning and coordinating knowledge exchange, learning, and deliberations around key decisions. Facilitators may encourage self-reflexivity around power, diversity, and interdependence, and provide spaces for creative cross-fertilization (Bos et al., 2013; Innes & Booher, 2018). Orchestrating stakeholders' contributions and responsibilities in a fair and equitable way is another important role of a facilitative project manager, creating the conditions for boundary spaces for all stakeholders (Touati et al., 2019; Zietsma & Lawrence, 2010).

Reflexivity and co-learning could occur during *Phase 3: Monitoring & Refinement (Co-Monitoring)*, through a facilitated process to develop an implementation and monitoring framework observing intended and unintended outputs and outcomes. These include formal project deliverables and lessons learned on the process of collaboration and implementation of solution, through reflexive reporting which some funding institutions have begun to adopt, e.g. Most Significant Change (MSC) monitoring and

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reflection method (Davies & Dart, 2005) which could yield immediate learnings for *Phase 2: Implementation (Adaptive Co-Management)* and implementation. These learnings and refinements could include technical improvements, additional stakeholders with needed knowledge and skills, or improvement in the process of stakeholder interactions.

4. Application of the practice framework

Without unpacking the process of collaboration and inquiring into stakeholder interactions and dynamics, the design and context of TD collaboration remains a black box and risks failure to deliver the outcomes and aspirations of system transformations. The proposed practice framework aims to shed light on stages of the stakeholder collaboration process and the factors influencing it. Figure 2 outlines how these stages come together, alongside the phases of TD research, and is to be used in tandem with Table 3, a matrix of reflexive practice questions providing specific guidance throughout the cycle of research collaboration. Although each collaboration will differ in specifics, the questions can facilitate the creation of a boundary space for diverse stakeholders to practice individual and collective reflexivity, discuss potential roles and contributions; governance, leadership, and culture; and alignment of aims, objectives, and team expectations (Brown et al., 2015, 2019; Hakkarainen et al., 2022; Wardani et al., 2023).

We propose that the framework would be most effectively applied from at start at or prior to *Phase 1: Predevelopment & Initiation (Co-Design)* by process initiators and funding institutions assessing TD process design proposals for potential funding. As previously identified, funding institutions are at the fulcrum of transformative shifts with significant leverage to influence process design (Wardani et al., 2022), and hence can use the questions to guide their assessment of TD funding proposals. Early application of the framework at *Phase 1: Predevelopment & Initiation (Co-Design)* would proactively set the stage for the collaboration. The framework can also be used by stakeholders subsequent joining the process, as reference point for discussing the complex, multi-faceted dimensions of collaboration. This helps create transparency by providing a view of the process as a whole, and thus aligning expectations. While outputs and outcomes will be observed later during *Phase 3: Monitoring & Refinement (Co-Monitoring)*, and may be less apparent initially, the reflexive practice questions in Table 3 can pre-empt important factors to be considered early on.

5. Conclusion

Despite increasing recognition of the importance of TD approaches in producing credible, relevant, and legitimate (CRL) knowledge and solutions for 'wicked' and complex sustainability challenges (Clark et al., 2016a; Innes & Booher, 2018; Rittel & Webber, 1973), progress towards the SDGs remains slow and multi-stakeholder processes need more substantial guidance in its design and implementation. As LMICs and the world's poorest will face the greatest threats and disproportionate burden from climate and environmental degradation (Thiery et al., 2021), indigenous peoples and knowledges have proven most effective in conservation and management efforts (Dawson et al., 2021). We propose that additional emphasis on addressing knowledge inequities by practicing reflexivity, consciously mapping power dynamics, and reconfiguring the collaborative process (Forester, 2013; Hakkarainen et al., 2022; Littman et al., 2021; Zeinali et al., 2020).

The research and analyses leading to the development of this practice framework included (1) a theoretical meta-analysis of existing TD frameworks in the EHD fields; (2) a literature review of enabling and constraining factors synthesized from recent practice in these fields (Wardani et al., 2022), and (3) an empirical case study (Wardani et al., 2023). Such theoretical and practical syntheses were helpful in connecting across diverse fields' perspectives; while the in-depth case study offered a unique and instructive context to understanding a broad, large-scale collaboration, and a focus on the early stages of conceptualization and implementation in an LMIC setting. These contribute towards a good starting point for such a framework guiding TD practice, but further empirical research is needed to continue refining the framework and more fully understand such collaborative process, as well as its design and implementation.

The application and audience of this practice framework is envisioned to be in TD collaborations involving HIC and LMIC stakeholders. However, with its particular attention to power dynamics and stakeholder engagement, the framework may also be applicable in resource-poor, power-diverse, and vulnerable settings within HICs and in LMIC-LMIC collaborations. These may include indigenous communities or low-income or culturally and linguistically diverse groups in areas of public health and sustainability in HICs, or in informal settlements or refugee communities in LMICs. Such settings are vulnerable to well-intentioned collaborators bringing resources and associated power from outside the community (Avelino, 2021), and requires power reflexivity to avoid unintended consequences.

Admittedly, a broad application of the framework may raise limitations in meeting the specificity required in practice; however, we hope the framework offers an expansive space to carefully reflect upon a broad diversity of stakeholders and their potential interests and contributions. Moreover, further testing and refinement through reflexive practice over time could increase the relevance and enhance the usefulness of the framework for specific contexts. For the foreseeable future, more prioritization of LMIC perspectives is needed to shift the balance towards knowledge equity.

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