Geoscience for Earth Stewardship, Sustainability and Human Well-being: a conceptual framework for integrating planet, prosperity and people

Iain S Stewart[1, 2]

[1] El Hassan Research Chair for Sustainability, Royal Scientific Society, Amman, Jordan
Iain.stewart@rss.jo

[2] Sustainable Earth Institute, University of Plymouth, Plymouth, UK
istewart@plymouth.ac.uk

This submission is a postprint which has been recently published (reference and link below) with the following DOI: https://doi.org/10.1016/B978-0-443-15654-0.00029-3

The full reference is:

Stewart, I.S., 2024. Geoscience for Earth stewardship, sustainability, and human well-being: A conceptual framework for integrating planet, prosperity, and people. In Geoethics for the Future (pp. 173-189). Elsevier.

The link to the published article is:

https://www.sciencedirect.com/science/article/pii/B9780443156540000293

It is a peer-reviewed article.

ABSTRACT

There is a growing view that the mission of the Earth sciences ought to be reframed around the global sustainability agenda, and specifically the grand challenges of the UN Sustainable Development Goals. Yet the SDGs are criticised for lacking a coherent sense of the complex interconnections and synergies between its economic, environmental and social ambitions, for maintaining the impetus of economic growth, and for the absence of a compelling narrative for what a sustainable future world might look like.

Given those limitations, this paper offers an alternative meta-narrative to the global sustainability challenge in the form of coupled planetary and human well-being. It is a narrative that emerges from an overview of five decades of environmental discourse and debate to emphasise the central importance of Earth stewardship as a unifying theme. It presents the Daly Triangle as a holistic conceptual framework to link the health of the planet's natural resource base, through the operations of a sustainable economy, to the ultimate ends of long-term well-being for all.

Introduction

In the last decade or so, a view has emerged that the geosciences have a pivotal role to play in advancing global sustainability ambitions and addressing international development challenges (De Mulder & Cordani 1999, Cordana 2000, Stewart 2016, 2020, 2022, Gill 2017, 2021, Gill et al. 2019, Stewart & Gill 2017, Petterson 2019, Ludden 2020, Scown 2020, Fildani & Hessler 2021, Gray & Crofts 2022). For some it represents a pragmatic repositioning of geoscience to more effectively meet 21st century societal needs, but to others it demands a deeper, fundamental re-purposing of geoscience to better serve the public good. Fildani & Hessler (2021, p.4), for example, contend that ''To us, this is an ethical call. We cannot let our society move forward with energy and economic plans without understanding the behavior and limits of the environment we are trying to sustain. Our unique and hard-earned understanding of the past must educate global decisions about climate and energy, and so we have to speak up."

Much of the attention has focused on how geoscientific mindsets and skillsets can support the UN's 2030 Agenda for Sustainable Development - 'a plan of action for people, planet and prosperity' - to deliver long-term well-being for all (United Nations 2015). At its heart are the Sustainable Development Goals (SDGs), a comprehensive dashboard of 17 policy ambitions (and 169 targets) that aim to end world poverty and hunger, address climate change and environmental protection, and ensure universal access to healthcare, education and equality (Figure 1).

FIGURE 1: The UN Sustainable Development Goals (United Nations 2015). Although there is a lack of geoscientific expression to the SDGs, there have been multiple efforts to map Earth science knowledge and practices against the broad needs and diverse demands of the goals and their underlying targets.

Although there is no explicit geoscientific expression to the SDGs, there have been multiple efforts to map Earth science knowledge and practices against the broad needs and diverse demands of the SDGs (e.g. Gill & Smith 2021, Capello et al. 2021, 2023). A suite of studies stress the potential geological input into specific SDG challenges, such as the transition to affordable and clean energy and decarbonisation (Ringrose 2017, Stevenson et al. 2019, Stevenson 2021), responsible sourcing and extraction of minerals (Ali et al. 2017, Mudd 2021, Bendixen et al. 2021, Gloaguen et al. 2022, Franks et al. 2023), urban development (Marker 2016, Lagesse et al. 2022) and community-based tourism (Henriques and Brilha 2017, Catana & Brilha 2020, Frey 2021). On the face of it, therefore, the global Sustainable Development Goals would seem to offer a common vision, or meta-purpose, with which the breadth of geoscience and geoscientists could align.

But while the SDGs offer a shared reference framework for society's sustainability ambitions, they arguably lack a coherent sense of the interconnections and synergies between the various goals. The colourful collection of building blocks presents an iconic graphic formulation of key societal challenges but it conveys little about the underpinning interdependency and interrelations between them (Barton and Gutiérrez-Antinopai, 2020). Essentially it is a list, a compendium of thematic blocks, with an implicit suggestion that Goal 1 (an absolute end to poverty) is the headline indication (as had been the case in the preceding Millenium Development Goals (Barton and Gutiérrez-Antinopai, 2020). This absence of a clearly expressed ultimate end goal of the SDGs – "… a compelling narrative to describe how the world could look when the SDGs are fully achieved" (ICSU and ISSC, 2015, pp. 9–10) - limits the ability to inspire and mobilise action amongst policymakers, stakeholders and the general public.

In this paper, an alternative meta-narrative to the SDGs is presented in the form of coupled planetary and human well-being. It is a narrative that emerges from five decades of environmental discourse and debate to emphasise the central importance of Earth stewardship as a unifying theme, linking the health of the planet's natural resource base, through the needs of a low-carbon, circular economy, to the ultimate ends of long-term well-being for all.

A Planet in Peril

> "Surely it is obvious enough, if one looks at the whole world, that it is becoming daily better cultivated and more fully peopled than anciently. All places are now accessible, all are well known, all open to commerce; most pleasant farms have obliterated all traces of what were once dreary and dangerous wastes; cultivated fields have subdued forests; flocks and herds have expelled wild beasts; sandy deserts are sown; rocks are planted; marshes are drained; and where once were hardly solitary cottages, there are now large cities. No longer are (savage) islands dreaded, nor their rocky shores feared; everywhere are houses, and inhabitants, and settled government, and civilized life. What most frequently meets our view (and occasions complaint), is our teeming population: our numbers are burdensome to the world, which can hardly supply us from its natural elements; our wants grow more and more keen, and our complaints more bitter in all mouths, whilst Nature fails in affording us her usual sustenance."

Tertullian, *Treatise on the Soul*, 2nd century AD

The notion that humanity is living beyond its planetary means is not new. And yet, whilst the concept has deep roots (Mebratu 1998, Gober 2007), the notion of 'sustainability' is a fairly modern construct. The concept of nachhaltigkeit (sustainability) emerged out of an 18th century energy crisis when spreading Industrial Revolution impelled a rampant demand for wood fuel that cleared forests across much of Europe (Nef 1977, Perlin 1989). The Industrial Revolution - set in motion by James Watt's modification of the steam-engine in 1773 – may have marked the onset of 'the human age', the Anthropocene (Crutzen and Stoermer, 2000, Crutzen 2002), but it has left only a partial imprint in global geological records. Instead, it is the frenzy of the post-war industrialization and urbanisation that forced a dramatic reconfiguration of the planetary system (Steffen et al. 2007).

> "The second half of the twentieth century is unique in the entire history of human existence on Earth. Many human activities reached take-off points sometime in the twentieth century and have accelerated sharply towards the end of the century. The last 50 years have without

doubt seen the most rapid transformation of the human relationship with the natural world in the history of humankind." (Steffen et al., 2004: 131)

Even as the post-1950 'Great Acceleration' (McNeill 2000) was taking hold, an environmental consciousness was awakening in the West. With basic economic needs having been broadly met following in the post-war boom times, attention turned to environment and quality of life issues (Dunlap and Mertig 1991; Martınez-Alier 1995). Popular books such as Rachel Carson's *Silent Spring* (1962), on the damaging impacts of pesticides, and Paul Ehrlich's *The Population Bomb* (1968), on humanity's soaring environmental demands, fanned the flames of ecological awareness. The fragility of our planetary home was brought into further focus in 1968 with the famous 'Earthrise' photograph, snapped by astronaut William Anders, which showed a resplendent Earth hanging in the sky over the sterile terrain of the Moon.

As environmental activism grew, the state of the planet moved to the political centreground, particularly in the USA. On April 22, 1970, millions took to the streets across America for the world's first 'Earth Day' (Tortell 2020). Grassroot demonstrations, teach-ins, and community cleanups across the country were largely led white, middle-class, and young protesters, but with champions in the older generation. The hugely trusted veteran news broadcaster Walter Cronkite hosted a half-hour Earth Day special on the CBS Evening News. Lamenting '…the fouled skies, the filthy waters, and the littered earth', Cronkite concluded the broadcast with a call for the public to heed '…the unanimous voice of the scientists warning that halfway measures and business as usual cannot possibly pull us back from the edge of the precipice.' (Tortell 2020).

This social tipping point around the perception of 'a planet in peril' impelled important policy action on the ground. By the end of 1970, the US government had established the Environmental Protection Agency, brought in sweeping amendments to the Clean Air and Clean Water Acts, and introduced an Endangered Species Act. Two years later, at the United Nations Conference on the Human Environment, the 'Stockholm Declaration' acknowledged the power of humanity to "…transform his environment in countless ways and on an unprecedented scale".

A Planet of Prosperity

Even as planetary degradation was emerging as potent political issue, the means to tackle it, alongside poverty alleviation and social inequity, was widely viewed as economic development. Since the 1950s, 'economic development' had become almost synonymous with 'economic growth', which in turn had become a centrepiece of Western economic policy. Propelled in the 1970s by Friedman and others at the 'Chicago School of free-market economists', unfettered economic growth was seen as the engine to generate prosperity, with the 'trickle down' of wealth creation expected to raise living standards and deliver a better quality of life (Daly 2005).

Economic growth and wealth creation was largely fueled by fossil fuel energy and fed by mineral and metal extraction, both of which relied on geological knowledge and expertise. "It can be said, without exaggeration, that the development of geosciences goes hand in hand with industrial growth. In other words, industry can never expand fast enough to promote the economy of human society without sophisticated geosciences and relevant technology"(Xun et al. 1997, p.84).

Economic growth as the panacea for all major socio-economic ills was becoming the prevailing paradigm for international development, but alternative economic models were proposed for humanity's changing relationship with its planetary home. In Small is Beautiful - 'a study of economics as if people mattered' - the ecological economist Ernst Schumacher (1973) argued that the modern growth-based economy was unsustainable on a finite planet, and instead advocated for a decentralised, human-scale approach to development that prioritized the well-being of individuals and communities over the relentless pursuit of growth.

In a similar vein, the former World Bank senior economist Herman Daly envisaged a steady-state economy delivering human well-being and rooted in planetary well-being in the form of a hierarchial triangle (Daly 1973) (Fig. 2). At the base of the so-called 'Daly Triangle', supporting everything, are what he regarded as the ultimate means – the biophysical properties of nature. This constitutes the natural resource base of the biosphere, its ecosystems, biochemical cycles, and its raw materials. From that foundational life-support system, materials were extracted and processed by scientific know-how and technological tools to provide intermediate means which then fueled and fed the industrial engine. In contrast to mainstream economic thinking that viewed material wealth and financial maximization as the end goals of the economic engine, for Daly these represented only intermediate ends. Instead, the ultimate ends were the intrinsic well-being components beyond merely physical or material basic needs - welfare, or similar constructions such as happiness, harmony, or community. The real purpose of economic development was not just to have money but to have better lives.

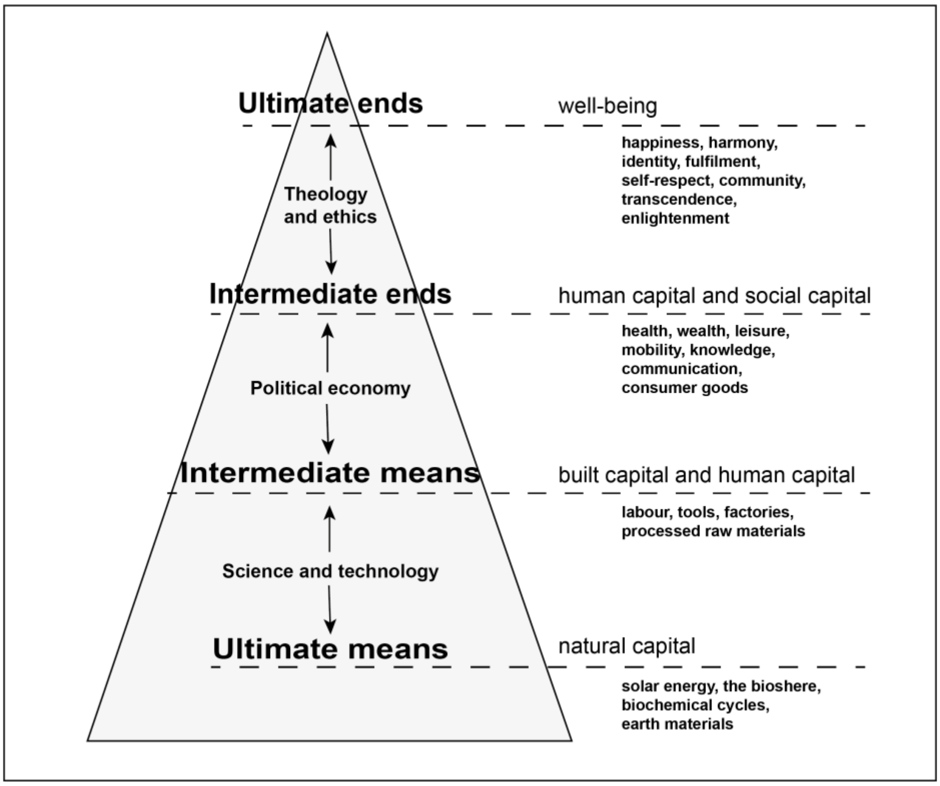

Figure 2: The Daly Triangle of sustainability (Daly 1973), modified by Meadows (1998) to incorporate the concept of multiple capitals.

According to Meadows (1998, p.46) "Integration of the triangle from bottom to top requires good science *and* just and efficient political and economic systems *and* a culture that illuminates the higher purposes of life. The focus of such a society would be wholeness, not maximizing one part of the system at the expense of other parts. The goal of perpetual economic growth would be seen as nonsensical, partly because the finite material base cannot sustain it, partly because human fulfillment does not demand it." (Meadows 1998, p.46). In contrast to the myopic fixation of market-led economics on wealth creation, sustainable development, viewed through the Daly's Triangle, expands the role of the economy to include the top (development) and bottom (sustainability) of the triangle.

This notion that the economy was not the problem but rather the solution (through prosperity) was brought into sharp focus in 1987 when UN World Commission on Environment and Development published its report 'Our Common Future' (the Brundtland Report). Directly confronting the 'planet versus prosperity' paradox, it advocated for ''a new era of economic growth—growth that is forceful and at the same time socially and environmentally sustainable''. In doing so, the Brundtland Report gave the first coherent definition of the 'new' concept of 'sustainable development': "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

With the publication of the Brundtland Report, 'sustainable development' became the dominant paradigm of the environmental movement. It became conceptualised as the interaction between economic, social, and environmental (or ecological) factors (Purvis et al. 2019). These factors, or dimensions, are initially depicted as three pillars or intersecting circles of society, environment, and economy, with sustainability being placed at the intersection (Fig 3a and 3b), or visualised as nested circles, with social and the economic dimensions situated as subsystems within the environment (Fig 3c). Later, drawing on the concept of 'capital' in economics, whereby capital stocks (assets) provide the flows of goods and services that contribute to human well-being, sustainable development was recast as the intricate interdependencies between 'multiple capitals': environmental (natural capital), social (social capital and human capital capital) and economic (built or manufactured capital and financial capital) dimensions (Ekins 1992; Porritt 2005) (Figure 3d).

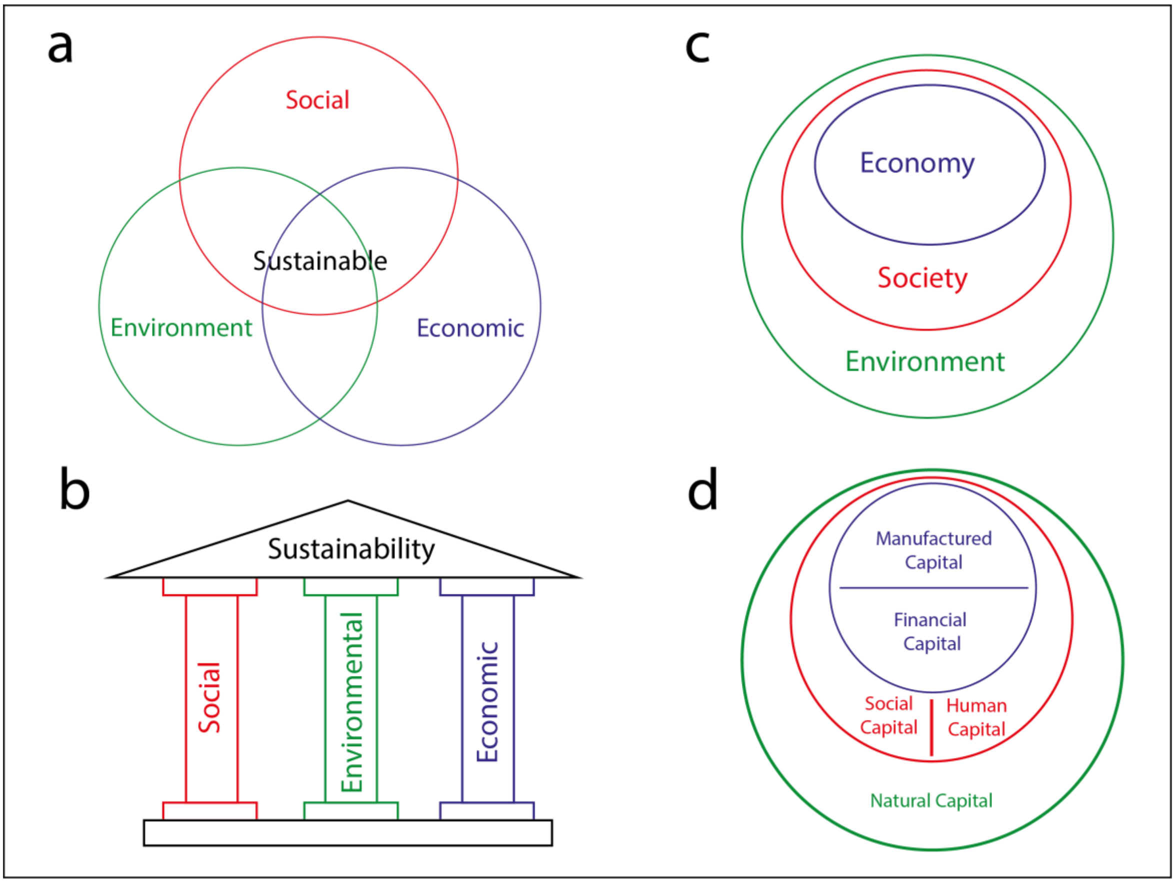

Figure 3: Contrasting visualisations of sustainability, as depicted with the three intersecting circles (a) or pillars (b) of social, environmental and economic factors. In some schemes, the circles are

nested, highlighting that society is a subset of the environment, whilst the economy is a subset of society (c). Later depictions convey a more complex hierarchy of nested 'multiple capitals' (d).

These interdependencies can be regarded as 'weak sustainability' if they can be traded off against each other. Thus, the environment can be viewed as less essential if its impoverishment can be offset by benefits gained by enhanced economic growth (under the assumption that rising manufactured output will maintain future human welfare. For mainstream market-led economists, as long as there was no downturn in economic growth, substitutes for exhaustible natural resources would always be found.

The problem with the idea of trade-offs is that some forms of capital are non-substitutable. 'Strong sustainability' is the premise that offsetting natural capital loss against and between economic (manufactured or financial) capital gain is untenable because such substitution cannot deliver truly sustainable assets for future generations' well-being needs. In recent decades, geoscientists have demonstrated a compelling argument for 'strong sustainability' through the realization that there are limits and boundaries to the planet's well-being.

Earth System Science: Limits, Boundaries and Tipping Points

The notion of planetary limits first became apparent during the heyday of environmental awareness. In 1968 the Club of Rome invited Donella Meadows and her colleagues at the Massachusetts Institute of Technology to examine the consequences of continued exponential economic and population growth on the Earth system. Published four years later as *The Limits to Growth* (Meadows et al. 1972), the landmark study used computer simulations for the first time to model future potential impacts of population increase, resource depletion, and environmental pollution (Weinberger 2015). The base case scenario (the so-called Standard Run) took the prevailing trends from 1900 to 1970 of population, food production, industrial production, pollution, and consumption of non-renewable resources, and projected them forward to 2100. Across multiple human development scenarios, global systems were shown to be dependent on non-renewable finite natural resources. The clear message from *The Limits to Growth* simulations was that continued unfettered growth in the global economy would lead to biophysical planetary limits being exceeded during the 21st century, resulting in a collapse of both the economic system and human population; in the Standard Run, the window of collapse was projected to be between 2015 and 2025.

In setting out a counter notion of a desirable 'state of global equilibrium, Meadows et al (1972) introduced the first appearance of the term 'sustainable' in its modern global context (Purvis et al. 2019), stating that "We are searching for a model output that represents a world system that is: 1. sustainable without sudden and uncontrolled collapse; and 2. capable of satisfying the basic material requirements of all of its people." But despite its resonance with the popular environmentalism of the time, academic criticism of *The Limits to Growth* was so extensive and almost universal (Nordhaus & Tobin 1972, Solow 1973, Simon 1980) that it created an enduring impression that the simulations were flawed and inaccurate (Atkisson 2010). And yet, over time, the MIT group's first-order projections have proven to be surprisingly accurate. A comparison of historical data with model predictions confirmed that the base case scenario model was broadly correct (Turner 2008), at least up until around 2010 (Jackson et al. 2016). Moreover, more recent studies have confirmed the basic thesis that business-as-usual economic growth is exceeding fundamental planetary boundaries (Wackernagel et al. 2002, Randers et al. 2019).

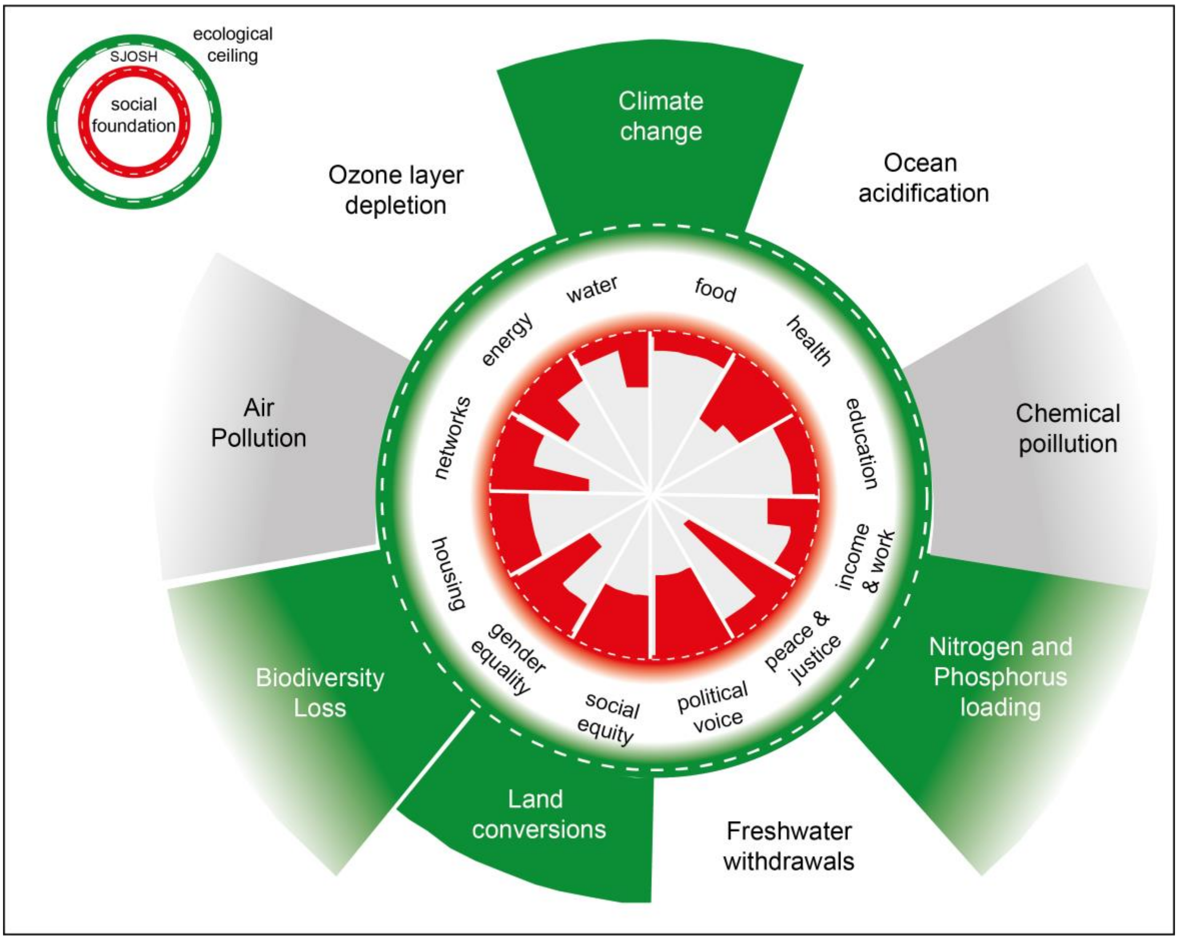

Figure 4: A combined visualization of the planetary boundaries concept (green and grey outer arc) (Rockstrom et al. 2009) and the Oxfam doughnut of social limits (red inner) (Raworth 2012).

The 'planetary boundaries' hypothesis (Rockström et al. 2009) highlighted the urgent linkage between environmental problems and human development, instead of the importance of the environment for its own sake (Elder & Olsen 2019). It contends that there are nine planetary biophysical subsystems or processes that determine the self-regulating capacity of the Earth system. Exceeding the limits of these subsytems — land-use change, biodiversity loss, nitrogen and phosphorous levels, freshwater use, ocean acidification, climate change, ozone depletion, aerosol loading, and chemical pollution — may have catastrophic consequences for the long-term well-being of humanity (Figure 4). Responding to the geoscientific notion of the planet's life support system having ecological ceilings, Raworth (2012) combined planetary boundaries with the idea of a social foundation, an inner boundary below which lie shortfalls in well-being, such as hunger, ill health, illiteracy, and energy poverty. Environmental and socio-economic aspects or dimensions of development ought not to be viewed as discrete pillars or overlapping circles, but rather as intertwined and interdependent socio-ecological dimensions (Elder & Olsen 2019) (Figure 4). Paired in this way, the challenge is how to meet societal needs at an acceptable level without risking the exceedance of critical planetary thresholds (Raworth 2017).

This delicate planetary balancing act had been understood early on, and was captured in the 1974 UNEP/UNCTAD 'Cocoyoc Declaration', which recognised the need to transcend the "'inner limit' of satisfying fundamental human needs" while respecting the "'outer limits' of the planet's physical integrity" (UNEP and UNCTAD 1974). But with its modern socio-ecological expression defining a 'safe and just operating space for humanity' (Raworth 2012, Dearing et al. 2014), the concept attracted considerable attention in the sustainable development sector (Hajer et al., 2015, Häyhä et al., 2016; Hoff and Alva, 2017).

In the decade that followed, the planetary boundaries concept was updated and fine-tuned (Steffen et al. 2015), with improved baselines and assessments, alternative configurations, and renewed attention on the nature of environmental thresholds (Carpenter and Bennett, 2011; Gerten et al., 2013; Mace et al., 2014, Running, 2012). In doing so, Earth system science extended its purview into the complex interactions between planetary processes and human impacts (De Vries et al., 2013; Van Vuuren et al., 2016). Augmenting the concept of planetary boundaries was the contention that there are multiple 'tipping elements' in the Earth system where a tiny change could tip the whole planetary system into a completely new state (Lenton et al. 2008, Schellnhuber 2009, Lenton 2013). Tipping behavior is found across the Earth system, in ecosystems, ice sheets, and the circulation of the ocean and atmosphere. The loss of the West Antarctic ice sheet, tropical coral reefs, the Amazon rainforest, and Arctic sea ice, along with extensive thawing of the permafrost, are among nine 'global core' tipping points which in the geological past have been shown to cross critical thresholds, and then abruptly and irreversibly change, nd which if they happened again would have severe impacts for human society.

The Sustainable Development Goals (SDGs)

As the United Nations contemplated the follow-on from its 2000-2015 Millenium Development Goals (MDGs), attempts were made to integrate the new ideas emerging from Earth system science (Griggs et al. 2013, Rockstrom et al. 2013) (Figure 5). Arguing that the protection of Earth's life-support systems and poverty reduction ought to be the twin priorities for the upcoming Sustainable Development Goals, Griggs et al. (2013) reframed the Brundtland definition as: "development that meets the needs of the present while safeguarding Earth's life-support systems, on which the welfare of current and future generations depends". They stressed the need to give ultimate priority to the environmental goals "so that today's advances in development are not lost as our planet ceases to function for the benefit of the global population" (Griggs et al. 2013).

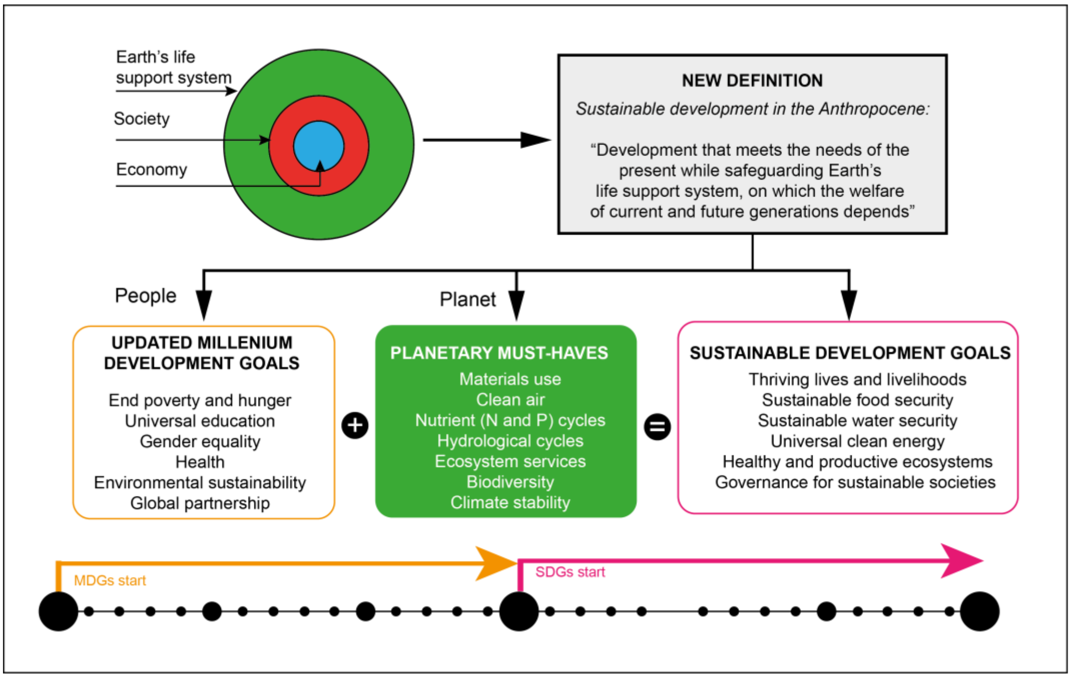

Figure 5: A unified framework with conditions necessary to assure the stability of Earth's systems. (Griggs et al. 2013)

Other integrated frameworks were also proposed, including fusing Daly's ultimate means-ends triangle with key sustainability ambitions as an alternative holistic conceptual framework for policy development (Pinter 2014) (Figure 6). Ultimately, however, when the UN's 2030 Agenda finally presented its Sustainable Development Goals (SDGs) in 2015 neither of these two ecologically-tuned frameworks were centrestage.

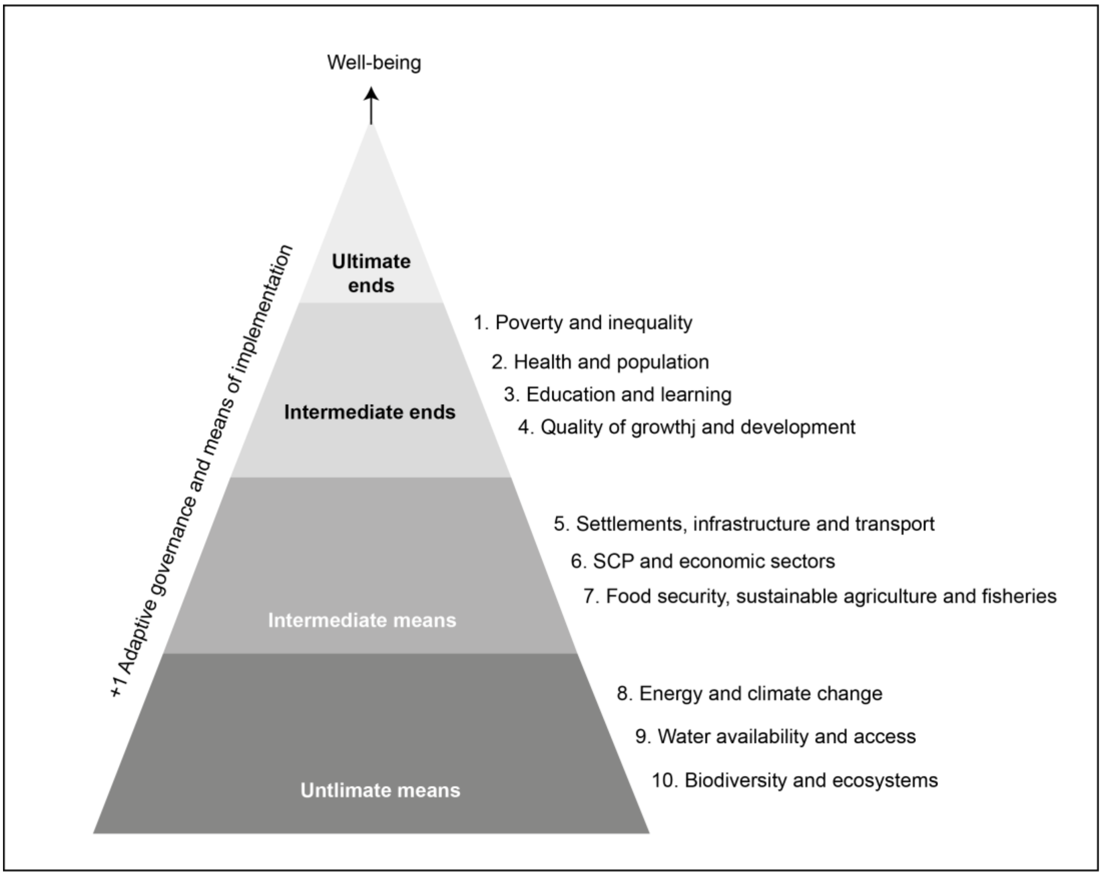

Figure 6: The alignment of the 10+1 Small Planet goals with the ultimate means-ends framework (Pinter et al. 2014, fig. 3.1)

The SDGs present a checkerboard of 17 grand societal challenges, - 14 broadly 'socio-economic' goals and 3 largely 'environmental goals' (SDGs 13, 14 and 15) - each tied to specific and measurable underpinning targets. Behind its iconic dashboard of ambitions lies a deeper, more overt environmental perspective than was evident in the preceding MDGs. Environmental elements have been extensively incorporated across all the goals, and among them are broad-ranging, ambitious and measurable environmental aspirations (Elder & Olsen 2019). Collectively, the SDGs committed the global community to "achieving sustainable development in its three dimensions—economic, social and environmental—in a balanced and integrated manner". That underpinning logic, however, maintains the view established by the Brundtland Report in 1987 that economic growth can be made environmentally sustainable. Thus, in SDG 8 (Decent Work and Economic Growth) growth appears as the key to prosperity and poverty reduction.

Planetary boundary	Related SDG targets	
Climate change	13.2	Integrate climate change measures into national policies, strategies and planning
Ocean acidification	14.3	Minimise and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels
Stratospheric ozone depletion	12.4	By 2020, achieve environmemtally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their impacts on human health and the environment.
Change in biosphere integrity	15.5	Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity, and, by 2020, protect and prevent the extinction of threatened species..
Land-system change	15.2	By 2020, promote the implementation of sustainable management of all types of forest, halt deforestation, restore drgraded forests, and substantially increase afforestation and reforestation globally.
	15.3	By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neitral world.
Biochemical flows (N and P cycles)	2.4	By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, help maintain ecosystems, strengthen capacity for adaptation to climate change, extreme weather, and other disasters and progressively improve land and soil quality.
	14.1	By 2025, prevent and significantly reduce marine polution of all kinds,, in particular from land-based activities, including marine debris and nutrient pollution.
Freshwater use	6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals.
Atmospheric aerosol loading	3.9	By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
	11.6	By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality, municipal and other waste management.
Introduction of novel entities	6.3	By 2030, improve water quality by reducing pollution, eliminating dumping and minimising release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and increasing recycling and safe reuse globally.
	12.4	By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment.

Figure 7: Planetary boundaries and related SDG targets (from Lucas & Whiting 2018, based on Häyhä et al. 2018).

Although the collective aspiration of the 2030 Agenda and its goals broadly serves the meta-purpose of 'sustainability' – namely, improved long-term wellbeing for all – it lacks a coherent sense of what the most urgent actions are. Collectively, the SDGs imply human development within a safe and just operating space for society to thrive in but, rejected by some national governments, the concept of planetary boundaries is not mentioned explicitly (Elder & Olsen 2019). Instead, all nine ecological ceilings were incorporated in some way and to some degree amongst the SDG environmental targets (Figure 7). Yet, because overarching planetary boundaries define the global biophysical preconditions within which national, regional and local sustainable development can operate, this leaves uncertain how potential conflicts between the environment-led priority of Earth's life-support systems and the economy-led priority of poverty reduction can and ought to be resolved (Elder & Olsen 2019). Rather than being a bold 'call to arms' centred on planetary integrity, the SDGs offered a shared vision for pragmatic collective action for national governments to tackle a broad swathe of development targets (Lucas & Whiting 2018).

In response to this absence of a motivating 'Earthshot' mission, others have re-configured the SDG dashboard to convey a more coherent visual narrative. For example, Rockström & Sukhdev (2016) presented the SDG 'wedding cake', which visualises the economic, social and ecological aspects of the Goals in terms of their direct or indirect connection to sustainable and healthy food, illustrating how the economy and society should be seen as embedded parts of the biosphere *(*Stockholm Resilience Center 2016). Similarly, Lucas et al. (2016) depicted the SDGs as three clusters that mimic the Daly Triangle (Figure 8). The top cluster, with people at the centre, contains social goals and can be represent the minimum standards for human well-being. Achieving these top goals relies on supporting goals that relate to production, consumption and distribution of goods and services (middle cluster). Finally, realisation of these resource and economy goals depends on conditions in the biophysical systems or natural resource base (bottom cluster), including climate, oceans, land and biodiversity (and include parts of SDG6). These goals address protection, conservation, restoration and sustainable use of critical parts of the Earth system and directly relate to the planetary boundaries. The three clusters are underpinned by goals addressing governance (SDG 16) and means of implementation (SDG 17).

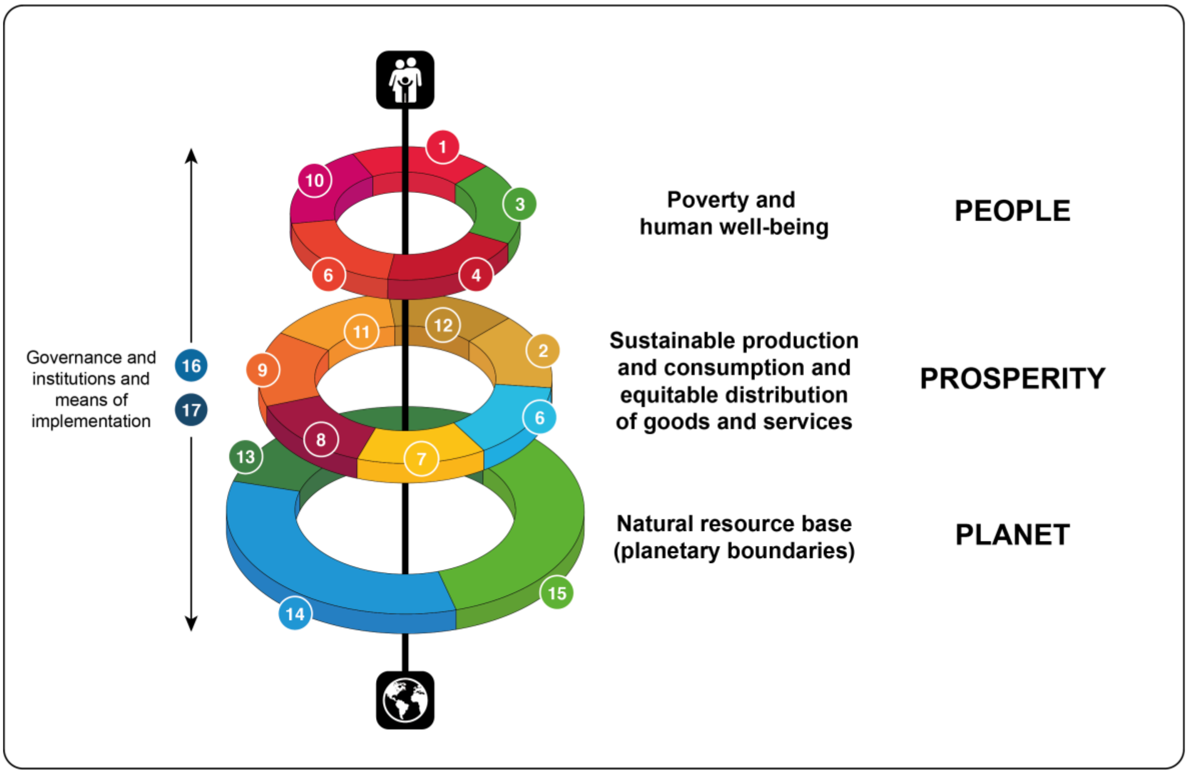

Figure 8: Visualising the economic, social and environmental clusters of the Sustainable Development Goals (SDGs) in terms of a hierarchy of priorities, from planet to people, via prosperity. (From Lucas et al. 2016).

Human Well-being and the Well-being Economy

Although economic development has delivered significant improvements in human well-being (Pinker 2018, Rosling 2019), intensified growth in Gross Domestic Product (GDP) and resource exploitation across the world is associated with the simultaneous acceleration in biodiversity loss, climate change, pollution and destruction of natural capital (Costanza et al. 2016). Despite the rhetoric, economic growth has not been decoupled from resource consumption and environmental pressures and is unlikely to become so, at least within the urgent timescales for action (Hickel and Kallis, 2020; Wiedmann et al., 2020; EFA 2021). The global material footprint, GDP and greenhouse gases emissions have increased rapidly over time, and strongly correlate (Coscienne et al. 2019). While population growth was the leading cause of increasing consumption from 1970 to 2000, the emergence of a global affluent middle class has been the stronger driver since the turn of the century (Panel, 2019; Wiedmann et al., 2020). For all these reasons, indefinite economic growth is increasingly viewed as incompatible with the pursuit of sustainable development (Hickel 2019, Hoekstra 2019).

While mainstream economics regarded growth as the global imperative for delivering human well-being, the environmental and social fallout from its legacy has ushered in an alternative economic paradigm: the Well-being Economy. (Costanza et al. 2007, Fioramonti 2017). The well-being economy not only seeks to measure the level of economic activity, but also material living conditions, quality of life outcomes and various other sustainability implications (Costanza et al., 2018; Fioramonti et al., 2022; McGregor and Pouw, 2016; OECD, 2013; Wellbeing Economy Alliance 2019). Costanza et al. (2018, p.1) articulated that the well-being economy has "…the fundamental goal of achieving sustainable well-being with dignity and fairness for humans and the rest of nature…A well-being economy recognises that the economy is embedded in society and nature. It must be understood as an integrated, interdependent system."

Costanza et al. (2018, p.3) determined five goals for the well-being economy that derive from this overarching aim:

- Staying within planetary biophysical boundaries – a sustainable size of the economy within our ecological life support system.
- Meeting all fundamental human needs, including food, shelter, dignity, respect, education, health, security, voice, and purpose, among others.
- Creating and maintaining a fair distribution of resources, income, and wealth – within and between nations, current and future generations of humans and other species.
- Having an efficient allocation of resources, including common natural and social capital assets, to allow inclusive prosperity, human development and flourishing. A well-being economy recognises that happiness, meaning, and thriving depend on far more than material consumption.
- Creating governance systems that are fair, responsive, just and accountable.

Defined by its pursuit of human and ecological wellbeing rather than material growth, and measured by various indices and criteria (e.g. the OECD's 2020 'Better Life Index'), the Wellbeing Economy is finding increasing favour among many corporations and governments as a better way of measuring their economic and social value. Currently, six countries - Iceland, New Zealand, Finland, Scotland and Wales and Canada - are prioritizing well-being and sustainable development over traditional economic growth. And what this WeGo Alliance of nations is promoting internationally, businesses are doing at the corporate level through the rise of social purpose Hurth & Vrettos 2021). In 2019, for example, the British Academy report into the 'Future of the Corporation' concluded that "the purpose of business is to solve the problems of people and planet profitably, and not profit from causing problems" (Hurth & Stewart 2022).

This shift to a new economic and social paradigm that puts people and the planet at its heart would seem broadly consistent with UN's global sustainability goals. After all, endeavours to advance sustainable development goals would seem likely to improve human well-being measures. But the picture is more complex than that. For a start, modelling the 'business-as-usual' scenario into future decades indicates that 'conventional efforts to achieve the 14 socio-economic SDGs will raise pressure on planetary boundaries, moving the world away from the three environmental SDGs' (Randers et al. 2019, p.1).

Also, whilst there is a strong general correlation between achieving sustainable development and subjective indices of human well-being, Neve & Sachs (2020) reported that SDG12 (Responsible Consumption and Production) and SDG13 (Climate Action) were negatively correlated. Given that the world economy has long relied on economic growth and the consumption of natural resources to generate human welfare at the expense of its environmental and climate, these results are not surprising. But the implications are stark. If we are to avoid ecological collapse we must bring our consumption of natural and material resources within ecological limits, yet that will involve major real reductions in emissions and fundamental changes to consumption and production patterns. Under current structures, advancing on SDG12 and SDG13 could have serious socio-economic consequences, particularly in lesser developed countries, and the required scale of the interventions may well adversely impact well-being levels, particularly those of the most vulnerable (Bengtsson 2018). Given that SDG 12 and 13 are two of the global sustainability goals that are most closely associated with geoscience, through the energy transition / new mineral revolution and subsurface carbon sequestration, this is an important concern for geoscientists.

Conclusion

The emergence of wellbeing as a driver for a reconfigured market-based economy offers a fresh conceptual framework in which the Earth can be conceived as a single system, 'people included' (Bohle & Marone 2019). Projected through the fifty-year old prism of the Daly Triangle (Fig 8) the three narrative themes of planet, prosperity and people are neatly coupled (Stewart 2023). In turn, in terms of offering coherent and compelling narratives for the contribution of the geosciences towards a sustainable future, three different storylines emerge:

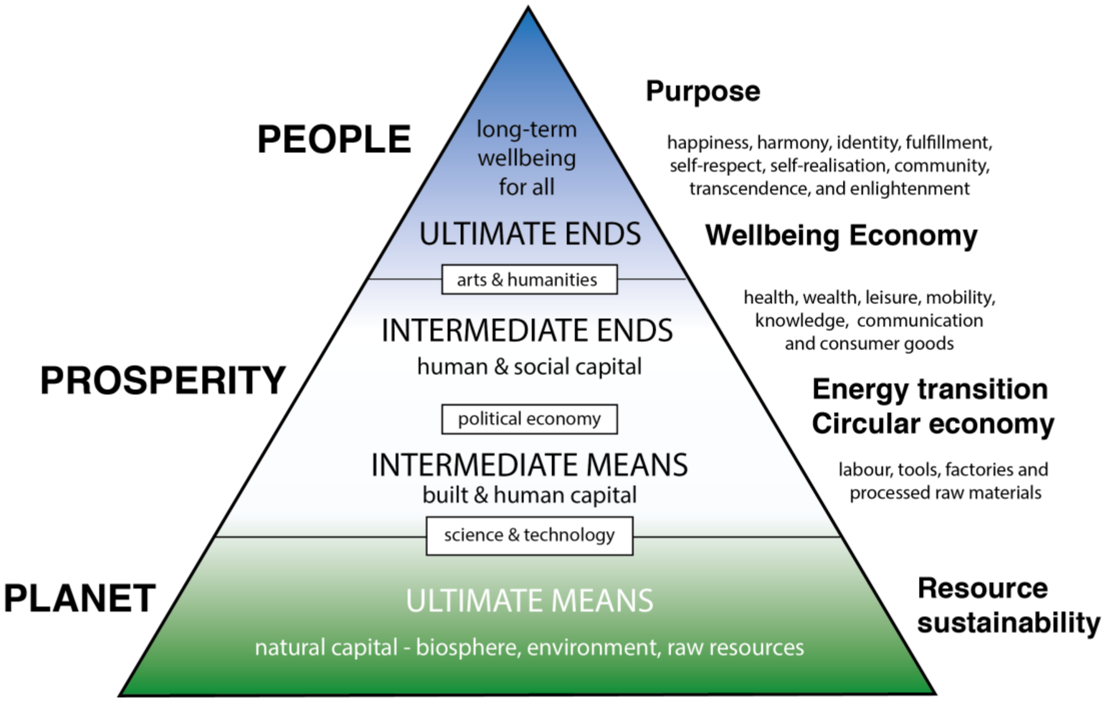

Figure 8: The wellbeing framework Daly (1973), as re-visualised by Meadows (1998), offers a holistic view of how planet, prosperity and people can be integrated to address Earth stewardship and sustainability concerns (From Stewart 2023)

Stortyline #1: Geoscientists as key workers for the planet

Geoscientists are *Earth* scientists, and we can apply our scientific understanding of the planet's past rhythms, sensitivities and thresholds to concerns over its future integrity and viability for all life. As well as emphasisng the broad sweep of Earth system science in monitoring planetary boundaries, limits and tipping points, geoscientists are the vital guardians for protecting land, air, water and raw materials to ensure the sustainability of the precious natural resource base. We are the stewards of the planet.

Storyline #2: Geoscientists as key workers for the economy

Economic growth will remain an essential part of development for many countries of the world, but a more sustainable production and consumption of our raw materials is needed for if we are to transition to a low-carbon, circular economy. Geoscientists have a vital role in exploring for and more efficiently extracting not only the critical minerals required for the new 'green economy' and renewable energy transition (Gloaguen et al. 2022) but the far larger flux of 'development minerals' that routinely support local industries such as construction, manufacturing, infrastructure and agriculture (Franks & Keenan 2023). As well as contributing widely to resource and energy efficiency gains, subsurface geoscience will be crucial for advancing decarbonization and 'geological net-zero' through deep geological storage of carbon dioxide (Fankhauser et al. 2022). In other words, geoscientists provide real-world solutions to a planet in peril.

Storyline #3: Geoscientists as key workers for advancing human well-being

Whilst narratives 1 and 2 map readily onto current practices within the geosciences, the challenge to extend the social purpose of the Earth science mission to the ultimate ends of helping deliver 'long-term wellbeing for all' presents a more radical vision. It compels geologists to consider how they might more directly contribute to the enduring human well-being aspirations of zero hunger and no poverty, alongside securing good health and clean water as basic requirements for a 'good life'. This will include the geochemistry of the 'critical zone' that is essential for food security, the geophysical study of natural hazards which are a persistent impediment to sustainable development, and the medical geology expertise that can works across multiple SDGs to identify the presence of toxic or potentially harmful elements in the environment or absence of essential nutritional elements for healthy living.

But 'human geoscience' is more than ensuring the provision of basic human needs and levels of health. It demands a deeply considered geoethical framework (Peppoloni & Di Capua 2012, 2021), a motivation to broaden diversity and inclusivity (Atchison et al. 2019, Dutt 2020, Ali et al. 2021, Downey et al. 2021), a desire for a more purposeful and participatory engagement with communities to help solve their problems on their terms (Stewart et al. 2017, Stewart & Hurth, 2021), and the commitment to work in equitable, transparent ways that promote peace and social justice (Gill et al. 2022). Examples of many of these principles can be seen in the emergence of new geoscience social enterprise organisations, such as the Seattle-based nonprofit 'Geology in the Public Interest', whose mission is to 'enhance and expand applications of geoscience in service of the common good and to aid in local and regional efforts to advance resilience and sustainability'. Another example is 'Geology for Global Development', a UK charitable organisation with a remit to 'improve lives and livelihoods in the Global South, through access to geological science'.

All three storylines are likely to be important if geoscience and geoscientists are to be influential in the sustainability arena. No single intervention will transform the world, so an integrated earth stewardship approach is needed to shift society from its current unsustainable trajectory. According to Chapin III et al. (2022) to make that shift, three leverage levels are required. Firstly, a guiding vision for how sustainable earth processes (both social and biophysical) are a prerequisite for wellbeing of people and the rest of nature. Secondly, changes in both social norms and incentives to move a market economy toward more sustainable production/consumption outcomes. Thirdly, revitalized agency to engage new actors and novel institutions in new pathways toward sustainability in ways that are sensitive to local contexts and conditions.

Arguably, geoscience has all three leverage points entwined within its triple helix of planet, prosperity and people. Our increasing understanding that our planet's natural integrity is being compromised, threatening humanity's long-term viability, offers an ambitious, clear, enduring and overarching mission that can motivate action. At the same time, our technical and material contributions to the energy transition, decarbonisation, and the circular economy offer practical and tangible solutions to the challenges of moving toward a low-carbon future. Finally, the recent emergence of bottom-up movements within the geoscience community suggests a growing impetus to foster a more people-centred science dedicated to actionable public good. Transformation toward a more sustainable future is never guaranteed but without geoscientists fully onboard it is far less likely to happen. That, however, will require geoscientists to embrace their role as Earth stewards and more directly confront issues of planetary and human well-being, coupled through the engine of a prosperous but sustainable economy.

REFERENCES

Ali, H.N., Sheffield, S.L., Bauer, J.E., Caballero-Gill, R.P., Gasparini, N.M., Libarkin, J., Gonzales, K.K., Willenbring, J., Amir-Lin, E., Cisneros, J. and Desai, D., 2021. An actionable anti-racism plan for geoscience organizations. Nature Communications, 12(1), pp.1-6.

Ali, S.H., Giurco, D., Arndt, N., Nickless, E., Brown, G., Demetriades, A., Durrheim, R., Enriquez, M.A., Kinnaird, J., Littleboy, A. and Meinert, L.D., 2017. Mineral supply for sustainable development requires resource governance. Nature, 543(7645), pp.367-372.

Amezaga, J.M., Rötting, T.S., Younger, P.L., Nairn, R.W., Noles, A.J., Oyarzún, R. and Quintanilla, J., 2011. A rich vein? Mining and the pursuit of sustainability. Environmental science & technology, 45(1), pp.21-26.

Atchison, C.L., Marshall, A.M. and Collins, T.D., 2019. A multiple case study of inclusive learning communities enabling active participation in geoscience field courses for students with physical disabilities. Journal of Geoscience Education, 67(4), pp.472-486.

Atkisson, A. 2010. Believing Cassandra: How to Be an Optimist in a Pessimist's World; Routledge: Abingdon, UK.

Barton, J.R. and Gutiérrez-Antinopai, F., 2020. Towards a Visual Typology of Sustainability and Sustainable Development. Sustainability, 12(19), p.7935.

Baue, B., 2019. Compared to what? A three-tiered typology of sustainable development performance indicators from incremental to contextual to transformational (No. 2019-5). UNRISD Working Paper.

Bendixen, M., Iversen, L.L., Best, J., Franks, D.M., Hackney, C.R., Latrubesse, E.M. and Tusting, L.S., 2021. Sand, gravel, and UN Sustainable Development Goals: Conflicts, synergies, and pathways forward. One Earth, 4(8), pp.1095-1111.

Bengtsson, M., Alfredsson, E., Cohen, M., Lorek, S. and Schroeder, P., 2018. Transforming systems of consumption and production for achieving the sustainable development goals: moving beyond efficiency. Sustainability science, 13, pp.1533-1547.

Bohle, M. and Marone, E., 2019. Humanistic geosciences and the planetary human niche. Exploring Geoethics: Ethical Implications, Societal Contexts, and Professional Obligations of the Geosciences, pp.137-164.

Capello, M.A., Shaughnessy, A. and Caslin, E., 2021. The geophysical sustainability atlas: Mapping geophysics to the UN Sustainable Development Goals. The Leading Edge, 40(1), pp.10-24.

Capello, M. A. et al. 2023. Geoscience in Action, co-published UNESCO AGU, Washington.

Catana, M.M. and Brilha, J.B., 2020. The role of UNESCO global geoparks in promoting geosciences education for sustainability. Geoheritage, 12(1), p.1.

Chapin III, F.S., Weber, E.U., Bennett, E.M., Biggs, R., Van Den Bergh, J., Adger, W.N., Crépin, A.S., Polasky, S., Folke, C., Scheffer, M. and Segerson, K., 2022. Earth stewardship: Shaping a sustainable future through interacting policy and norm shifts. Ambio, 51(9), pp.1907-1920.

Collste, D., Cornell, S.E., Randers, J., Rockström, J. and Stoknes, P.E., 2021. Human well-being in the Anthropocene: limits to growth. *Global Sustainability*, *4*, p.e30.

Cordani, U.G., 2000. The role of the earth sciences in a sustainable world. Episodes Journal of International Geoscience, 23(3), pp.155-162.

Coscieme, L., Sutton, P., Mortensen, L.F., Kubiszewski, I., Costanza, R., Trebeck, K., Pulselli, F.M., Giannetti, B.F. and Fioramonti, L., 2019. Overcoming the myths of mainstream economics to enable a new well-being economy. Sustainability, 11(16), p.4374.

Costanza, R., Fioramonti, L. and Kubiszewski, I., 2016. Editorial - The UN Sustainable Development Goals and the dynamics of well-being. Frontiers in Ecology and the Environment. 14, 59.

Costanza, R., Fisher, B., Ali, S., Beer, C., Bond, L., Boumans, R., Danigelis, N.L., Dickinson, J., Elliott, C., Farley, J. and Gayer, D.E., 2007. Quality of life: An approach integrating opportunities, human needs, and subjective well-being. Ecological economics, 61(2-3), pp.267-276.

Costanza, R., Daly, L., Fioramonti, L., Giovannini, E., Kubiszewski, I., Mortensen, L.F., Pickett, K.E., Ragnarsdottir, K.V., De Vogli, R. and Wilkinson, R., 2016. Modelling and measuring sustainable wellbeing in connection with the UN Sustainable Development Goals. Ecological Economics, 130, pp.350-355.

Daly, H.E. 1973. Toward a steady-state economy (Vol. 18). San Francisco: WH Freeman.

Daly, H.E., 2005. The concept of a steady-state economy. *Sustainability, London*, pp.121-156.

De Mulder, E.F. and Cordani, U.G., 1999. Geoscience provides assets for sustainable development. Episodes Journal of International Geoscience, 22(2), pp.78-83.

De Neve, J.E. and Sachs, J.D., 2020. Sustainable development and human well-being. World happiness report, pp.112-127.

De Neve, J.E. and Sachs, J.D., 2020. The SDGs and human well-being: a global analysis of synergies, trade-offs, and regional differences. Scientific reports, 10(1), pp.1-12.

De Vries, W., Kros, J., Kroeze, C. and Seitzinger, S.P., 2013. Assessing planetary and regional nitrogen boundaries related to food security and adverse environmental impacts. Current Opinion in Environmental Sustainability, 5(3-4), pp.392-402.

Dearing J.A., Wang R., Zhang K., Dyke J.G., Haberl H., et al. (2014). Safe and just operating spaces for regional social–ecological systems. Global Environmental Change 28(0), pp. 227–238.

Dietz, T., Rosa, E.A. and York, R., 2009. Environmentally efficient well-being: Rethinking sustainability as the relationship between human well-being and environmental impacts. Human Ecology Review, pp.114-123.

Dowey, N., Barclay, J., Fernando, B., Giles, S., Houghton, J., Jackson, C., Khatwa, A., Lawrence, A., Mills, K., Newton, A. and Rogers, S., 2021. A UK perspective on tackling the geoscience racial diversity crisis in the Global North. Nature Geoscience, 14(5), pp.256-259.

Dutt, K., 2020. Race and racism in the geosciences. Nature Geoscience, 13(1), pp.2-3.

Elder, M. and Olsen, S.H., 2019. The Design of Environmental Priorities in the SDG s. Global Policy, 10, pp.70-82.

Fankhauser, S., Smith, S.M., Allen, M., Axelsson, K., Hale, T., Hepburn, C., Kendall, J.M., Khosla, R., Lezaun, J., Mitchell-Larson, E. and Obersteiner, M., 2022. The meaning of net zero and how to get it right. Nature Climate Change, 12(1), pp.15-21.

Fildani, A. and Hessler, A.M., 2021. Sustainability without geology? A shortsighted approach. The Sedimentary Record, 19(2), pp.1-4.

Fioramonti, L., 2017. Well-being economy. Pan Macmillan, Johannesburg.

Franks, D.M., Keenan, J. and Hailu, D., 2023. Mineral security essential to achieving the Sustainable Development Goals. Nature Sustainability, 6(1), pp.21-27.

Frey, M.L., 2021. Geotourism—examining tools for sustainable development. Geosciences, 11(1), p.30.

Gerten, D., Hoff, H., Rockström, J., Jägermeyr, J., Kummu, M. and Pastor, A.V., 2013. Towards a revised planetary boundary for consumptive freshwater use: role of environmental flow requirements. Current Opinion in Environmental Sustainability, 5(6), pp.551-558.

Gill, J.C., 2017. Geology and the sustainable development goals. Episodes Journal of International Geoscience, 40(1), pp.70-76.

Gill, J.C., 2021. Reshaping geoscience to help deliver the Sustainable Development Goals. Geosciences and the Sustainable Development Goals, pp.453-468.

Gill, J.C. and Smith, M. eds., 2021. Geosciences and the sustainable development goals. Springer Nature.

Gill, J.C., Mankelow, J. and Mills, K., 2019. The role of Earth and environmental science in addressing sustainable development priorities in Eastern Africa. Environmental Development, 30, pp.3-20.

Gill, J.C., Barich, A., Bilham, N., Caven, S., Donovan, A., de Ruiter, M. and Smith, M., 2021. Peace, justice, and strong institutions. Geosciences and the Sustainable Development Goals, pp.393-421.

Gloaguen, R., Ali, S.H., Herrington, R., Ajjabou, L., Downey, E. and Stewart, I.S., 2022. Mineral revolution for the wellbeing economy. Global Sustainability, 5, p.e15.

Gray, M. and Crofts, R., 2022. The potential role of the geosciences in contributing to the UN’s Sustainable Development Goals. In Parks Stewardship Forum (Vol. 38, No. 1).
Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M.C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N. and Noble, I., 2013. Sustainable development goals for people and planet. Nature, 495(7441), pp.305-307.
Grober, U. 2007. Deep Roots – A Conceptual History of ‘Sustainable Development’ (Nachhaltigkeit) (Social Science Research Center Berlin).
Guite, H.F., Clark, C. and Ackrill, G., 2006. The impact of the physical and urban environment on mental well-being. Public health, 120(12), pp.1117-1126.
Hajer, M., Nilsson, M., Raworth, K., Bakker, P., Berkhout, F., De Boer, Y., Rockström, J., Ludwig, K. and Kok, M., 2015. Beyond cockpit-ism: Four insights to enhance the transformative potential of the sustainable development goals. Sustainability, 7(2), pp.1651-1660.
Häyhä, T., Lucas, P.L., van Vuuren, D.P., Cornell, S.E. and Hoff, H., 2016. From Planetary Boundaries to national fair shares of the global safe operating space—How can the scales be bridged? Global Environmental Change, 40, pp.60-72.
Hickel, J., 2019. The contradiction of the sustainable development goals: Growth versus ecology on a finite planet. Sustainable Development, 27(5), pp.873-884.
Hoekstra, R., 2019. Replacing GDP by 2030: Towards a common language for the well-being and sustainability community. Cambridge University Press.
Hoff, H. and Alva, I.L., 2017. How the Planetary Boundaries framework can support national implementation of the 2030 Agenda.
Henriques, M.H. and Brilha, J., 2017. UNESCO Global Geoparks: A strategy towards global understanding and sustainability. Episodes Journal of International Geoscience, 40(4), pp.349-355
Hund, K., La Porta, D., Fabregas, T.P., Laing, T. and Drexhage, J., 2020. Minerals for climate action: the mineral intensity of the clean energy transition. World Bank
Hurth, V., & Vrettos, A. 2021. Unleashing the Sustainable Business: How Purposeful Organisations Can Break Free of Business-as-Usual (University of Cambridge Institute for Sustainability Leadership, 2021)
Hurth, V. & Stewart, I.S. Frontiers in Sustainability, 2:762271 (2022)
ICSU, ISSC (2015): Review of the Sustainable Development Goals: The Science Perspective. Paris: International Council for Science (ICSU)
Jackson, T.; Webster, R. Limits Revisited: A Review of the Limits to Growth Debate. Report to the All-Party Parliamentary Group on Limits to Growth; Creative Commons: Mountain View, CA, USA, 2016.
Jørgensen, S.E.; Fath, B.D.; Nielsen, S.N.; Pulselli, F.M.; Fiscus, D.A.; Bastianoni, S. Flourishing Within Limits to Growth—Following Nature’s Way; Earthscan from Routledge Taylor & Francis Group: Florence, KY, USA, 2015.
Kim, R.E. and Bosselmann, K., 2015. Operationalizing sustainable development: ecological integrity as a grundnorm of international law. Review of European, Comparative & International Environmental Law, 24(2), pp.194-208.
Lagesse, R.H., Hambling, J., Gill, J.C., Dobbs, M., Lim, C. and Ingvorsen, P., 2022. The role of engineering geology in delivering the United Nations Sustainable Development Goals. Quarterly Journal of Engineering Geology and Hydrogeology, 55(3).
Lèbre, É., Stringer, M., Svobodova, K., Owen, J.R., Kemp, D., Côte, C., Arratia-Solar, A. and Valenta, R.K., 2020. The social and environmental complexities of extracting energy transition metals. Nature communications, 11(1), pp.1-8.
Leiserowitz, A.A., Kates, R.W. and Parris, T.M., 2006. Sustainability values, attitudes, and behaviors: A review of multinational and global trends. Annu. Rev. Environ. Resour., 31, pp.413-444.
Lenton, T.M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S. and Schellnhuber, H.J., 2008. Tipping elements in the Earth's climate system. Proceedings of the national Academy of Sciences, 105(6), pp.1786-1793.

Lenton, T.M., 2013. Environmental tipping points. Annual Review of Environment and Resources, 38, pp.1-29.
Levinson, A., 2012. Valuing public goods using happiness data: The case of air quality. Journal of Public Economics, 96(9-10), pp.869-880.
Lucas, P. and Wilting, H., 2018. Using Planetary Boundaries to Support National Implementation of Environment-related: Sustainable Development Goals: Background Report. PBL Netherlands Environmental Assessment Agency.
Lucas, P., Ludwig, K., Kok, M. and Kruitwagen, S., 2016. *Sustainable Development Goals in the Netherlands: Building blocks for environmental policy for 2030*. PBL Netherlands Environmental Assessment Agency.
Ludden, J., 2020. Where is geoscience going?. Geological Society, London, Special Publications, 499(1), pp.69-77.
Luechinger, S., 2009. Valuing air quality using the life satisfaction approach. The Economic Journal, 119(536), pp.482-515.
McPhearson, T., M. Raymond, C., Gulsrud, N., Albert, C., Coles, N., Fagerholm, N., Nagatsu, M., Olafsson, A.S., Soininen, N. and Vierikko, K., 2021. Radical changes are needed for transformations to a good Anthropocene. Npj urban sustainability, 1(1), p.5.
Mace, G.M., Reyers, B., Alkemade, R., Biggs, R., Chapin III, F.S., Cornell, S.E., Díaz, S., Jennings, S., Leadley, P., Mumby, P.J. and Purvis, A., 2014. Approaches to defining a planetary boundary for biodiversity. Global Environmental Change, 28, pp.289-297.
Marker, B.R., 2016. Urban planning: the geoscience input. Geological Society, London, Engineering Geology Special Publications, 27(1), pp.35-43.
Mata-Perello, J.M., Mata-Lleonart, R., Vintro-Sanchez, C. and Restrepo-Martinez, C., 2012. Social Geology: A new perspective on geology. Dyna, 79(171), pp.158-166.
Meadows, D. 1998. Indicators and Information Systems for Sustainable; Sustainable Institute: Pennsylvania, VT, USA,.
Mebratu, D. 1998. Sustainability and Sustainable Development: Historical and Conceptual Review, 18:6 Environmental Impact Assessment Review, 493;
Mudd, G.M., 2021. Sustainable/responsible mining and ethical issues related to the Sustainable Development Goals. Geological Society, London, Special Publications, 508(1), pp.187-199.
De Neve, J.E. and Sachs, J.D., 2020. The SDGs and human well-being: a global analysis of synergies, trade-offs, and regional differences. Scientific reports, 10(1), pp.1-12.
Nordhaus, W.D. and Tobin, J., 1973. Is growth obsolete?. In: The measurement of economic and social performance (pp. 509-564). NBER. Cowles Foundation for Research in Economics at Yale University.
OECD. Accelerating Climate Action: Refocusing Policies Through a Well-being Lens (OECD Publishing, Paris, 2019).
Oliver, M.A. and Gregory, P.J., 2015. Soil, food security and human health: a review. European Journal of Soil Science, 66(2), pp.257-276.
Patrick, R., Shaw, A., Freeman, A., Henderson-Wilson, C., Lawson, J., Davison, M., Capetola, T. and Lee, C.K., 2019. Human well-being and the health of the environment: Local indicators that balance the scales. Social Indicators Research, 146(3), pp.651-667.
Peppoloni, S. and Di Capua, G., 2012. Geoethics and geological culture: awareness, responsibility and challenges. Annals of geophysics, 55(3), pp.335-341.
Peppoloni, S. and Di Capua, G., 2021. Geoethics as global ethics to face grand challenges for humanity. Geological Society, London, Special Publications, 508(1), pp.13-29.
Petterson, M.G., 2019. Interconnected geoscience for international development. Episodes Journal of International Geoscience, 42(3), pp.225-233.
Pinter, L., Almassy, D., Antonio, E., Niestroy, I., Olsen, S. and Pulawska, G., 2013. Sustainable development goals and indicators for a small planet. Part I: Methodology and goal framework.
Porritt, Jonathon. 2005. Capitalism as if the World Matters. London: Earthscan.

Randers, J., Rockström, J., Stoknes, P.E., Goluke, U., Collste, D., Cornell, S.E. and Donges, J., 2019. Achieving the 17 Sustainable Development Goals within 9 planetary boundaries. *Global Sustainability*, *2*, p.e24.
Raworth, K., 2012. A safe and just space for humanity: can we live within the doughnut?. Oxfam.
Raworth, K., 2017. A Doughnut for the Anthropocene: humanity's compass in the 21st century. The lancet planetary health, 1(2), pp.e48-e49.
Ringrose, P.S., 2017. Principles of sustainability and physics as a basis for the low-carbon energy transition. Petroleum Geoscience, 23(3), pp.287-297.
Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F.S., Lambin, E., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J. and Nykvist, B., 2009. Planetary boundaries: exploring the safe operating space for humanity. Ecology and society, 14(2).
Rockström, J., Sachs, J.D., Öhman, M.C. and Schmidt-Traub, G., 2013. Sustainable development and planetary boundaries. Sustainable Development Solutions Network.
Rockström, J.; Sukhdev, P. How Food Connects All the SDGs; Keynote Speech; EAT Stockholm Food Forum: Stockholm, Sweden, 13 June 2016
Running, S.W., 2012. A measurable planetary boundary for the biosphere. science, 337(6101), pp.1458-1459.
Scown, M.W., 2020. The sustainable development goals need geoscience. Nature Geoscience, 13(11), pp.714-715.
Schellnhuber, H.J., 2009. Tipping elements in the Earth System. Proceedings of the National Academy of Sciences, 106(49), pp.20561-20563.
Simon, J.L., 1980. Resources, population, environment: an oversupply of false bad news. Science, 208(4451), pp.1431-1437.
Solow, R.M., 1973. Is the End of the World at Hand? Challenge, 16(1), pp.39-50.
Solow, R.M. 1974. The economics of resources or the resources of economics. American Economic Review, 64(2), 1-14.
Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O. and Ludwig, C., 2015. The trajectory of the Anthropocene: the great acceleration. The Anthropocene Review, 2(1), pp.81-98.
Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., De Vries, W., De Wit, C.A. and Folke, C., 2015. Planetary boundaries: Guiding human development on a changing planet. Science, 347(6223), p.1259855.
Stephenson, M.H., Ringrose, P., Geiger, S., Bridden, M. and Schofield, D., 2019. Geoscience and decarbonization: current status and future directions. Petroleum Geoscience, 25(4), pp.501-508.
Stephenson, M.H., 2021. Affordable and Clean Energy: Energy Geoscience and Human Capacity. Geosciences and the Sustainable Development Goals, pp.159-182.
Stewart, I., 2016. Sustainable geoscience. Nature Geoscience, 9(4), pp.262-262.
Stewart, I., 2020. Geology for society: Earth science for sustainable development. Humanistic futures of learning, p.39.
Stewart, I.S., 2022. Integrating the 'the triangle of geography, geology and geophysics' into sustainable development. Jordan Journal of Earth and Environmental Sciences, 13 (2): 97-104.
Stewart, I.S. and Gill, J.C., 2017. Social geology—integrating sustainability concepts into Earth sciences. Proceedings of the Geologists' Association, 128(2), pp.165-172.
Stewart, I.S. and Hurth, V., 2021. Selling planet Earth: re-purposing geoscience communications. Geological Society, London, Special Publications, 508(1), pp.265-283.
Stewart, I.S., Ickert, J. and Lacassin, R., 2017. Communicating seismic risk: The geoethical challenges of a people-centred, participatory approach.
Stockholm Resilience Center (2016). How food connects all the SDGs. Available at: https://www.stockholmresilience.org/research/researchnews/2016-06-14-how-food-connects-all-the-sdgs.html
Tortell, P.D., 2020. Earth 2020: Science, society, and sustainability in the Anthropocene. Proceedings of the National Academy of Sciences, 117(16), pp.8683-8691

Trebeck, K.; Williams, J. The Economics of Arrival: Ideas for a Grown up Economy; Policy Press: Bristol, UK, 2019.
Turner, G.M. 2008. A comparison of The Limits to Growth with 30 years of reality. Glob. Environ. Chang. **2008**, 18, 397–411.
United Nations 2015. Transforming our world: the 2030 Agenda for Sustainable Development. United Nations: New York, NY, USA.
UN Environment Global Environment Outlook—GEO6: Healthy Planet, Healthy People. Nairobi, Kenya, 2019.
UNEP (United Nations Environment Programme), and UNCTAD (United Nations Conference on Trade and Development). 1974. The Cocoyoc Declaration. Accessed 2 March 2019. https://helsinki.at/projekte/cocoyoc/COCOYOC_DECLARATION_1974.pdf.
van Vuuren, D.P., Lucas, P.L., Häyhä, T., Cornell, S.E. and Stafford-Smith, M., 2016. Horses for courses: analytical tools to explore planetary boundaries. Earth System Dynamics, 7(1), pp.267-279.
Wackernagel, M., Schulz, N.B., Deumling, D., Linares, A.C., Jenkins, M., Kapos, V., Monfreda, C., Loh, J., Myers, N., Norgaard, R. and Randers, J., 2002. Tracking the ecological overshoot of the human economy. Proceedings of the national Academy of Sciences, 99(14), pp.9266-9271.
Weinberger, K., Rankine, H., Amanuma, N., Surendra, L., Van Hull, H.V., Foran, T., Reyes, R., Malik, A. and Murray, J., 2015. Integrating the three dimensions of sustainable development: A framework and tools. United Nations, Bangkok: ESCAP (environmental and social commission for Asia and the Pacific).
Xun, Z., Jianzhao, Y. and Yueqing, Y., 1997. Sustainable geology-Sociogeosciences. Episodes Journal of International Geoscience. 20(2), pp.84-88.