



Insight

An integrated framework for sustainable development goals

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ABSTRACT. The United Nations (UN) Rio+20 summit committed nations to develop a set of universal sustainable development goals (SDGs) to build on the millennium development goals (MDGs) set to expire in 2015. Research now indicates that humanity's impact on Earth's life support system is so great that further global environmental change risks undermining long-term prosperity and poverty eradication goals. Socioeconomic development and global sustainability are often posed as being in conflict because of trade-offs between a growing world population, as well as higher standards of living, and managing the effects of production and consumption on the global environment. We have established a framework for an evidence-based architecture for new goals and targets. Building on six SDGs, which integrate development and environmental considerations, we developed a comprehensive framework of goals and associated targets, which demonstrate that it is possible, and necessary, to develop integrated targets relating to food, energy, water, and ecosystem services goals; thus providing a neutral evidence-based approach to support SDG target discussions. Global analyses, using an integrated global target equation, are close to providing indicators for these targets. Alongside development-only targets and environment-only targets, these integrated targets would ensure that synergies are maximized and trade-offs are managed in the implementation of SDGs.

Key Words: *development; environment; sustainability; sustainable development; sustainable development goals*

INTRODUCTION

The eight Millennium Development Goals (MDGs), adopted in 2000 by 189 nations, were designed to improve the lives of the world's poor (Appendix 1, Table A1). Set to expire in 2015, the MDGs have had notable successes, such as achieving the target to halve the number of people living on less than US\$1.25 a day, though many targets will be unmet (UN 2012a). Despite the absence of any legally binding framework, the MDGs generated considerable public and policy support nationally and among international agencies and foundations, ensuring efficient channeling of significant funds (Vandemoortele 2011). Although economic development in countries such as China has been a major factor, it is also clear that success is partly thanks to the choice of a few focused goals, many with measurable targets (UN 2012a).

However, a prerequisite for future human development, including poverty reduction, is the stable functioning of Earth's life support system. Since 2000, accumulating research shows that this functioning is at risk (Rockström et al. 2009, Steffen et al. 2011), and that further human pressure may lead to large-scale, abrupt, and potentially irreversible changes to it (Lenton 2011, Barnosky et al. 2012). Likely impacts on humanity include: diminishing food production, water shortages, extreme weather, ocean acidification, deteriorating ecosystems, and sea-level rise. Without economic, technological, and societal transformations, these authors argued that the potential for large-scale humanitarian crises is significant and could undermine any gains made by meeting the MDGs, necessitating a fundamental re-evaluation of the relationship between people and planet.

In 2012 at the UN's Rio+20 conference, nations agreed to establish sustainable development goals (SDGs; UN 2012b). Reaching

beyond the MDGs, it was agreed that these goals should be universal, applying to all nations. The agreement stressed that the new goals should build logically on the MDGs, with an anticipated 2030 target date. The SDG process provides a unique opportunity to create a unified framework for furthering human prosperity in an era of growing evidence of rising global environmental risks. Science can provide independent guidance on goal and target formulations (Glaser 2012) to help increase the likelihood of meeting policymakers' stated sustainable development objectives by guiding sustainable action and being measurable, verifiable, and reportable, and to help them set priorities by identifying the most serious environmental challenges.

The overarching aims of the SDGs, as agreed by nations at Rio+20, can be summarized as poverty elimination, sustainable lifestyles for all, and a stable resilient planetary life-support system. However, it is challenging to define, create, and agree on SDGs that meet these overarching aims while resolving potential interactions between sectoral goals. For example, some approaches to increasing food security may come at a significant cost to the global climate system, in turn putting food security itself at risk in the long term.

This risk was highlighted in a recent United Nations report that recommended SDGs that are integrated, that is, where each goal incorporates social, economic, and environmental dimensions (UNEP 2013). To that end, David Griggs and colleagues (Griggs et al. 2013) first proposed a framework of six integrated sustainable development goals, and these have been echoed in complementary formulations by the UN Sustainable Development Solutions Network (UN SDSN 2013) and the report of the high-level panel of eminent persons (UN 2013); most

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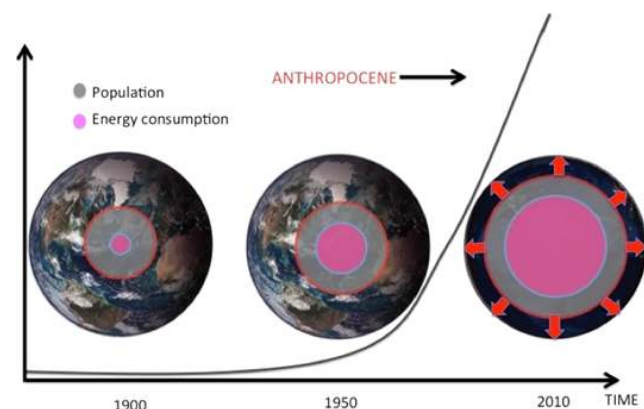
recently these have been outlined in the recommendations of the Open Working Group (OWG; UN OWG 2014) to the UN General Assembly (Appendix 1). We argue that to maximize synergies and to avoid perverse outcomes such integration must flow through to the targets as well, and we show that it is feasible to formulate exemplar targets for a set of comprehensive SDGs, which integrate these dimensions and provide strong guidance for humanity to prosper in the long term. These targets can be as focused and measurable as MDG targets, and, where necessary, tackle interactions explicitly.

GLOBAL SUSTAINABILITY OBJECTIVES

Griggs et al. (2013) based their framing on the need (Folke 1991) to reconceptualize the United Nations' original sustainable development paradigm of economic development, social development, and environmental protection being "interdependent and mutually reinforcing pillars" (UN 2005:12). Given the scale of humanity's impact on the planet, they argued that long-term sustainable development needs to be conceptualized in terms of an economy and society sustained within Earth's life-support system (Folke 1991; Fig. 1). As a result, Griggs et al. (2013) argued that the Brundtland Commission's 1987 definition of sustainable development as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission 1987:clause 1 of Section IV Conclusions) also needs reframing in the Anthropocene as follows: 'development that meets the needs of the present while safeguarding Earth's life support system, on which the welfare of current and future generations depends'.

Securing stable Holocene-like conditions on Earth, in terms of sea level, stratospheric ozone, air pollution, eutrophication,

Fig. 1. An appropriate conceptualization for sustainable development places the economy and society within Earth's life-support system. The figure illustrates how the balance between these components has changed rapidly over the past century, leading to the need to reappraise the relationship among components today. Energy is used as a surrogate for consumption and economic growth; population growth is used to illustrate changes in the relative size of the social domain compared to the Earth system's ability to deliver services, which has not changed greatly.



temperature, ice-sheet stability, carbon-sink stability, etc., provides a scientific reference point (Steffen et al. 2011) for a set of what Griggs et al. (2013) called 'planetary must-haves,' which are priorities for the Earth system, here termed global sustainability objectives (GSOs). These environmental priorities were derived in part from a recent analysis, which sought to quantify nine boundaries beyond which it would be unsafe to transgress without risking large-scale health and economic impacts (Rockström et al. 2009). Acknowledging uncertainties, they identified seven priority GSOs (Appendix 1, Table A2), which are associated with strong scientific evidence for their role in providing the environmental conditions, from planetary to local, necessary to support long-term human prosperity (Steffen et al. 2011) and for which it is possible to estimate global environmental targets. Importantly, in outlining them in more detail (Appendix 1, Table A2), we have attempted to minimize the number of potential targets, a lesson from the MDG experience, to those with high credibility in existing international processes or in recent scientific literature. The SDGs must now be linked to human development.

HUMAN DEVELOPMENT OBJECTIVES

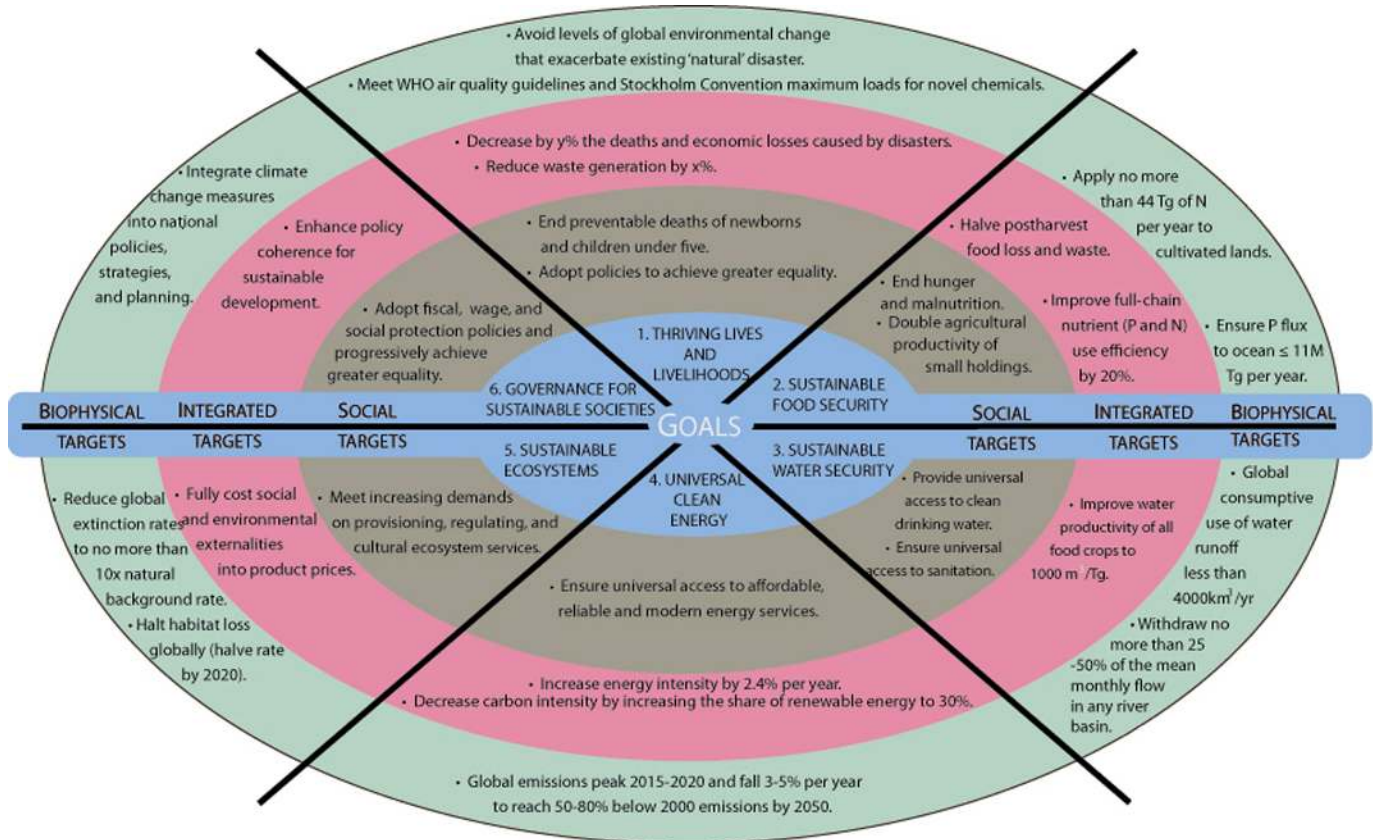
In 2012, nations asserted that "poverty eradication...promoting sustainable patterns of consumption and production, and protecting and managing the natural resource base of economic and social development are the overarching objectives of... sustainable development" (United Nations 2012b:clause 4). There is understandable reluctance for extensive reshaping of existing human development goals (Appendix 1, Table A1), but it is now widely accepted (UN OWG 2013, UN SDSN 2013) that some changes to the MDGs are essential. Some targets have been met and other targets are out-of-date or can now be better defined, for example, success in meeting MDG target 1A, i.e., halving, between 1990 and 2015, the proportion of people whose income is < US\$1.25 a day, means that this must be updated, e.g., eliminate extreme poverty by 2030, target 1.1 in OWG 2014. Moreover, MDGs were not designed to be universal, but, e.g., MDG3 on gender equality can now be extended to all countries, and beyond education, see goal five in OWG 2014. Updates can also draw on new knowledge and include new elements such as the need for universal access to clean energy (Birol 2012), the social benefits of reducing relative inequality within countries (Wilkinson and Pickett 2009), and access to information technology.

In framing a post-MDG suite of social objectives, a 'social foundation' of 11 components were proposed before the Rio summit to complement the 'environmental ceiling' of the GSOs noted above, defining a "safe and just operating space for humanity" (Leach et al. 2013:84). Regardless of exactly how they are expressed (UN SDSN 2013, UN HLP 2013, UN OWG 2014), this provides a suite of economic and social objectives that can be brought together with the global sustainability objectives to form a critical component of the new SDGs, i.e., GSO targets + socioeconomic targets = SDGs.

IDENTIFYING SUSTAINABLE DEVELOPMENT GOALS (SDGs)

Reducing poverty and hunger, as well as a sustained improvement in health and human wellbeing will remain the driving principles for any future SDGs. Griggs et al. (2013) argued for the six SDGs listed in Appendix 1, Table A1, but provided scant details on potential targets.

Fig. 2. Selected examples of targets for the six proposed SDGs (centre, see Table A1), emphasizing those that are important to meeting the Global Sustainability Objectives (Table A2), including biophysical only (outer green ring), socioeconomic only (inner brown ring), and integrated (intermediate pink ring) targets. This figure contains a subset of a larger suite of possible targets shown in Table A3, with a focus on illustrating the need for some integrated targets.



Why this particular six? This analysis was framed pragmatically and with a particular focus on long-term, Earth-system stability. The MDG experience shows that a small number of goals is essential for policy and public focus, and this is what is sought by the 2012 Rio outcomes document (UN 2012); hence some systems judgment must be applied to select a necessary and sufficient set of goals that together draw many other indicators along in their wake. The focus of development is on peoples' livelihoods, in particular poverty eradication, so this must underpin the SDGs (hence SDG 1). Furthermore, development is closely related to lifestyles and consumption, which are linked directly to the pressures on the planet. Then, closely linked to poverty eradication in all analyses (Leach et al. 2013, UN SDSN 2013, UN HLP 2013), people have fundamental needs in terms of food, water, and energy (SDGs 2-4). These have profound sustainability implications. As widely acknowledged (Brundtland Commission 1987, UN 2012), the fundamental needs of humanity are underpinned by natural ecosystems (SDG 5). Last, the importance of institutional issues and governance for development have long been recognized (as indicated by MDG 8), and have been re-emphasized in recent research on the governance of the Earth system (SDG 6) (Biermann et al. 2012).

In total, this provides six foundational goals with scope for further subdivision, particularly within SDG 1. The SDSN suggested 10

goals (UN SDSN 2013), the UN report of the high-level panel listed 12 (UN HLP 2013), and the Open Working Group (UN OWG 2014) have 17; all cases are generally aligned with the 6 proposed by Griggs et al. (2013), but with more subdivision (Appendix 1, Table A1). We argue that there is virtue in focus. In the end, negotiations may legitimately suggest others or organize these six differently, but any modifications should ensure that the core GSOs are all encompassed along with socioeconomic objectives, while maintaining focus and meeting other principles laid out below. Otherwise, the SDGs risk failing to meet the stated policy aims in the long term. Therefore we now develop the logic for integrated targets around the six goals of Griggs et al. (2013), which should appear in some form within any final set to be adopted by the UN General Assembly in September 2015. The OWG (2014) proposes reasonably well-defined social and economic goals with some well-quantified targets. However, the environmental sustainability goals are not yet well integrated in their proposal, and quantified environmental targets are almost completely missing.

SUSTAINABLE DEVELOPMENT GOALS (SDG) TARGETS

The MDG experience has shown that quantifiable targets could be even more important than the goals for focusing efforts. We highlight two issues. First, some targets can safely aim at a single social or an environmental outcome without specifying interactions, but some targets should deliberately address

interactions, providing a mechanism to deal with potential synergies and trade-offs, where trade-offs are taken to mean unintended consequences of pursuing targets independently. Second, targets need implementation at multiple scales and across sectors.

We are particularly concerned with interactions between social and biophysical targets. There are essential social development targets that have no direct interactions with global sustainability concerns; for example, many equality, education, and empowerment issues can be tackled without significant environmental sustainability implications, notwithstanding that they may contribute to future human capital for achieving better sustainable development outcomes. We likewise suggest that there are some environmental targets in which social implications are at most second-order concerns. These types of targets (Fig. 2: biophysical and social rings) can be implemented without the overhead of considering interactions.

However, several contentious issues in the context of sustainable development result from perceived trade-offs between socioeconomic development and global environmental sustainability, for example between energy use and climate change caused by greenhouse gas emissions or land-use change for food production and biodiversity loss. In these cases, addressing socioeconomic and environmental sustainability targets independently will lead to undesired and long-term costly outcomes (UNEP 2013). Socioeconomic goals may be met in the short term but damage long-term sustainability. Alternatively, blind attention to environmental targets may distract from socioeconomic development. Our approach is to identify targets, which focus on the interdependencies between two or more issues so that they are tackled in an integrated way, delivering the desired outcomes for both.

For example, the UN OWG (2014) proposals include a target (8.1) on economic growth as well as a separate assertion (notes to their goal 13) that the United Nations Framework Convention on Climate Change's targets for climate change should be met. In the absence of significant decarbonization of the economy, we know these targets are incompatible: in fact Rogelj et al. (2013) explored the trade-offs between the UN's commitment to clean energy for all and commitments to a 2°C climate target. They noted that the socioeconomic development objective of sufficient energy to meet potential global GDP growth is linked to a global sustainability objective of restraining greenhouse gas emissions within 2°C are linked according to the relationship:

$$\text{CO}_2 \text{ emissions} = \text{CI} * \text{EI} * \text{GDP},$$

where CI is the carbon intensity (CO₂ release per unit energy) and EI is the energy intensity (energy use per unit of GDP) averaged globally. If a particular GDP trajectory, with consequent energy use, is to be achieved while restraining CO₂ emissions, then a constrained trend in CI * EI must be achieved globally. This creates a clear operational pair of targets for the indicators CI and EI, which express the trade-off between these objectives at a global level, which can then be implemented in various ways regionally. The UN OWG (2014) does address this trade-off, but weakly, their target 8.4 aims to “endeavor to decouple economic growth from environmental degradation” without specifying anything quantitative; and target 7.2 aims to increase the share

of renewable energy, whereas 7.3 provides the only quantified target in doubling the rate of energy efficiency by 2030. The lessons of the MDGs highlight the need for clear and quantified targets: in Appendix 1, Table A3, we show one set of possible values under SDG 4, but given a policy decision on the acceptable level of climate change, specific target values for CI and EI can be proposed, for reasonably expected rates of GDP growth, and these can be monitored to help countries to focus on policies to reduce carbon intensity and improve energy efficiency. Of course, a desired level of GDP growth should not be an end in itself, but merely one means to the end of advancing human well-being.

This example can be generalized to create a simplified intuitive relationship to derive integrated global targets (inverted from the example above):

$$\text{socioeconomic objective} = k * \text{biophysical objective},$$

where k expresses the critical trade-off between biophysical and socioeconomic objectives. This Integrated Global Target Equation may be seen as a generalized version of the IPAT equation, i.e., Human Impact (I) on the environment equals the product of population (P), affluence (A), and technology (T) or Kaya identities, i.e., an equation relating factors that determine the level of human impact on climate, in the form of greenhouse gas emissions (section 3.1 Nakićenović and Swart 2000), but here deployed for the purpose of identifying trade-offs. The parameter k may be compound.

We provide a preliminary analysis of the potential use of the Integrated Global Target relationship in the specific examples of food and water security, where OWG (2014) does not yet identify clear biophysical targets. A detailed analysis on trade-offs is required in each case to confirm target values, but we can propose which integrated indicators are needed. The equivalent relationships for food and water security (SDGs 2, 3) concern the trade-offs between increasing food availability, i.e. social objective, while meeting ‘planetary must haves’ on land use conversion, biodiversity, phosphorous and nitrogen cycles, climate, and water use, i.e., biophysical objectives (see Fig.2 in Foley et al. 2011; Appendix 1, Table A3). Acknowledging that there are other factors driving availability in the global food system (Ericksen et al. 2009), the Integrated Global Target Equation may here be written as:

$$\text{food consumption} = \text{FCI} * \text{AP} * \text{resources},$$

where food consumption intensity (FCI, i.e., food consumed per unit food produced) and agricultural productivity (AP, i.e., food produced per unit resource used) with respect to key resources are primary determinants of the trade-off. Aspects of FCI and AP can be considered under SDG 2, with the water aspect a focus of SDG 3.

For SDG 2 targets, reduced waste in food use is a vital and reasonably uncontroversial element of FCI, considering this is estimated to be 30-40% of production (Godfray et al. 2010), e.g., the European Parliament has adopted a resolution on food waste, which set a reduction target of 50% of all food waste by 2025 and a 50% reduction in all post-harvest food loss and waste by 2030 has been proposed globally (Lipinski et al. 2013). This is recognized in OWG (2014) as target 12.3. For AP, key resources other than water are land, and P and N; these are not addressed

explicitly or quantitatively in OWG (2014). Land-use conversion is a significant driver of greenhouse gas emissions and biodiversity loss, especially in the tropics, for relatively little gain in production (West et al. 2010, Foley et al. 2011), so we propose that ceasing land clearance in the tropics should be an eventual biophysical objective at the global level under SDG 5. Overuse of P and N, leading to water pollution among other effects (Carpenter and Bennett 2011, de Vries et al. 2013), drives the remaining key trade-off, which can be addressed by increasing the indicator AP (Foley et al. 2011, Garnett et al. 2013). A global target for 2020 of a relative improvement in full-chain nutrient (P and N) use efficiency, dominated by agriculture, by 20% has been proposed (Sutton et al. 2013) and is probably feasible with existing technologies (van der Velde et al. 2013). As for SDG 4, a global target must be approached in differentiated ways below the global level.

For water security (SDG 3), irrigated agriculture accounts for 92% of the total withdrawals of water from rivers, lakes, and groundwater (Hoekstra and Mekonnen 2012), totalling some 2000 km³ yr⁻¹ consumptive use of freshwater (blue water), which is half the proposed GSO for sustainable freshwater use (Appendix 1, Table A2). Agricultural production will have to increase 50-70% by 2050 to secure adequate access to food for all people in the world (IAASTD 2008). On current practices, estimates show that this will increase the pressure on global freshwater from the current global use of ~7000 km³ yr⁻¹ (2000 'blue water, for irrigation and 5000 'green water' for rain-fed agriculture) to 12000 km³ yr⁻¹ (Falkenmark et al. 2009). Thus, increases in global food demand imply a major water trade-off between irrigation requirements and freshwater needed to secure other ecosystem services (Bennett et al. 2009).

The degree of trade-off between competing water demands, for food, ecosystems, and society, is largely determined by water productivity (WP) in agriculture, giving the Integrated Global Target Equation:

agricultural production = WP * water extracted,

where WP (m³/ton) varies between different crops, management systems, and hydro-climatic zones and has been extensively studied from different perspectives (e.g., Brauman et al. 2013, Hanasaki et al. 2013, Hayashi et al. 2013). Despite this complexity, at a global scale, WP for basic food crops, such as wheat, maize, rice, sorghum, and millets, has a remarkably similar average of ~1500 m³ ton⁻¹, though with a wide range: ~900-5000 m³ ton⁻¹ (Falkenmark and Rockström 2004). For an adequate diet, the vegetarian portion of foods, i.e., vegetables, roots, pulses, grain, oil, and sugar crops, ~80% of an average global diet, has a weighted global average WP of ~1100-1400 m³ ton⁻¹.

For agriculture to provide for a world population of around 9 billion people in 2050, and still meet global sustainability criteria for freshwater use, the global water use for food would have to increase to no more than 9000 km³ yr⁻¹, i.e., no more than 2000 km³ yr⁻¹ more 'blue water' than today, rather than the 12000 km³ yr⁻¹ that the business-as-usual approach suggests (Falkenmark et al. 2009). This translates to an integrated water target for WP of 1000 m³ ton⁻¹ for all food crops, which is a 9-29% improvement on today, i.e., the 1100-1400 m³ ton⁻¹ cited above; agricultural research suggests this is an attainable WP average even with

current technologies (Molden 2007). Paying attention to this interaction thus permits considerable synergies between SDGs 2 and 3, producing more 'crop-per-drop' through improved agricultural systems. However, spatial variability means that improved water use must be implemented with local contextual sensitivity and will have complex between-region implications, including potential trade in virtual water (Calzadilla et al. 2010, Hoekstra 2011).

At present GSOs for water, nitrogen phosphorus, and land are entirely missing in OWG (2014); some of the integrative targets identified above are weakly included (Appendix 1, Table A3), but without quantification in most cases. The only quantified one is 12.3: to halve per capita global food waste. This is despite the fact that these three SDG areas are the easiest in which to apply the Integrated Global Target Equation.

Although there are analogous issues for SDGs 1, 5, and 6, the simple division into environmental, social, and integrated targets is less immediately evident. Figure 2 illustrates some specific examples, and the Appendix outlines some examples of possible approaches to these in association with Table A3, drawing noncomprehensively on OWG (2014).

The domain of SDG 1 is dominated by social targets, many of which have no more than weak direct interactions with global sustainability; we do not address these further here, important as they are, and despite the fact that there are opportunities to manage synergies and trade-offs among these also. However, some social targets expressed by OWG (2014) could affect sustainability. Appendix Table A3 explores some examples under the topics of health, equitable consumption, and disasters. The environmental targets are often an agglomeration of GSOs in relation to their potential impacts on social targets; most integrative targets require further quantification.

For SDG 5, the intent is essentially to deliver a growing level of provisioning and regulatory, and perhaps also cultural, ecosystem services while maintaining biodiversity and ecosystem function, and the operational elements of k require management to reduce the impacts on biodiversity of each unit of ecosystem services used. This in turn requires the proper valuation of the services to maximize the efficiency of other aspects of k in the Integrated Global Target Equation.

Finally, SDG 6 relating to governance is a different type of goal, because governance provides part of the enabling conditions for the other goals. Nonetheless, examples of governance targets, which are primarily aimed at biophysical issues, or at socioeconomic issues, or seek to integrate these, are provided in Appendix Table A3. Issue-specific governance arrangements could be tailored for each SDG, usually at subglobal levels, such as implementing integrated water resources management (OWG 2014). More generally, Biermann et al. (2014) argued that three types of governance must be considered: (1) good governance, i.e., the processes of decision making and their institutional foundations, (2) effective governance, i.e., the capacity of countries to pursue sustainable development, and (3) equitable governance with distributive outcomes. The integration of environmental and socioeconomic policies at all levels to ensure that the other SDGs are achieved would contribute to effective governance. By contrast, the establishment of the High-Level Political Forum on Sustainable

Development by the UN General Assembly in July 2013 was an important step toward good governance, as might introducing new decision-making mechanisms, such as a stronger reliance on qualified majority voting (Biermann et al. 2012, Kanie et al. 2013).

Objectives may also interact in a synergistic way (Shindell et al. 2012). We argue that it is less crucial to capture this formally in the targets, although there may be significant efficiencies to be gained by doing so. For example, it is known that the use of fuel efficient or LPG-based cooking stoves could improve the health of poor women and children by reducing acute respiratory disorders. Similarly, access to clean water and sanitation results in a significant decline in diarrhoea incidence. It would be possible, therefore, to articulate a synergistic target such as ‘X% increase in access to clean energy and Y% increase in access to clean water and sanitation, at the same time contribute Z% reductions in incidence of key diseases’.

Of course the intuitive relationship for trade-offs above is very simplified, but it provides guidance commensurate with the level of precision and detail appropriate at a global level, summarized in Figure 2. It also hides a richness of interpretation below the global level to which we now turn.

OPERATIONALIZING TARGETS ACROSS LEVELS

The energy case above usefully exemplifies differentiation among regions: as Rogelj et al. 2013 points out, this will be fundamental to achieving the targets in the most cost-effective manner. For example, EI can drop quickest in fast developing regions, such as Asia, caused by rapid turnover of the capital stock, whereas solar or wind power is likely to provide a bigger contribution via CI in many developed nations. We thus envisage that the global targets would be interpreted at national levels in negotiated ways, and the totality of the response reviewed regularly in a global forum, such as the UN High Level Political Forum. Discussions about whether the global target will be met can take place, and, if targets will not be met, where the most cost and socially effective interventions can be made at more local levels. This is a necessary adaptive management and adaptive governance process in the face of uncertainty in many parts of the complex, multiscale social-ecological system.

Many GSOs have a spatial dimension (Steffen and Stafford Smith 2013), such that they can be implemented regionally in ways that are significantly more efficient than averaging global targets, and such that additional cobenefits can thus be achieved. For example, the management of phosphorus use (GSO 5) to intensify food production (SDG 2) and minimize ecosystem impacts (SDG 5; Carpenter and Bennett 2011) could be addressed at the same time as deliberately and constructively, and possibly more efficiently, seeking to ensure food security in poorer nations, by redistributing phosphorus use from excess to deficit regions. Comparable considerations are possible for the nitrogen cycle (Conant et al. 2013), water (Hoekstra 2011), land-use change (Thomas et al. 2012), and pollution.

As a result, it is clear that there will need to be global and national level expressions of many targets, whether these are simple biophysical or social targets, or integrated ones (Fig. 2). For example, the global water consumptive use target of no more than 4000 km³ y⁻¹ would be complemented by regional targets of

withdrawing no more than 25-50%, specified for the region (Appendix 1, Table A2), of the mean monthly flow of any individual river basin to sustain minimum environmental water flow requirements, food waste targets would require differential implementation at national and subnational levels (Lipinski et al. 2013), and, although some Aichi targets aim at the global level, others must be specified nationally, e.g., in terms of species richness or habitat protection.

There are also other possible modes of implementation; the Rio+20 conference was notable for the presence of networks outside the level of national government, whether in industry, nongovernmental organizations, or cities. Given that many of the SDGs will play out through the actions of the growing world population living in cities, global networks of cities (Seitzinger et al. 2012) may also share subglobal targets and the expertise to achieve them.

CONCLUSIONS

Development and implementation of SDG targets has the potential to be a genuine coproduction between science and policy (Leach et al. 2012), in which science is in service to society. Recent scientific findings articulate strong reasons why we must pay attention to certain global thresholds or other biophysical boundaries, even though it is ultimately a social decision whether to accept the risks of transgressing them or not. At the same time, local conditions and aspirations play large roles in determining how individual countries or other entities wish to respond in detail; this is a bottom up element, which engenders local ownership of the solutions to the local expressions of these targets. Science can continue to play a ‘trusted advisor’ role by assisting to mediate the local targets and whether these are likely to meet the global intentions.

Taking lessons from the experience of the MDGs, it is important to have focus and measurability. We have drawn on diverse areas of recent research to identify a set of SDGs and related indicators with some targets that, if met, would ensure dramatic progress toward sustainable development, with spillover benefits in many other areas. Critically, not only does each SDG integrate economic, social, and environmental dimensions, but some of the underlying targets do as well, explicitly highlighting trade-offs and synergies that require attention. This has been achieved by developing targets that focus on the interdependencies between two or more issues so that they are tackled in an integrated way, delivering the desired outcomes for both.

Many of these targets are already individually embedded in international agreements, so that the SDGs as proposed provide a coordinating and synthesizing framework (see footnote to Appendix 1, Table A2). Research efforts, under initiatives such as Future Earth (Glaser 2012), should continue to elaborate other key indicators and targets for existing and future pressures and initiate appropriate monitoring, evaluation, and implementation schemes. Meanwhile, we urge policy makers at all levels to embrace a much more unified environmental and socioeconomic framing for the SDGs along the lines outlined, which goes beyond the good beginning provided by OWG (2014). One of the biggest challenges ahead lies in defining and then implementing key sets of integrated targets. Sustainable development goals can be the leverage that facilitates enhanced collaboration among government institutions to this end.

Responses to this article can be read online at:
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Appendix 1. Recent (2013-2014) proposals for sustainable development goals.

The United Nation's (UN) parallel processes relating to SDGs – defining the Post-2015 development agenda (focusing on the unfinished business of the MDGs) and the SDG process – are set to converge. Both processes include a number of activities; the key element in the SDG process up to August 2014 was the 30-member intergovernmental Open Working Group (OWG) of the General Assembly, which submitted its proposal on SDGs to the 2104 UN General Assembly convened in September 2014 ([UN Open Working Group 2014, hereafter OWG 2014](#)).

Prior to the OWG report the Post-2015 development agenda process had already led to a report ([United Nations HLP 2013, hereafter HLP 2013](#)) from the UN's High Level Panel (HLP) that emphasized the critical contributions of the MDGs, but also identified additional targets that would help meet some fundamental gaps. This report proposed a transformative shift in the global agenda post-2015 and argued for a universal charter to: a) remove extreme poverty; b) bring sustainable development to the core of the post-2015 agenda; c) enhance jobs and inclusive growth; d) promote peace and reduce conflicts and e) create a global partnership that strengthens governance across different scales.

The HLP report identified 12 universal goals that would enable countries in the world to meet this vision (see Table A1), including updated social targets.

The SDG process and the OWG was supported by various stakeholder groups, including the Sustainable Development Solutions Network (SDSN) which published a report outlining 10 SDGs ([UN SDSN 2013](#)) that also contain updated social targets and an emphasis on the necessity of promoting growth within planetary boundaries. Other stakeholder groups have been proposing goals and themes on an ongoing basis and available at various online depositories (UN Sustainable Development Knowledge Platform, SDGs-eInventory, Overseas Development Institute SDG Tracker). [Griggs et al. \(2013\)](#) proposed six overarching areas assessed as being essential for long-term Earth-system stability whilst delivering improved human wellbeing (Table 1 in the main text), derived from their identification of seven planetary must-haves" or global sustainability objectives (GSOs – see Table A2).

There are striking similarities between the proposals from OWG, HLP, SDSN and Griggs *et al.* Sustainable food, water and energy security are common to all and, significantly, given separate goals. Governance in some form too, features prominently and is given its own goal in all except the OWG. Healthy and productive ecosystems are deemed a necessity in all proposals but worded differently in each.

Education, health and gender equality are also common. Griggs *et al* argue for more equality generally as a foundational support for sustainability ([e.g. Wilkinson and Pickett 2009](#)). The proposals differ in the treatment of these challenges; some give each their own goal, others bring them together under a single goal. Griggs *et al*, for example, collect many social challenges under "Thriving lives and livelihoods," reflecting a focus on global sustainability aspects.

The HLP and the OWG specifically have goals on economic growth, which is implicit in Thriving Lives and Livelihoods in Griggs *et al.* Only the OWG sets sustainable consumption and production as a specific goal; the others choose to embed it throughout a suite of goals. The HLP and Griggs *et al* identify sustainable livelihoods as a high priority goal, SDSN only implicitly. SDSN and OWG give cities a goal of their own.

Only the OWG has a goal specifically on implementation. Other documents (e.g. concept paper by Governments of Colombia and Guatemala to the OWG on SDGs, March 2013) have noted issues related to the implementation of targets, some of which this paper (see main text) seeks to address.

We note the importance of research in supporting development, implementation, monitoring and interpretation of the goals, a point that is not made strongly in the OWG (2014) draft.

Table A1: A comparison of the approximate scope of different goal formulations: the Millennium Development Goals (MDGs), the UN Sustainable Development Solutions Network (11) and High Level Panel (HLP) (12) proposals, the OWG (2014) and the Sustainable Development Goals as proposed by Griggs et al. (10). The details of goals differ considerably in some cases.

Millennium Development Goals	SDSN	HLP Universal Goals	Open Working Group	Griggs et al.
1. Eradicate extreme poverty and hunger	1. End extreme poverty including hunger	1. End Poverty	1. End poverty in all its forms everywhere	<p>SDG1: Thriving lives and livelihoods. End poverty and improve well-being through access to education, employment and information; better health and housing; and reduced inequality while moving towards sustainable consumption and production.</p>
2. Achieve universal primary education	3. Ensure effective learning for all children and youth for life and livelihood	3. Provide Quality Education and Life Long learning	4. Ensure inclusive and equitable quality education and promote life-long learning opportunities for all.	
3. Promote gender equality and empower women	4. Achieve gender equality, social inclusion, and human rights for all	2. Empower Girls and Women	5. Attain gender equality and empower all women and girls	
4. Reduce child mortality	5. Achieve health and wellbeing at all ages	4. Ensure Healthy Lives	3. Attain healthy lives and promote well-being for	
5. Improve maternal health				
6. Combat				

HIV/AIDS, malaria and other diseases			all at all ages	
<i>(No real parallel)</i>	2. Achieve development within planetary boundaries	8. Create jobs, sustainable livelihoods and equitable growth	8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	
			12. Ensure sustainable consumption and production patterns	
			9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	
	6. Improve agriculture systems and raise rural prosperity	5. Ensure Food Security and Nutrition	2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	SDG2: Sustainable food security. End hunger and achieve long-term food security — including better nutrition — through sustainable systems of production, distribution and consumption.
		6. Achieve Universal Access to Water	6. Ensure availability and sustainable management of water and sanitation for all	SDG3: Sustainable water security. Achieve universal access to clean water and basic sanitation, and ensure efficient allocation through integrated water-resource management.

	8. Curb human-induced climate change and ensure sustainable energy	7. Secure sustainable energy	7. Ensure access to affordable reliable, sustainable and modern energy for all 13. Take urgent action to combat climate change and its impacts	SDG4: Universal clean energy. Ensure universal, affordable access to clean energy that minimizes local pollution and health impacts and mitigates global warming.
	7. Empower inclusive, productive, and resilient cities		11. Make cities and human settlements inclusive, safe, resilient and sustainable	<i>(No direct parallel)</i>
7. Ensure environmental sustainability	9. Secure ecosystem services and biodiversity, and ensure good management of water and other natural resources	9. Manage natural resources sustainably	14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification and halt and reverse land degradation and halt biodiversity loss	SDG5: Healthy and productive ecosystems. Sustain biodiversity and ecosystem services through better management, valuation, measurement, conservation and restoration.
8. Develop a global partnership	10. Transform governance	10. Ensure good governance	10. Reduce inequality within and	SDG6: Governance for sustainable societies. Transform governance and

for development	for sustainable development	and effective institutions	among countries	institutions at all levels to address the other five sustainable development goals.
		11. Ensure peaceful and stable societies	16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable and inclusive institutions at all levels	
		12. Create a global enabling environment	17. Strengthen the means of implementation and revitalize the global partnership for sustainable development	

Table A2: “Planetary must-haves” or global sustainability objectives (GSOs: Griggs et al. 2013), and potential targets for these that are more or less justifiable from current literature or international processes.

Global sustainability objectives	Potential targets
GSO 1: Maintain a stable climate system limiting global temperature increases to no more than 2C (and address ocean acidification)	global greenhouse gas emissions to peak 2015-2020, with an annual reduction rate of 3-5 % per year between the peak and 2030 (on track to reach global reductions by 50-80% of 2000 emissions by 2050) (Huntingford et al. 2012)
GSO 2: Reduce the rate of global biodiversity loss	reduce extinction rates to no more than ten times the natural background rate, halting rate of habitat loss (assuming rate is at least halved by 2020 in line with Aichi targets [http://www.cbd.int/sp/targets/]) keep at least 85% of the potential area of tropical rainforests and boreal forests sustainable management of ecosystems that safeguards terrestrial, inland waters, coastal and marine areas of critical importance for biodiversity and ecosystem

	<p>services (building on Aichi targets [http://www.cbd.int/sp/targets/] of protecting 17% terrestrial and 10% coastal systems by 2020)</p> <p>secure marine ecosystem services through sustainable management of oceans and seas, to safeguard diversity and abundance of fish stocks</p>
GSO 3: Safeguard ecosystem services from critical biomes	<p>better cost social and environmental externalities (greenhouse gas emissions, freshwater usage, pollution and waste) into product prices by 2030</p> <p>building on developments in climate and biodiversity policy, comprehensive national monitoring, reporting and verification systems are established for all SDG targets to ensure compliance and coherence</p>
GSO 4: Maintain the capacity of the global hydrological cycle to provide freshwater to sustain the resilience of ecosystems	<p>keep the global consumptive use of runoff water below $4000 \text{ km}^3 \text{ y}^{-1}$ (Rockstrom et al. 2009)</p> <p>withdraw no more than 25-50% of the mean monthly flow in any river basin (depending on hydrological regime) (Pastor et al. 2013)</p>
GSO 5: Maintain well-functioning nitrogen and phosphorous cycles	<p>improve by 20% full-chain nutrient use efficiency by 2020 (Sutton et al. 2013)</p> <p>apply to cultivated lands via fertilizers no more than 44M tons of nitrogen per year from industrial and intended biological fixation processes (building on de Vries et al. 2013)</p> <p>ensure that the flux of phosphorous to the ocean remains no more than 11 M tons y^{-1} (Rockstrom et al. 2009)</p> <p>reduce eutrophication of freshwater in rivers and lakes by reducing the flow of phosphorous to erodible soils to 3.7 Tg P yr^{-1} (Carpenter and Bennett 2011)</p>
GSO 6: Maintain clean air for health and regional environments	<p>existing World Health Organization (WHO) guidelines and address air pollutants such as black carbon (Shindell et al. 2012)</p>
GSO 7: Sustainable and precautionary use of new entities and abiotic natural resources	<p>precautionary critical loads for anthropogenic chemical compounds and extraction of toxic materials (heavy metals, nuclear materials etc.)</p> <p>adopt resource efficiency and circular processes as strategies for extracting and using scarce minerals and metals</p> <p>reduce emissions of ozone depleting substances to maintain a stratospheric ozone layer thickness no less than 276 Dobson units (Rockstrom et al. 2009)</p>

Many targets for the GSOs are derived from existing international agreements, as follows, illustrating how their use in SDGs can provide a global coordinating and

synthesizing framework for these many existing agreements; others draw on recent research:

GSO1: These targets represent one track to achieving the UNFCCC commitment to stay within 2C global warming, applying a global emissions budget approach as raised in the latest IPCC Assessment Report; avoiding further ocean acidification requires the same action, though focused specifically on CO₂ – we have not set a separate target here. Forthcoming work may emphasize a lower boundary of a change in radiative forcing of no more than +1.0 W m⁻², but the target suggested here would in any case be a reasonable one for the 2030 time horizon of the SDGs.

GSO2: These are drawn from the Aichi agreement, noting that these differ from known boundaries in the sense that the latter represent proven tipping points whereas a target is a safe level to aim not to exceed; these indicators will be improved and sharpened as the science progresses

GSO3: These topics are being explored in various fora, including the Intergovernmental Panel for Biodiversity and Ecosystem Services

GSO4: These are drawn from the sources noted but sometimes modified by recent results

GSO5: No global agreements for P and N cycles yet exist, although proposals are circulating, as referenced but sometimes modified by recent results

GSO6: Existing World Health Organisation guidelines

GSO7: A rapidly developing recent area of understanding, based mostly on the existing Stockholm Convention on Persistent Organic Pollutants (www.pops.int) and related Conventions

ILLUSTRATING THE BALANCED DEVELOPMENT OF BIOPHYSICAL, SOCIAL AND INTEGRATIVE TARGETS.

Table A3 explores how social and biophysical targets interact within the SDGs and how these interactions can be made explicit and tracked through integrated targets. Where possible we have used targets proposed in the OWG (2014) report, noting where these could be made more quantitative (these are labeled in the form of x.y, being the y'th target of the x'th goal in the July 2014 version). In other cases we have used proposals from HLP (UN HLP 2013 – shown as HLP #.#) or proposed new targets where these are missing from the current debate, mostly from Table A2, sometimes simplified.

Our principal intent is to be illustrative; the table does not attempt to list all targets comprehensively. All of the GSO targets in Table A2 should appear somewhere in the Biophysical column; and many of the OWG 'pure' social targets could appear in the Socio-economic column but without a particular need to be linked to sustainability concerns. The OWG targets are therefore not all listed in the table, which aims to focus on illustrating where biophysical and socio-economic targets need an integrated target to handle trade-offs and synergies appropriately. As noted in the main text, our principal focus is on integrating global sustainability concerns; thus there are many targets related to SDG1 that do not materially interact with the biophysical outcomes, and we do not include these ones, important as they are. Here we illustrate just three areas where there is an interaction under SDG1, before examining the other SDGs. Some explanatory notes about each row, and their connections to proposed OWG targets, follow:

SDG1 (Health): this row highlights a case where significant synergies can be achieved by considering how the targeted management of pollutants in the environment generally and from less-clean sources of energy such as burning dung and wood can deliver health co-

benefits that are more substantial than those likely to be achieved in the absence of integrated targets. The listed integrated target, OWG 3.7, could additionally specifically target environments that affect mothers and young children. The biophysical target could be made more quantitative by referring explicitly to specific international standards such as the WHO Air Quality Guidelines (2005) for particulate matter and the Stockholm Convention for novel chemical compounds (see GSOs 6 and 7). We suggest a quantitative integrated target here that is related to achieving SDG4 at the same time as health and education social targets.

SDG1 (Equitable consumption): Consumption ultimately drives most of the GSOs, but this line specifically addresses the interactions between the management of the impacts of consumption and equality. As consumption by the less well-off increases, the distribution of the use of the remaining resources must also become more equitable in order to meet the GSOs. The biophysical targets will be identified in other SDGs below, but integrated targets are needed both to minimize the degree of trade-off by increasing resource use efficiency in general and through waste management; and then we propose a third to capture synergies with other social targets through fair distribution. The integrated targets would benefit from a more quantitative expression, which might occur at sub-global levels. For example, OWGs 8.4, 9.4 and 12.5 could be made more concrete for individual sectors or regions with an integrated target which defined a rate of improvement in resource efficiency or waste reduction by some standard (e.g. rate of resource use per unit of services delivered by particular infrastructure and industries); in fact these three could be combined.

SDG1 (Disasters): The OWG document contains 3 separate approaches to decreasing the effects of disasters on people, without relating these (where appropriate) to global change drivers (in fact a fourth, OWG 2.4, also refers strongly to extreme events and disasters in an agricultural context). This relationship could be made explicit as shown, where the types of disasters that are affected by global change include climate-related disasters as a result of climate change, landslips and flooding as a result of land use change, famines and water crises as a result of land degradation and over exploitation of water resources, etc.

SDG2: this row seeks to manage the tradeoff between food for a growing and more affluent population and not damaging the environment. Most items here are described in the main text. Note that the reason for reducing phosphorus loss is to avert widespread eutrophication of freshwater systems on land. The GSO-related biophysical targets here are not explicitly represented in OWG (2014), so are inserted here, along with an unquantified target for land degradation (OWG 15.3). In the integrated targets, OWG 12.3 should be more quantitative as noted, and the OWG has no target on agricultural resource use efficiency except in relation to water (captured under SDG3). As described in the main text, these are a crucial part of managing the interaction between obtaining more production for less environmental impact. We therefore add a resource use efficiency target for P and N (water is picked up in SDG3) – see main text. In addition, better use of P and N in particular could be achieved in ways that enhance social equity more or less effectively (cf. SDG1 Equitable consumption above); [de Vries et al. \(2013\)](#) argue that it is possible to establish regional targets for N use which enhance production in many developing countries with poor soil fertility at the same time as reducing surplus N use in regions where this does not help yields and causes environmental impacts, and

from these quantify a global target also (see also [Steffen and Stafford Smith \(2013\)](#)), and for phosphorus [Carpenter and Bennett \(2011\)](#)). Finally, the sense of increasing agricultural productivity has been lost in the OWG draft (e.g. OWG 2.3 focuses only on small-holders), so we have retained the HLP 5c formulation for the related social goal, in addition to OWG 2.1.

SDG3: this row addresses the trade-off between water accessibility for all needed uses and impacts on the water cycle, as discussed in the main text. As for P and N, the biophysical water targets have important regional elements, such that a global target can be articulated but this requires regionally specific management of aquifers and catchment withdrawals. These biophysical targets are no longer explicit in the OWG (an earlier draft contained “bring freshwater withdrawals in line with sustainable supply”), so we suggest these from the GSOs. The integrative OWG 6.4 is for general water use efficiency; for reasons given in the main text, it would be most important to focus on the dominant use of fresh water in agriculture (as in HLP 6c), so this could be made more quantitative and achievable as shown. OWG 6.3 addresses water quality and recycling – recycling would be better incorporated in water use efficiency, but water quality is important and could be framed to ensure that it delivers industrial production, health and biodiversity benefits through SDG1 and SDG5. The OWG social targets here focus on drinking water and sanitation; trade-offs arise in the use of water for increased production in other sectors, which are noted here but could in fact be linked to other SDGs.

SDG4: this row addresses the interactions between energy use and environmental impacts, in particular climate change, as discussed in the main text. The OWG provides no climate targets as yet (although part of OWG 14.2 addresses ocean acidification); we therefore retain our GSO target from Table A2, noting that this needs to be in line with the UNFCCC negotiations. OWG 7.2 and 7.3 approximately address the integrative targets that are needed here, but could be more quantitative, as suggested by our preferred wording that draws on [Rogelj et al. \(2013\)](#).

SDG5: this row addresses the trade-offs between meeting global demands for ecosystem services without continuing to increase impacts on biodiversity and ecosystems. In essence the social goal is the sum of meeting demands on ecosystem services for human well-being, and the integrated targets need to provide the means to better value the balance between these services and conservation goals established for a variety of purposes. OWG (2014) divides targets between marine (OWG 14) and terrestrial (OWG 15) ecosystem goals and we provide possible wording here that could be disaggregated again. For the biophysical targets, OWG 14.4 is specific about areas to be protected, but OWG 15 is not; therefore we suggest quantitative targets based on the Aichi targets (<http://www.cbd.int/sp/targets/>). OWG (2014) contains a number of targets that are more integrative, some examples noted here, but omits one on valuing ecosystem services.

SDG6: this row addresses governance – as noted in the main text, it is questionable whether governance is sensibly considered in quite the same way as previous goals, but we show some OWG (2014) targets that plausibly sit in each column. Some of these have both global and sub-global aspects.

Table A3: Goals with examples of possible biophysical, socio-economic and integrated targets, drawing on the OWG (2014) report where possible (see text

accompanying this table). Many global targets will need to be applied in a differentiated way at a regional or local scale. Figure 2 in the main text illustrates key examples from this Table, with a focus on those targets, whether biophysical, socio-economic or integrated, that relate to delivering the biophysical ‘planetary must-haves’ or Global Sustainability Objectives (Table A2).

	Global targets		
SDGs	Biophysical	Integrated	Socio-economic
SDG1: Thriving lives and livelihoods (Health)	12.4 by 2020 achieve 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 to minimize their adverse impacts on human health and the environment [cf. GSOs 6, 7]	3.9 by 2030 substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination By 2025 ensure that all households with mother and young children have access to energy sources for cooking and heating that avoid effects on health and free up time for education	3.1 by 2030 reduce the global maternal mortality ratio to less than 70 per 100,000 live births 3.2 by 2030 end preventable deaths of newborns and under-five children
SDG1: Thriving lives and livelihoods (Equitable consumption)	[All GSOs] Ensure that total resource use stays within sustainable limits	8.4 improve progressively through 2030 global resource efficiency in consumption and production, and endeavour to decouple economic growth from environmental degradation [...] 9.4 by 2030 upgrade infrastructure and retrofit industries to make them sustainable, with increased resource use efficiency 12.5 by 2030, substantially reduce waste generation through prevention,	8.5 by 2030 achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value 10.1 by 2030 progressively achieve and sustain income growth of the bottom 40% of the population at a rate higher than the national average

		reduction, recycling, and reuse Achieve a fair distribution of the remaining global budget for emissions of CO2 (estimated at approximately 1000 GtCO2 for a 66 % chance of < 2C); the remaining N and P budgets; and other critical natural resources	10.4 adopt policies especially fiscal, wage, and social protection policies and progressively achieve greater equality 11.1 by 2030, ensure access for all to adequate, safe and affordable housing and basic services, and upgrade slums
SDG1: Thriving lives and livelihoods (Disasters)	[GSOs1,2,3] Avoid levels of global environmental change that exacerbate existing ‘natural’ disasters, which implies safeguarding current biological diversity and ecosystem resilience, and ensuring global emissions of CO2 peak within 5-10 years	11.5 by 2030 significantly reduce the number of deaths and the number of affected people and decrease by y% the economic losses relative to GDP caused by disasters, including water-related disasters, with the focus on protecting the poor and people in vulnerable situations	1.5 by 2030 build the resilience of the poor and those in vulnerable situations, and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters 13.1 strengthen resilience and adaptive capacity to climate related hazards and natural disasters in all countries
SDG 2: Sustainable food security	[GSO5] Keep flux of phosphorous to the ocean at no more than 11 million tons per year. [GSO5] Reduce input of phosphorus via fertilizers to cultivated land to 3.7 million tons per year No additional land conversion in the	[GSO5] Improve full-chain nutrient use efficiency by 20% by 2020 12.3 by 2030 halve per capita global food waste at the retail and consumer level, and reduce food losses along production and supply chains including post-harvest losses [e.g. by 50% by 2030: Lipinski et al. (2013)] 2.4 by 2030 ensure sustainable food production systems and implement	2.1 by 2030 end hunger and ensure access by all people, in particular the poor and people in vulnerable situations including infants, to safe, nutritious and sufficient food all year round 2.3 by 2030 double the agricultural productivity and the incomes of smallscale food producers [...] Increase agricultural productivity by x%, with

	<p>tropics [GSO5] Limit input of new reactive nitrogen from industrial and intended biological fixation processes to cultivated land via fertilizers to 44 million tons per year 15.3 by 2020, combat desertification, and restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land-degradation neutral world</p>	<p>resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters, and that progressively improve land and soil quality Redistribute nutrients (N, P) from areas where they are in excess to areas where they are scarce</p>	<p>a focus on sustainably increasing smallholder yields and access to irrigation [HLP 5c]</p>
<p>SDG3: Sustainable water security</p>	<p>Maintain and restore groundwater aquifers [GSO4] Global consumptive use of water runoff less than 4000km³/yr (4) [GSO4] Withdraw no more than 25-50% of the mean monthly flow in any river basin (depending on hydrological regime)</p>	<p>6.4 by 2030, substantially increase water-use efficiency across all sectors...[Suggested: Improve Water Productivity of all food crops to 1000 m³/ton by 2030] 6.3 by 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and increasing recycling and safe reuse by x% globally</p>	<p>6.1 by 2030, achieve universal and equitable access to safe and affordable drinking water for all 6.2 by 2030, achieve access to adequate and equitable sanitation and hygiene for all, and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations Enough water for increased production (x%) of food, fibre and industrial products</p>
<p>SDG 4: Universal</p>	<p>[GSO1] Global emissions peak</p>	<p>Decrease carbon intensity by increasing the share of</p>	<p>7.1 by 2030 ensure universal access to</p>

clean energy	2015-2020 and follow an annual reduction of 3–5% p.a. thereafter to be on track to reach 50-80% below 2000 emissions by 2050 14.3 minimize and address the impacts of ocean acidification [...]	renewable energy to x% (e.g., 30%) [OWG 7.2 increase substantially the share of renewable energy in the global energy mix by 2030] Increase energy intensity by y% p.a (e.g., 2.4% p.a.). [OWG7.3 double the global rate of improvement in energy efficiency by 2030]	affordable, reliable, and modern energy services
SDG5: Conservation and sustainable use of biodiversity and ecosystems	15.4 take urgent and significant action to reduce degradation of natural habitat, halt the loss of biodiversity, and by 2020 protect and prevent the extinction of threatened species [GSO2] By 2020, protect at least 17% of terrestrial and 10% of coastal and marine systems by 2020 [GS02] Reduce global extinction rates to no more than 10x the natural background rate [GSO2] Halt habitat loss globally (halve rate by 2020)	[GSO3] Fully cost all social and environmental externalities (greenhouse gas emissions, freshwater usage, pollution and waste) into product prices by 2030 14.6 by 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing [] 15.2 by 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests, and increase afforestation and reforestation by x% globally 15.8 by 2020 introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems, and control or eradicate the priority species	Increase delivery of ecosystem services to meet demands on provisioning, regulating and cultural services
SDG6: Governance for sustainable societies	13.2 integrate climate change measures into national policies, strategies, and planning	Establish qualified majority voting in key international bodies concerned with delivering outcomes relevant to the SDGs (Biermann et al. 2012)	10.4 adopt policies especially fiscal, wage, and social protection policies and progressively achieve greater equality

	13.3 improve [...] human and institutional capacity on climate change mitigation, adaptation, impact reduction, and early warning 15.2 by 2020, promote the implementation of sustainable management of all types of forests [...]	17.14 enhance policy coherence for sustainable development 6.5 by 2030 implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	16.3 promote the rule of law at the national and international levels, and ensure equal access to justice for all 10.6 ensure enhanced representation and voice of developing countries in decision making in global international economic and financial institutions in order to deliver more effective, credible, accountable and legitimate institutions
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APPENDIX LITERATURE

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