CellPress OPEN ACCESS
Gold Standard for the Global Goals 1 ton of CO_2 offset
One Earth

Perspective

Defining a sustainable development target space for 2030 and 2050

Detlef P. van Vuuren,[1,2,*] Caroline Zimm,[3] Sebastian Busch,[3] Elmar Kriegler,[4] Julia Leininger,[5] Dirk Messner,[6,14] Nebojsa Nakicenovic,[3] Johan Rockstrom,[4,7] Keywan Riahi,[3,8] Frank Sperling,[3,9] Valentina Bosetti,[10] Sarah Cornell,[7] Owen Gaffney,[4,7] Paul L. Lucas,[1] Alexander Popp,[4] Constantin Ruhe,[5,11] Armin von Schiller,[5] Jörn O. Schmidt,[12,13] and Bjoern Soergel[4]
[1]PBL Netherlands Environmental Assessment Agency, The Hague, the Netherlands
[2]Utrecht University – Copernicus Institute of Sustainable Development, Utrecht, the Netherlands
[3]IIASA – International Institute for Applied System Analysis, Laxenburg, Austria
[4]PIK – Potsdam Institute for Climate Impact Research, Member of the Leibniz Association, Potsdam, Germany
[5]DIE – Deutsches Institut für Entwicklungspolitik/German Development Institute, Bonn, Germany
[6]UBA German Environmental Agency, Dessau-Roßlau, Germany
[7]Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden
[8]Graz University of Technology, Graz, Austria
[9]University of Oxford – School of Geography and the Environment, Oxford, UK
[10]RFF-CMCC European Institute on Economics and the Environment, CMCC, Milan, Italy
[11]Goethe-Universität, Faculty of Social Sciences, Frankfurt am Main, Germany
[12]Center for Ocean and Society, Christian-Albrechts-Universität zu Kiel, Kiel, Germany
[13]International Council for the Exploration of the Sea, Copenhagen, Denmark
[14]University of Duisburg-Essen, Duisburg, Germany
*Correspondence: detlef.vanvuuren@pbl.nl
https://doi.org/10.1016/j.oneear.2022.01.003

SUMMARY

With the establishment of the sustainable development goals (SDGs), countries worldwide agreed to a prosperous, socially inclusive, and environmentally sustainable future for all. This ambition, however, exposes a critical gap in science-based insights, namely on how to achieve the 17 SDGs simultaneously. Quantitative goal-seeking scenario studies could help explore the needed systems' transformations. This requires a clear definition of the "target space." The 169 targets and 232 indicators used for monitoring SDG implementation cannot be used for this; they are too many, too broad, unstructured, and sometimes not formulated quantitatively. Here, we propose a streamlined set of science-based indicators and associated target values that are quantifiable and actionable to make scenario analysis meaningful, relevant, and simple enough to be transparent and communicable. The 36 targets are based on the SDGs, existing multilateral agreements, literature, and expert assessment. They include 2050 as a longer-term reference point. This target space can guide researchers in developing new sustainable development pathways.

INTRODUCTION

The 2030 Agenda for Sustainable Development,[1] adopted in 2015 by the UN General Assembly, sets an ambitious agenda for the universal pursuit of economic, social, environmental, and institutional objectives, concretized in 17 sustainable development goals (SDGs) and 169 associated targets. Together with other international agreements (such as the Paris Climate Agreement and the Aichi biodiversity targets[2,3]), the 2030 Agenda aims to ensure that development patterns lead to wellbeing and social inclusion while maintaining the Earth's biophysical life support stability systems. Achieving the SDGs will require a fundamental transformation of today's societies.[4–7] Still, it is not easy to understand exactly what is needed. Although for some goals (e.g., climate action, SDG13), literature exists showing how to achieve them, such literature is sparse or lacking for many others. More importantly, hardly any information exists on what is needed for achieving all SDGs together,[5] accounting for the linkages between SDGs and possible synergies or trade-offs.[4,8–12] For example, one way to pursue food security for all (SDG2) would be by increasing production, possibly through more intensive agriculture, which could lead to more fertilizer use and thus emissions of nitrous oxide (SDG13) or leading to water shortages (SDG6). Similarly, using bioenergy to reduce greenhouse gas emissions (SDG13) could lead to an expansion of agricultural land, possibly reducing biodiversity. However, many synergies also exist; e.g., reducing greenhouse gas emissions through expansion of renewable energy (SDG13) also reduces air pollutants emissions, thus improving health (SDG3). Recent studies have looked at achieving multiple SDGs at the national level[13,14] or specific groups of SDGs.[6,15–17] Still, with only a few exceptions, no studies have looked at scenarios to achieve all 17 SDGs simultaneously or the longer-term implications, which is critical for genuinely sustainable planning (noteworthy exceptions include the work of Randers et al.[18] and Soergel et al.[19]). This knowledge gap is also emphasized by various

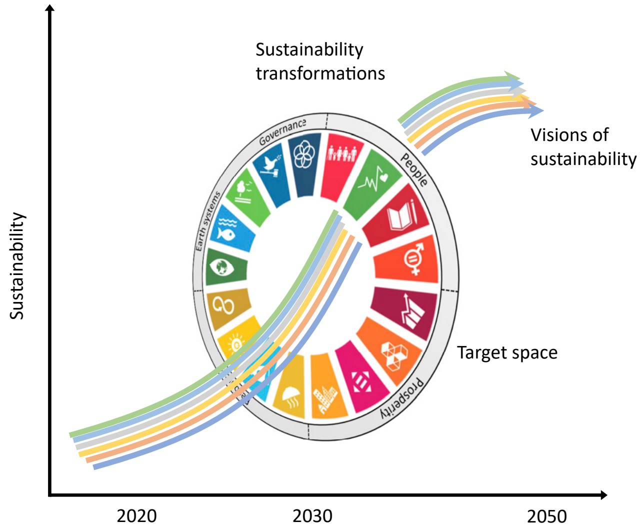

Figure 1. Conceptualization of the target space, showing how it relates to the required societal transformations and the long-term sustainability vision

policy reports and science programs such as the Science-based Targets Initiative[20] and the UN Global Sustainable Development Report.[21] The current situation caused by the COVID-19 pandemic and the recovery process, which could enable or impede pathways toward implementing the SDG, has made this even more important.[22,23] Scenarios showing how SDGs can be met could play a similar role as emission and climate scenarios have in the climate realm; i.e., spur scientific research and help policymakers translate ambitions into concrete action. Identifying pathways to implement the SDGs has become even more urgent due to the slow implementation record.

Any exercise aiming to provide a quantitative analysis of pathways toward meeting the SDGs would need a precise formulation of the target space[24–27]; i.e., a limited set of targets formulated unambiguously and providing comprehensive coverage of the ambition of the SDGs. Although the current 169 targets and 232 indicators allow tracking global and country-level progress on implementing the 2030 Agenda,[28] they are too broad, unstructured, and complex to support quantitative analyses of transformation trajectories and are not always science based. As a result, progress on scenario development at all scales (global, national, or local level) is slowed down by the lack of a relatively simple framework that includes all relevant, sustainable development dimensions. However, defining a target space is not easy. For instance, in several science areas relevant to the SDGs, quantitative projections are not common practice.[29,30] Moreover, any selection of targets automatically leaves out important topics.

Formulating a standardized target space could help the scientific community in analyzing pathways toward meeting the SDGs. A key reason for a standardized set is that no single model will be able to address all aspects of the target space meaningfully. As such, the community should work together with sets of (coupled) models to provide a more comprehensive analysis.[31] The target space and the transformation narratives can be critical for improving comparability and consistency across a broad set of quantitative studies on the SDGs (at the same time, it is also important to propose new indicators and targets than those proposed here to keep heterogeneity, stimulate innovation, and do justice to uncertainty[32]).

This paper proposes such a systematic set target space formulation that can be used for sustainable development scenarios and that can be tested and evaluated in scenario studies. The targets could be used to move beyond the more topic-oriented scenario exercises done so far, such as climate (Intergovernmental Panel on Climate Change [IPCC]), biodiversity (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES]), and food (Food and Agriculture Organization [FAO]), toward integrated analyses of the people-planet framework. In the paper and the supplemental information (Note S1), we explain why the targets were chosen. Future studies could contribute to this exercise by using it, engaging in further refinement of indicators or target values, and contributing to improved modeling of individual indicators or linkages. As such, the set can be tested in applications (see, for instance, Soergel et al.[33] for a first example) at the global, regional, national, and subnational level, providing insight into the usefulness and applicability of the set. In the paper, we briefly illustrate the use of this set of targets by applying it to available information for a middle-of-the-road scenario.[34] With increasing experience and scenario applications, the target space is expected to be adapted and improved.

DEFINING A SUSTAINABLE DEVELOPMENT TARGET SPACE

The formulation of the target space draws upon expert discussions as part of The World in 2050 (TWI2050) initiative; further information on this initiative and participating institutions can be found at www.twi2050.org. TWI2050 convenes scientists involved in scenario modeling, social and natural scientists, and policy analysts from around the world for collaboration and deliberative consultation for the development and use of sustainable development pathways[5] (Figure 1). TWI2050 has identified six fundamental transformations, describing a set of interventions for simultaneously achieving the SDGs and extending sustainable development beyond 2030: (1) advancing human capacities and demography, (2) establishing responsible consumption and production patterns, (3) achieving decarbonization and inclusive and sustainable energy systems, (4) establishing sustainable land use management and access to food while safeguarding biodiversity of terrestrial and aquatic ecosystems, (5) developing sustainable cities and communities, and (6) aligning the digital revolution with the SDGs[5] (Sachs et al.[7] provided a slightly adapted variant). These transformations were kept in mind in selecting the target space indicators (see Note S2 for the connections). Around 60 scientists involved in TWI2050 assisted in formulating the target space. This involved the selection of indicators, as well as the associated target values. There were several steps in the process (Figure 2): (1) formulation of key principles for the target space and selection criteria; (2) the review of existing sets of indicators and targets in the literature, international agreements, and associated with the SDGs; and (3) the final selection of a set of indicators and targets.

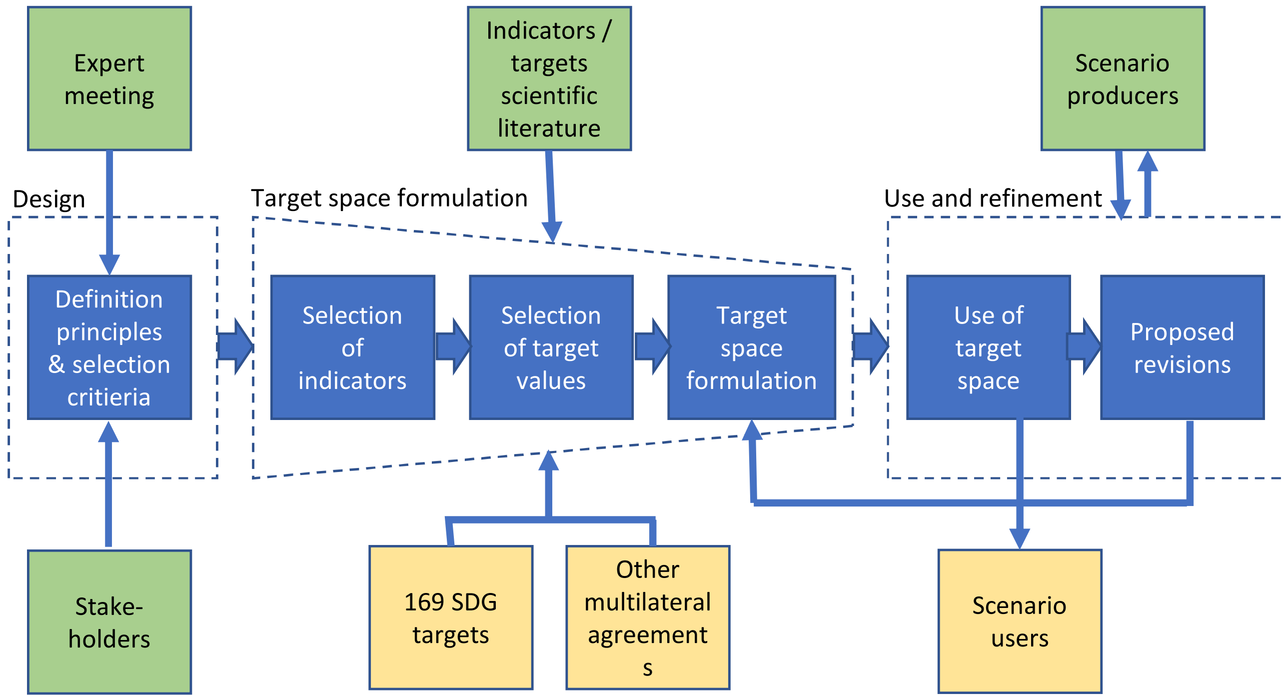

Figure 2. The process for defining and applying the target space

Principles and criteria for indicator selection

First, a list of principles for selecting indicators and setting targets was developed (Table 1). A first principle is to ensure that the indicators are relevant for society; i.e., they link to the societal agenda as expressed in the SDGs, which are the outcome of a global political consultation process. The set also needs to be science based; i.e., it should be consistent with the insights of global sustainability science. This leads to the third principle that a longer-term perspective must be included (valid for 2030 and beyond). The fourth principle emphasizes that indicators need to be robustly quantifiable to enable quantitative analysis. The fifth principle of operational simplicity, transparency, and usability aims to ensure the relevance of the quantitative analysis for policymakers (Table 1). This, for instance, means that the number of targets needs to be limited. A sixth principle is that targets need to be actionable (i.e., sensitivity to human decision making) and (at least theoretically) achievability. Finally, comparable data and knowledge also need to be available. A key argument for the relevance beyond 2030 is that the transformation toward sustainable development is a long-term process and that therefore it is essential to check whether developments are also in line with these long-term goals (e.g., for climate change, a significant emission reduction in 2030 is only a step toward achieving net-zero emissions mid-century; see also Moallemi et al.[35]). The fact that short-term targets are not always met provides another reason for also adding a long-term focus.

Our ambition to keep the sustainable development target space analytically tractable and transparent subsequently translated into a criterion to choose only two to three targets per SDG. One way to do so was (if relevant) prioritizing those targets that represent endpoints in terms of the actual desired state and not the means of achieving this state. Another way is to avoid overlap between target indicators. As the SDGs are interlinked, an indicator selected for a given SDG can also cover aspects of other SDGs (for example, access to the internet and financial institutions relates to SDG9 on innovation and covers aspects of SDG10 on reducing inequality). Each target should also be suitable for quantitative analysis and sensitive to policy choices. Table 1 discusses in more detail how the key principles were applied in indicator selection and setting targets.

Selection of targets and target values

Based on the above criteria, the expert deliberations proposed a set of targets[37] that has been iteratively refined based on the above criteria and existing literature (Table 2). Given the first principle, we started with an initial list of targets as part of the 2030 Agenda and multilateral agreements, complemented with the (scientific) literature, for instance, the Planetary Boundary indicators[27,36,38] (more specific references are provided in the paragraphs describing indicator choice). Regarding the choice of the specific numerical target values, the criteria set in Table 1 implied that values are (1) preferably, directly taken from the 2030 Agenda and other international agreements or (2) directly taken from the scientific literature. As an alternative, (3) the values of top-performing countries have been used, or (4) values that are assessed to be directly consistent with the basic principles underlying the SDGs (e.g., zero hunger). The Sustainable Development Solutions Network (SDNS) network applied a somewhat similar method for their domestic targets.[39] In some cases, the targets needed to be defined more precisely to allow quantitative evaluation (e.g., the notion of hunger needs a specification of a number of kilocalories per person per day). Finally, our final set also includes examples for

Table 1. Criteria for defining the sustainable development target space

Key principles underlying the target space: Target indicators should be	Derived criteria for selection of targets	Derived criteria for target values
Societal relevance	the target space addresses areas of sustainable development organized around the 17 SDGs; wherever possible, indicators and target values directly related to the SDGs or objectives from other international agreements are used	
Science-based	the indicators need to address the most pressing dimensions of human development (people), socio-economic wellbeing (prosperity), national and international security (peace), and global environmental change (planet) as discussed in the scientific literature, such as the processes prioritized in the Planetary Boundaries framework[36]	where consensus exists on science-based targets that must be achieved by 2030 or later, these should be used
Valid for 2030 and beyond	the indicators should relate to both the SDG time frame (2030) and the long-term (2050 and beyond) and account for path-dependency	for 2050, target values either retain absolute 2030 measures (e.g., zero hunger, energy access for all) or even improve upon these values; in the latter cases, the values are set to achieve a decent life for all
Quantifiable	the targets should be well suited for inclusion in quantitative analyses, capturing as many features as possible in state-of-the-art integrative models; they also need to be unambiguous and measurable	target values need to be specified clearly and with appropriate precision in order to be suitable for quantitative analysis
Transparent	the set should be clearly defined, and individual indicators should be easy to understand (e.g., avoiding multi-dimensional indices); the number of indicators per issue should be as low and complementary as possible while capturing the global features of Agenda 2030; we, therefore, aim to have at most two or three indicators per SDG, and some indicators assigned can be relevant for multiple SDGs; we prioritize selecting indicators that describe end values of system transformation rather than the means to achieve them	target values should ensure consistency across the indicators for the different SDGs and be linked to the principles underlying the SDGs and the objectives of other international agreements
Actionable and achievable	the indicators should be actionable and sensitive to policy initiatives (and thus link to system transformations)	the target values are derived from existing agreements; targets should be reachable, for instance, demonstrated by some countries reaching the target
Availability of data and knowledge	indicators are only useful if data are available to monitor progress	the target values need to be rooted in data and knowledge

which target values could not yet be provided, such as quantifying peace by measuring the reduction of conflict-related deaths until 2030 and 2050. Two challenges have to be kept in mind when applying the target space. First, the targets are interlinked.[10,11] Synergies between SDGs reinforce the achievement of different targets (e.g., access to drinking water improves health), whereas trade-offs may limit or hinder the achievement of other goals.[5,7] Second, although several targets are universal and can be applied at different geographic scales, others are currently focused on the global scale. We assume that, in quantitative analysis, model teams will find ways to deal with these challenges and encourage the international community to explore further elaboration in future applications of the proposed target space.[40]

THE SELECTED INDICATORS AND TARGET VALUES

We discuss the target and indicator selection in five clusters and provide additional information on the choices in the supplemental information (Note S1). The clusters are based on the key elements of sustainable development introduced in the preamble of the 2030 Agenda[1]; i.e., (1) mobilizing people's potentials in dignity and equality, above all requiring the end of poverty (people); (2) ensuring that all human beings can enjoy prosperous and fulfilling lives (prosperity); (3) protecting the planet from degradation, including ensuring more sustainable management of key resources (planet); and (4) ensuring the development of well-governed, peaceful, just and inclusive societies that are free from fear and violence (peace). We have split the planet element into

Table 2. Targets and indicators for the 2030 and 2050 target space

SDG	Normative goal	Indicator	Current situation (around 2015)	2030 target	2050 target
(1) No poverty	end extreme poverty	number of people below international poverty line	889 million (13%)[41]	0	0
(2) Zero hunger	end hunger	number of people undernourished (below MDER)	795 million (11%) people undernourished[42]	0	0
	healthy diets for all	number of people with obesity (BMI >30)[43]	636 (9%) million in 2010[44]	0	0
(3) Good health and wellbeing	achieve adequate health care for all	healthy life expectancy at birth (years)	global mean 63.12 years country range [45.6–75.2][45]	>65[27]	>70
		under 5 mortality rate (deaths per 1,000 live births)	global mean 43; 99 in sub-Saharan Africa[46]	25	12
(4) Quality education	universal lower secondary education	share of leaving cohort completing lower secondary education	90% primary and 76.7% lower secondary completion rate[41]	80% secondary; 100% primary	100% secondary
(5) Gender equality	end gender discrimination in education	the gender gap in mean years of schooling of population aged ≥15 years	global mean: 0.79[47]	0	0
	achieve gender pay parity	female estimated earned income over male	52%–87%[48]	1	1
(6) Clean water and sanitation	universal access to clean water	population without access to improved water source piped	660 million (9%)[41]	0	0
	universal access to sanitation	population without access to improved sanitation facility	2.4 billion (32%)[41]	0	0
	end water scarcity	the area under water stress (water stress index for most water-scarce month/season)	11%[49]	no increase	no increase
(7) Affordable and clean energy	universal modern energy services for all	population cooking with traditional biomass	2.8 billion (37%)[50]	0	0
		population without basic electricity access	1.1 billion (13%)[50]	0	0
(8) Decent work and economic growth	work for all	unemployment rate (formal economy)	6%[42]	6%[27]	6%
	global economic convergence	the ratio of GDP *per capita* of a country to the average OECD GDP *per capita* (both in PPP)[41]	average low-income countries: 5.0%; average lower-middle-income countries: 16.7% (both 2018)	low-income countries: 2-fold increase; lower-middle income countries: increase by 50%	low-income countries: 4-fold increase (reaching at least 15%); lower-middle-income countries: 3-fold increase

(*Continued on next page*)

CellPress
OPEN ACCESS

Table 2. *Continued*

SDG	Normative goal	Indicator	Current situation (around 2015)	2030 target	2050 target
(9) Industry, innovation and infrastructure	R&D	R&D intensity, i.e., private and government-financed gross domestic R&D expenditure (GERD) in per cent GDP	1.7%[51]	3%[52]	3%
	Universal access to ICT	the proportion of the population using the internet (%)	46%[53]	95%	95%
	universal access to finance	the proportion of the adult population with an account at a financial institution (%)[54]	69%	middle- and high-income countries: 90% low-income countries: 80%	95%
	fast access to an economic hub	travel time to the nearest city with at least 50,000 inhabitants[55]	high-income countries: less than 1 h for 90% of the population low-income countries: 20% have to travel for more than 3 h	middle- and high-income countries: less than 1 h for 90% of the population low-income countries: less than 3 h for 90% of the population	all countries: less than 1 h for 90% of the population
(10) Reduced inequalities	decrease relative poverty	number of people below 50% of median national daily income (% of the population)[56]	>1.4 billion (~20%) people	15%	10%
(11) Sustainable cities and communities	decent housing for all	population living in slums (urban)	880 million (30% of urban population)[42]	10%	0
	improve air quality in cities	population exposed to annual average PM2.5 > 25 $\mu g/m^3$[57]	65%[41]	20%	10%
(12) Responsible consumption and production	reduce waste and pollution	food loss and waste	33%[58]	<15%	<15%
		municipal material recovery	34% in OECD[59]	59% (top 5 countries 2015)	–
(13) Climate action	limit global warming	well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels	55 $GtCO_2$-eq[34]	pathway toward long-term goal; or globally at least below <27–40 GtCO2-eq[60] (1.5 and below 2°C, 50th percentile)	pathway toward long-term goal; or globally at least below <7–18 GtCO2-eq[60] (1.5 and below 2°C, 50th percentile)
(14) Life below water	balance phosphorus in oceans	P flow from freshwater systems into the ocean	~22 Tg P y–1[36]	11 Tg P y-1[36]	11 Tg P y-1[36]
	sustainably manage marine resources	the proportion of fish stocks within biologically sustainable levels[61]	65%[61]	90%[62]	100%[62]

(*Continued on next page*)

Table 2. *Continued*

SDG	Normative goal	Indicator	Current situation (around 2015)	2030 target	2050 target
(15) Life on land	halt land-system change (deforestation)	global: area of forested land as % of original forest cover biome: area of forested land as % of potential forest	~4,000 ha[63]	no further loss of primary forest	global: 75% (75%–54%), specified by forest type[36]
	balance nitrogen in soils	industrial and intentional biological fixation of N	~150 Tg N y^{-1}[136]	62 Tg N y^{-1}[136]	62 Tg N y^{-1}[136]
	protect biodiversity	BII		no degradation from 2020 onward	no degradation from 2020 onward
(16) Peace, justice, and strong institutions	reduce violence and related deaths	battle-related deaths and fatalities from one-sided violence	>93,000[64]	0 per country/year[b]	0 per country/year[b]
	promote the rule of law and ensure equal access to justice for all	equality before the law and individual liberty index[a]	global: 0.69 (based on Coppedge et al.[65])	increase all individual country scores, at least >0.9[b]	increase all individual country scores, at least >0.9[b]
	ensure responsive, inclusive, participatory, and representative decision making	equal access index[a]	global: 0.63 (based on Coppedge et al.[65])	increase all individual country scores, at least >0.9[b]	increase all individual country scores, at least >0.9[b]
(17) Partnerships for the goals	increase statistical capacities	statistical capacity score: source data (second dimension of the Statistical Capacity Indicator by the World Bank)	62.0 (global average for 149 countries)[66]	increase up to 100 for all countries	increase up to 100 for all countries
	strengthen domestic resource mobilization	total government revenue	global average: 24%–28% (w/o natural resources) for 2011–2015 (based on ICTD/UNU-WIDER[67])	increase to 20% for countries currently below this threshold, otherwise, maintain	maintain the level of 2030 the threshold without the revenue generated by the exploitation of natural resources
	enhance interconnection with global civil society	number of international NGOs of which a country is a member, whether directly or through the presence of members in that country[a]	Global average 386 (based on UIA,[68] countries <500,000 excluded)	increase value above the 25th percentile based on data of 2017 for countries below this threshold, otherwise maintain	increase value above the 25th percentile based on data of 2030 for countries below this threshold, otherwise maintain

Most targets can be applied at the regional or national level. MDER, minimum dietary energy requirement; BMI: body mass index; PPP, purchasing power parity; ICT, information and communication technology; PM2.5, fine particulate matter smaler than 2.5 micron: P = phosphorous; N = nitrogen; BII, biodiversity intactness index; NGOs, non-governmental organizations.

[a]Indicators for which we are unaware of model-based thresholds.

[b]Indicators where we are unaware of model-based long-term projections.

two clusters on planetary integrity and sustainable resource management. The first set focuses on the functioning of the Earth system itself; the second on the interface between the human and Earth system: the use of key resources, including land, energy, and water. The resulting clustering of targets and indicators serves as an accessible yet meaningful form of presenting the high number of indicators in a readable way. These clusters and the sequence of our discussion do not imply any form of hierarchy and do not consider interactions between SDGs yet. Using the indicators in model-based scenario analyses will do so (and could be combined with the six transformations[5,7]). Table 2 summarizes the target space organized by SDG. More information about alternative indicators and why we opted for our selection can be found in the supplemental information (Note S1).

People (SDGs 1, 3, 4, and 5)

The SDGs addressing poverty eradication, health, education, and gender equality together represent a concept of human

CellPress
OPEN ACCESS

development. Several indices have previously been used to capture the multi-dimensional nature of human development, aiming to assess progress over time beyond economic growth. A widely used indicator is the United Nations Development Programme (UNDP) Human Development Index (HDI), which encapsulates three dimensions of development: leading a long and healthy life, acquiring knowledge, and achieving a decent standard of living.[69] In selecting indicators, we build on this by including the number of people suffering from extreme poverty for SDG1, the healthy life expectancy and under-five mortality rate for SDG3, the completion of secondary education for SDG4, and gender gaps in education and income for SDG5.

For SDG1, it is clear that one indicator needs to be related to the objective of no one living in extreme poverty by 2030 as a basic requirement. A key question is how to define extreme poverty. The World Bank global poverty line[70] is chosen as the threshold for 2030 as it is well established and researched. The global poverty line has been periodically updated to reflect increasing costs of living across the world. Where Target 1.1 specifically mentions \$1.25 per day, the World Bank has updated the absolute poverty line to \$1.90 per day (US\$ 2011). We use US\$2 (US\$ 2015) *per capita* per day for 2030 and 2050 for practical reasons and kept it constant over the time period (given the correction for inflation). Relative poverty is also included under SDG10 and discussed in the Prosperity cluster. SDG3 aims at ensuring healthy lives. Healthy life expectancy at birth is often proposed as a summary indicator.[27] The set of SDG targets includes several other indicators, including maternal mortality rates, and many other indicators are also used in the literature. However, the advantage of the healthy life expectancy indicator is that it is all-encompassing. It provides an opportunity to reduce the number of indicators as envisaged by our selection criteria. The SDG target on under-five mortality rate is used to track progress in developing countries. The SDG target level of 25 deaths per 1,000 live births is taken for 2030, further halved by 2050 to increase progress. Although this is still far from levels currently recorded in developed countries, it is still ambitious and achievable. Alternative indicators that were considered include normal life expectancy at birth, a goal of avoiding 40% of premature deaths,[71] and the median health-related SDG index used by the Global Burden of Disease study.[45] Although the latter is also an encompassing indicator, it at the moment requires a too-comprehensive set of underlying indicators to be modeled. SDG4 aims for quality education. The addition of universal secondary education expanded the millennium development goals (MDGs) ambition, which targeted universal primary education only. This addition is based partly on insights that, for poor countries to escape from poverty, universal primary education is not enough and therefore needs to be complemented by secondary education for broad segments of the population.[72] We chose the share of young people achieving lower secondary education as this covers the compulsory schooling time in most countries and reliable data are available. Considering current enrollment rates in primary education, achieving 100% completion of lower secondary education by 2030 is practically impossible, so the target values proposed are 80% in 2030 and 100% in 2050 following medium education and population projections.[69] Alternative indicators may include literacy rates, expected years of schooling, participation in early childhood education, the share of the total population with lower secondary education, a measure of the quality of education through graduate employment, and mean years of schooling. SDG5 aims for gender equality. Out of the broad domains covered by this SDG, we chose education and income to track female empowerment. The target values aim at full equality in 2030, as called for by SDG5. Although some models cover differences in education, the wage gap is currently addressed in very few models and might be a future alternative indicator. The advantage of the education-gap indicator is that it is directly related to future capacity and has an established science-based link with other indicators such as fertility levels. Other indicators that are used to track current progress regarding gender equality include the female-to-male labor force participation rate, proportion of women in national parliaments, share of women in management roles, legal gender discrimination, and rates of sexual violence. However, none of these are currently captured by integrated assessment models, and data quality varies.

Prosperity (SDGs 8, 9, 10, and 11)

SDGs 8, 9, 10, and 11 are closely linked in their focus on socio-economic conditions and, as a cluster, envisage societies and economies that offer a prosperous and fulfilling life for all. SDG8 aims for sustained and inclusive economic growth and full and decent employment. As prosperity in high-income countries is no longer driven by economic growth per se,[73] a focus is placed on sufficient economic growth in low- and lower-middle-income countries, eventually leading to a convergence of living standards. We, therefore, propose an indicator of economic convergence as measured by the ratio of gross domestic product (GDP)/capita in the target country to the average Organization for Economic Co-operation and Development (OECD) GDP/capita (both measured in purchasing power parity, ppp). Our quantitative targets are based on historical examples of rapid GDP/capita growth and income convergence, particularly the Asian tiger economies in the 1960–1995 period and China post 1990. In these cases, GDP/capita relative to the developed economies multiplied by a factor of ≥ 4 in a few decades, with *per capita* growth rates of $\sim 7\%$.[74] As an aside, we note that these targets will be met for many countries under the GDP and population quantification of the Shared Socio-economic Pathways (SSP1) scenario, a set of community scenarios mostly used in climate research.[75] The second proposed indicator for SDG8 is related to employment and decent work (targets 8.5–8.8). Work serves two crucial purposes. It gives individuals access to financial income for entertaining a life of their choosing, and it provides meaning and organizing structure to life. Because a decent income for all is implied by the SDG10 target constraining relative poverty (see below), we focus here on sufficient availability of decent employment opportunities and choose the unemployment rate as indicator for the functioning of labor markets. However, we acknowledge that labor participation rates are also relevant indicators as higher participation can generate both social and economic value,[76] and that the future of work will likely change substantially with increasing digitalization and automation.[77] We, therefore, may eventually require a broader notion of activities with economic or societal value to cover the goal of decent work. Following O'Neill et al.,[27] we set a target of less than 6% of the labor force being unemployed (or, more broadly, being without valued activity). SDG8 also contains the fundamental goals of eradicating forced and child labor (target 8.7), protecting labor rights, and promoting a safe working environment (target 8.8). These fundamental goals are not singled out explicitly in our set of indicators. However, they are implied by a range of indicators relating to poverty eradication (SDG1), universal education (SDG4), broad access to socio-economic activities (SDG9), decent income (SDG10) and living conditions (SDGs 3, 6, 7, 11), and gender equality (SDG5).

The indicators proposed for SDG9 aim to capture multiple aspects of infrastructure (both physical and non-physical) and innovation, focusing on technologies and services that can serve as critical enablers. Following existing policy targets for investing into innovation, we select a country's research and development (R&D) intensity, including both private and government R&D expenditures, as a proxy for innovation. With regard to infrastructure, we select three complementary indicators broadly covering access to physical and digital markets, information, and finance: the fractions of the population with access to the internet, access to financial services, and access to economic hubs represented by travel time to the nearest major city[55] as proxies for infrastructure. SDG10 calls for reducing inequality both across and within countries. The inequality dimension across countries is already covered by the income convergence indicator proposed for SDG8. For inequality within countries, we focus on relative poverty and use the OECD definition[56] of people living below half of the national median income (cf. target 10.2.1). To derive a quantitative target for this indicator, we examine national statistics for the Gini index taken from the World Development Indicators.[41] In recent years, the lowest measured Gini indices are around 25, with around 15%–20% of the countries with available data having Gini indices below 30. We, therefore, take a value of ≤ 30 as an ambitious but still realistic target to be reached by 2050. Under the assumption of a log-normal income distribution, we can analytically relate the Gini coefficient to our proposed indicator. This yields a target of at most 10% of the population living below half of the median income (independently of the average income level) in 2050. We propose an intermediate target of at most 15% of the population in relative poverty by 2030. Finally, for SDG11, we focus on two central aspects of sustainable cities: adequate and safe housing, represented by the number of people living in slums, and a healthy environment represented by the share of people exposed to an annual average pollution level of particulate matter with a diameter of 2.5 μm or less (PM2.5). The threshold for PM2.5 follows the upper value (24-h mean) of the World Health Organization (WHO) guideline[57] (WHO, 2018) and coincides with the annual average threshold value used by the European Union (EU). As targets, we propose that less than 10% of the urban population is exposed to higher annual average levels of PM2.5 by 2050 and less than 20% by 2030. These values are comparable with current values in the EU.[78] Taken together, the selected indicators provide a robust proxy for the ability of an economy to deliver equal access to decent work, income, and living conditions.[73]

Planet integrity (SDGs 13, 14, and 15)

The SDGs on climate action and aquatic and terrestrial biodiversity relate to the condition of the natural environment and the planetary boundaries.[36,79] Given the successful application of the Planetary Boundary framework in many studies, we have decided to look for synergy for some indicators and goals. For SDG13, we follow the target of the Paris Agreement, i.e., well below 2°C, and pursue efforts to stay below 1.5°C. Global integrated assessment models (IAMs) can use this target directly. However, other models (e.g., at the national scale) need derived information, such as existing IAM emission profiles[60] or national carbon budgets over a specific period. We have selected a greenhouse gas emission target but did not specify the downscaling method given the political choices involved (which might relate to the national context). Moreover, we also left it up to the user to interpret the Paris Agreement for the temperature goals and only set an upper bound. Future work could further specify this target. One aspect of SDG14, ocean acidification, is also related to CO_2 emissions and is therefore assumed to be covered by the climate target. In addition, for SDG14, eutrophication can be covered by the phosphorous flow from freshwater systems into the ocean (based on the planetary boundaries) or the index of coastal eutrophication (selected from the SDGs).[80] The latter is more refined but does need further modeling of coastal systems. Further, the fraction of fish stocks within safe biological limits[61] represents the sustainable use of fish resources.[36] We also considered the Ocean Health index, or other work on biodiversity indicators for aquatic systems (such as the mean species abundance), but considered the work not advanced enough to add them at this stage, given the relatively complicated calculation schemes. For terrestrial biodiversity, in principle, multiple dimensions of biodiversity would need to be covered.[81] In order to limit the number of targets, however, the Planetary Boundary indicators are proposed; i.e., the minimum extent of forest cover in different forest biomes, the balance of nitrogen into soils, and the biodiversity intactness index (BII).[82] For the latter, alternative aggregated biodiversity indicators also exist (e.g., the number of species). A comparison project can possibly show whether these can be used as a replacement (if applied relative to reference year).

Sustainable resource management (SDGs 2, 6, 7, and 12)

The consumption and production of food, energy, and water (nexus resources) play a crucial role in many sustainable development challenges, while large parts of society still lack sufficient access.[83–85] The relevant SDGs aim to ensure access to these critical resources for all people while also limiting possible negative consequences of their production and use.

The first indicator is the number of undernourished people (proposed by many other publications, including O'Neill et al.[27]). The target of 0 people undernourished by 2030 is taken from the SDG and needs to be sustained beyond 2050. As the threshold for undernourishment, we apply the minimum daily energy requirement (MDER, kcal/capita/day) suggested by FAO (2017). FAO (2017) calculates country-specific MDERs. The 2030 and 2050 global average minimum thresholds are based on calculations by Hasegawa et al. for SSP1.[86] The future mean MDER is calculated for each year and country using the mean MDER in the base year at the country level[25] and allowing for an adjustment coefficient for the MDER in different age and sex groups.[26] This can be done using future population demographics[27] to reflect differences in the MDER across age and sex.[86] As SDG2 also covers malnourishment, the prevalence of malnourishment and stunting and wasting could also have been considered as alternative indicators, but the proposed indicator is assumed to be more encompassing. In the future, it might be interesting to include an indicator going beyond the mere energy content of diets (kcal) and include aspects related to health.[87,88] We also added an indicator related to obesity. Obesity is on the rise globally, also in developed countries, and has severe health impacts (linked to SDG3), but also clear links to consumption patterns (SDG12) and the overall impact of the agriculture system on the environment (also given the role of animal products). Work on diets in relation to sustainable development (e.g., EAT-Lancet Commission) and as well as health impacts (non-communicable diseases) is evolving,[89] but setting target values and related thresholds still poses a challenge as it is closely connected with lifestyle. SDG2 also covers agriculture and food production. We considered an indicator focusing on sustainable agriculture, but it should also be noted that it also links to the nutrient, energy, water, and climate indicators proposed under the environmental and resource SDGs (6, 7, 13, 14, and 15). For that reason, no additional indicator was added here.

SDG6 covers water demand by human beings and the environment. The first indicators look at access to clean water. We use a threshold of sufficient access of 50L/per/capita/day recommended as a basic water requirement.[90] This is proposed as a universal threshold focusing on meeting basic needs, including water for drinking, basic sanitation, plus some water for cooking and bathing. The second indicator is access to sanitation services. Finally, for water scarcity, we use the proportion of an area or region under water stress. Here, water stress is defined as the ratio between total water use and availability. A value above 40% is defined as areas suffering from severe water stress.

SDG7 calls for both access to energy for all and the sustainable use of energy. We propose to focus on energy service levels (final energy demand), including heating/cooling and mobility service per household per day that allow a decent life (see Grubler et al.[91]), going beyond mere access. What is deemed decent is subject to national circumstances (e.g., also related to climate zone). Because of advances in technology and living standards, energy requirements in 2050 are subject to change.

For SDG12, a range of indicators can be considered. Our selected indicators—food loss and waste and municipal material recovery—only cover a subset of the relevant resources involved in society's processes of production and consumption, and target values will have to be even more ambitious in the long run. However, they can be regarded as illustrative of the capabilities of society to manage and recycle resource flows. These indicators are also well established—at least in industrialized countries—in statistical reporting and can be captured in a modeling framework in a stylized way (technologies, economic incentives). Suitable alternatives could be more comprehensive indicators and indices such as the human appropriation of natural primary productivity (HANNP),[27] the ecological footprint, the material footprint, the global food loss index, or recycling rates, but these indicators are hardly covered by models yet. Further development could also focus more on circular economy indicators and overall efficiency.

Peace, institutions, and implementation (SDGs 16 and 17)

Peaceful, just, and inclusive societies and global partnership are not only desired outcomes of the 2030 Agenda but also serve as essential enablers to achieve all other SDGs.[92–94] Indicators to measure peace and political institutions have been used to project the future.[33,95] We use the number of battle-related deaths[64] to gauge progress toward more peaceful societies. We apply the equality before the law and individual liberty index[65] and the equal access index[65] to measure the development of robust and inclusive political institutions (see also Note S4). For SDG17, the inclusiveness of the international civil society (data provided by the Yearbook of International Organizations[96]) can be used to assess viable societal partnerships. As the availability of an adequate set of financial means will also be crucial,[97] we propose to measure the role of governments with the indicator of total revenue as a percentage of GDP,[27,67] excluding revenues earned from natural resources. This last aspect is key to avoiding goal conflict and trade-offs with other SDGs. Finally, we propose the source data dimension of the Statistical Capacity Indicator[98] to capture the availability of crucial data for designing, implementing, and evaluating policies toward the achievement of the SDG.

EXAMPLE APPLICATION BASED ON CURRENT SCENARIOS

In order to show the relevance of the targets, we use the target space to evaluate the projected trends in the so-called SSP2 scenario, the middle-of-the-road pathway from the set of SSPs mentioned before, which describe different trajectories for socio-economic development and consequences for the Earth system.[34] SSP2 represents a scenario describing median trends for population and economic growth, technology, lifestyle, and other variables within the set. Here, we use the SSP2 scenario to illustrate how the target space can be used within the broader range of values across other SSPs (see Note S3 for a brief description of the information used). The SSP2 scenario has been elaborated in multiple studies by different models but using the same storyline and key assumptions. The SSP values are illustrative as they are not based on a single model but have been derived from several publications elaborating on these scenarios.

The results (Table 3 and Figure 3) highlight that the SSP2 scenario depicts some improvements over time for most targets. However, these improvements are insufficient to meet all targets that were set for 2030 or 2050. For many environmental targets, developments continue to go in the wrong direction (i.e., away from the target) even in the scenario among the SSPs that moves most in the direction of sustainable development (SSP1). We conclude that the implementation of sustainability policies needs to be enhanced significantly across the socio-economic and environmental domains to reach the SDGs. The quantitative scenarios literature does not really include Sustainable Development Pathways that manage to meet all SDGs. Hence, the SSPs serve as a useful starting point that can be extended by additional elements to cover the full target space and thus enable a comprehensive assessment of SDG interactions and long-term sustainability.[99] Such scenarios can show the implications of

Table 3. Example of use of the target space using data published for the SSP scenarios in various studies

				2030		2050		
		Target 2050	2015	SSP2	SSP range	SSP2	SSP range	References
SDG1: # people in absolute poverty	millions	0	886	441$^{(0)}$	286–655	119$^{(0)}$	22–563	Rao et al.[100]
SDG2: # people suffering from hunger	millions	0	837	295$^{(0)}$	188–560	92$^{(0)}$	13–585	Hasegawa et al.[101]
SDG3: <5 mortality	per 1,000	12	43	45$^{(0)}$	31–71	32$^{(0)}$	15–70	Lucas et al.[102]
SDG4: # people w/o secondary education	millions	0	1,687	2,396$^{(-)}$	1,839–3,826	2,108$^{(-)}$	1,607–4,875	Kc and Lutz[103]
SDG5: schooling gender gap	years	0	1	0.5$^{(0)}$	0.5–0.7	0.3$^{(0)}$	0.2—0.6	Kc and Lutz[103]
SDG6: water stress	% area	0	7	7.0$^{(-)}$	7–7.1	8.3$^{(-)}$	7–8	Byers et al.[104]
SDG6: # people w/o sanitation/ clean water	millions	0	4,127	3,636$^{(0)}$	79–4,251	2,199$^{(0)}$	84–3,979	Parkinson et al.[105]
SDG7: # people w/o access to clean cooking	millions	0	2,590	3,240$^{(+)}$	1,232–3,742	2,323$^{(0)}$	574–3,904	Van Vuuren et al.[106]
SDG7: # people w/o access to electricity	millions	0	1,810	845$^{(0)}$	144–1,080	471$^{(0)}$	89–1,015	Van Vuuren et al.[106]
SDG10: # people in relative poverty	millions	0	2,232	2,621$^{(-)}$	2,326–2,909	2,816$^{(-)}$	2,055–3,621	Rao et al.[100]
SDG11: # people with poor air quality	millions	0	4,684	4,825$^{(-)}$	4,683–5,184	4,966$^{(-)}$	4,683–5,685	Rao et al.[107]
SDG13: CO_2 emissions	$GtCO_2$/y	18	42	47$^{(-)}$	42–55	57$^{(-)}$	42–64	Riahi et al.[34]
SDG15: loss of forest cover	Mkm^2	1,500	2,206	2,232$^{(-)}$	2,211–2,332	2,253$^{(-)}$	2,122–2,429	Popp et al.[108]

The symbols show the evaluation of the scenario against the target values: $^{(-)}$, situation becomes worse compared to 2015; $^{(0)}$, situation improves but the target is not met; $^{(+)}$, target is met). The SSP2 scenario currently only provides information for a subset of the indicators of the target space.

achieving all (or a comprehensive set of) SDGs and highlight the synergies and trade-offs associated with specific response strategies, the critical choices, and the (im)possibilities of meeting the SDG goals in 2030 under different assumptions. A first example is provided by Soergel et al.[19]

THE WAY FORWARD

The target space formulation presented above is critically important to provide a consistent analytical framing for quantitative analysis of the required transitions toward sustainable development. It provides an initial framework to guide the analyses of how to achieve the SDGs simultaneously. Using a common, transparent, and science-based definition of the targets permits the scientific community to work together on this endeavor and to start from a set of comparable and internally consistent assumptions. In many ways, the proposed approach for the SDGs is similar to how the climate research community has formulated pathways for meeting the goals of the Paris Agreement, which were subsequently used in the scientific assessments of the IPCC to formulate consistent messages for policymakers. Developing a set of Sustainable Development Pathways requires organizing a comprehensive program for model-based scenario analysis focusing on systems transformations toward the quantitative goals of the target space. This, in turn, requires the pursuit of model improvements to deal better with sustainable development needs.[109] The current formulation of the target space should be understood as the first step of an iterative process among the worldwide scientific community and the policymakers and other stakeholders with interests in these pathways.

One challenge in application represents scale. In principle, the targets selected here should also be applicable at the regional or national scale (instead of the global scale). However, this will sometimes involve specific choices. This is even stronger moving to the subnational scale. Such choices might be related to distributional questions, to the local context (including even the understanding of sustainable development issues) and local capacity and data availability. This becomes even stronger for local communities and small businesses. Moallemi et al.[110] discuss some of these issues in more detail. By itself, scalability is a highly desirable characteristic as it can relate global-scale concerns to action at the national or local scale. To illustrate some of the issues, looking at climate change at the national scale does require allocating the emission budget at the global scale to the national level, related to fairness issues. Similar issues relate to the total phosphorous flow into the ocean. Political discussions on how much an individual country can and will achieve and the question of compensation payments are relevant, as we already see in the climate debate. Another example involves targets like no extreme poverty or hunger, which strongly depend on local contexts. All in all, this means that further attention to the applicability of the target space at local levels and the methods involved is needed.

Other critical issues for further refinement are related to evaluating the indicators and target values, the treatment of non-linearities and interdependences within the target space as it evolves to 2050 and beyond, and the coherent use of indicators at different geographical scales.[40] In several cases, we have not yet formulated concrete targets. In other cases, we indicated that our current initial proposals could be improved, for example, due to limitations of data and modeling capacity. All these improvements will require more interdisciplinary engagement across sustainability science communities. Especially social science communities interested in modeling need to be

CellPress
OPEN ACCESS

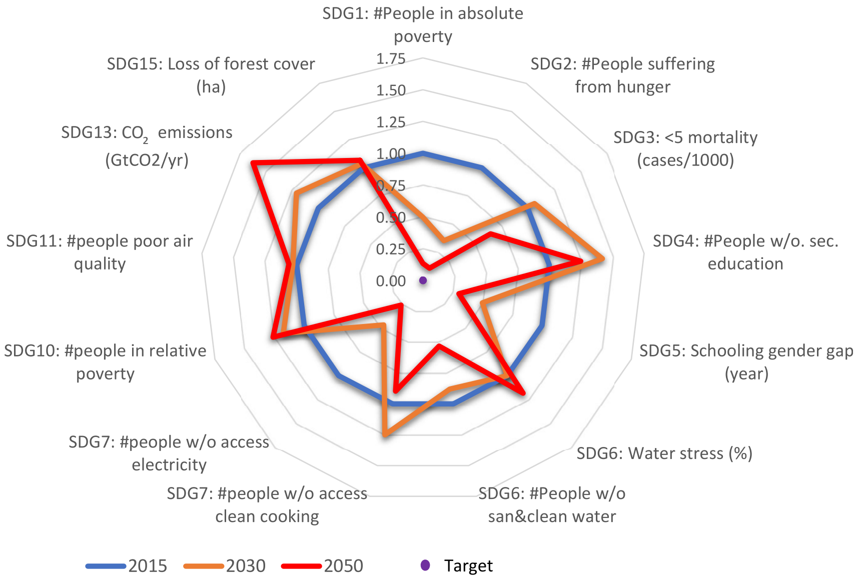

Figure 3. Example of use of the target space, using data published for the SSP2 scenario in various studies

1 = 2015, 0 = target value (values larger than 1 indicate a worsening compared to 2015; in between 0 and 1 indicates an improvement but target is not met).

engaged to advance the target space further. We see the need for an SDG-focused science-policy network, facilitating regular meetings to compare results and exchange experiences with the target space framework. Ultimately, it will thus be up to societal actors, policymakers, and scientists to refine this target space by developing a tractable set of indicators and targets that can be used realistically in integrated policy and impact assessments consistent with the spirit and goals of the original 2030 Agenda.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.oneear.2022.01.003.

ACKNOWLEDGMENTS

The target space development benefitted from consultations during the TWI2050 annual meetings and follow-up consultations. The authors would like to thank in particular the following experts for their suggestions and feedback during this process: Karl-Heinz Erb, Nicklas Forsell, Petr Havlik, Francesco Burchi, David Hole, Wolfgang Lutz, Samir KC, Simon Langan, Reinhard Mechler, Frank Neher, Michael Obersteiner, Narasimha Rao, Ayyoob Sharifi, Tomoko Hasegawa, Hugo Valin, Will Steffen, Anne Goujon, Bilal Barakat, Simon Parkinson, Ed Byers, and Anteneh Dagnachew. The scientific community is invited to engage with the authors and the TWI2050 initiatives and share relevant conceptual and analytical papers that could contribute to developing the knowledge base and using the target spaces proposed here. The paper also benefitted from funding from the European Research Council under grant no. ERC-2016-ADG 743080 (J.R. and S.E.C.) and ERC-CG 819566 (D.v.V.) and support from the SHAPE project (SHAPE is part of AXIS, an ERA-NET initiated by JPI Climate and funded by FORMAS (SE), FFG/BMWFW (AT), DLR/BMBF (DE, grant no. 01LS1907A), NWO (NL) and RCN (NO) with cofunding by the European Union (grant no. 776608)).

AUTHOR CONTRIBUTIONS

D.v.V. coordinated the writing of the paper. C.Z. coordinated the data collection for the sample application. All authors contributed to the analysis and the writing of the paper.

REFERENCES

1. UN (2015). Transforming Our World: the 2030 Agenda for Sustainable Development. In UN (United Nations General Assembly), A/RES/70/1.
2. UNFCCC (2015). Report of the Conference of the Parties on its Twenty-First Session, Held in Paris from 30 November to 13 December 2015. Decision 1/CP.21 (United Nations Framework Convention on Climate Change).
3. CBD (2010). The Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets (Convention on Biodiversity), UNEP/CBD/COP/DEC/X/2.
4. Stafford-Smith, M., Griggs, D., Gaffney, O., Ullah, F., Reyers, B., Kanie, N., Stigson, B., Shrivastava, P., Leach, M., and O'Connell, D. (2017). Integration: the key to implementing the Sustainable Development Goals. Sustain. Sci. *12*, 911–919. https://doi.org/10.1007/s11625-016-0383-3.
5. TWI2050 (2018). The World in 2050. Transformations to Achieve the Sustainable Development Goals. Report Prepared by the World in 2050 Initiative (International Institute for Applied Systems Analysis (IIASA)).
6. van Vuuren, D.P., Kok, M., Lucas, P.L., Prins, A.G., Alkemade, R., van den Berg, M., Bouwman, L., van der Esch, S., Jeuken, M., Kram, T., and Stehfest, E. (2015). Pathways to achieve a set of ambitious global sustainability objectives by 2050: explorations using the IMAGE integrated assessment model. Technol. Forecast. Soc. Change *98*, 303–323. https://doi.org/10.1016/j.techfore.2015.03.005.
7. Sachs, J.D., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., and Rockström, J. (2019). Six transformations to achieve the Sustainable Development Goals. Nat. Sustain. *2*, 805–814. https://doi.org/10.1038/s41893-019-0352-9.
8. Liu, J., Mooney, H., Hull, V., Davis, S.J., Gaskell, J., Hertel, T., Lubchenco, J., Seto, K.C., Gleick, P., Kremen, C., and Li, S. (2015). Systems integration for global sustainability. Science *347*, 1258832. https://doi.org/10.1126/science.1258832.
9. Elder, M., Bengtsson, M., and Akenji, L. (2016). An optimistic analysis of the means of implementation for Sustainable Development Goals: thinking about goals as means. Sustainability *8*, 962. https://doi.org/10.3390/su8090962.
10. Nilsson, M., Griggs, D., and Visbeck, M. (2016). Policy: map the interactions between Sustainable Development Goals. Nature *534*, 320–322. https://doi.org/10.1038/534320a.
11. Breuer, A., Janetschek, H., and Malerba, D. (2019). Translating SDG interdependencies into policy advice. Sustainability *11*, 1–20.
12. Pradhan, P., Costa, L., Rybski, D., Lucht, W., and Kropp, J.P. (2017). A systematic study of Sustainable Development Goal (SDG) interactions. Earth's Future. https://doi.org/10.1002/2017EF000632.
13. Allen, C., Metternicht, G., Wiedmann, T., and Pedercini, M. (2019). Greater gains for Australia by tackling all SDGs but the last steps will

be the most challenging. Nat. Sustain. *2*, 1041–1050. https://doi.org/10.1038/s41893-019-0409-9.

14. Gao, L., and Bryan, B.A. (2017). Finding pathways to national-scale land-sector sustainability. Nature *544*, 217–222. https://doi.org/10.1038/nature21694.
15. Obersteiner, M., Walsh, B., Frank, S., Havlík, P., Cantele, M., Liu, J., Palazzo, A., Herrero, M., Lu, Y., Mosnier, A., et al. (2016). Assessing the land resource–food price nexus of the Sustainable Development Goals. Sci. Adv. *2*. https://doi.org/10.1126/sciadv.1501499.
16. Humpenöder, F., Popp, A., Bodirsky, B., Weindl, I., Biewald, A., Lotze-Campen, H., Dietrich, J., Klein, D., Kreidenweis, U., Müller, C., et al. (2018). Large-scale bioenergy production: how to resolve sustainability trade-offs? Environ. Res. Lett. *13*, 024011.
17. Ringler, C., Bhaduri, A., and Lawford, R. (2013). The nexus across water, energy, land and food (WELF): potential for improved resource use efficiency? Curr. Opin. Environ. Sustain. *5*, 617–624. https://doi.org/10.1016/j.cosust.2013.11.002.
18. 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. Glob. Sustain. *2*, e24. https://doi.org/10.1017/sus.2019.22.
19. Soergel, B., Kriegler, E., Weindl, I., Rauner, S., Dirnaichner, A., Ruhe, C., Hofmann, M., Bauer, N., Bertram, C., Bodirsky, B.L., et al. (2021). A sustainable development pathway for climate action within the UN 2030 Agenda. Nat. Clim. Change *11*, 656–664. https://doi.org/10.1038/s41558-021-01098-3.
20. Science Based Targets Initiative. https://sciencebasedtargets.org/about-the-science-based-targets-initiative/.
21. Independent Group of Scientists Appointed by the Secretary-General (2019). Global Sustainable Development Report 2019: The Future is Now – Science for Achieving Sustainable Development (United Nations).
22. Naidoo, R., and Fisher, B. (2020). Reset Sustainable Development Goals for a pandemic world. Nature *583*, 198–201.
23. Andrijevic, M., Crespo Cuaresma, J., Muttarak, R., and Schleussner, C.-F. (2020). Governance in socioeconomic pathways and its role for future adaptive capacity. Nat. Sustain. *3*, 35–41.
24. Hák, T., Janoušková, S., and Moldan, B. (2016). Sustainable development goals: a need for relevant indicators. Ecol. Indic. *60*, 565–573. https://doi.org/10.1016/j.ecolind.2015.08.003.
25. Allen, C., Nejdawi, R., El-Baba, J., Hamati, K., Metternicht, G., and Wiedmann, T. (2017). Indicator-based assessments of progress towards the Sustainable Development Goals (SDGs): a case study from the Arab region. Sustain. Sci. *12*, 975–989. https://doi.org/10.1007/s11625-017-0437-1.
26. Schmidt-Traub, G., Kroll, C., Teksoz, K., Durand-Delacre, D., and Sachs, J.D. (2017). National baselines for the Sustainable Development Goals assessed in the SDG index and dashboards. Nat. Geosci. *10*, 547–555. https://doi.org/10.1038/NGEO2985.
27. O'Neill, D.W., Fanning, A.L., Lamb, W.F., and Steinberger, J.K. (2018). A good life for all within planetary boundaries. Nat. Sustain. *1*, 88–95. https://doi.org/10.1038/s41893-018-0021-4.
28. Xu, Z., Chau, S.N., Chen, X., Zhang, J., Li, Y., Dietz, T., Wang, J., Winkler, J.A., Fan, F., Huang, B., et al. (2020). Assessing progress towards sustainable development over space and time. Nature *577*, 74–78. https://doi.org/10.1038/s41586-019-1846-3.
29. Hegre, H., Allansson, M., Basedau, M., Colaresi, M., Croicu, M., Fjelde, H., Hoyles, F., Hultman, L., Högbladh, S., Jansen, R., et al. (2019). ViEWS: a political violence early-warning system. J. Peace Res. https://doi.org/10.1177/0022343319823860.
30. Joshi, D.K., Hughes, B.B., and Sisk, T.D. (2015). Improving governance for the post-2015 Sustainable Development Goals: scenario forecasting the next 50 years. World Dev. *70*, 286–302. https://doi.org/10.1016/j.worlddev.2015.01.013.
31. Allen, C., Metternicht, G., and Wiedmann, T. (2016). National pathways to the Sustainable Development Goals (SDGs): a comparative review of scenario modelling tools. Environ. Sci. Policy *66*, 199–207. https://doi.org/10.1016/j.envsci.2016.09.008.
32. Guivarch, C., Rozenberg, J., and Schweizer, V. (2016). The diversity of socio-economic pathways and CO_2 emissions scenarios: insights from the investigation of a scenarios database. Environ. Model. Softw. *80*, 336–353. https://doi.org/10.1016/j.envsoft.2016.03.006.
33. Soergel, B., Kriegler, E., Bodirsky, B.L., Bauer, N., Leimbach, M., and Popp, A. (2021). Combining ambitious climate policies with efforts to eradicate poverty. Nat. Commun. *12*, 2342. https://doi.org/10.1038/s41467-021-22315-9.
34. Riahi, K., van Vuuren, D.P., Kriegler, E., Edmonds, J., O'Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., et al. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: an overview. Glob. Environ. Change *42*, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009.
35. Moallemi, E.A., Eker, S., Gao, L., Hadjikakou, M., Kwakkel, J., Reed, P.M., Obersteiner, M., and Bryan, B.A. (2020). Global pathways to sustainable development to 2030 and beyond. https://arxiv.org/abs/2012.04333.
36. 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., et al. (2015). Planetary boundaries: guiding human development on a changing planet. Science *347*, 1259855. https://doi.org/10.1126/science.1259855.
37. IIASA (2017). The World in 2050 project. (IIASA) http://www.iiasa.ac.at/web/home/research/researchPrograms/TransitionstoNewTechnologies/170403-TWI2050.html.
38. Sachs, J., Schmidt-Traub, G., Kroll, C., Durand-Delacre, D., and Teksoz, K. (2017). SDG Index and Dashboards Report 2017 (Bertelsmann Stiftung and Sustainable Development Solutions Network (SDSN)).
39. Lafortune, G., Fuller, G., Moreno, J., Schmidt-Traub, G., and Kroll, C. (2018). SDG index and dashboards: detailed methodological paper. The Sustainable Development Solutions Network (SDSN). https://github.com/sdsna/2018GlobalIndex/raw/master/2018GlobalIndexMethodology.pdf.
40. 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? Glob. Environ. Change *40*, 60–72. https://doi.org/10.1016/j.gloenvcha.2016.06.008.
41. World Bank (2019). World Development Indicators (World Bank).
42. UN (2016). The Sustainable Development Goals Report 2016 (United Nations, Department of Economic and Social Affairs (DESA)).
43. Bodirsky, B., Dietrich, J., Martinelli, E., Gabrysch, S., Mishra, A., Weindl, I., et al. (2020). The ongoing nutrition transition thwarts long-term targets for food security, public health and environmental protection. Sci. Rep. *10* (19778). https://doi.org/10.1038/s41598-020-75213-3.
44. NCD-RisC (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. Lancet *390*, 2627–2642.
45. GBD (2017). Global burden of disease - 2017. http://www.healthdata.org/node/835.
46. WHO (2019). Global Strategy for Women's, Children's and Adolescents' Health (2016-2030) (World Health Organization), Under-5 mortality rate [SDG 3.2.1].
47. Lutz, W., Muttarak, R., and Striessnig, E. (2014). Universal education is key to enhanced climate adaptation. Science *346*, 1061–1062. https://doi.org/10.1126/science.1257975.
48. WEF (2016). Global Gender Gap Report 2016 (World Economic Forum).
49. Burek, P., Satoh, Y., Fischer, G., Kahil, M.T., Scherzer, A., Tramberend, S., Nava, L.F., Wada, Y., Eisner, S., Flörke, M., et al. (2016). Water Futures and Solution (International Institute for Applied Systems Analysis).
50. IEA (2017). World Energy Outlook 2017 (IEA). https://www.iea.org/reports/world-energy-outlook-2017.
51. UNESCO Institute for Statistics (2019). Global Investments in R&D (UNESCO Institute for Statistics).
52. European Commission (2010). Europe 2020: A Strategy for Smart, Sustainable and Inclusive Growth, COM(2010) 2020 Final (Publications Office of the European Union).
53. ITU (2019). Statistics. Time Series of ICT Data (International Telecommunication Union (ITU)).
54. Demirgüç-Kunt, A., Klapper, L., Singer, D., Ansar, S., and Hess, J. (2018). The Global Findex Database 2017: Measuring Financial Inclusion and the Fintech Revolution (World Bank).
55. Weiss, D.J., Nelson, A., Gibson, H.S., Temperley, W., Peedell, S., Lieber, A., Hancher, M., Poyart, E., Belchior, S., Fullman, N., et al. (2018). A global map of travel time to cities to assess inequalities in accessibility in 2015. Nature *553*, 333–336.
56. OECD (2018). Poverty Rate (Indicator) (OECD). https://doi.org/10.1787/0fe1315d-en.
57. World Health Organization (2018). Air pollution fact sheet. https://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health.

58. Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., and Meybeck, A. (2011). Global Food Losses and Food Waste. Extent, Causes and Prevention (FAO). http://www.fao.org/3/a-i2697e.pdf.
59. OECD (2017). Green Growth Indicators 2017 (OECD). https://doi.org/10.1787/9789264268586-en.
60. IPCC (2018). Global Warming of 1.5°C (Intergovernmental Panel on Climate Change).
61. FAO (2020). Indicator Proportion of fish stocks within biologically sustainable levels. (Food and Agriculture Organization of the United Nations). http://www.fao.org/sustainable-development-goals/indicators/1441/en/.
62. OHI (2019). Goal: biodiversity. Supporting healthy marine ecosystems (Ocean Health Index). http://www.oceanhealthindex.org/methodology/goals/biodiversity.
63. Keenan, R.J., Reams, G.A., Achard, F., de Freitas, J.V., Grainger, A., and Lindquist, E. (2015). Dynamics of global forest area: results from the FAO global forest resources assessment 2015. For. Ecol. Manag. *352*, 9–20. https://doi.org/10.1016/j.foreco.2015.06.014.
64. Allansson, M., Melander, E., and Themnér, L. (2017). Organized violence, 1989-2016. UCDP battle-related deaths dataset, version number: 17.1. J. Peace Res. *54*, 574–587. https://doi.org/10.1177/0022343317718773.
65. Coppedge, M., Gerring, J., Lindberg, S.I., Skaaning, S.-E., Teorell, J., Altman, D., Andersson, F., Bernhard, M., Fish, M., Glynn, A., et al. (2017). V-dem codebook v7.1. SSRN Electron. J. Varieties of democracy (V-dem) project. https://doi.org/10.2139/ssrn.2968274.
66. World Bank (2018). Statistical capacity score. Source data (second dimension of the statistical capacity indicator). http://datatopics.worldbank.org/statisticalcapacity/.
67. ICTD/UNU-WIDER (2018). Government revenue dataset. https://www.wider.unu.edu/project/government-revenue-dataset.
68. UIA (2018). Yearbook of International Organizations 2018/2019 (Union of International Associations). https://uia.org/yearbook.
69. UNDP (2018). Human Development Report - 2018 Statistical Update (United Nations Development Programme).
70. World Bank (2015). Policy Research Note No. 3: Ending Extreme Poverty and Sharing Prosperity: Progress and Policies (The World Bank).
71. Brende, B., and Høie, B. (2015). Towards evidence-based, quantitative Sustainable Development Goals for 2030. Lancet *385*, 206–208. https://doi.org/10.1016/S0140-6736(14)61654-8.
72. Lutz, W., Cuaresma, J.C., and Sanderson, W. (2008). Economics: the demography of educational attainment and economic growth. Science *319*, 1047–1048. https://doi.org/10.1126/science.1151753.
73. Jones, C.I., and Klenow, P.J. (2016). Beyond GDP? Welfare across countries and time. Am. Econ. Rev. *106*, 2426–2457.
74. Feenstra, R.C., Inklaar, R., and Timmer, M.P. (2015). The next generation of the Penn World Table. Am. Econ. Rev. *105*, 3150–3182.
75. Dellink, R., Chateau, J., Lanzi, E., and Magné, B. (2017). Long-term economic growth projections in the Shared Socioeconomic Pathways. Glob. Environ. Change *42*, 200–214. https://doi.org/10.1016/j.gloenvcha.2015.06.004.
76. Hsieh, C.-T., Hurst, E., Jones, C.I., and Klenow, P.J. (2019). The allocation of talent and U.S. Economic growth. Econometrica *87*, 1439–1474.
77. Frey, C.B., and Osborne, M. (2013). The Future of Employment: How Susceptible Are Jobs to Computerisation? Working Paper (Oxford Martin School, University of Oxford).
78. EEA (2019). Exceedance of air quality standards in urban areas (European Environment Agency). https://www.eea.europa.eu/data-and-maps/indicators/exceedance-of-air-quality-limit-3/assessment-5.
79. Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S., III, Lambin, E., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., et al. (2009). Planetary boundaries: exploring the safe operating space for humanity. Ecol. Soc. *14*, 32.
80. UNEP (2020). Index of coastal eutrophication; and (b) plastic debris density (United Nations Environment Programme). https://environmentlive.unep.org/indicator/index/14_1_1.
81. Pereira, H.M., Ferrier, S., Walters, M., Geller, G.N., Jongman, R.H.G., Scholes, R.J., Bruford, M.W., Brummitt, N., Butchart, S.H.M., Cardoso, A.C., et al. (2013). Essential biodiversity variables. Science *339*, 277–278. https://doi.org/10.1126/science.1229931.
82. Scholes, R.J., and Biggs, R. (2005). A biodiversity intactness index. Nature *434*, 45–49. https://doi.org/10.1038/nature03289.
83. Conijn, J.G., Bindraban, P.S., Schröder, J.J., and Jongschaap, R.E.E. (2018). Can our global food system meet food demand within planetary boundaries? Agric. Ecosyst. Environ. *251*, 244–256. https://doi.org/10.1016/j.agee.2017.06.001.
84. Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B.L., Lassaletta, L., de Vries, W., Vermeulen, S.J., Herrero, M., Carlson, K.M., et al. (2018). Options for keeping the food system within environmental limits. Nature *562*, 519–525. https://doi.org/10.1038/s41586-018-0594-0.
85. Bijl, D.L., Bogaart, P.W., Dekker, S.C., and van Vuuren, D.P. (2018). Unpacking the nexus: different spatial scales for water, food and energy. Glob. Environ. Change *48*, 22–31. https://doi.org/10.1016/j.gloenvcha.2017.11.005.
86. Hasegawa, T., Fujimori, S., Havlík, P., Valin, H., Bodirsky, B.L., Doelman, J.C., Fellmann, T., Kyle, P., Koopman, J.F.L., Lotze-Campen, H., et al. (2018). Risk of increased food insecurity under stringent global climate change mitigation policy. Nat. Clim. Change *8*, 699–703. https://doi.org/10.1038/s41558-018-0230-x.
87. Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., et al. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. Lancet *393*, 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4.
88. Lloyd, S.J., Bangalore, M., Chalabi, Z., Kovats, R.S., Hallegatte, S., Rozenberg, J., Valin, H., and Havlík, P. (2018). A global-level model of the potential impacts of climate change on child stunting via income and food price in 2030. Environ. Health Perspect. *126*. https://doi.org/10.1289/EHP2916.
89. Springmann, M., Wiebe, K., Mason-D'Croz, D., B Sulser, T., Rayner, M., and Scarborough, P. (2018). Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. Lancet Planet. Health *2*, 451–461.
90. Gleick, P.H. (1996). Basic water requirements for human activities: meeting basic needs. Water Int. *21*, 83–92. https://doi.org/10.1080/02508069608686494.
91. Grubler, A., Wilson, C., Bento, N., Boza-Kiss, B., Krey, V., McCollum, D.L., Rao, N.D., Riahi, K., Rogelj, J., De Stercke, S., et al. (2018). A low energy demand scenario for meeting the 1.5°C target and Sustainable Development Goals without negative emission technologies. Nat. Energy *3*, 515–527. https://doi.org/10.1038/s41560-018-0172-6.
92. Biermann, F., Kanie, N., and Kim, R.E. (2017). Global governance by goal-setting: the novel approach of the UN Sustainable Development Goals. Curr. Opin. Environ. Sustain. *26-27*, 26–31. https://doi.org/10.1016/j.cosust.2017.01.010.
93. Tosun, J., and Leininger, J. (2018). Governing the interlinkages between the Sustainable Development Goals: approaches to attain policy integration. Glob. Challenges *13*. https://doi.org/10.1002/gch1002.201700036.
94. Gates, S., Hegre, H., Nygård, H.M., and Strand, H. (2012). Development consequences of armed conflict. World Dev. *40*, 1713–1722. https://doi.org/10.1016/j.worlddev.2012.04.031.
95. Hegre, H., Buhaug, H., Calvin, K.V., Nordkvelle, J., Waldhoff, S.T., and Gilmore, E. (2016). Forecasting civil conflict along the Shared Socioeconomic Pathways. Environ. Res. Lett. *11*, 054002. https://doi.org/10.1088/1748-9326/11/5/054002.
96. Union of International Associations (2019). Yearbook of International Organizations: Guide to Global Civil Society Network (Brill/Martinus Nijhoff Publishers).
97. Schmidt-Traub, G., and Sachs, J. (2015). Financing Sustainable Development: Implementing the SDGs through Effective Investment Strategies and Partnerships (United Nations Sustainable Development Solutions Network).
98. World Bank (2018). World Development Indicators. https://datacatalog.worldbank.org/dataset/world-development-indicators.
99. van Soest, H.L., van Vuuren, D.P., Hilaire, J., Minx, J.C., Harmsen, M.J.H.M., Krey, V., Popp, A., Riahi, K., and Luderer, G. (2019). Analysing interactions among Sustainable Development Goals with integrated assessment models. Glob. Transit. *1*, 210–225. https://doi.org/10.1016/j.glt.2019.10.004.
100. Rao, N., Sauer, P., Gidden, M., and Riahi, K. (2018). Income inequality projections for the Shared Socioeconomic Pathways (SSPs). Futures. https://doi.org/10.1016/j.futures.2018.07.001.
101. Hasegawa, T., Fujimori, S., Takahashi, K., and Masui, T. (2015). Scenarios for the risk of hunger in the twenty-first century using Shared Socioeconomic Pathways. Environ. Res. Lett. *10*, 014010. https://doi.org/10.1088/1748-9326/10/1/014010.
102. Lucas, P.L., Hilderink, H.B.M., Janssen, P.H.M., Kc, S., van Vuuren, D.P., and Niessen, L. (2019). Future impacts of environmental factors on

achieving the SDG target on child mortality—a synergistic assessment. Glob. Environ. Change *57*, 101925. https://doi.org/10.1016/j.gloenvcha.2019.05.009.

103. Kc, S., and Lutz, W. (2017). The human core of the Shared Socioeconomic Pathways: population scenarios by age, sex and level of education for all countries to 2100. Glob. Environ. Change *42*, 181–192. https://doi.org/10.1016/j.gloenvcha.2014.06.004.

104. Byers, E., Gidden, M., Leclere, D., Balkovic, J., Burek, P., Ebi, K., Greve, P., Grey, D., Havlik, P., Hillers, A., et al. (2018). Global exposure and vulnerability to multi-sector development and climate change hotspots. Environ. Res. Lett. *13*, 055012. https://doi.org/10.1088/1748-9326/aabf45.

105. Parkinson, S., Krey, V., Huppmann, D., Kahil, T., McCollum, D., Fricko, O., Byers, E., Gidden, M.J., Mayor, B., Khan, Z., et al. (2019). Balancing clean water-climate change mitigation trade-offs. Environ. Res. Lett. *14*, 014009. https://doi.org/10.1088/1748-9326/aaf2a3.

106. Van Vuuren, D.P., Stehfest, E., Gernaat, D.E.H.J., Doelman, J.C., van den Berg, M., Harmsen, M., de Boer, H.S., Bouwman, L.F., Daioglou, V., Edelenbosch, O.Y., et al. (2017). Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm. Glob. Environ. Change *42*, 237–250. https://doi.org/10.1016/j.gloenvcha.2016.05.008.

107. Rao, S., Klimont, Z., Riahi, K., Amann, M., Fricko, O., Havlik, P., and Heyes, C. (2017). Future air pollution in the shared socio-economic pathways. Glob. Environ. Change *42*, 346–358. https://doi.org/10.1016/j.gloenvcha.2016.05.012.

108. Popp, A., Calvin, K., Fujimori, S., Havlik, P., Humpenöder, F., Stehfest, E., Bodirsky, B.L., Dietrich, J.P., Doelmann, J.C., Gusti, M., et al. (2017). Land-use futures in the shared socio-economic pathways. Glob. Environ. Change *42*, 331–345. https://doi.org/10.1016/j.gloenvcha.2016.10.002.

109. Zimm, C., Sperling, F., and Busch, S. (2018). Identifying sustainability and knowledge gaps in socio-economic pathways vis-à-vis the Sustainable Development Goals. Economies *6*, 6. https://doi.org/10.3390/economies6020020.

110. Moallemi, E.A., Malekpour, S., Hadjikakou, M., Raven, R., Szetey, K., Ningrum, D., Dhiaulhaq, A., and Bryan, B.A. (2020). Achieving the Sustainable Development Goals requires transdisciplinary innovation at the local scale. One Earth *3*, 300–313. https://doi.org/10.1016/j.oneear.2020.08.006.