



# Six Transformations to Achieve the Sustainable Development Goals (SDGs)

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**Working Paper**

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### About the SDSN

The UN Sustainable Development Solutions Network (SDSN) mobilizes scientific and technical expertise from academia, civil society, and the private sector to support practical problem solving for sustainable development at local, national, and global scales. The SDSN has been operating since 2012 under the auspices of the UN Secretary-General. The SDSN is building national and regional networks of knowledge institutions, solution-focused thematic networks, and the SDG Academy, an online university for sustainable development.

**Abstract**

*The Sustainable Development Goals (SDGs) and the Paris Agreement on Climate Change call for deep transformations in every country that require complementary actions by governments, civil society, science, and business. Yet stakeholders lack a shared understanding of how the 17 SDGs can be operationalised. Drawing on earlier work by The World in 2050 initiative<sup>1</sup>, we introduce six SDG Transformations as modular building-blocks of SDG achievement: 1. Education, Gender, and Inequality; 2. Health, Wellbeing, and Demography; 3. Energy Decarbonisation and Sustainable Industry; 4. Sustainable Food, Land, Water, and Oceans; 5. Sustainable Cities and Communities; and 6. Digital Revolution for Sustainable Development. Each Transformation identifies priority investments and regulatory challenges calling for actions by well-defined parts of government working with business and civil society. Transformations may therefore be operationalised within the structures of government while respecting the strong interdependencies across the 17 SDGs. The paper also outlines an action agenda for science to provide the knowledge required for designing, implementing, and monitoring the SDG Transformations.*

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By adopting the 2030 Agenda with its 17 Sustainable Development Goals (SDGs) and the Paris Climate Agreement, member states of the United Nations have created a framework for national action and global cooperation on sustainable development<sup>1</sup>. The SDGs focus on time-bound targets for Prosperity, People, Planet, Peace, and Partnership – known as the five Ps. The Paris Agreement commits countries to achieve net-zero greenhouse gas emissions by the middle of the century<sup>2</sup>. SDG 13 on climate change links to the Paris Agreement noting that the UN Framework Convention on Climate Change “is the primary international, intergovernmental forum for negotiating the global response to climate change.”

Evidence suggests that international development goals, such as those around public health, can accelerate progress towards complex development goals<sup>3</sup>, but achieving the SDGs will require deep, structural changes across all sectors in society. This raises the critical question of how strategies to achieve the 17 SDGs can be organised.

Several authors have shown that SDG outcomes, including the objectives of the Paris Agreement, are interdependent<sup>1,4,5</sup> with complex coupling between human, technical and natural systems. Yet, available studies do not emphasise how the implementation of the SDGs should be organised.

To help fill these gaps, we outline a systemic policy approach to help achieve each SDG (Annex 1). As with the much simpler Millennium Development Goals<sup>6</sup>, many policy interventions (such as public investments and regulations) are needed to achieve each SDG, and each intervention generally contributes to several goals. Governments need a strategy to design and implement key interventions. Building on *The World in 2050*<sup>1</sup> and earlier work, we propose six Transformations to organise SDG interventions through a semi-modular action agenda that can be designed by discrete, yet interacting, parts of government. Each Transformation engages a different subset of business and civil society, facilitating targeted problem-solving, clear communication, and the mobilization of stakeholders<sup>7</sup>. We outline how the Transformations can be operationalised with a focus on government action and conclude with an action agenda for science.

## I. Organising implementation of 17 SDGs

We first consider which key interventions are necessary to achieve the SDG outcomes (Table 1 and Annex 1) and how their implementation might be organised into a limited set of six Transformations. To simplify the discussion of interlinkages between interventions and SDGs, we identify intermediate outputs generated by combinations of interventions, which in turn contribute to the achievement of each SDG. Drawing on established methodologies<sup>4,5</sup>, we describe the strength of the relationship between intermediate outputs and each SDG on a 4-point scale: 3: directly targets the SDG; 2: reinforces the SDG; 1: enables the SDG; and 0: has no interaction with the SDG (Annex 1).

The table presents no negative relationships between intermediate outputs and SDG outcomes since major trade-offs, as identified in the literature<sup>4,5</sup>, are addressed in three ways: First, some trade-offs (for example, between agricultural production and biodiversity loss) are addressed through systems-based approaches that combine potentially antagonistic interventions inside a Transformation. Second, key interventions are designed to be consistent with the Leave-No-One-Behind Principle (Box 1) to ensure that investments in services, infrastructure, and technologies promote equity. Third, natural resource trade-offs are addressed through the Principle of Circularity and Decoupling within a stable Earth system (Box 2).

**Box 1: The Leave-No-One-Behind Principle**

The 2030 Agenda pledges that no one will be left behind in implementing the SDGs. This principle of equity and fairness aims to overcome inequalities and discrimination by gender, race, social status, or other qualifiers, which result from a range of factors, including power dynamics, discrimination, poor system design, and insufficient financing<sup>64,21</sup>. The SDGs may not be able to overcome all drivers of inequality, but by underpinning the design, implementation, and monitoring of all six Transformations with the Leave-No-One-Behind Principle, substantial progress could be achieved. For example, health outcomes are undermined by inequalities, so health strategies must address the needs of the most vulnerable<sup>27,28</sup>. Similar considerations apply in education<sup>17,19,20</sup>. Recent protests against the social costs of strategies to decarbonise energy systems in France, Germany, and other countries underscore that the energy Transformation can only succeed if it is underpinned by the Leave-No-One-Behind Principle. Strategies to transform cities and human communities require participatory urban planning to identify and address the needs of the poorest<sup>52</sup>. As described under Transformation 6, the digital revolution holds tremendous promise to better meet the needs of the extreme poor, but unless well managed it threatens jobs, undermines governance capabilities, and may exacerbate inequalities<sup>22,58</sup>.

**Box 2: The Principle of Circularity and Decoupling**

To achieve the SDGs countries must change patterns of consumption and production to decouple human well-being from environmental degradation, including through circularity that promotes reuse and recycling of materials<sup>81</sup>. Circularity and Decoupling without lowering human wellbeing must underlie all SDG Transformations. The most important decoupling is decarbonisation, i.e. the reduction of net greenhouse gas emissions to zero by mid-century<sup>2</sup>. Countries must also make material systems sustainable<sup>82</sup> and dissociate the net release of nitrogen, phosphorous, chemicals, plastics, particulates, and other pollutants from human wellbeing<sup>44</sup>. Similarly, the use of freshwater, land, and non-renewable resources needs to be decoupled from social and economic progress<sup>38</sup>. Life-cycle approaches to electric vehicles and other key energy technologies are critical for reducing the resource intensity of Transformation 3 to decarbonise energy and make industry sustainable<sup>11</sup>. In agriculture and food systems (Transformation 4), circularity is widely applied, particularly for livestock management<sup>83</sup> as well as food loss and waste<sup>84</sup>. Similarly, cities and urban areas (Transformation 5) need to adopt principles of circularity in design and management of resource flows<sup>52</sup>. The digital revolution (Transformation 6) is an important enabler of Circularity and Decoupling.

**Table 1 | How SDG Transformations contribute to the achievement of the SDGs.**

Each Transformation comprises key SDG interventions that together generate intermediate outputs, which serve as inputs into achieving the SDGs. Relationships with SDG outcomes are described using a four-point scale: 3: intermediate outputs target directly SDG outcomes; 2: reinforce the SDGs; 1: enable the SDGs; and 0: do not interact with the SDGs. Table also lists line ministries that would oversee the implementation of each Transformation (excluding central coordinating agencies, such as project management offices, planning, and finance). Source: ref<sup>8</sup>. See Annex 1 for more information.

SDG Transformation	Principal line ministries involved in transformation	SDG interventions	Intermediate outputs	SDG 1	SDG 2	SDG 3	SDG 4	SDG 5	SDG 6	SDG 7	SDG 8	SDG 9	SDG 10	SDG 11	SDG 12	SDG 13	SDG 14	SDG 15	SDG 16	SDG 17	
1. Education, Gender, and Inequality	Education Science and Technology Family and Social Affairs	Early childhood development	Education and human capital	2	1	2	3	3	1	1	2	2	2	1	1	1	1	1	1	1	1
		Primary & secondary education																			
		Vocational training & higher education																			
		Social protection system and labour standards	Decent work and income support to vulnerable groups	3	3	2	1	2	1	2	3	1	3	1	1	2	2	2	2	1	0
Research & development	Innovation	1	2	1	1	1	1	1	2	2	3	1	1	2	2	1	1	1	1	2	
2. Health, Wellbeing and Demography	Health	Universal health coverage	Public health services	2	3	3	2	3	0	0	2	1	2	1	1	0	0	0	0	1	0
		Healthy behaviours and social determinants of health and wellbeing																			
3. Energy Decarbonisation and Sustainable Industry	Buildings/Construction Energy Environment Transport	Access to clean energy	Energy access for all	2	1	2	2	2	1	3	2	3	2	3	2	3	1	2	1	0	
		Zero-carbon electricity generation	Energy decarbonisation	1	2	2	0	1	2	3	2	2	2	2	2	3	3	2	2	2	1
		Energy efficiency																			
		Electrification and zero-carbon fuels																			
		Curbing pollution	Clean air and water	1	1	3	1	1	3	1	2	1	1	3	3	2	3	3	1	1	
4. Sustainable Food, Land, Water, and Oceans	Agriculture Environment Fisheries and Marine Resources Forestry Health Water and Natural Resources	Efficient and resilient agricultural systems and fisheries that support healthy diets and farm livelihoods	Sustainable land-use, oceans, and food systems	2	3	3	1	2	3	1	2	1	2	2	3	3	3	3	3	1	1
		Protection of terrestrial and marine biodiversity, including forests																			
		Healthy food promotion and regulation																			
		Trade and supply chains consistent with sustainable development																			
		Integrated land-use and water management																			
5. Sustainable Cities and Communities	Transport Urban Development Water and Sanitation	Urban access to water, sanitation, and waste management	Transport, water and sanitation infrastructure services	2	2	2	2	2	3	1	2	3	2	3	3	2	2	2	0	0	
		Sustainable mobility and transport networks																			
		More compact settlements																			
		Urban adaptation and resilience	Urban resilience	1	1	1	1	1	2	1	1	2	2	3	1	3	0	0	1	0	
6. Digital Revolution for Sustainable Development	Science and Technology Telecommunications	Universal broadband and IT infrastructure	Digital technologies and infrastructure	2	2	2	2	1	1	2	2	3	2	2	2	2	1	1	1	1	2
		Digital inclusion, skills, privacy protection, and universal identity																			
		Mobilizing digital technologies to achieve all SDGs																			

Our proposal to organise SDG interventions into six discrete SDG Transformations (Figure 1) builds on The World in 2050<sup>1</sup> and is guided by five criteria:

1. **Mutually exclusive and collectively exhaustive (MECE).** Each key intervention should be assigned to a single Transformation to avoid overlaps and to ensure that the Transformations cover all key SDG interventions.
2. **Systems-based.** Each Transformation must address the most important synergies and trade-offs across key interventions. For example, Transformation 3 covers all major uses of energy to promote system-wide decarbonisation<sup>9-11</sup>. Similarly, Transformation 4 integrates across agriculture, food, and biodiversity, since the first two are major drivers of biodiversity loss<sup>12-14</sup>.
3. **Aligned with government organisation.** Achieving the SDGs depends heavily on public investments and policies<sup>15</sup>, so the Transformations must align with how governments are organised. Table 1 identifies the principal line ministries involved in designing and implementing each transformation, excluding central coordinating agencies, such as project management offices, planning, and finance.
4. **Easily communicable.** The Transformations must be easily communicable since meeting the SDGs will require widespread mobilisation of all parts of government, business, civil society, and science.
5. **Few in number.** There should be as few Transformations as necessary to cover all major SDG interventions.

At times these five principles can conflict. For example, systems-based approaches can be complex to implement. Similarly, a trade-off exists between an easily communicable Transformation and the need for technical precision and comprehensiveness. Finally, some overlap across Transformations may be unavoidable, as illustrated by transport investments that must in parts be integrated with the decarbonisation of energy systems.



Figure 1 | Six SDG Transformations.

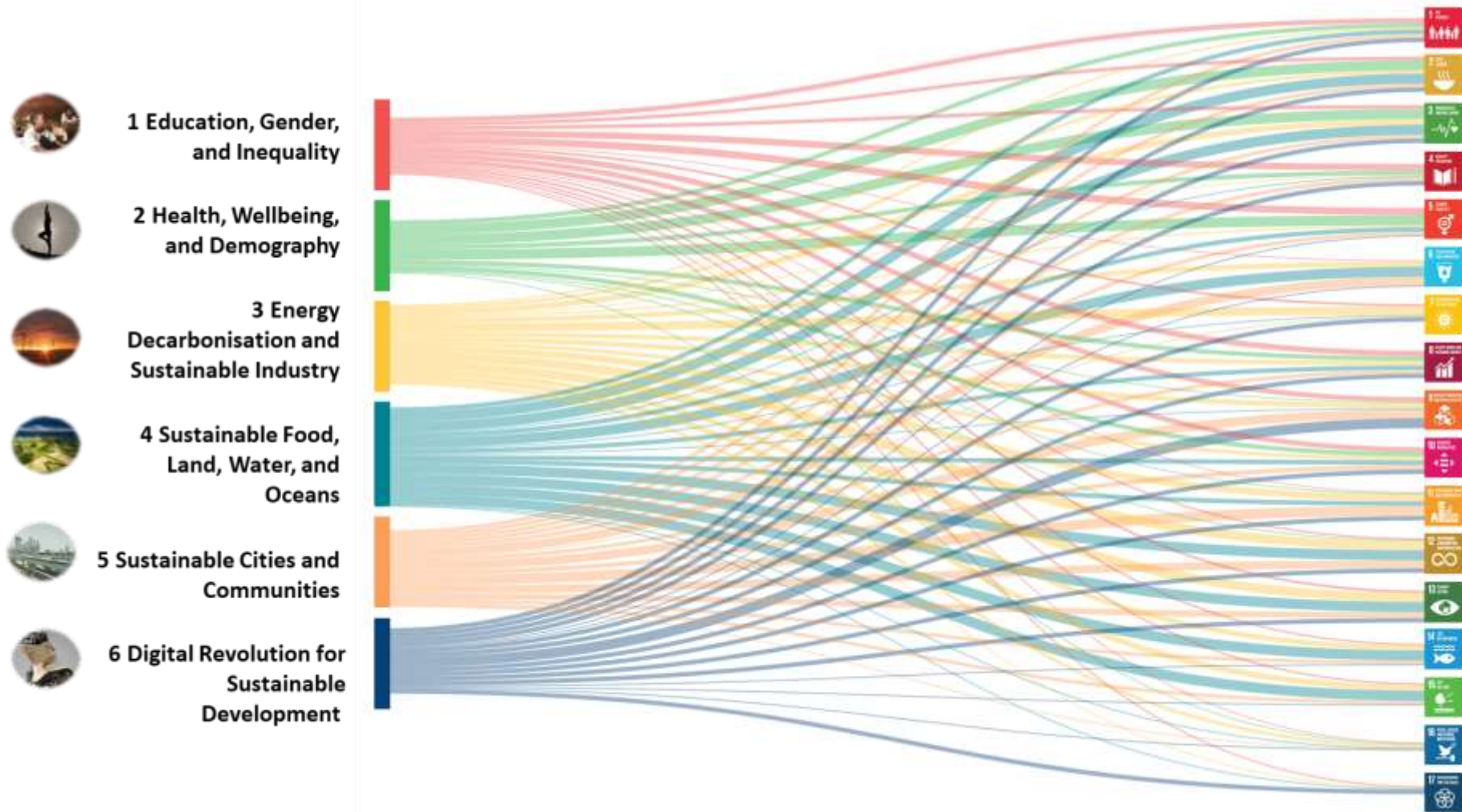
Each Transformation describes a major change in the organisation of societal, political, and economic activities that transforms resource use, institutions, technologies, and social relations in order to achieve key SDG outcomes. Source: ref<sup>3</sup> developed from *The World in 2050* (ref<sup>1</sup>). SDG icons courtesy of UN/SDG.



Each SDG Transformation describes a major change in societal structure (economic, political, technological, and social) to achieve long-term sustainable development. The six Transformations are necessary for achieving the SDGs and the objectives of the Paris Agreement (Annex 1). Each contributes to multiple SDGs (Figure 2). Dropping any of them would make it impossible to achieve the SDGs. The Transformations work at global, regional, and national scales. They need to be adapted to country contexts, such as levels of development, natural resource base, ecosystem challenges, and structures of governance.

Figure 2 | Contribution of each SDG Transformation towards the 17 SDGs.

Sankey diagram illustrating the relationships between each Transformation and the SDGs (Table 1). The thicker the line, the greater the contribution of that Transformation to meeting the SDGs (see Annex 2 for methods). Source: ref<sup>8</sup>. SDG icons courtesy of UN/SDG.



## II. Key SDG Interventions by Transformation

We describe below the rationale for each Transformation, key interventions, and how they generate intermediate outputs (Table 1). Issues arising out of implementation and the contributions each Transformation makes towards meeting the SDGs are also explored. Annex 1 provides additional details.

### Transformation 1. Education, Gender, and Inequality

Education builds human capital, which in turn promotes economic growth<sup>16</sup>, the elimination of extreme poverty, decent work, and overcoming gender and other inequalities<sup>17,18</sup>. The first Transformation comprises three sets of interventions to promote education and gender equality and to lower inequalities.

First, countries need to expand and transform education systems. Early childhood development boosts the cognitive and emotional development of children with persistent effects into adulthood, but has been underinvested in many countries, including high-income economies<sup>19</sup>. Universal quality primary and secondary school education is the backbone of education systems. It requires enhanced teacher training, curriculum development, and continuous evaluation of learning outcomes<sup>18,20</sup>, as offered by the Organisation for Economic Co-operation and Development's (OECD) Program for International Student Assessment (PISA). Vocational training, school-to-work programs, and higher education are underdeveloped in most countries, although they improve the school-to-work transition, increase lifetime earnings, and reduce inequalities<sup>18</sup>. Together, these interventions build human capital, which directly targets SDGs 4 (education), 5 (gender equality), and 10 (reduced inequalities).

Second, to further reduce inequalities, countries need to expand social safety nets<sup>21,22</sup>. These need to be complemented by anti-discrimination measures, improved labour standards, and measures to end all forms of modern slavery, trafficking, and child labour<sup>23</sup>.

Finally, to promote economic growth, which can contribute to lowering inequalities (Annex 1), most countries need to boost innovation and ensure diffusion from research and development<sup>24</sup>. The adoption of new technologies can be accelerated through tertiary education; national science funding mechanisms and science advisory bodies; innovation hubs; and the promotion of entrepreneurship through public-private financing mechanisms and incubators<sup>25</sup>.

The interventions under this Transformation are synergistic with no major trade-offs – provided the Leave-No-One-Behind Principle is applied. The Transformation will require integrated design and implementation of interventions through close coordination between ministries of education, science and technology, and social affairs, or their equivalents.

### Transformation 2. Health, Wellbeing, and Demography

This Transformation promotes key investments in health and well-being. Design and implementation will be led by health ministries in coordination with other ministries, such as labour and industry. As with Transformation 1, the key interventions under this Transformation are synergistic without any major trade-offs, provided the Leave-No-One-Behind Principle is applied. Interventions under other Transformations, particularly relating to environmental health and healthy behaviours, reinforce health outcomes and well-being<sup>26–29</sup>.

The principal intermediate output is universal health coverage (UHC). It requires a publicly financed health system that integrates prevention, therapeutic, and palliative services; integrated information

systems; and disease surveillance and control<sup>28</sup>. Health systems need to focus on primary healthcare and offer interventions for maternal, new-born, and child health; effective prevention and treatment of infectious diseases; and non-communicable disease control, including mental health and basic surgery<sup>28</sup>. In combination with improved girls' education and gender equality, investments in child health and sexual and reproductive health will accelerate the voluntary transition towards low fertility rates<sup>17,30</sup>. Community health programs can improve health outcomes significantly<sup>28</sup>.

Health interventions outside the health sector improve the social determinants of health. They include policies and metrics to raise wellbeing and quality of life. Changes to social norms and behaviours promote healthy lifestyles through better hygiene; lower consumption of tobacco, alcohol, and other harmful substances; and abstaining from risky behaviour (for example, practicing safe sex prevents the spread of sexually transmitted diseases). Countries should consider subjective wellbeing in policy design<sup>29</sup>, improve product design and labour standards to reduce accidents; and lower traffic deaths. Healthy diets, a critical determinant of health outcomes<sup>14,31</sup>, are covered under Transformation 4, and Transformation 5 includes measures to curb the pollution of water and air.

### Transformation 3. Energy Decarbonisation and Sustainable Industry

This Transformation aims to ensure universal access to modern energy sources<sup>32</sup>, decarbonise the energy system by mid-century in line with the Paris Agreement<sup>2</sup>, and reduce industrial pollution of soil, water, and air<sup>33,34</sup>. The implementation of this Transformation requires close coordination among several government ministries, including buildings and construction, energy, environment, and transport. Interventions are synergistic, but trade-offs can arise from poor design.

Ensuring access to modern energy services translates into providing access to electricity to some 1.1 billion people through grid extensions or microgrids, as well as access to modern fuels for cooking and heating to the 2.8 billion who lack this today<sup>32</sup>.

Decarbonising energy systems requires integrated approaches across power generation, transmission, buildings, transport, and industry<sup>11,35,36</sup>, which fall into three distinct areas<sup>10</sup>. The first covers the decarbonisation of electricity generation by shifting from fossil fuels to zero-carbon sources, including wind, solar, hydro, geothermal, and tidal energy, among others. Some countries may also expand nuclear power or consider continued fossil fuel use with carbon capture and storage (CCS). Smart-grid management and long-distance power transmission can address intermittency, reduce electricity storage needs, and increase the efficiency of power grids<sup>11</sup>. Second, countries need to improve energy efficiency in final energy use, including transport, heating and cooling of buildings, industrial energy use, and household appliances<sup>41</sup>. Third is the electrification of current uses of fossil fuels outside of power generation, such as the internal combustion engine, through electric or hydrogen vehicles, boilers and heaters, and various industrial processes, such as steel and cement production. Biofuels and biomass can provide clean thermal energy, but their use must ensure consistency with food security, biodiversity conservation, and other SDGs<sup>37</sup>.

A related set of SDG interventions focuses on managing industrial pollutants of air, water, and land, including through circularity (Box 2). Key industrial pollutants include methane, nitrous oxides, sulphur dioxide, as well as organic and other inorganic pollutants and plastics. Water and waste management, life-cycle approaches, and other tools of circular economy can increase resource efficiency and lower pollution<sup>34,38</sup>.

Design and implementation of this Transformation are complex. One trade-off can arise from neglecting to pursue energy access and affordability in parallel to decarbonisation. Such a failure may generate public resistance to climate policies<sup>39</sup>. Similarly, while improving air quality and reducing greenhouse gas emissions are generally complementary, coal-to-gas and similar technologies may improve air quality but increase greenhouse gas emissions<sup>33</sup>. Moreover, a more

efficient and low-cost energy system may generate a substantial rebound effect, in which demand growth compensates for increased resource efficiency. The use of other scarce resources, such as scarce metals, might rise with serious environmental and social consequences. Anticipating and addressing these trade-offs will require sound accounting frameworks, applying the Principles of Leave No One Behind (Box 1) and Circularity and Decoupling (Box 2), and social activism (addressed in Section III below).

#### Transformation 4. Sustainable Food, Land, Water, and Oceans

Today, land-use and food systems lead to persistent hunger, malnutrition, and obesity<sup>14,31</sup>. They account for a quarter of greenhouse gas emissions<sup>2</sup>, over 90 percent of scarcity-weighted water use<sup>40</sup>, most losses of biodiversity<sup>41,42</sup>, overexploitation of fisheries<sup>43</sup>, eutrophication through nutrient overload<sup>44</sup>, and pollution of water and air<sup>45</sup>. At the same time, food systems are highly vulnerable to climate change and land degradation<sup>2</sup>. Integrated strategies are needed to make food systems, land-use, and oceans sustainable and healthy for people.

This Transformation exhibits the highest potential for trade-offs across interventions. Increases in agricultural production may exacerbate biodiversity loss and water scarcity. Rising incomes around the world will add pressure on food systems, unless diets become healthier and more environmentally sustainable. As a result, the interventions must be pursued in an integrated manner<sup>12</sup> with attention to the Principles of Leave No One Behind (Box 1) and Circularity and Decoupling (Box 2). Strategies should be designed and implemented by ministries of agriculture and forestry, environment, water and natural resources, fisheries and marine resources, and health. Most governments will need to strengthen coordination mechanisms across these ministries to anticipate and manage trade-offs.

The first intervention area focuses on efficient and resilient agricultural systems and fisheries that support livelihoods. Major increases are needed in yields and resource use efficiency in terms of nutrients, water, greenhouse gas emissions, and chemicals<sup>40,41</sup>, and in the reduction of post-harvest losses. This will in turn require context-specific strategies for major cropping systems, livestock, aquaculture, fisheries, forestry, and biofuel production. In parallel, agricultural practices must better protect biodiversity through intercropping, agroforestry, biosphere reserves, and careful use of chemicals<sup>46</sup>. Improved management practices are needed for coastal and high sea fisheries to curb overfishing and maintain yields<sup>43,47</sup>.

Second, forests, soils, peat lands, wetlands, savannahs, coastal marine areas, and other ecosystems must be conserved and restored<sup>42</sup>. Conservation measures must be designed and implemented in cooperation with local communities. The same applies to large-scale restoration programs and measures to increase soil fertility and capture more carbon in the biosphere, as illustrated by experiences in China<sup>48</sup>.

Third, food insecurity and hunger need to be curbed through complementary safety nets and targeted interventions<sup>49</sup>. Consumer demand must shift towards healthier diets, including a shift away from highly processed food and red meat, as well as reduced losses and waste along food supply chains<sup>14,31,40</sup>.

International supply chains must ensure sustainable resource use and curb pollution. Importing countries need to consider the environmental impact of imports in exporting countries, in particular, and stop the trade in endangered species. International investments in agricultural land must be carefully managed to ensure long-term sustainability and acceptability to the local population. Finally, countries require strategic land-use, ocean-use, and water management approaches to help manage competing claims on land and water for food production, urban development, industry and



mining, ecosystem management, carbon sequestration, and biodiversity conservation<sup>12</sup>, as well as on the ocean for transport, food production, energy harvesting, mining and tourism<sup>50</sup>.

### Transformation 5. Sustainable Cities and Communities

Cities and other urban areas (“cities”) are home to around 55 percent of humanity and 70 percent of global economic output. By 2050, these shares will increase to 70 and 85 percent, respectively<sup>51</sup>. Cities are particularly vulnerable to climate change, but most cities are far from meeting the triple objective of being economically productive, socially inclusive, and environmentally sustainable<sup>2,52,53</sup>. Almost a third of urban dwellers live in informal settlements<sup>54</sup>. Many villages and small towns lack access to water, sanitation, transport<sup>32,55</sup>, and energy (Transformation 4).

A first focus of this Transformation is on ensuring access to water supply, sanitation, and appropriate sewage and waste disposal in urban and rural areas. An estimated 1.2 billion people lack access to safely managed drinking water services, and 2.4 billion people do not have access to safely managed sanitation<sup>56</sup>. Investments in water supply and sanitation are synergistic with measures to address water scarcity that align water demand from agriculture with sustainable supply (Transformation 4). Recycling and sustainable waste management practices are also critical (Box 2).

Sustainable and efficient mobility is a second priority. This includes infrastructure for roads, rail, and ports, as well as public transport systems and ride sharing. Infrastructure should be deployed according to participatory and inclusive urban planning that takes into account expected population growth<sup>52</sup> and manages trade-offs between infrastructure services and other policy objectives as well as competing interests within cities. Particular attention must be paid towards reducing air pollution from transport<sup>33</sup> and ensuring the long-term sustainability of transport.

Third, cities need to promote more compact, safe, and healthy settlements to accommodate rising urban populations, enhance resource-use efficiency (Box 2), and avoid excessive land conversion (Transformation 4). This will require adequate green spaces, infrastructure for cycling and walking, and other interventions to increase resource efficiency and quality of life<sup>52</sup>.

Cities also need to enhance resilience against climate change and extreme weather events, including more heat waves, droughts, flooding, and enhanced disease transmission<sup>2,53</sup>. This will require participatory and inclusive urban planning to address difficult trade-offs, such as resettlement<sup>52-54</sup>.

Organising this Transformation is particularly complex owing to the large number of stakeholders involved and the distribution of responsibilities between national and local levels of government. Ministries of transport, water and sanitation, and urban development will play central roles. But most importantly, cities require competent and adequately resourced local authorities that can pursue integrated strategies and ensure participatory design<sup>52</sup>.

### Transformation 6. Digital Revolution for Sustainable Development

Artificial Intelligence and other digital technologies – sometimes referred to as the Fourth Industrial Revolution – are disrupting nearly every sector of the economy, including agriculture (precision agriculture), mining (autonomous vehicles), manufacturing (robotics), retail (e-commerce), finance (e-payments, trading strategies), media (social networks), health (diagnostics, telemedicine), education (online learning), public administration (e-governance, e-voting), and science and technology. Digital technologies can raise productivity, lower production costs, reduce emissions, expand access, dematerialise production, improve matching in markets, enable the use of big data, and make public services more readily available. They can also improve resource-use efficiencies, support the circular economy (Box 2), enable zero-carbon energy systems, help monitor and protect ecosystems, and assume other critical roles in support of the SDGs<sup>1,57,58</sup>.

Yet there are risks and downsides that countries must identify and tackle through integrated strategies and a focus on the Leave-No-One-Behind Principle (Box 1). Perhaps the most feared risk is the loss of jobs, particularly for lower-skilled workers, and the shift of income distribution from labour to capital<sup>22</sup>. While new jobs might replace existing ones, these new jobs may come with lower real earnings and worse working conditions<sup>22</sup>. Base erosion, profit shifting, and a concentration of industries threaten to undermine countries' tax bases<sup>59</sup>. Other threats from the digital revolution include the theft of digital identities, invasion of privacy by governments or businesses, discrimination based on personal data, monopoly positions due to control of big data, challenges to deliberative decision-making processes, cyber warfare, hacking of election data, or the manipulation of social media.

The sixth SDG Transformation calls for a comprehensive set of regulatory standards, physical infrastructure, and digital systems, to capture the benefits of the digital revolution for the SDGs while avoiding the many potential downsides. It comprises four sets of interventions. First, universal access to high-quality, low-cost mobile broadband. Second, measures to promote digital inclusion, skills, privacy protection, and universal identity. These include the digitization of government facilities, universal public online identity for official purposes, income redistribution to address income inequalities, tax and regulatory systems to avoid monopolization of internet services and big data, online data governance and interoperability provisions, and democratic oversight of cutting-edge technologies<sup>58</sup>. Third, countries need to harness the digital revolution for SDG achievement, including through the digitization of healthcare and education, online finance and payments, and supporting public goods<sup>60</sup>. Fourth, public institutions need to be strengthened to govern and shape digital innovations towards sustainable development. Technology missions, as considered below, can harness technologies to tackle implementation challenges across the six SDG Transformations.

This Transformation requires leadership from ministries of science and technology as well as telecommunications. They must coordinate closely with other parts of government and stakeholders – particularly through public-private partnerships – to anticipate and manage deep societal changes both triggered by and needed for the digital revolution, particularly regarding inequalities, the future of work, and how artificial intelligence may affect societal decision making<sup>61</sup>.

### III. Implementing the Six Transformations

The six Transformations require deep, deliberate, long-term structural changes in resource use, infrastructure, institutions, technologies, and social relations that must be undertaken in a short period of time. Previous societal transformations, such as the industrialisation in 19<sup>th</sup> century Europe, were spurred by technological changes (for example, the steam engine and railroad) and were largely undirected, though the roll-out of technologies often occurred with government support. In the 20<sup>th</sup> century, technologies like semiconductors, the Internet and Global Positioning System, were promoted through directed innovation to meet military aims<sup>62</sup>. SDG Transformations must be directed to meet time-bound, quantitative targets, such as net-zero carbon emissions by mid-century.

The six Transformations can be designed and directed in several ways. First, they must meet the standards of technical feasibility. Second, the Transformations need to address and resolve trade-offs. Third, they will be financed through a combination of public and private financing<sup>15</sup>. Fourth, they need to accelerate development and deployment of new technologies. Fifth, policy coherence is needed across branches of government (horizontal), between levels of government (vertical), and over time (temporal)<sup>63</sup> to manage trade-offs and ensure timely implementation. Sixth, business can provide co-financing and drive many of the organisational and technology changes required, so each Transformation must engage the business community, through a coherent set of policies, market incentives, and regulations. And finally, the transformations require civil society engagement and public debates about sustainable development pathways.

Drawing on the transformation literature<sup>64–66</sup> as well as our own research and experiences in advising governments, we propose four major governance mechanisms to design and operationalise the Transformations. Since the SDG Transformations are without historic precedent, any description of transformative governance mechanisms is necessarily exploratory and subject to later refinements through ‘learning by doing’.

### Goal-based Design and Technology Missions

Two design mechanisms can support long-term SDG Transformations in every country. First, governments, with support from science, engineering, and public policy disciplines, need to set medium-term targets with time horizons of 10-30 years (i.e. 2030 for the SDGs and 2050 for the Paris Agreement) and develop detailed policy pathways for achieving these targets. This requires working backwards from these time-bound targets to identify the systems design, investment trajectories, and technologies that can deliver the long-term goals<sup>1,7,12,36</sup>. In some cases, the pathways can be set up as a formal multi-dimensional, multi-period, non-linear programming problem (for example, how to achieve decarbonisation at minimum cost). Pathways should provide insights on time-bound technology benchmarks, such as the phase-out of the internal combustion engine around 2030, that help educate the public about the Transformation and can guide investment decisions by industry<sup>7,35,36</sup>. Given the complexity of the Transformations and the need for broad societal buy-in, this design process must be transparent and participatory.

The health sector shows how to use pathways as methods for complex problem solving<sup>7</sup>. Pathways synthesise our understanding of how multi-dimensional goals and targets can be achieved, highlight knowledge gaps, focus on systems and technologies, and enable stakeholder engagement.

The balance between rigorous technical pathway analyses and stakeholder engagement is critical, as illustrated by California’s experience in operationalising the energy transition. The State asked leading engineers to develop technology pathways for deep decarbonisation using high-resolution bottom-up models of the energy systems. Results were then discussed with energy utilities, the finance sector, trade unions, and other stakeholders. Each group provided new insights and identified shortcomings in the analyses and recommendations, which were incorporated into improved pathways. This yielded better pathways and societal acceptance<sup>67</sup>. Potential losers from the transition were identified early on, and strategies were developed to compensate them and ease the transition into new jobs. Europe has followed a similar analytical process<sup>68</sup>, though with less stakeholder engagement and public discussion.

The second mechanism for operationalising long-term transformations are missions for directed technological change. These promote problem solving by combining top-down visions with bottom-up experimentation across many sectors<sup>25</sup>. Historic examples include the United States’ “Moon Shot”, the sequencing of the human genome, the development of the Internet, and the promotion of renewable energy. Each mission requires strategic decisions on how general-purpose technologies (for example, internet-based applications, battery storage for intermittent renewable energy) can create opportunities across sectors; finance, regulations, and standards to promote innovation and investment; and use of government procurement to scale up new technologies. The more ambitious and inspirational missions are, the stronger their ability to crowd in different forms of private finance<sup>25</sup>. Each SDG Transformation requires such missions as frameworks for accelerating innovation, technology development, and deployment.

### Goal-based Organisation of Government and Financing

Next, government organisation, budgetary frameworks, and financing must be aligned with long-term pathways. Most countries will need to increase domestic resource mobilization, and low-income developing countries will require increased international financial assistance<sup>15</sup>. To mobilise



private financing and direct it towards each Transformation, governments can use corrective pricing through taxes, charges, or tradable permits or direct regulation and mandates, such as land/ocean-use planning, building codes, or bans on hazardous products.

To organise around the six Transformations, governments require cabinet-wide coordination, typically in the office of the president or prime minister. Sub-cabinet groups can be organised around each Transformation. Broadly, such structured approaches are currently lacking, including in most advanced economies<sup>69</sup>.

The Transformations can only succeed if they enjoy societal legitimacy, so political processes should engage the public in participatory decision making and promote transparency and accountability. Novel ways for decision making to engage social movements—such as those around decarbonisation—are important. When policy challenges are complex, politically charged, and with a long time horizon, countries may establish an independent agency or commission to bring about long-term systems change, subject to general democratic scrutiny by elected officials<sup>70</sup>.

### Social Activism to Change Norms and Behaviours

The six Transformations require fundamental changes of norm, belief systems, and cognitive heuristics. Large-scale shifts in perspective, normative and cognitive innovations (for example, from linear growth to circularity; taking responsibility for the global commons; global fairness as a condition for human survival) drive transformations and ensure their public acceptance<sup>71,72</sup>. Such changes cannot be driven solely by governments and emerge instead from dialogues and learning processes between stakeholders. They can be supported by governments, including through transdisciplinary research and education. Often, large-scale societal change is achieved first in the hearts and minds of the people, and only afterward accepted in legislation and economic policies. Social movements, public activism, and awareness campaigns should explain the ethics of sustainable development, promote grassroots activism and community participation, shareholder activism, and fair-trade consumer movements. Moral leaders should expound the ethical teachings of the world's major religions in the context of sustainable development, such as Pope Francis' encyclical *Laudato Si'*<sup>73</sup>.

### Diplomacy and International Cooperation for Peace, Finance, and Partnerships

International diplomacy and law can promote the six Transformations in several ways. First, the most essential foundation of sustainable development is peace, which requires international cooperation to resolve disputes through norms and institutions, support peace keeping, and curb meddling in other countries' affairs<sup>74</sup>. Second, achieving the SDGs in low-income developing countries will require substantial and greatly increased development financing, including official development assistance, to close SDG financing gaps in low-income countries<sup>15</sup>. Third, international collaboration is needed to combat crime, curb sexual violence, and end human trafficking, which has become a major driver of modern forms of slavery. Fourth, a fair, rules-based trade system would support economic development in rich and poor countries alike. It promotes export-led development, which has driven unprecedented poverty reduction over the last decades, particularly in Asia. Finally, international cooperation (for example, through treaties, technical working groups, regional and international development banks, city alliances, or UN agencies) is required to tackle air pollution, biodiversity loss, climate change, freshwater scarcity, ocean degradation, and other environmental challenges<sup>75</sup>.

## IV. An Action Agenda for Science

The six SDG Transformations provide a framework for mobilising governments, business, and civil society around targeted problem-solving and SDG implementation. A shared framework is critical since different ways of framing SDG implementation lead to confusion and dissipate energy. We are

therefore very encouraged that international business organisations like the World Business Council on Sustainable Development and the World Benchmarking Alliance already embrace the concept of SDG Transformations.

Important knowledge gaps exist in designing pathways and strategies for each Transformation, implementing them, and monitoring results. The scientific community should embrace the following four-point action agenda.

### Capacity for Designing Transformations

Sophisticated tools are needed to design pathways for the six Transformations. These pathways require the integrated efforts of scientists, engineers, and policy specialists. Such tools have been developed in the health sector<sup>6</sup> and are now routinely used for UHC strategies<sup>28</sup>. Tools also exist for education<sup>76</sup>, but are less commonly used at the country level. The Food, Agriculture, Biodiversity, Land, and Energy (FABLE) Pathways Consortium, which operates as part of the Food and Land-Use Coalition ([weblink](#)), is a global network of country teams that collaborate around building new capacity for data integration and spatially explicit pathways towards sustainable land-use and food systems<sup>12</sup>. So far 20 country teams participate in the FABLE initiative. The Deep Decarbonisation Pathways Project<sup>7,36</sup> has been building capacity for the design of national energy decarbonisation pathways, complementing regional and global pathways. TWI2050 Initiative ([weblink](#)) uses Integrated Assessment Models for pathways covering all SDGs.

New and improved tools are needed for all six Transformations. They need to help model structural changes over a time horizon of 10-30 years, including financial and economic cost estimates; integrate science, engineering, and policy analysis; identify and quantify trade-offs; and communicate strategies and investment trajectories clearly to the public and business sectors. Major efforts are needed to vet and improve available tools and databases, which should be open and made freely available using Creative Commons licenses. They must also be integrated with economy-wide assessments of SDG investment needs and financing strategies, as recently published by the International Monetary Fund<sup>15</sup>.

### Time-bound Benchmarks

To make the Transformations tangible and operational for businesses, governments, and other stakeholders, their complexity needs to be broken down into time-bound benchmarks derived from the pathways. Under the Millennium Development Goals, the health sector adopted such time-bound benchmarks, such as the 2003 objective to provide anti-retroviral therapy to 3 million people in developing countries by 2005, which became an organised effort of the World Health Organisation (WHO) to promote rapid implementation. Benchmarks have been developed in the energy sector<sup>35,77</sup>, such as phasing out the internal combustion engine by 2030-2035, and decarbonising the power sector by 2050. Such benchmarks should be derived from integrated pathways, and should offer clarity for the corporate sector and governments on how to implement the six Transformations<sup>77</sup>. They are also critical for defining technology missions<sup>78</sup>. The recently launched Science-Based Targets Partnership ([weblink](#)) and other efforts require support from the scientific community to fill these gaps.

### Stakeholder Engagement and Co-design

Transformations cannot be designed and imposed from the top down. Broad public support and buy-in are needed for each Transformation, and their implementation must draw on a broad range of communities and sectors<sup>10,64</sup>. In the health sector, the Global Fund to Fight AIDS, Tuberculosis and Malaria has become a key driver of stakeholder engagement and learning<sup>79</sup>. Yet, we lack clear models for organising these discussions and consultation processes in other areas, and successful models will differ across countries, as they must be mindful of history, customs, and government

capacity. The scientific community should take on the challenge of developing tools and methods for multi-stakeholder engagement and co-design that help identify perceived trade-offs, ensure technical feasibility of long-term pathways, and explain the urgency to act.

### Policy Tracking, Monitoring and Evaluation

Finally, the SDGs call for a major effort to mobilise the data and monitoring frameworks to track the Transformations and share lessons on best practice. Outcome data on the SDGs remains highly incomplete<sup>80</sup>. Filling these gaps will require the integration of official and unofficial data, including from remote sensing and big data using mechanisms, such as the Group on Earth Observations ([weblink](#)) or the Global Partnership for Sustainable Development Data ([weblink](#)). These and other efforts need to be scaled up with support from the scientific community.

Yet, a far greater data and knowledge gap exists in the tracking of policies and inputs into the SDG Transformations. The Climate Action Tracker ([weblink](#)) has done ground-breaking work in assessing the presence and adequacy of national greenhouse gas emission-reduction targets with the Paris Agreement, inventorying national policy instruments (policies, regulation, budgets, etc.) for energy decarbonisation, and determining their adequacy for meeting national targets (Transformation 3). In this way, the Climate Action Tracker has greatly enhanced our collective understanding of whether countries are on track towards the Paris commitments and of the policies and investments needed for this. We consider it an invaluable tool for international climate policy, but it currently only covers G20 members and a few other countries. To our knowledge, no such efforts exist for the other five Transformations, where the monitoring of progress draws only on outcome data. This, we believe, is one of the most urgent deficits facing the international scientific community in the next few years.

## Annex 1: Key interventions to achieve the SDGs and interactions with individual SDGs

In this annex we summarize the key outcomes to be achieved for each SDG and describe the key interventions and intermediate outputs (Table 1) needed to achieve these outcomes. For the purposes of this global analysis, we follow the guidance of the 2030 Agenda, which calls on governments to set their own national targets based on the aspiration and guidance provided by the SDG targets<sup>85</sup>, and focus on the principal objectives identified under each goal. The discussion focuses on interventions (investments and regulatory changes) for infrastructure, services, and environmental protection. Governance mechanisms are covered in Section III of the paper.

### Method for identifying and quantifying contributions by an intervention to each SDG

Studies into SDG interactions focus on relationships between SDG outcomes. These are either assessed heuristically drawing on established relationships in the literatures (e.g. ref<sup>f5,86,87</sup>) or using statistical relationships between SDG outcomes (e.g. refs<sup>88,89</sup>). Given the paucity of SDG data available for all countries, gaps in the official SDG indicator framework<sup>90</sup>, and the difficulty of deducing causal relationships from bivariate correlations, we favour the former approach. A number of sector-based assessments of SDG interactions exist for health<sup>26</sup>, infrastructure<sup>91</sup>, energy<sup>92,93</sup>, water<sup>56,94</sup>, ecosystem services<sup>95</sup>, and oceans<sup>96</sup>. SDG interactions have also been studied through resource nexus approaches<sup>1,97–99</sup>.

In our case and in order to construct Table 1, we are interested in which major inputs are required to achieve each SDG. These inputs will then help us identify the intermediate outputs described in Table 1 and in turn design the SDG Transformations. To this end we survey the literature to identify the major inputs for each goal. Relationships between intermediate outputs and the SDGs are scored on a four-point scale derived from refs<sup>4,5</sup>:

- 3 – Directly targets SDG: The intermediate output directly addresses the SDG. Since earlier studies<sup>4,5</sup> focus on the relationship between SDG outcomes, we use the term “directly targets SDG”.
- 2 – Reinforcing: The intermediate output is necessary for achieving the SDG.
- 1 – Enabling: The intermediate output enables the achievement of the SDG.
- 0 – Neutral: The intermediate output does not significantly interact with the SDG. We do not discuss these outputs below.

The assessments below serve to derive the principles of the SDG Transformations and therefore focus on broad relationships, whereas the actual relationships between intermediate outputs and the SDGs can be highly context-specific. Our synthesis derives from reviews of the literature with a focus on those countries and regions furthest away from achieving the SDGs, as described in the SDG Index and Dashboards<sup>90</sup>. For example, assessments of the social goals will focus on the challenges in poor countries where the greatest achievement gaps are. As a result, access to basic infrastructure (electricity, water, sanitation, transport) will reinforce education outcomes (rated 2), as is common in many poor countries<sup>93,100</sup>, whereas these relationships make minor contributions in richer countries that have achieved universal access to basic infrastructure. Conversely, the richest countries face the greatest challenges in meeting the climate and other environmental goals.

Below, we discuss outputs that directly target SDGs (rated 3) in detail with references to the scientific literature. Key references are also provided for intermediate outputs that are rated 2 (reinforcing). Enabling outputs (rated 1) generally describe broad synergistic relationships that are widely recognised in the development literature. For example, enhanced urban resilience will reduce the impact of

disasters, which in turn will enhance education outcomes. Within the scope of this paper we cannot systematically provide scientific references for enabling relationships. Likewise, we do not cite references for neutral relationships.

As is also common with assessments of interactions across SDG outcomes<sup>4,101</sup>, the scoring of the contribution that intermediate SDG outputs make towards achieving SDG outcomes may vary across countries and across time. This applies in particular to the distinctions between reinforcing (2) and enabling outputs (1) as well as enabling and neutral (0) outputs. For these reasons, our analysis below should be seen as illustrative and in need of ground-truthing at national levels.

### Trade-offs across SDG interventions

As also described briefly in Section 2, negative relationships (trade-offs) between SDG interventions are addressed by (i) integrating key trade-offs inside each Transformation through systems-based approaches; (ii) applying the Leave-No-One-Behind Principle, particularly to investments in infrastructure and services; and (iii) applying the Principle of Circularity and Decoupling to all Transformations. Table 1 and the text below therefore do not report any trade-offs between intermediate outputs and SDG outcomes.

Based on our review of the literature and experience in supporting SDG implementation, we believe this approach addresses the most important trade-offs across SDG interventions. As emphasized throughout, though, the application of the six SDG Transformations needs to take account of local circumstances, which may give rise to additional trade-offs not considered in this global analysis. Identifying these trade-offs will require scientific analyses combined with the stakeholder engagement process described in Section III of the paper and discussed further in the concluding Section IV. Such processes are particularly important as stakeholders' perceived trade-offs may be greater than suggested by scientific assessments.

### SDG 1.

SDG 1 aims for the eradication of extreme poverty, defined as incomes below USD 1.90 per day in purchasing power parity, and the halving of poverty according to national definitions of poverty. The goal underscores the multidimensional nature of poverty and calls for universal access to economic resources and basic infrastructure. It further highlights the need for resilience against climate-related disasters and other shocks.

According to the World Bank over 700 million people live in extreme poverty<sup>102</sup>. Poverty rates according to national definitions vary widely. As recognised in the framing of SDG 1, poverty is multidimensional<sup>103</sup>, and changes in poverty levels correlate highly with economic growth<sup>104,105</sup>. Therefore, interventions to end poverty must target economic growth (as described under SDG 8 below) and other forms of human deprivation, including lack of access to social services and basic infrastructure.

Social protection systems and labour standards directly target income poverty (rated 3) by providing income support and insurance against catastrophic health expenditures, weather and climate-related fluctuations of farmers' incomes, the economic effects of conflict and social strife, and a whole range of events and circumstances that can induce or sustain poverty<sup>21,104–108</sup>.

Several intermediate SDG outputs reinforce SDG 1 (rated 2):

- Collectively, investments in women's education, sexual and reproductive health, maternal health, and gender equality, raise women's productivity and labour force participation, and

support the voluntary reduction of fertility rates<sup>17,30</sup>. The demographic transition provides an important impetus for human capital accumulation per child, poverty reduction, and economic growth<sup>17,109,110</sup>.

- More generally, investments in human capital (public health services<sup>111</sup> and education<sup>17</sup>), infrastructure services<sup>91</sup> (energy access for all<sup>32</sup>, water and sanitation<sup>56</sup>, transport and mobility, and digital technologies and infrastructure<sup>57</sup>) contribute to economic growth<sup>16,24,109,110,110,112,113</sup> and poverty reduction<sup>103,104</sup>.
- A disproportionate number of the extreme poor are smallholder farmers, pastoralists, or engaged in artisanal fishing<sup>104,114</sup>. They depend on increased productivity of agriculture and fisheries to improve their livelihoods, which in turn requires interventions to promote sustainable land-use and food systems<sup>115–117</sup>. Such interventions will also increase resilience to natural disasters and to the impacts of climate change<sup>2,118</sup>.

Intermediate SDG outputs that enable SDG 1 (rated 1) include:

- Innovation through investments in research and development.
- The decarbonisation of energy systems mitigates climate change and therefore lowers the incidence of extreme weather events and other climate impacts.
- Clean air and water, particularly through their impact on improved health.
- Urban resilience that lessens the impact of climate change and extreme events on the poor.

## SDG 2.

SDG 2 has two major components. First, it calls for ending hunger and malnutrition. This will require access for all to safe and nutritious food. The second component addresses the need to make agriculture more productive, resource efficient, and sustainable.

The first component of the goal is directly targeted through a range of SDG interventions. Sustainable land-use and food systems can raise agricultural production among smallholder farmers, which directly increases their incomes and reduces the incidence of hunger and malnutrition. More generally, rising agricultural production can lower food prices, which are a major determinant of the nutrition status of the urban poor. It can also buffer the effect of extreme weather events on food availability and prices<sup>49,98</sup>. In addition, a range of food supplementation programs can increase nutrition outcomes<sup>14,119</sup>. Improved public health interventions that inter alia lower the incidence of diarrheal diseases can further improve nutrition outcomes<sup>28,119</sup>. Finally, direct income support programs to the poor, including food deliveries, further enhance nutrition outcomes<sup>28,49,120</sup>.

Resilient and sustainable agriculture requires the range of SDG interventions described under sustainable land-use and food systems. These include measures to increase input use efficiency (e.g. for water<sup>56,121</sup> and nitrogen fertiliser<sup>44,122</sup>); more efficient germplasm and seed varieties<sup>49,123,124</sup>; and increased investments in infrastructure for storage, irrigation, and transport<sup>49,125</sup>. Such interventions, particularly improvements in water management infrastructure and new crop varieties, can also increase the resilience of agriculture to climate change and extreme weather events<sup>126</sup>. In the case of fisheries, marine reserves and other measures have been shown to increase maximum sustainable yields of coastal and high-sea fisheries<sup>47,127,128</sup>.

Several intermediate SDG outputs reinforce SDG 2 (rated 2):

- Major advances in crop varieties and farming practices are needed to increase agricultural productivity in the context of climate change and without further undermining ecosystems and other forms of natural capital<sup>129</sup>. Alternative proteins can substitute animal protein and lower

environmental footprints. This will require substantial outlays on research and development to promote innovation across agricultural supply chains<sup>2,123,130,131</sup>.

- Energy decarbonisation mitigates climate change and thereby reduces climate-induced pressures on water resources and food production systems around the world<sup>2</sup>.
- Universal access to water supply and sanitation reduces the incidences of diarrheal and infectious diseases, which has been shown to be a critical driver of improving nutrition outcomes, particularly for young children<sup>56,119,132,133</sup>. Improved transport infrastructure can help reduce food losses<sup>125</sup>.
- Digital technologies can play a critical role in enhancing the resilience and productivity of the food system, including through precision agriculture, strengthening agricultural extension services, reducing food loss and waste, connecting farmers to markets, and improving short and medium-term climate forecasts<sup>131,134–137</sup>.

Intermediate SDG outputs that enable SDG 2 (rated 1) include:

- Improved education and human capital are synergistic with better nutrition outcomes.
- Among other benefits, energy access for all frees up household resources for better nutrition.
- Interventions to promote clean air and water are complements to ensuring universal access to safe water supply and sanitation.
- Urban resilience is broadly synergistic with improved food outcomes.

### SDG 3.

SDG 3 targets health and wellbeing by avoiding preventable deaths of new-borns, children, and mothers; ending the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases; and fighting other infectious diseases; reducing mortality from non-communicable diseases; and promoting healthy behaviours, including curbing substance abuse and decreasing road traffic accidents. The goal also calls for universal access to sexual and reproductive health as well as universal health coverage. Finally, it recognises the critical contribution of curbing pollution to improve health outcomes.

As described in the consensus strategy to achieve SDG 3, investments in universal health care (UHC) are the main input into meeting the goal<sup>28,138</sup> (rated 3). UHC interventions integrate prevention, therapeutic, and palliative services; integrated information systems; and real-time surveillance and control of epidemics<sup>28</sup>. They directly address SDG 3 priorities, including maternal, new-born and child health; effective prevention and treatment of infectious diseases; sexual and reproductive health; non-communicable disease control, such as mental health and basic surgery<sup>17,26,138</sup>, including all the major interventions that drove progress towards the Millennium Development Goals<sup>111</sup>.

A second major set of SDG interventions to support SDG 3 address healthy behaviours and social determinants of health and wellbeing (rated 3)<sup>28,139</sup>. These include promoting hygiene; prevention and treatment of substance abuse; curbing consumption of tobacco and harmful use of alcohol; abstaining from risky behaviours (e.g. in relation to sexually-transmitted diseases); improved product design and labour standards to reduce accidents; and road safety campaigns to lower traffic deaths<sup>140</sup>.

Third, healthy diets, as promoted through sustainable land-use and food systems (Transformation 4) are a critical determinant of health outcomes (rated 3)<sup>14,26,28,31</sup>. Alongside energy decarbonisation, sustainable land-use and food systems are a key input for climate change mitigation, which is necessary to prevent critical threats to health outcomes<sup>141,142</sup>. Moreover, sustainable livestock management practices can help curb zoonotic diseases, which are a major driver of global disease pandemics<sup>28,116</sup>. Measures to curb the pollution of water and air (Transformation 3) are a fourth set of interventions that directly targets SDG 3<sup>26,28</sup>.



Several intermediate SDG outputs reinforce SDG 3 (rated 2):

- Social protection systems, including conditional cash-transfer programs, increase access to and utilisation of healthcare, a key dimension of UHC<sup>28</sup>.
- Improved education, particularly of women, reinforces child health and other health outcomes<sup>28</sup>.
- Access to basic infrastructure services, particularly for water, sanitation, and modern energy services, greatly enhance health outcomes<sup>26,28,91,143</sup>.
- Energy decarbonisation promotes improvements in air quality, which is a key determinant of good health<sup>26,33</sup>. Alongside sustainable land-use and food systems, it is also a key input for climate change mitigation, which is necessary to prevent critical threats to health outcomes<sup>141,142</sup>.
- Digital technologies and infrastructure can make a major contribution towards meeting the health SDG, e.g. through mobile and digital health<sup>57,144</sup> or ICT-enabled community health workers<sup>145</sup>.

Intermediate SDG outputs that enable SDG 3 (rated 1) include:

- Research and development, particularly focused on improved health interventions.
- Urban resilience reduces health risks.

#### SDG 4.

The goal focuses on complete, free, equitable, and quality education for all girls and boys at primary, secondary, and pre-school levels<sup>146</sup>. It also calls for affordable and quality post-secondary education, including university. Above all, this will require investments in early childhood development<sup>19,147</sup>, and primary and secondary education, as well as higher education and vocational training<sup>20,76</sup>. Targeted measures are needed to support the transition from school to work. Together these SDG interventions will enhance education and human capital as intermediate outputs<sup>17,18</sup>, which directly target SDG 4 (score 3).

Several intermediate SDG outputs reinforce SDG 4 (rated 2):

- Public health services promote good health, particularly among learners, which is critical to good education outcomes<sup>111,147,148</sup>. Sexual and reproductive health services are particularly important for young girls and women to complete secondary and higher education<sup>17</sup>.
- Similarly, access to infrastructure (energy, water and sanitation, and transport) is a key enabler of the education goal<sup>91</sup>, as it reduces demand for household labour (particularly from girls), which reduces school attendance and time available for studying at home<sup>149</sup>. Energy access for schools is also a critical enabler of improved education outcomes<sup>143</sup>.

Intermediate SDG outputs that enable SDG 4 (rated 1) include:

- Social protection systems, including conditional cash-transfer programs, increase school participation rates among children.
- Curbing pollution and sustainable food and land-use systems are important contributors to improved health<sup>31,150</sup>, which in turn may increase school participation and learning outcomes.
- Finally, urban resilience, particularly to climate impacts, may increase school attendance and learning outcomes in the face of rising climate-related extreme weather events.



## SDG 5.

Gender-based discrimination is widespread<sup>151</sup>. Meeting the gender goal will require an end to all discrimination against women and girls, sexual violence, and trafficking. The goal also calls for the full participation of women and girls in political, economic, and public life. A special reference is made to universal access to sexual and reproductive health and reproductive rights.

As emphasised in the paper (Transformation 1 and Box 1), a large number of interventions across all Six Transformations contribute towards meeting SDG 5. It is therefore difficult to separate between interventions that directly target gender equality (rated 3) and reinforcing interventions (rated 2). The two perhaps most direct interventions (rated 3) in SDG 5 are education and UHC. Achieving universal secondary school completion for all girls will substantially improve gender equality and enable these girls to participate more fully in all aspects of private and public life<sup>17,18,146,151</sup>. UHC includes critical investments in gender equality, such as sexual and reproductive health, child health, and maternal health<sup>26,28,30,119,152,153</sup>. Empowering women and girls through these interventions also helps curb violence against them<sup>154</sup>.

Several intermediate SDG outputs reinforce SDG 5 (rated 2):

- Social protection systems, such as conditional cash transfers<sup>155</sup>, can have disproportional benefits for girls and women<sup>106,120,156</sup>.
- Universal energy access particularly benefits the health of mothers who suffer from acute lower respiratory diseases caused by indoor air pollution<sup>26,157</sup>. It also enhances young girls' school enrolment and completion rates since they no longer have to fetch fuelwood<sup>158</sup>.
- Sustainable land-use and food systems generate disproportionate benefits to girls and women, including through higher incomes to farmers (some 80 percent of farmers in sub-Saharan Africa are women<sup>120</sup>) and improved nutrition<sup>119,159</sup>.
- Improved water supply and sanitation infrastructure also disproportionately benefits women and girls, e.g. by reducing time poverty<sup>103,146,151</sup>, lowering rates of diarrheal infections<sup>26,132,160</sup>, and improving safety<sup>56,161</sup>.

Intermediate SDG outputs that enable SDG 5 (rated 1) include:

- Innovation in technologies and policies that benefit women and girls is synergistic with SDG 5.
- Energy decarbonisation enables the gender goal, including through the lowering of indoor air pollution.
- Similarly, clean air and water are broadly synergistic with gender equality.
- Interventions to promote urban resilience will enable SDG 5.
- Similarly, digital technologies and infrastructure – if implemented using the Leave-No-One-Behind Principle – can be synergistic with the gender goal.

## SDG 6.

This SDG has two major components. First, it calls for universal access to safe and affordable drinking water and sanitation facilities with adequate wastewater treatment and pollution control. An estimated 1.2 billion people lack access to safely managed drinking water services and 2.4 billion people do not have access to safely managed sanitation facilities<sup>56</sup>. Second the goal requires countries to increase water-use efficiency and to ensure sustainable water withdrawals and supply. Today, 4 billion people, some two thirds of the world's population, experience severe water scarcity during at least one month every year and 0.5 billion people experience severe scarcity all year round<sup>162</sup>. SDG 6 recognises that improving water management requires the conservation of water-related ecosystems, as is also called for under SDG 15.

Investments in water supply and sanitation facilities and infrastructure, including sewage treatment, directly target the first component of the SDG<sup>56</sup> (rated 3). Sustainable land-use and food systems make three major contributions towards meeting the second component of the goal. Since agriculture accounts for two thirds of overall water use and 90-95% of scarcity-weighted water use<sup>40</sup>. Second, conserving and restoring water-related ecosystems contributes to targets 5 and 6 under this goal. Third, it curbs net greenhouse gas emissions, which mitigates climate change – a major driver of future water scarcity<sup>2,162</sup>. In this way it makes another indirect contribution towards SDG 6. Finally, measures to control water pollution from industry also target the second component of this goal directly<sup>34</sup>.

Several intermediate SDG outputs reinforce SDG 6 (rated 2):

- Decarbonising energy systems is critical for curbing up to three quarters of global greenhouse gas emissions. By mitigating climate change, this intermediate output can reduce climate-induced water scarcity, which reinforces SDG 6<sup>56,162</sup>.
- By reducing the incidence and the impact of extreme weather events, urban resilience helps ensure long-term sustainability and operability of urban water supply and sanitation infrastructure<sup>2,118,163</sup>.

Intermediate SDG outputs that enable SDG 6 (rated 1) include:

- Better education outcomes that are synergistic with the outcomes of this goal, including by improving hygiene behaviour in households.
- Income support to vulnerable groups enhances the affordability of water and sanitation services for the poor and can help close the revenue loop of water utilities, which helps ensure adequate budgets for operations and maintenance.
- Innovation, particularly on water use efficiency, is synergistic with this goal.
- Access to clean energy can power boreholes and water pumps, which improve water access. However, unless coupled with integrated water resources management, cheap electricity can drive water scarcity, as is common across much of Northern India<sup>56,162</sup>.
- Digital technologies and infrastructure can improve water supply and resources management, for example by lowering the cost of monitoring leaks in water networks, enabling highly efficient drip irrigation, and lowering the cost of collecting water use charges<sup>56</sup>.

## SDG 7.

SDG 7 focuses on ensuring universal access to electricity and modern fuels for cooking. Today some 1.1 billion people lack access to electricity, and 2.8 billion do not have access to modern fuels for cooking and heating<sup>32</sup>. The goal also calls for increasing the share of renewable power generation and energy efficiency, which are two key components of strategies to decarbonise energy systems<sup>9,11,36</sup>.

Investing in access to electricity and modern energy sources directly targets SDG 7<sup>32,164</sup>. Decarbonisation of energy systems increases energy efficiency as well as the share of renewable power generation technologies in the energy mix<sup>9,11,36</sup>.

Several intermediate SDG outputs reinforce SDG 7 (rated 2):

- Social protection can reinforce access to energy services by increasing their affordability. It also helps mitigate the social cost of the decarbonisation of energy systems<sup>39,64,165</sup>.
- Innovation is required to further bring down the cost of novel energy access technologies and increase their efficiency<sup>92,143,164</sup>. Similar considerations apply to renewable energy and energy efficiency technologies<sup>11,166,167</sup>.
- The sustainable design and operation of infrastructure for transport, water and sanitation reduces air pollution, which reinforces SDG 7<sup>2,33</sup>.

- Digital technologies and infrastructure play a critical role in providing energy access by facilitating the revenue collection and metering of usage<sup>168–170</sup>.

Intermediate SDG outputs that enable SDG 7 (rated 1) include:

- Improved education and human capital are broadly complementary with the energy goal.
- Clean air is synergistic with the energy goal.
- Sustainable land-use and food systems can support the energy goal by enhancing the sustainable supply of biomass, though most biomass technologies are not considered improved fuels<sup>32</sup>.
- Improved infrastructure for transport, water supply, and sanitation support sustainable development outcomes, including the energy goal.
- Urban resilience helps protect energy infrastructure against disasters and extreme climate events.

## SDG 8.

This goal focuses on economic growth and higher economic productivity, resource efficiency, full employment, and decent work, including ending all forms of forced labour, child labour, and modern slavery. Standard growth regressions<sup>24,109,110,171,172</sup> identify a number of SDG interventions as proximate drivers of economic growth that should be complemented by sound governance. Some exogenous factors, such as tropical or landlocked geography and climate can encourage or inhibit economic growth, but these effects can be mitigated through increased investments<sup>173</sup>. The single most important determinant of long-term economic growth is economic progress through innovation and adoption of new technologies (“catch-up”).

Resource efficiency can be promoted through the Principle of Circularity and Decoupling (Box 2) and is covered more extensively under SDG 12.

Employment with decent work is promoted through human capital accumulation and economic growth in conjunction with active labour market policies and social safety nets, particularly in the context of rapid technological changes<sup>22,58,107,174,175</sup>. For this reason, decent work and income support to vulnerable groups, which are promoted through social safety nets and labour standards, contribute directly to SDG 8 (rated 3).

Several intermediate SDG outputs reinforce SDG 8 (rated 2):

- Key investments in human capital, including education<sup>17</sup> and public health services<sup>111,176</sup>, increase the productivity of labour and capital<sup>16,24,107,110</sup>.
- Sustainable infrastructure is another critical driver of economic growth<sup>91,112</sup>. This includes investments in energy access for all<sup>32</sup> and power infrastructure and energy decarbonisation<sup>9</sup>, water and sanitation<sup>56</sup>, transport and mobility<sup>112</sup>, and digital technologies and infrastructure<sup>57</sup>.
- Long-term economic growth is largely determined by technological progress, which requires innovation and adoption of advanced technologies through research and development, as well as harnessing digital technologies and infrastructure<sup>24,110,172</sup>.
- Through a fall in the dependency ratio, the demographic transition provides an important impetus for human capital accumulation per child, poverty reduction, and economic growth, as has occurred in North America, Europe, Latin America, and most recently Asia<sup>17,177</sup>. The demographic transition is enabled through broad-based investments in education (particularly women’s education), public health services (sexual and reproductive health, maternal and child health), and gender equality, which collectively can support the voluntary reduction of fertility rates<sup>17,30</sup>.

- Agriculture, forestry, and fisheries are important sectors in most countries' economies, particularly among low-income countries<sup>109,110,173</sup>. Investments in sustainable land-use and food systems<sup>115–117</sup> can improve the productivity of agriculture (including livestock and aquaculture), forestry, and fisheries, which in turn supports economic growth<sup>109</sup>.
- Pollution of air, water, and soils generates high economic costs<sup>33,178</sup> that may lower long-term growth rates, though the relationship between environment and growth is complex<sup>179</sup>.

Intermediate SDG outputs that enable SDG 8 (rated 1) include:

- Social protection systems and income support to the poor.
- Urban resilience that lessens the impact of climate change and extreme events.

## SDG 9.

SDG 9 focuses on upgrading and expanding national and cross-border infrastructure, technological upgrading, and sustainable industrialisation.

Investments in infrastructure (transport, energy, and water) directly target the outcomes under this goal (rated 3). Similarly, investments in research and development drive the innovation targets under SDG 9.

Several intermediate SDG outputs reinforce SDG 9 (rated 2):

- Education and human capital are critical drivers of innovation systems<sup>180,181</sup>.
- Energy decarbonisation is a major mission<sup>180</sup> that can reinforce a country's innovation system. Moreover, decarbonised energy systems provide new infrastructure that directly reinforces SDG 9.
- Urban resilience may require substantial investments in infrastructure<sup>118,163,182</sup>.

Intermediate SDG outputs that enable SDG 9 (rated 1) include:

- Social protection systems are broadly synergistic with this goal.
- Public health services support a healthy workforce, which enables SDG 9.
- Clean air and water broadly enable SDG 9.
- Sustainable land-use and food systems are synergistic with SDG 9. They may require substantial investments in large-scale infrastructure<sup>121,123</sup>, which would directly reinforce the goal. They can also give rise to significant innovation spill-overs if pursued as mission-driven innovation challenges, as recommended in ref<sup>183</sup>.

## SDG 10.

This goal calls for equal opportunity and reduced inequalities of outcomes within countries, including ending discrimination based on social or ethnic identifiers. The goal also requires that inequalities across countries be reduced. Furthermore, it specifies a number of policy mechanisms (including migration frameworks and financial regulation) to achieve these outcomes.

Strengthening social protection systems directly targets income inequalities by redistributing income towards the poor<sup>21,107,184,185</sup> (rated 3).

All SDG interventions that aim for universal coverage of infrastructure or services reduce inequalities of outcomes and increase equality of opportunity reinforce SDG 10 (rated 2):

- One of the most important tools for reducing inequalities and lifting incomes at the bottom end of the income distribution curve are investments in universal, high-quality education and human capital<sup>18,21,76</sup>.

- Similarly, expanded public health services can reduce inequalities in outcomes and opportunities<sup>28,111,184,186</sup>.
- Access to basic infrastructure services, particularly for water, sanitation, and modern energy services, and digital technologies, can reduce inequalities in outcomes and promote equality of opportunities<sup>21,184</sup>.
- Investments in energy decarbonisation drive down greenhouse gas emissions, which reduces the impacts of climate change. Such impacts tend to affect poor people the most, so investing in decarbonisation reinforces SDG 10<sup>118</sup>.
- Sustainable land-use and food systems can increase incomes of smallholder farmers, which reinforce the inequality goal<sup>49,123</sup>.
- Urban resilience benefits the urban poor in particular and therefore reinforces this goal<sup>53,118</sup>.

Intermediate SDG outputs that enable SDG 10 (rated 1) include:

- Innovation supports economic growth, which can be a means to reduce inequalities<sup>21</sup>.
- Interventions to promote clean air and water can be synergistic with reductions in inequality.

### SDG 11.

SDG 11 focuses on implementing the SDGs in urban areas. It comprises targets on universal access to affordable housing and basic services, including basic transport solutions; safeguards to the world's natural and cultural heritage; enhanced disaster resilience; improving air quality; and access to green spaces.

Access to urban infrastructure services directly targets SDG 11, including energy access, water, sanitation, and transport (all rated 3). Interventions to promote clean air and water directly target some of the goal's targets, as do measures to enhance urban resilience.

Several intermediate SDG outputs reinforce SDG 11 (rated 2):

- Energy decarbonisation reinforces urban sustainability through clean, efficient infrastructure services. Moreover, it helps curb the rise in average global temperatures, which in turn will reduce the vulnerability of urban areas to climate-related disasters and extreme weather events<sup>2,53,163</sup>.
- Similarly, sustainable land-use and food systems target climate change mitigation, which reduces the need for investments in urban resilience<sup>2,53,163</sup>. Moreover, efficient and sustainable food systems provide nutritious food at affordable prices, which increases welfare in urban areas<sup>14,116</sup>.
- Digital technologies and infrastructure are a critical enabler of smart cities<sup>52,58</sup>.

Intermediate SDG outputs that enable SDG 11(rated 1) include:

- Education and human capital enable safe, resilient, and sustainable cities.
- Decent work and income support for vulnerable groups can support slum upgrading and reduce poverty in urban areas.
- Innovation is a broad enabler of Transformation 5 to urban sustainability.
- Public health services also enable sustainable development in urban areas.

### SDG 12.

This goal calls for changing consumption and production patterns to ensure sustainable management of all natural resources by 2030. It includes specific targets on halving food waste, life-cycle management of chemicals, and prevention of waste generation through recycling and reuse.

The framing of sustainable consumption, as described in SDG 12, is broad. It targets all activities that affect the use of natural resources or generate waste<sup>187</sup> (Box 2). Conversely, all related interventions contribute towards meeting SDG 12.

Energy decarbonisation targets SDG 12 directly (rated 3) as it decouples energy use from greenhouse gas emissions and other resource implications. Similarly, interventions to promote clean air and water target the goal directly. The same applies to investments in sustainable land-use and food systems, which inter alia reduce food loss and food waste, lower greenhouse gas emissions, and increase the efficiency of agriculture with regards to water, fertiliser, and other inputs. In the same way, infrastructure for transport, water supply, sanitation, and sewage target SDG 12 directly.

Several intermediate SDG outputs reinforce SDG 12 (rated 2):

- Many solutions for decoupling resource use from human wellbeing are insufficient or not widely known<sup>11,40,122,123,187</sup>. Investments in research and development reinforce SDG 12 by improving technologies and supporting their adoption.
- Access to clean energy can increase resource efficiencies by shifting away from the unsustainable use of biomass<sup>32,164</sup>.
- Digital technologies and infrastructure are critical instruments for increasing resource efficiency through all sectors of society<sup>57,58,134,187</sup>.

Intermediate SDG outputs that enable SDG 12 (rated 1) include:

- Education and human capital are synergistic as they help raise awareness of sustainable consumption and production.
- Decent work and income support for sustainable groups are also synergistic with SDG 12 as they improve people's ability to participate in, and support the transformations in, material use and resource efficiencies needed to achieve the goal.
- If implemented pursuant to the Principle of Circularity and Decoupling (Box 2), interventions to promote public health will also increase resource use efficiency in the health sector, which constitutes an important part of countries' economies.
- Finally, urban resilience maintains and improves the functioning of urban areas, which supports them in increasing resource use efficiencies.

### SDG 13.

SDG 13 acknowledges the UNFCCC negotiations as the "primary international, intergovernmental forum for negotiating the global response to climate change"<sup>85</sup>. Following the adoption of the Paris Climate Agreement<sup>188</sup>, the targets under SDG 13 were not revised to take into account its outcomes. The goal is therefore widely interpreted as covering the agreements reached in Paris, principally to keep the global rise in average global temperatures to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels. Moreover, the Agreement calls for increased investments in adaptation to climate change<sup>188</sup>.

To meet the "well below 2°C" objective, global greenhouse gas emissions need to fall to zero by mid-century. This requires the decarbonisation of energy systems as well as sustainable land-use and food systems, which account for over a quarter of greenhouse gas emissions<sup>2</sup> (both rated 3). Access to affordable modern energy services is required to ensure the feasibility of long-term decarbonisation and to ensure the social acceptability of long-term transformations towards zero carbon emissions<sup>32,64,189</sup>, particularly in view of the highly unequal distributional impacts of climate change<sup>165</sup> and the likely impacts on employment<sup>190,191</sup>.

Urban resilience directly targets the adaptation objectives of SDG 13<sup>2,53</sup> (rated 3).

Several intermediate SDG outputs reinforce SDG 13 (rated 2):

- Given the unequal distributional impact of climate change<sup>165</sup>, social protection and labour standards can help mitigate the social cost of the decarbonisation of energy systems and the shift towards sustainable land-use and food systems<sup>39,64,108</sup>.
- While the technologies exist to decarbonise energy systems, innovation is required to further bring down their costs and increase efficiency<sup>9,11,166,167</sup>. Meanwhile spending on innovation for the low-carbon transition is low<sup>167,192,193</sup>.
- Clean air reinforces the climate goal, including through the suppression of short-term climate pollutants<sup>2,33</sup>.
- The sustainable design and operation of infrastructure for transport, water and sanitation reduces air pollution, which reinforces SDG 13<sup>2,33</sup>.
- Digital technologies and infrastructure play a critical role in decarbonising energy systems, including through the Internet of Things, and thereby reinforce Goal 13 (refs.<sup>11,167</sup>).

Intermediate SDG outputs that enable SDG 13 (rated 1) include:

- Improved education and human capital are synergistic with the outcomes of SDG 13.

#### SDG 14.

SDG 14 calls for reducing marine pollution and ensuring the safe management of marine and coastal ecosystems, including the conservation and restoration of biodiversity. A particular focus is placed on sustainable fisheries.

The most direct inputs for this goal are SDG interventions under sustainable land-use, oceans, and food systems. This includes marine biodiversity conservation and management<sup>127,194</sup>, effective regulation of fisheries<sup>47,117,128,195</sup>, and shifts towards sustainable diets<sup>14</sup> (rated 3). Land-based activities also contribute substantially to SDG 14, particularly by providing alternatives to protein from wild ocean catch<sup>13,14</sup>, and by reducing inflows of sediment, phosphorous, and nitrogen<sup>44,122</sup>. The second direct contributor to SDG 14 comes from interventions to promote clean air and water<sup>56</sup> (rated 3).

Several intermediate SDG outputs reinforce SDG 14 (rated 2):

- Social protection and labour standards help reduce poverty, which, through small-scale artisanal fishing practices, can be a driver of degradation of coastal and marine ecosystems<sup>195,196</sup>.
- One of the greatest threats to marine ecosystems is global warming, which threatens corals and many other marine ecosystems<sup>2,196,197</sup>. High carbon dioxide concentrations lead to ocean acidification<sup>2</sup>, so mitigating climate change and reducing carbon dioxide emissions through the decarbonisation of energy systems reinforces SDG 14.
- The sustainable design and operation of infrastructure for water and sanitation directly reduces water pollution<sup>56</sup>, which reinforces this goal.

Intermediate SDG outputs that enable SDG 14 (rated 1) include:

- Improved education and human capital are synergistic with the improved management of marine biodiversity and ecosystem services.
- Increased innovation supports novel and improved approaches to the monitoring, conservation, and restoration of marine ecosystems.
- Improved access to modern energy services helps improve land-use, reducing siltation and other pollution into marine ecosystems.



- Digital technologies and infrastructure can enhance the monitoring of biodiversity and ecosystem loss and reduce the cost of conservation and restoration efforts in coastal and marine areas.

## SDG 15.

Goal 15 focuses on the Aichi Biodiversity Targets adopted under the Convention on Biological Diversity (CBD), as they relate to terrestrial ecosystems. These targets call for efforts to conserve and restore critical ecosystems.

Sustainable land-use and food systems directly target the achievement of this goal (rated 3). In particular, efforts to increase protected areas and to scale up restoration make a direct contribution<sup>198,127,199</sup>. This intermediate outcome covered under Transformation 4 also addresses agriculture and food demand, which are the two principal drivers of ecosystem degradation and biodiversity loss<sup>13,14,98,123</sup>.

Clean air and water constitute a second intermediate output that directly supports the target outcomes of SDG 15<sup>33,34</sup> (rated 3).

Several intermediate SDG outputs reinforce SDG 15 (rated 2):

- Social protection and labour standards help reduce poverty, which is an important driver of deforestation and other ecosystem losses<sup>200</sup>.
- When people lack access to modern energy services for cooking, they consume biomass and charcoal, which can be an important driver of forest fragmentation and deforestation, particularly in developing countries<sup>33,164,201</sup>. Improving access to modern energy services therefore reinforces SDG 15.
- Decarbonising energy systems is critical for mitigating climate change, which is an important driver of ecosystem degradation and biodiversity loss<sup>2,202–204</sup>. Consequently, decarbonising energy systems reinforces SDG 15.
- The sustainable design and operation of infrastructure for transport<sup>205</sup>, water and sanitation<sup>56</sup> reinforces this goal.

Intermediate SDG outputs that enable SDG 15 (rated 1) include:

- Improved education and human capital are synergistic with the improved management of terrestrial biodiversity and ecosystem services.
- Increased innovation supports novel and improved approaches to the monitoring, conservation, and restoration of terrestrial ecosystems.
- Digital technologies and infrastructure can enhance the monitoring of biodiversity and ecosystem loss and reduce the cost of conservation and restoration efforts.

## SDG 16.

SDG 16 calls for reductions in violence; ending abuse of and violence against children; promoting domestic and international rule of law, including the fight against organised crime and illicit financial flows; promoting transparent, representative, and accountable institutions and decision-making that curb corruption and provide open access to information; and ensuring legal identity for all, including birth registrations.

As described in the paper, these principles of good governance contribute towards achieving all SDGs and underpin the six SDG Transformations. Hence no SDG intervention considered in this paper directly targets SDG 16. Two intermediate outputs reinforce some SDG 16 targets: Education and UHC (rated 2).



Education empowers children and can reduce violence against children<sup>206,154</sup>. Vital registrations are usually administered through health systems, so UHC offers an effective way to ensure universal birth registration<sup>207,208</sup>. Governance affects development outcomes and vice versa<sup>113,209</sup>. As a result, other SDG interventions enable SDG 16 (rated 1).

### SDG 17.

This goal focuses on domestic and international development finance, international cooperation on technology and diffusion, a rules-based international trade system with preferential treatment for the least developed countries (LDCs), and systemic governance issues. These areas constitute means of implementation for the SDGs. In other words, this goal largely serves as an input into supporting SDG interventions and achieving the other SDGs. No SDG intervention directly targets SDG 17.

Increased innovation, including through greater spending on research and development, as well as digital technologies and infrastructure, both reinforce the technology-related targets of SDG 17 (rated 2). In particular, applying research and development spending and the digital revolution to solving technology challenges for SDG implementation will reinforce the global partnership for development. Technology missions, as described in the paper, provide an operational framework for mobilising and developing technologies for the SDGs<sup>25</sup>.

Several intermediate SDG outputs broadly enable SDG 17 (rated 1): Education and human capital contribute to societies' abilities to innovate and to adopt new technologies from abroad. Long-term investments and policy frameworks for climate change mitigation (including energy decarbonisation and sustainable land-use systems) support greater investments in emission-reduction technologies and their diffusion. They also strengthen the multilateral partnership for sustainable development.

## Annex 2: Method for designing Sankey Diagram (Figure 2)

To design the Sankey diagram, we raise the scores reported in Table 1 to the power of two in order to highlight the far greater contribution interventions rated 3 make to achieving the respective SDGs in comparison to interventions rated 1. Each intervention in Table 1 is weighted equally, and to account for differences in the number of interventions across Transformations, we divide each intervention score by the total number of interventions included in the Transformation. Adding up the weighted scores for each intermediate output yields the results in presented in Table 2.

*Table 2 | Scores used for constructing the Sankey Diagram (Figure 2)*

Transformation	Intermediate outputs	SDG 1	SDG 2	SDG 3	SDG 4	SDG 5	SDG 6	SDG 7	SDG 8	SDG 9	SDG 10	SDG 11	SDG 12	SDG 13	SDG 14	SDG 15	SDG 16	SDG 17
1	Education and human capital	2.4	0.6	2.4	5.4	5.4	0.6	0.6	2.4	2.4	2.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6
1	Decent work and income support to vulnerable groups	1.8	1.8	0.8	0.2	0.8	0.2	0.8	1.8	0.2	1.8	0.2	0.2	0.8	0.8	0.8	0.2	0
1	Innovation	0.2	0.8	0.2	0.2	0.2	0.2	0.8	0.8	1.8	0.2	0.2	0.8	0.8	0.2	0.2	0.2	0.8
2	Public health services	4	9	9	4	9	0	0	4	1	4	1	1	0	0	0	1	0
3	Energy access for all	0.8	0.2	0.8	0.8	0.8	0.2	1.8	0.8	1.8	0.8	1.8	0.8	1.8	0.2	0.8	0.2	0
3	Energy decarbonisation	0.6	2.4	2.4	0	0.6	2.4	5.4	2.4	2.4	2.4	2.4	5.4	5.4	2.4	2.4	2.4	0.6
3	Clean air and water	0.2	0.2	1.8	0.2	0.2	1.8	0.2	0.8	0.2	0.2	1.8	1.8	0.8	1.8	1.8	0.2	0.2
4	Sustainable land-use, oceans, and food systems	4	9	9	1	4	9	1	4	1	4	4	9	9	9	9	1	1
5	Transport, water and sanitation infrastructure services	3	3	3	3	3	6.8	0.8	3	6.8	3	6.8	6.8	3	3	3	0	0
5	Urban resilience	0.3	0.3	0.3	0.3	0.3	1	0.3	0.3	1	1	2.3	0.3	2.3	0	0	0.3	0
6	Digital technologies and infrastructure	4	4	4	4	1	1	4	4	9	4	4	4	4	1	1	1	4

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