

A Doughnut for the Anthropocene:
humanity's compass in the 21st century

by Kate Raworth

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A Doughnut for the Anthropocene: humanity's compass in the 21st century



A new model of human wellbeing is emerging to guide humanity in the Anthropocene. In essence, it recognises that wellbeing depends on enabling every person to lead a life of dignity and opportunity, while safeguarding the integrity of Earth's life-supporting systems. The conceptual framework of social and planetary boundaries—which has come to be known as the Doughnut—contributes to this paradigm by concisely visualising its ambition (appendix), and so providing a compass for humanity's 21st century progress.

Since I created the Doughnut at Oxfam in 2012,¹ it has been widely applied within academia, policymaking, progressive business, urban planning, and civil society as a tool for reconceptualising sustainable development.²⁻⁶ Here I present a renewed and strengthened framework, based on recent advances in both internationally agreed social standards and in Earth-system science, which respectively provide the basis for establishing the Doughnut's social and ecological boundaries.

The Doughnut combines two concentric radar charts to depict the two boundaries—social and ecological—that together encompass human wellbeing (figure). The inner boundary is a social foundation, below which lie shortfalls in wellbeing, such as hunger, ill health, illiteracy, and energy poverty. Its twelve dimensions and their illustrative indicators are derived from internationally agreed minimum standards for human wellbeing, as established in 2015 by the Sustainable Development Goals adopted by all member states of the United Nations.⁷

The Doughnut's outer boundary is an ecological ceiling, beyond which lies an overshoot of pressure on Earth's life-supporting systems, such as climate change, ocean acidification, and biodiversity loss. Its nine dimensions and their indicators are defined by the planetary boundaries framework, which seeks to identify and safeguard critical processes that regulate Earth's ability to sustain Holocene-like conditions, and this framework was likewise revised in 2015.⁸ Between these two sets of boundaries lies an ecologically safe and socially just space in which all of humanity has the chance to thrive (appendix).

By quantifying and visualising the global scale of shortfalls and overshoot, the Doughnut acts as a concise compass for assessment of the current state of human wellbeing (the appendix contains the full data and methods).

Millions of people currently lead lives that fall far short of the social foundation's internationally agreed minimum standards, ranging from nutrition and health care to housing, income, and energy. At the same time, human activity has led to overshoot for at least four planetary boundaries: climate change, biodiversity loss, nitrogen and phosphorus loading, and land conversion. Improving humanity's wellbeing this century depends on eliminating this social shortfall and ecological overshoot simultaneously (figure).

The Doughnut raises four key implications for the pursuit of human wellbeing in the Anthropocene. First,

See Online for appendix

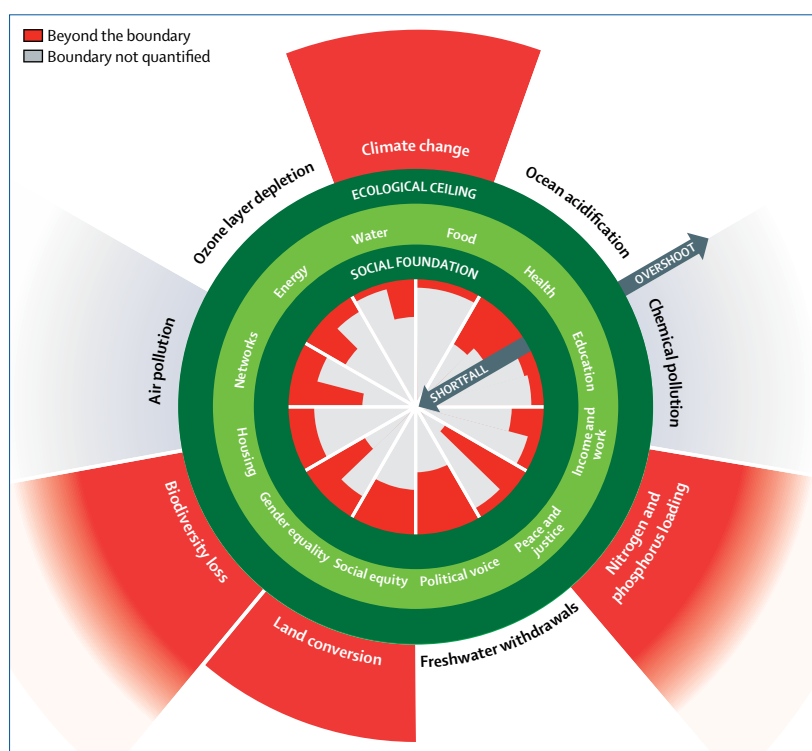


Figure: Shortfalls and overshoot in the Doughnut
 Dark green circles show the social foundation and ecological ceiling, encompassing a safe and just space for humanity. Red wedges show shortfalls in the social foundation or overshoot of the ecological ceiling. The extent of pressure on planetary boundaries that are not currently being overshoot is not shown here (see appendix for all graphics).

it highlights the dependence of human wellbeing on planetary health. The Holocene is the only epoch in Earth's history in which it is known that humanity can thrive.⁹ The best chance of enabling a life of dignity and opportunity for more than 10 billion people over the coming century therefore depends on sustaining Holocene-like conditions, such as a stable climate, clean air, a protective ozone layer, thriving biodiversity, and healthy oceans. Second, the concurrent extent of social shortfall and ecological overshoot reflects deep inequalities—of income and wealth, of exposure to risk, of gender and race, and of political power—both within and between countries. The Doughnut helps to focus attention on addressing such inequalities when both theorising and pursuing human wellbeing. Third, the Doughnut implies the need for a deep renewal of economic theory and policymaking so that the continued widespread political prioritisation of gross domestic product growth is replaced by an economic vision that seeks to transform economies, from local to global, so that they become regenerative and distributive by design, and thus help to bring humanity into the Doughnut.¹⁰ Last, the Doughnut might act as a 21st century compass, but the greater task is to create an effective map of the terrain ahead. Thanks to ongoing socioecological systems research, this century is likely to be the first in which humanity begins more fully to understand and appreciate the complex interdependence of human wellbeing and planetary health.

Kate Raworth

Environmental Change Institute, Oxford University, Oxford
OX1 3QY, UK
kate.raworth@ouce.ox.ac.uk

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- 1 Raworth K. A safe and just space for humanity: can we live within the doughnut? 2012. <https://www.oxfam.org/sites/www.oxfam.org/files/dp-a-safe-and-just-space-for-humanity-130212-en.pdf> (accessed Feb 20, 2017).
- 2 Dearing J, Wang R, Zhang K, et al. Safe and just operating spaces for regional social-ecological systems. *Glob Environ Change* 2014, **28**: 227–38.
- 3 Costanza R, Alperovitz A, Daly HE, et al. Building a sustainable and desirable economy-in-society-in-nature, United Nations Division for Sustainable Development. 2012. https://sustainabledevelopment.un.org/content/documents/Building_a_Sustainable_and_Desirable_Economy-in-Society-in-Nature.pdf (accessed Feb 20, 2017).
- 4 Article 13. Planetary boundaries and social thresholds: how do companies measure up? A practitioner's perspective. 2016. <http://www.article13.com> (accessed Feb 20, 2017).
- 5 City Think Space. Kokstad and Franklin integrated sustainable development plan. 2012. https://issuu.com/city_think_space/docs/kisd_p_final_report (accessed Feb 20, 2017).
- 6 Sayers M, Trebeck K. The UK doughnut: a framework for environmental sustainability and social justice. 2015. <http://policy-practice.oxfam.org.uk/publications/the-uk-doughnut-a-framework-for-environmental-sustainability-and-social-justice-344550> (accessed Feb 20, 2017).
- 7 UN Department of Economic and Social Affairs. Sustainable development goals. <https://sustainabledevelopment.un.org/?menu=1300> (accessed Feb 20, 2017).
- 8 Steffen W, Richardson K, Rockström J, et al. Planetary boundaries: guiding human development on a changing planet. *Science* 2015; **347**: 736.
- 9 Rockström J, Steffen W, Noone K, et al. Planetary boundaries: exploring the safe operating space for humanity. *Nature* 2009; **461**: 472–75.
- 10 Raworth K. *Doughnut economics: seven ways to think like a 21st century economist*. London: Penguin Random House, 2017.

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Supplementary appendix

This appendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

Supplement to: Raworth K. A Doughnut for the Anthropocene: humanity's compass in the 21st century. *Lancet Planet Health* 2017; **1**: e48–49.

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A Doughnut for the Anthropocene Appendix

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1. Introduction.

The Doughnut of social and planetary boundaries combines two concentric radar charts to create a concise visualization of the dual conditions – social and ecological – that together underpin human wellbeing. The social foundation demarks the Doughnut’s inner boundary, below which lies critical human deprivation, while the ecological ceiling demarks its outer boundary, beyond which lies critical planetary degradation in terms of stress on major Earth-system processes. Between the two sets of boundaries lies the ecologically safe and socially just space for humanity (Figure A1).

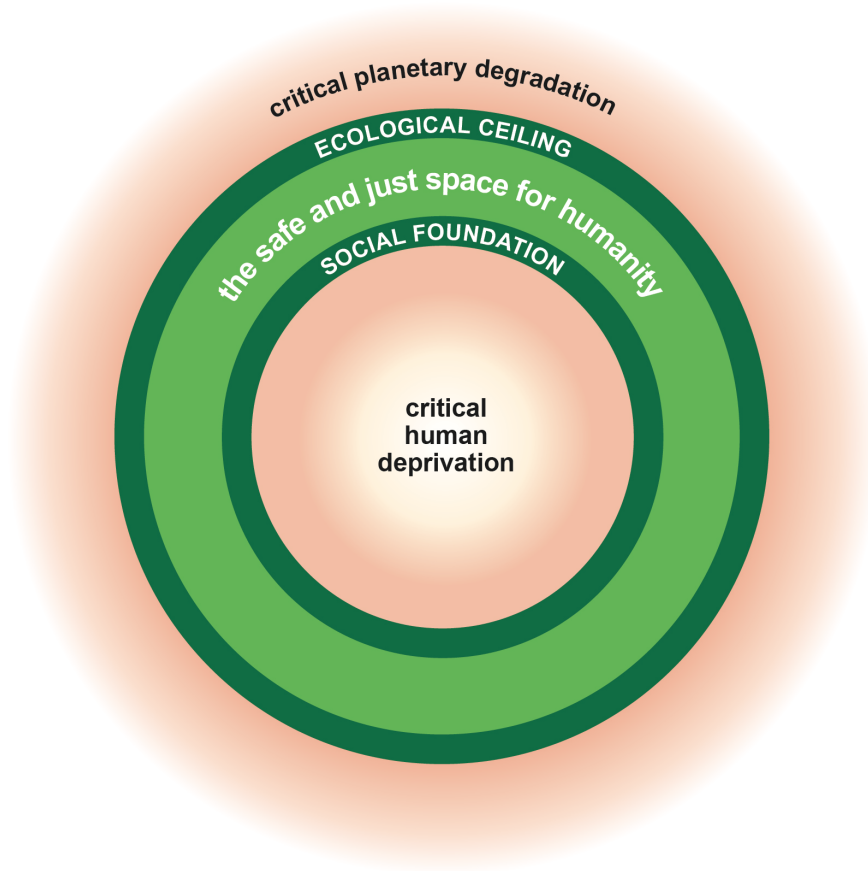
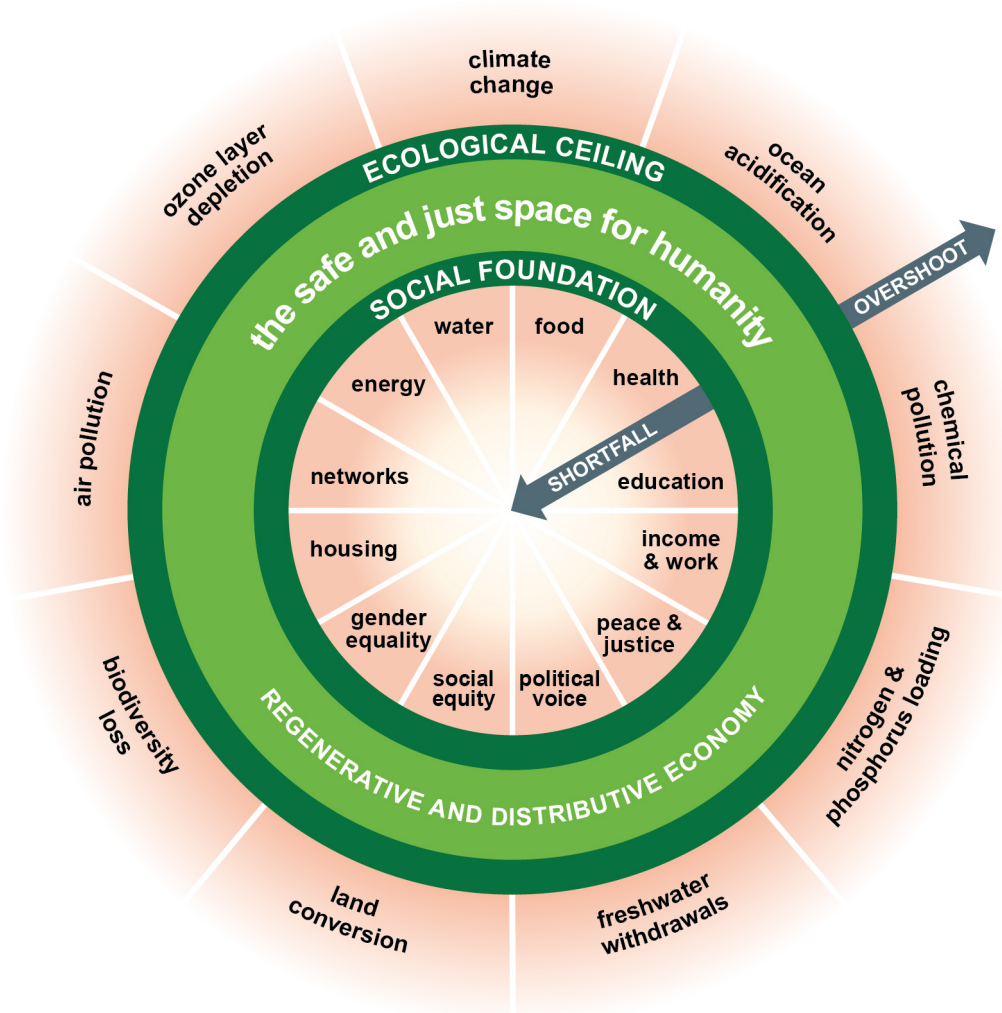


Figure A1. Conceptualizing the safe and just space for humanity

An initial iteration of the Doughnut was published in 2012. In that first version, the social foundation’s dimensions were determined by the social priorities set out in the official submissions made by the world’s governments to the 2012 United Nations Conference on Sustainable Development in Rio de Janeiro (Raworth 2012). The ecological ceiling (then labeled ‘environmental ceiling’) was defined by the first iteration of the planetary boundaries framework (Rockström et al 2009).

In light of 2015’s unprecedented political ambition on global sustainable development, and significant updating of the planetary boundaries framework, I have substantially renewed and strengthened the Doughnut framework, including by adding new social dimensions and indicators, and by using the most recent available data, resulting in a contemporary depiction of humanity’s 21st century challenge (Figure A2). This appendix sets out the criteria and methods used for doing so.



A2. The Doughnut of social and planetary boundaries.

2. The Social Foundation

The dimensions of the Doughnut’s social foundation are derived from the social priorities established in the internationally agreed Sustainable Development Goals (UN 2015). Indicators for assessing the current status of each of the twelve social dimensions are selected against the following five clusters of criteria: globally relevant indicators that serve as effective proxies for broader concerns; sufficiently recent data with extensive international coverage; a focus on monitoring global deprivations (as opposed to national averages), indicators that have been selected for monitoring the Sustainable Development Goals, and indicators that have officially recognised thresholds of minimum acceptable standards. A maximum of two indicators are used for illustrating each dimension of the social foundation (Figure A3).

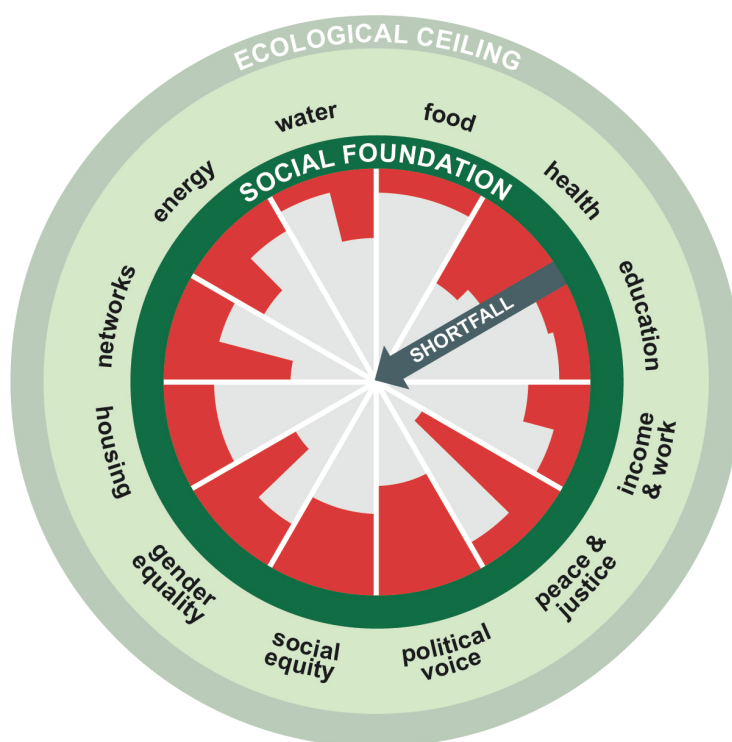


Figure A3: Shortfalls below the social foundation. Shortfalls in each of the twelve dimensions of the social foundation are quantified using one or two indicators. Each indicator illustrates the extent of shortfall, with the social foundation boundary signifying 0% shortfall and the centre of the circle signifying 100%. For complete data see Table 1.

Table 1. The Social Foundation and its indicators of shortfall

Dimension	Illustrative indicators (% of global population unless otherwise stated)	%	Year	Data source
Food	Population undernourished	11	2014-16	FAO
Health	Population living in countries with under-five mortality rate exceeding 25 per 1,000 live births	46	2015	World Bank
	Population living in countries with life expectancy at birth of less than 70 years	39	2013	World Bank
Education	Adult population (aged 15+) who are illiterate	15	2013	UNESCO
	Children aged 12-15 out of school	17	2013	UNESCO
Income & Work	Population living on less than the international poverty line of \$3.10 a day	29	2012	World Bank
	Proportion of young people (aged 15-24) seeking but not able to find work	13	2014	ILO
Water & Sanitation	Population without access to improved drinking water	9	2015	WHO/UNICEF
	Population without access to improved sanitation	32	2015	WHO/UNICEF
Energy	Population lacking access to electricity	17	2013	OECD/IEA
	Population lacking access to clean cooking facilities	38	2013	OECD/IEA
Networks	Population stating that they are without someone to count on for help in times of trouble	24	2015	Gallup
	Population without access to the Internet	57	2015	ITU
Housing	Proportion of global urban population living in slum housing in developing countries	24	2012	UN

Gender equality	Representation gap between women and men in national parliaments	56	2014	World Bank
	Worldwide earnings gap between women and men	23	2009	ILO
Social equity	Population living in countries with a Palma ratio of 2 or more (the ratio of the income share of the top 10% of people to that of the bottom 40%)	39	1995-2012	World Bank
Political voice	Population living in countries scoring 0.5 or less out of 1.0 in the Voice and Accountability Index	52	2013	World Bank
Peace & justice	Population living in countries scoring 50 or less out of 100 in the Corruption Perceptions Index	85	2014	Transparency International
	Population living in countries with a homicide rate of 10 or more per 10,000	13	2008-13	UNODC

All percentages are rounded to the nearest decimal.

The indicators selected for each of the twelve dimensions are presented below, along with their limitations.

Food

Ending hunger and achieving food security is the focus of SDG Goal 2. Here undernourishment is assessed in terms of inadequate caloric intake. The indicator used, as defined by the UN FAO, is the probability that a randomly selected individual from the population consumes below the minimum dietary energy requirement, which varies by gender and age, and for different levels of physical activity. Data are given as a three-year average for 2014-16 (FAO 2015a).

These data would ideally be accompanied by an indicator of malnourishment to reflect the lack of nutrient balance in many people's diets. An internationally comparable indicator of women's dietary diversity is currently under development but data are not yet available globally (FAO 2015b). In future it will provide a highly valuable complementary measure.

Health

Ensuring healthy lives and promoting wellbeing for all is the focus of SDG Goal 3. Two indicators are used here to assess shortfalls in access to health care: under-five child mortality and life expectancy at birth, both selected for being recognised proxies for wider health outcomes.

The under-five mortality rate is the probability per 1,000 that a newborn baby will die before reaching age five, based on age-specific mortality rates of the specified year. Data are given for 2015 (World Bank 2015b). The benchmark is the international target for all countries to reduce under-five mortality to at least as low as 25 per 1,000 live births by 2030 (WHO 2015).

Life expectancy at birth indicates the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life. Data are given for 2013 (World Bank 2015b). No equivalent international benchmark has been established. A life expectancy at birth of 70 years is selected here as a benchmark, being an outcome typically achieved by countries classified under medium human development according to UNDP's Human Development Index (UNDP 2015).

Education

Ensuring quality education and lifelong learning opportunities for all is the focus of SDG Goal 4. Here, two indicators for educational deprivations are used so as to reflect achievements and outcomes across diverse population age groups.

For the school-aged population, the proportion of adolescents not enrolled in lower secondary school (typically ages 12 to 15 years) is used. Data are given for 2013 (UNESCO 2015a).

For the adult population, the chosen indicator is the rate of adult illiteracy, defined as adults aged over 15 years who are unable to read and write a simple sentence. Data are given for 2013 (UNESCO 2015b).

Income and Work

Ending poverty, including income poverty, is the focus of SDG 1 and promoting decent work is among the commitments of SDG 8. Deprivation in terms of income is assessed with the internationally established poverty line of \$3.10 per person per day, calculated by the World Bank on the basis of purchasing power parity at 2011 prices. Data are given for

2012 (World Bank 2015a). This indicator is used instead of the often-cited extreme poverty line of \$1.90 per person per day (popularly known as the ‘dollar a day’ measure) because the cut-off point for extreme poverty does not constitute a social foundation of income for a life of dignity and opportunity.

Given the importance of paid work as a means to income, and its centrality in many people’s lives, it would be highly desirable to include a composite indicator of decent work, defined as ‘the opportunity of women and men to obtain decent and productive work in conditions of freedom, equity, security and human dignity’ (ILO 1999). However such a composite indicator is not yet available. As a proxy indicator for assessing the availability of work, youth unemployment is used instead, measuring the proportion of young people (aged 15-24) who are seeking but unable to find work (ILO 2015). It is likely, however, to undercount those youth who, through force of poverty and circumstance, must accept any work, no matter how poorly paid or exploitative.

Water & sanitation

Ensuring safe water and adequate sanitation for all is the focus of SDG 6. Deprivations in access to water and sanitation services are assessed here on the basis of two widely used indicators.

Inadequate access to water is given by the proportion of people who do not have access to an improved drinking water source, such as piped household water, public taps, protected wells and springs, or collected rainwater.

Inadequate access to sanitation is given by the proportion of people who do not have access to improved sanitation facilities such as flush toilets, ventilated improved pit latrines, or composting toilets. For both indicators, data are given for 2015 (WHO/UNICEF 2015).

Energy

Ensuring access to energy for all is the focus of SDG 7. Deprivations in access to energy assessed here include both electricity and the quality of cooking facilities.

Inadequate access to electricity is assessed as the proportion of people who do not enjoy a household electricity supply accompanied by a minimum level of electricity consumption. In rural areas the specified minimum per household is 250 kWh per year, which provides, for example, for the use of a floor fan, a mobile phone, and two compact fluorescent light bulbs for about five hours per day. In urban areas, the specified minimum per household is 500 kWh per year, for which consumption might additionally include an efficient refrigerator, a second mobile telephone, and another appliance such as a computer or small television.

Inadequate cooking facilities are assessed as the proportion of people who do not have access to electricity and who rely on the traditional use of solid biomass (such as fuelwood, charcoal, tree leaves, crop residues and animal dung) for cooking. For both indicators, data are given for 2013 (OECD/IEA 2015).

Networks

Digital communications networks and person-to-person social support networks are both important means of generating opportunity, building community and increasing resilience, and they tend to be mutually supportive. In the context of the SDGs, Target 9.c promotes ‘universal and affordable access to the Internet’ and Target 1.5 commits to ‘build the resilience of the poor and those in vulnerable situations’.

Here, deprivation in terms of access to digital communications networks is assessed as the proportion of people not using the Internet, and estimated global data are given for 2015 (ITU 2015). These estimates are derived from data on the percentage of households with Internet access at home, and so overestimate the shortfall. Future international data will preferably also take account of users of public Internet access, such as through libraries, post offices, community centres, Internet cafes, and schools (ITU 2014).

Deprivation in terms of lacking a network of social support is assessed here on the basis of self-reported data through the Gallup World Poll survey. Conducted in 140 countries, the survey asks the question, ‘If you were in trouble, do you have relatives or friends you can count on to help you whenever you need them, or not?’ Data are given for 2015 (Gallup World Poll).

Housing

Ensuring safe and affordable housing and upgrading slums is central to SDG 11. Internationally comparable data on housing conditions are currently limited to the proportion of the urban population in developing countries who are living in slums. Such slum housing is defined as having at least one of the following four characteristics: lack of access to improved drinking water; lack of access to improved sanitation; overcrowding (more than three persons per room); and dwellings made of non-durable material. Given this definition, there will be some overlap with indicators assessing deprivations in access to improved water and sanitation. Here the data are expressed as the proportion of the global urban population that is living in slum conditions in developing countries. Data are given for 2012 (UN 2014).

Given that just under half of the global population lives in rural areas, a highly desirable complementary indicator for assessing housing deprivation would address the conditions of rural housing but such an indicator has not yet been developed. Data on the percentage of people living in inadequate housing conditions, both urban and rural, in high-income countries would also be desirable to include.

Social equity

Reducing inequality within and among countries is the focus of SDG 10. Here the shortfall in social equity is measured on the basis of national income inequalities. The indicator used is the Palma ratio, which is the ratio of the income of the top 10% to that of the bottom 40% within a nation. The Palma ratio is chosen here over the Gini coefficient because it is more sensitive to inequalities of income at the extremes of wealth and poverty (Cobham, Schlogl and Sumner 2015). A benchmark is set at a Palma ratio of 2, which occurs when the richest 10% in a country have double the annual income of the poorest 40%, and is equivalent to a Gini coefficient of approximately 0.35 (Cobham and Sumner, 2013). Hence the indicator gives the proportion of the global population that lives in countries in which the Palma ratio is 2 or greater. Data are given for the most recent available year, 1995-2012 (World Bank 2015b)

Gender equality

Achieving gender equality and empowering all women and girls is the focus of SDG 5. It would be ideal to assess the extent of gender inequality in each of the social foundation's dimensions but as proxy measures, two indicators are chosen which are indicative of inequalities in women and men's roles and status in political and economic life.

For assessing inequalities in the political realm, the indicator is derived from the proportion of seats held by women in national parliaments. Data are given for 2014 (World Bank 2015b). The indicator value is calculated such that if women held no parliamentary seats globally, the deprivation would be 100%, whereas if women held exactly half of all parliamentary seats, the deprivation would be 0%.

For assessing inequalities in the economic realm, the gender pay gap is used, which is based on survey data from a diverse sample of 48 countries. Data are given for 2008-09. The indicator is the percentage gap between women and men's pay, based on international estimates of women's earnings as a proportion of men's (ILO 2011).

Gender inequalities and income inequalities are of course just two among many dimensions of social inequality. Internationally comparable indicators of inequalities based on other social differences, such as ethnicity, age, religion, disability, language, sexual orientation, and location, would also be desirable for inclusion.

Political voice

Ensuring 'responsive, inclusive, participatory and representative decision-making at all levels' is the focus of SDG Target 16.7. The indicator used here as a proxy for the shortfall of political voice is the Voice and Accountability Index, which is a component of the World Bank's Worldwide Governance Indicators. The Index is scored on a scale of 0 (very poor performance) to 1 (very high performance) and includes measures of democracy, vested interests, accountability of public officials, human rights, and freedom of association. It is created through expert assessment by over 500 correspondents and is reviewed for consistency by a panel of regional experts. Data are given for 2013 (World Bank 2015c). Here, a benchmark is set at 0.5, hence the social foundation indicator denotes the proportion of the global population living in countries with a score of 0.5 or less on the Voice and Accountability Index.

Peace & justice

Promoting peaceful and inclusive societies and providing access to justice for all are both central to SDG 16. Two indicators are used here in order to assess shortfalls in peace and in justice respectively.

The indicator used as a proxy for the shortfall in peace is the rate of intentional homicide, which is unlawful death purposefully inflicted on a person by another person. It does not include killings in war or conflicts, however an indicator that did also take account of these would be preferable. A benchmark is set at 10 or more homicide deaths per 100,000 population per year and data are given for the most recent year, 2008-2013 (UNODC 2015).

The indicator used as a proxy for shortfall in justice is Transparency International’s Corruption Perceptions Index, which scores countries according to how corrupt their public sector is perceived to be, on a scale of 0 (highly corrupt) to 100 (very clean). National scores are compiled using data sources from independent institutions specialising in governance and business climate analysis. Data are given for 2014 (Transparency International 2014). Here, a benchmark is set at a score of 50 or below, hence the social foundation indicator denotes the proportion of the world’s population living in countries that score 50 or less in the Corruption Perceptions Index.

3. The Ecological Ceiling

The Doughnut’s ecological ceiling is defined by the framework of planetary boundaries, specifically its nine critical Earth-system processes, which are explained in non-technical terms below. Several of the boundary names have been altered to make them more accessible to a wide public audience, however the control variables, boundary levels, and data are drawn directly from Steffen et al 2015. In accordance with the precautionary principle, the ecological ceiling’s boundary is defined as the crossover between the safe zone and the zone of uncertainty as described in Steffen et al 2015, and as illustrated in Figure A4.

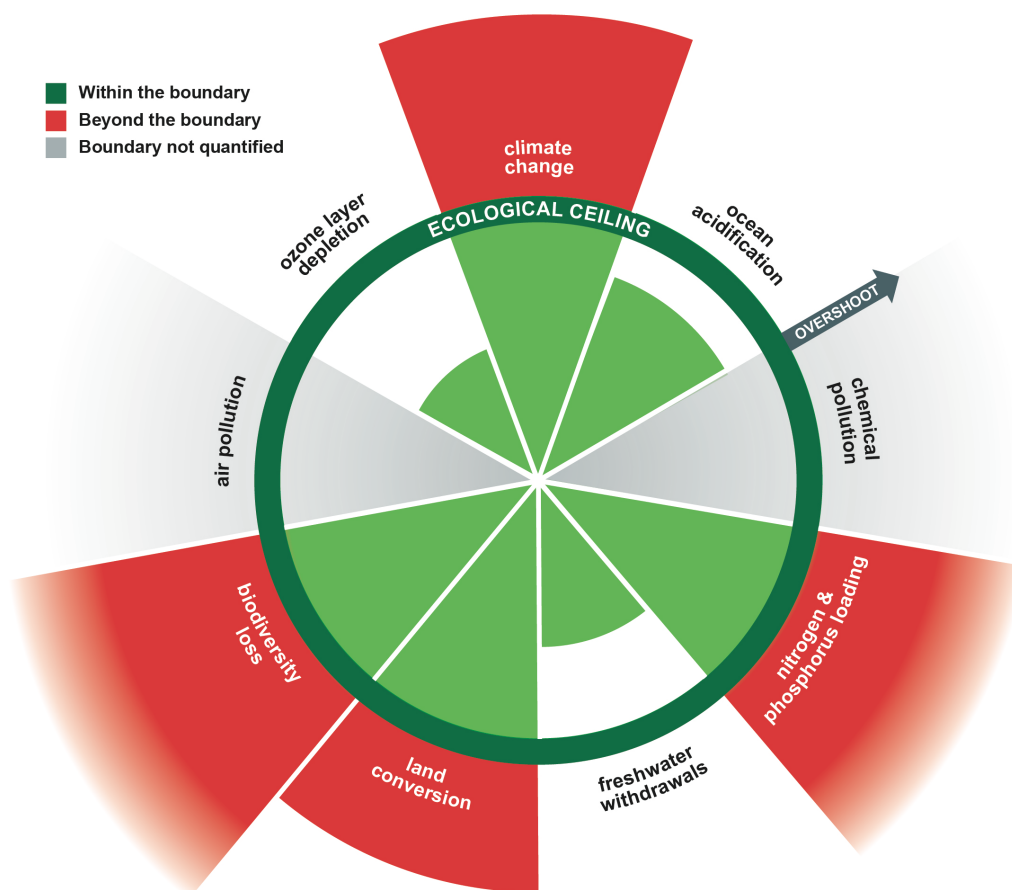


Figure A4: Overshoot of the planetary boundaries. *The current extent of anthropogenic pressure on each of the critical Earth system processes is quantified, using either one or two variables for each of the nine dimensions of the ecological ceiling. The centre of the circle demarks the pre-industrial state of each Earth-system process (0% pressure) and the ecological ceiling demarks the point of transition (100%) between the safe zone within the boundary and the risk zone beyond the boundary.*

Table 2. The Ecological Ceiling and its indicators of overshoot

Earth-system pressure	Control Variable	Planetary boundary	Current value and trend	Current value as % of the planetary boundary
Climate change	Atmospheric carbon dioxide concentration, parts per million	At most 350ppm	400ppm and rising (worsening)	169%
Ocean acidification	Average saturation of aragonite (calcium carbonate) at the ocean surface, as a percentage of pre-industrial levels	at least 80% of pre-industrial saturation levels	~84% (worsening)	78%
Chemical pollution	No global control variable yet defined	-	-	-
Nitrogen & phosphorus loading	Phosphorus applied to land as fertilizer, millions of tons per year	at most 6.2 million tons per year	~14 million tons per year and rising (worsening)	229%
	Reactive nitrogen applied to land as fertilizer, millions of tons per year	at most 62 million tons per year	~150 million tons per year and rising (worsening)	217%
Freshwater withdrawals	Blue water consumption, cubic kilometres per year	at most 4000 km ³ per year	~2600 km ³ per year (intensifying)	61%
Land conversion	Area of forested land as a proportion of forest-covered land prior to human alteration	at least 75%	62% and shrinking (worsening)	152%
Biodiversity loss	Rate of species extinction per million species per year	at most 10	Around 100-1000 and rising (worsening)	1,000%
Air pollution	No global control variable yet defined	-	-	-
Ozone layer depletion	Concentration of ozone in the stratosphere, in Dobson Units	at least 275 DU	283 DU and rising (improving)	47%

Source: Steffen W, Richardson K, Rockström J, *et al.* 2015. All percentages are rounded to the nearest decimal

The processes and indicators of the nine planetary boundaries are based on Steffen et al 2015 and are set out below.

Climate change

When greenhouse gases such as carbon dioxide, methane, and nitrous oxide are released into the air, they enter the atmosphere and amplify Earth's natural greenhouse effect, trapping more heat within the atmosphere. This results in global warming whose effects include rising temperatures, more frequent extremes of weather, and sea level rise. The control variable is the atmospheric concentration of carbon dioxide.

Ocean acidification

Around one quarter of the carbon dioxide emitted by human activity is eventually dissolved in the oceans, where it forms carbonic acid and decreases the pH of the surface water. This acidity reduces the availability of carbonate ions that are an essential building block used by many marine species for shell and skeleton formation. This makes it hard for organisms such as corals, shellfish, and plankton to grow and survive, thus endangering the ocean ecosystem and its food chain. The control variable is the average saturation of aragonite at the ocean surface as a percentage of its pre-industrial levels.

Chemical pollution

When toxic compounds, such as synthetic organic pollutants and heavy metals, are released into the biosphere they can persist for a very long time with effects that may be irreversible. And when they accumulate in the tissue of living creatures, including birds and mammals, they reduce fertility and cause genetic damage, endangering ecosystems on land and in the oceans. Control variables have yet to be identified and quantified.

Nitrogen and phosphorus loading

Reactive nitrogen and phosphorus are widely used in agricultural fertilizers but only a small proportion of what is applied is actually taken up by crops. Most of the excess runs off into rivers, lakes, and oceans, where it causes algae blooms that turn the water green. These blooms can be toxic and they kill off other aquatic life by starving it of oxygen. The control variables are the amount of reactive nitrogen and phosphorus applied to land as fertilizer per year.

Freshwater withdrawals

Water is essential for life and is widely used by agriculture, industry, and households. Excessive withdrawals of water, however, can impair or even dry up lakes, rivers, and aquifers, damaging ecosystems and altering the hydrological cycle and climate. The control variable is the volume of blue water consumption per year.

Land conversion

Converting land for human use – such as turning forests and wetlands into cities, farmland, and highways – depletes Earth's carbon sinks, destroys rich wildlife habitats, and undermines the land's role in continually cycling water, nitrogen, and phosphorus. The control variable is the area of forested land as a proportion of forest-covered land prior to human alteration.

Biodiversity loss

A decline in the number and variety of living species damages the integrity of ecosystems and accelerates species extinction. In doing so it increases the risk of abrupt and irreversible changes to ecosystems, reducing their resilience and undermining their capacity to provide food, fuel, fibre, and to sustain life. The control variable would ideally provide a measure of the integrity of biomes but data currently available permit only a measure of biodiversity loss in terms of the rate of species extinction per year.

Air pollution

Micro-particles, or aerosols, emitted into the air – such as smoke, dust, and pollutant gases – can damage living organisms. Furthermore, they interact with water vapour in the air and so affect cloud formation. When emitted in large volumes these aerosols can significantly alter regional rainfall patterns, including shifting the timing and location of monsoon rains in tropical regions. A control variable for the global boundary has yet to be identified and quantified.

Ozone layer depletion

Earth's stratospheric ozone layer filters out ultraviolet radiation from the sun. Some human-made chemical substances, such as chlorofluorocarbons (CFCs) will, if released, enter the stratosphere and deplete the ozone layer, exposing Earth and its inhabitants to the sun's harmful UV rays. The control variable is the concentration of stratospheric ozone measured in Dobson Units.

4. Future iterations of the Doughnut

The Doughnut of social and planetary boundaries will continue to evolve. Its social foundation – including the dimensions, indicators, thresholds, and data – will continue to be revised as internationally agreed social norms and standards continue to evolve and as improved international data become available. Future iterations of the social foundation could, for example, include dimensions concerning cultural rights, community resilience, and self-assessed wellbeing.

Likewise, the ecological ceiling's dimensions, control variables, thresholds, and data will continue to be revised and refined as scientific research and understanding of planetary boundaries proceeds. Future iterations could, for example, include more specific forms of chemical pollution, just as understanding of the damaging properties of chlorofluorocarbons gave rise to a specific planetary boundary for ozone layer depletion.

References:

Cobham, A., Schlogl, L. & Sumner, A. *Inequality and the Tails: the Palma proposition and ratio revisited* (UNDESA, 2015) http://www.un.org/esa/desa/papers/2015/wp143_2015.pdf

Cobham, A. & Sumner, A. *Putting the Gini back in the bottle? 'The Palma' as a policy-relevant measure of inequality* (Kings College London, 2013) <http://www.kcl.ac.uk/sspp/sga/idi/people/Sumner/Cobham-Sumner-15March2013.pdf>

FAO (2015a) *Statistics: food security indicators* <http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.VnkpRZOLQlk>

- FAO (2015b) *Moving forward on choosing a standard operational indicator of women's dietary diversity*. <http://www.fao.org/documents/card/en/c/678ab9d4-e7a8-4388-9f9f-1c709ea47752/>
- Gallup (2015) Gallup World Poll www.gallup.com
- ILO (1999) *Decent Work: report of the Director-General*, 87th Session, Geneva. <http://www.ilo.org/public/english/standards/reln/ilc/ilc87/rep-i.htm>
- ILO (2011) *A New Era of Social Justice*, Report of the Director-General. Geneva: ILO http://www.ilo.org/wcmsp5/groups/public/@ed_norm/@relconf/documents/meetingdocument/wcms_155656.pdf
- ILO (2015) 'Global Youth Unemployment 1995-2015', available at: http://www.ilo.org/global/about-the-ilo/multimedia/maps-and-charts/WCMS_411196/lang--en/index.htm
- ITU (2014) *Measuring the Information Society Report 2014*, Geneva: ITU https://www.itu.int/en/ITU-D/Statistics/Documents/publications/mis2014/MIS2014_without_Annex_4.pdf
- ITU (2015) *ICT Facts and figures: the world in 2015*. <http://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2015.pdf>
- OECD/IED (2015) *World Energy Outlook*. <http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/>
- Raworth, K. (2012) *A safe and just space for humanity: can we live within the doughnut?* Oxfam Discussion Paper, Oxford: Oxfam International
- Rockstrom, J. *et al.* *Nature* **461**, 472-475 (2009)
- Steffen, W. *et al.* *Science* **347**: 6223 (2015).
- Transparency International (2014) *Corruption Perceptions Index 2014*, <http://www.transparency.org/cpi2014>
- UN (2014) *The Millennium Development Goals Report 2014*, New York: United Nations <http://www.un.org/millenniumgoals/2014%20MDG%20report/MDG%202014%20English%20web.pdf>
- UNODC (2015) *Statistics, UN Office of Drugs and Crime*. <https://data.unodc.org/>
- UNDP (2015) *Human Development Report 2015*, New York: UNDP
- UNESCO (2015a) *A growing number of children and adolescents are out of school as aid fails to meet the mark*, Policy paper 22 / Fact sheet 31, July 2015. <http://www.uis.unesco.org/Education/Documents/fs-31-out-of-school-children-en.pdf>
- UNESCO (2015b) *Adult and youth literacy: UIS Fact Sheet no. 32*. <http://www.uis.unesco.org/literacy/Documents/fs32-2015-literacy.pdf>
- WHO (2015) *Global Health Observatory data: under-five mortality*. http://www.who.int/gho/child_health/mortality/mortality_under_five_text/en/
- WHO/UNICEF (2015) *Progress on sanitation and drinking water – 2015 update and MDG assessment*, New York: UNICEF, http://www.wssinfo.org/fileadmin/user_upload/resources/JMP-Update-report-2015_English.pdf
- World Bank (2015a) *Poverty Overview*, <http://www.worldbank.org/en/topic/poverty/overview>
- World Bank (2015b) *World Development Indicators* Washington DC: World Bank <http://data.worldbank.org/products/wdi>
- World Bank (2015c) *Worldwide Governance Indicators*, <http://info.worldbank.org/governance/wgi/index.aspx#home>