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# Tracking sustainable development with a national barometer for South Africa using a downscaled "safe and just space" framework

**Megan J. Cole**[a,b,1], **Richard M. Bailey**[a], **and Mark G. New**[a,b]

[a]School of Geography and the Environment, University of Oxford, Oxford OX1 3QY, United Kingdom; and [b]African Climate and Development Initiative, University of Cape Town, Rondebosch 7000, South Africa

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**Nations in the 21st century face a complex mix of environmental and social challenges, as highlighted by the on-going Sustainable Development Goals process. The "planetary boundaries" concept [Rockström J, et al. (2009) *Nature* 461(7263):472–475], and its extension through the addition of social well-being indicators to create a framework for "safe and just" inclusive sustainable development [Raworth K (2012) *Nature Climate Change* 2(4):225–226], have received considerable attention in science and policy circles. As the chief aim of this framework is to influence public policy, and this happens largely at the national level, we assess whether it can be used at the national scale, using South Africa as a test case. We developed a decision-based methodology for downscaling the framework and created a national "barometer" for South Africa, combining 20 indicators and boundaries for environmental stress and social deprivation. We find that it is possible to maintain the original design and concept of the framework while making it meaningful in the national context, raising new questions and identifying priority areas for action. Our results show that South Africa has exceeded its environmental boundaries for biodiversity loss, marine harvesting, freshwater use, and climate change, and social deprivation is most severe in the areas of safety, income, and employment. Trends since 1994 show improvement in nearly all social indicators, but progression toward or over boundaries for most environmental indicators. The barometer shows that achieving inclusive sustainable development in South Africa requires national and global action on multiple fronts, and careful consideration of the interplay between different environmental domains and development strategies.**

sustainable development | South Africa | planetary boundaries | social deprivation | sustainable development goals

Human impact on the Earth's biophysical processes and resources is a global concern. It is seen by many as a new geological era, the Anthropocene (1), with natural resource consumption accelerating in the past 50 y—food, freshwater, and fossil fuel use have more than tripled (2)—and these trends are likely to continue as global population grows to 9.6 billion by 2050 (3). This concern has led to international treaties that seek to address global environmental challenges through negotiation and agreement among the nations of the world, such as the United Nations (UN) Convention for the Protection of the Ozone Layer, the UN Convention on Biological Diversity (UNCBD), and the UN Framework Convention on Climate Change (UNFCCC). This impact has also led to the proliferation of sustainable development indicators (SDIs). The outcome of the 1992 UN Conference on Environment and Development, Agenda 21, calls for SDIs to "provide solid bases for decision-making at all levels and to contribute to a self-regulating sustainability of integrated environment and development system" (4). Over 900 SDI initiatives have been undertaken to date (5), in recognition of the fact that indicators provide a quantitative and rational basis for decision making (6), simplify a complex reality to a manageable level (7), create a body of knowledge and comparable data for policy applications, measure progress (8), and allow the public to evaluate society and its leaders (9). Individual indices, such as the Human Development Index and the Ecological Footprint, have been used to compare countries, and sustainability frameworks, such as Ostrom's framework for social-ecological systems (10) and the "ecosystems approach" adopted by the UNCBD (11), have been developed to better understand the relationships between social and ecological systems.

In 2009 a new conceptual framework, "planetary boundaries," was proposed by Rockström et al. (12, 13) as "a bid to reform environmental governance at multiple scales" (14). The planetary boundaries are an estimated "safe distance" from thresholds associated with nine global environmental change processes that, when crossed, will take humanity into unchartered environmental territory (13). The nine processes (or dimensions) are: climate change, ocean acidification, freshwater use, land-use change, biodiversity loss, nutrient cycles (nitrogen and phosphorous), ozone depletion, atmospheric aerosol loading, and chemical pollution. Three of these global boundaries (climate change, biodiversity loss, and nitrogen fixation) have been transgressed and several others are in danger of being exceeded. Rockstrom et al. proposed there should be a global goal to stay within the "safe operating space for humanity" defined by these boundaries.

Despite a mixed reaction from the academic community, who have raised concerns about the existence of global tipping points for some of the dimensions (15–17) and the specific metrics used (18–23), the planetary boundaries concept has been used in proposals for defining the UN Sustainable Development Goals (SDGs) (24–26). The SDGs will guide the international sus-

## Significance

**We have downscaled planetary boundaries and applied the "safe and just space for humanity" framework at the national scale, for the first time, creating a "barometer" for inclusive sustainable development for South Africa. The barometer presents the state and trajectory of a broad but manageable set of indicators for environmental and social priorities, and highlights the country's proximity to environmental boundaries and the distance from eradication of social deprivation. This creates a monitoring and communication tool for national government for thinking in an integrated manner about environmental and social-development issues. Our case study provides insight into the challenges and complexities of developing indicators and targets for the proposed global Sustainable Development Goals that that are globally, regionally, and nationally relevant.**

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[1]To whom correspondence should be addressed. Email: megan.cole@ouce.ox.ac.uk.

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tainable development agenda after 2015 and they represent an opportunity for science to inform policy making (27–29), for the UN to implement the lessons from the Millennium Development Goals (MDGs) and to expand them to include all countries, and for greater integration of environmental and social metrics in decision-making. In this context, the planetary boundaries concept was extended by Raworth (30, 31) to include a set of 11 social dimensions, defining "a social foundation" below which exists unacceptable human deprivation. This approach highlighted the notion that access to the benefits of natural resources is also of global concern, and Raworth (30) argued that ending current global deprivation could be achieved with a minimal impact on the planetary boundaries. Raworth reframed Rockström et al.'s (12, 13) planetary boundaries concept as a "safe and just space for humanity"; this new framework brought together the dual objectives of poverty eradication and environmental sustainability as socio-economic priorities (30).

Raworth's safe and just space (SJS) framework has gained interest from the UN General Assembly (32), policy think tanks (e.g., ref. 33), and development agencies (e.g., ref. 34) because it provides a platform for integrated analysis and debate about global goals. The framework appears in the Worldwatch Institute's latest State of the World report (35) and Griggs et al. (25) have since developed a similar framework to reframe the UN paradigm of three pillars of sustainable development as a nested concept.

However, social and environmental concerns are intrinsically scale-dependent and need to take local circumstances into account if they are to be acted upon by national governments, which are ultimately responsible for taking action. The downscaling of the SJS to subglobal spatial scales, with heterogeneity of biophysical and social conditions and the instruments of governance, is not straightforward. The particular challenges for the biophysical dimensions are highlighted by Nykvist et al. (36), who assessed national "environmental performance" on four planetary boundaries (climate change, water, land, and nitrogen) for 60 countries. Because the chief aim of the SJS is to influence public policy, and this happens largely at the national level, our objective in this report is to assess whether the SJS concept can be used at the national scale, using South Africa as a test case.

In this report we first review the SJS concept and explore how it might be applied at the national scale. We then present a decision-based methodology and results for our case study on South Africa. Finally, we discuss the applicability of the tool in South Africa, the local-regional-global links and the SDGs, and the data limitations, scientific challenges, and further research needs.

## A Safe Operating Space

The focus of the planetary boundaries concept is staying within the safe operating space in which human civilizations have developed: that is, the relatively stable biophysical conditions of the Holocene (the past approximately10,000 y). The concept combines global environmental change and resilience science, which focuses on understanding the effects of and response to abrupt change in social-ecological systems (SES) in the context of sustainable development (37). Resilience can be defined as the "capacity of a SES to continually change and adapt yet remain within critical thresholds" (38). Crossing a planetary boundary represents a risk of moving from the current known state to a new, unknown, and possibly dangerous state. These boundaries could be (but are not necessarily) critical thresholds or tipping points beyond which systemic planetary-scale regime shifts [the Earth system processes involved being referred to as "tipping elements" (39)] may occur or dangerous levels of environmental change may be reached. Critical transitions are often referred to as abrupt (in that the rate of response is considerably greater than the rate at which the driving factors change), but many unfold slowly in absolute terms after a threshold is transgressed (40). An important potential property of such shifts is "hysteresis," which describes the need to reduce forcing back beyond threshold-crossing levels to return the system to its previous state (41).

Barnosky et al. (42) identified global-scale critical transitions in the Earth's past and pointed out that the current global-scale forcing mechanisms, such as resource consumption, far exceed the rate and magnitude of the most recent global-scale state shift of the last glacial–interglacial transition. The authors also argued that local-scale drivers have accumulated to the extent that global-scale drivers have emerged; 38% of Earth's terrestrial surface has been converted to agricultural land (43), $CO_2$ concentrations are 35% higher than preindustrial times (44), rates of nitrogen fixation have more than doubled (45), and ocean acidity has increased by a pH of 0.05 (46).

For the planetary boundaries, Rockström et al. (12, 13) distinguish between thresholds driven by systemic global-scale processes impacting subsystems "top-down," such as climate change, and thresholds that may arise at the local scale that become a global concern when aggregated, impacting the global system "bottom-up," such as freshwater use. The authors (12) defined 10 indicators to measure the state of their nine dimensions, noting that determining a safe boundary involves "normative judgements of how societies choose to deal with risk and uncertainty" (12, 13). As Cornell (47) pointed out, these indicators actually comprise a mix of system properties, which results in conceptual tensions. Nykvist et al. (36) used the driving forces-pressures-states-impact-response framework to categorize the dimensions as one driver (nitrogen), three pressures (phosphorous loading, freshwater use, chemical pollution), five states (ozone depletion, climate change, ocean acidification, aerosol loading, land-use change), and one impact (biodiversity loss). Each indicator has an associated (safe) boundary, defined using the precautionary principle given the notorious difficultly in predicting where critical thresholds lie in natural systems. Hughes et al. (48) have subsequently defined the boundaries as safe levels of drivers of environmental change. Because all drivers of environmental change are essentially driven locally, boundaries could be determined at scales other than global, including the national scale, which is the focus of the present work.

## A Just Space

In Raworth's (30) SJS framework, the term "just" describes the avoidance of unacceptable human deprivation and extreme global inequality in the context of human rights. The term focuses on the opportunities component of justice and supports Rawl's "Difference Principle" (which promotes propoor distribution of social and economic benefits) as described by Sen (49). The SJS highlights the multidimensional nature of deprivation, thus it builds on work by Townsend (who pioneered the relative deprivation approach) and Sen's capabilities approach (50). Townsend defined deprivation as "a state of observable and demonstrable disadvantage relative to the local community or the wider society" (51), and thus the local, national, and global contexts are important when selecting deprivation indicators. International agreements for human needs are more clearly articulated and institutionalized than environmental needs (52) and date back to the 1948 Universal Declaration of Human Rights. The MDGs, which represent voluntary time-bound targets that developing countries are evaluated on until 2015 (53), have created global awareness for extreme poverty and mobilized funds and established new organizations to promote basic human rights (54).

Raworth's (30) global "social foundation" has 11 dimensions of well-being: food security, energy, water and sanitation, education, health care, income, jobs, voice, resilience, social equity, and sex inequality. These dimensions were drawn from the national social development priorities in 80 government submissions to the UN Rio+20 Conference in 2012, and therefore are both global and national in nature. The dimensions are measured with deprivation indicators largely taken from the MDGs, although Raworth specifically selected indicators that measure the percentage of the total population who are deprived. The boundary for each indicator is argued to be zero deprivation, based on human rights, thus the selection of the indicator determines the just boundary of unacceptable deprivation. As the social foundation measures the well-being of a population, it can be scaled to any level, including the national scale, which we will show in this report.

## National Case Study: South Africa

We chose South Africa as our case study for testing the SJS framework at the national scale for three reasons. First, it has large, good quality environmental and social datasets and established national research institutes, which enables rigorous analysis and debate. Second, as the largest economy in Africa (55), it is influential both on the continent and globally as part of the BRICS group of emerging economies (Brazil, Russia, India, China, and South Africa), and research is more likely to be shared through South–South cooperation. Third, it is ecologically megadiverse (56), has widespread poverty and extreme inequality (57), and this heterogeneity will provide a stringent test for the framework.

South Africa is one of the youngest democracies in the world, with elections in 1994 marking the end of white minority rule. Twenty years on, its planned development pathway is described in the "National Development Plan" (58), which has two overarching goals: to eliminate income poverty and to reduce inequality by 2030. The National Climate Change Response Strategy has been a catalyst for mainstreaming environmental issues in South Africa and is supported by the National Strategy for Sustainable Development (59), which promotes stewardship of limited natural resources, and the Green Economy Accord (60), which focuses on technology and job creation to meet development goals in a sustainable way. South Africa is a signatory to a number of international environmental treaties, including the Montreal Protocol, the UNCBD and the UNFCCC.

## Summary of Methodology

To apply the SJS framework at the national scale, we developed a decision-based methodology (Fig. 1) to assess the environmental and social dimensions, indicators and boundaries in a repeatable and consistent way. Details are provided in the *Supporting Information* (sections A and B) and are summarized here. Our criteria for selecting the dimensions were: "Is this relevant at the national scale?" and "Does the set of dimensions include the main environmental and social concerns in South Africa?" Our criteria for indicator selection were: "Is the indicator the best available direct measure of that dimension?", "Are there sufficient reliable data that are measured on a regular basis?" and "Can a national boundary be determined?" If the existing dimension or indicator did not meet the criteria then it was removed or replaced with a more appropriate national-scale choice. The data were taken from relevant national databases and reports, international databases, and academic papers, and we sought expert judgment through semistructured interviews with 43 South African experts from national, provincial, and metropolitan government, national research institutes, universities, and international nongovernment organizations (*Supporting Information*, section C). The experts were identified based on their experience, academic or professional credibility, and involvement in national policy-making, as well as through recommendations by other experts.

**Environmental Stress.** We used the Environmental Sustainability Indicators technical report (61) published by the Department of Environmental Affairs (DEA) as a starting point for our analysis because it was developed based on a comprehensive review of potential national indicators, Yale's Environmental Performance Index, and the driving forces-pressures-states-impact-response framework. We then reviewed relevant national policies, reports, and assessments, as well as academic literature to identify the most suitable dimensions, indicators, and boundaries. Although we changed only two of Rockström et al.'s (12, 13) global dimensions—ocean acidification became marine harvesting and aerosol loading became air pollution—we adjusted all of the indicators and boundaries to suit national circumstances. The current status is a national average or aggregation of local data

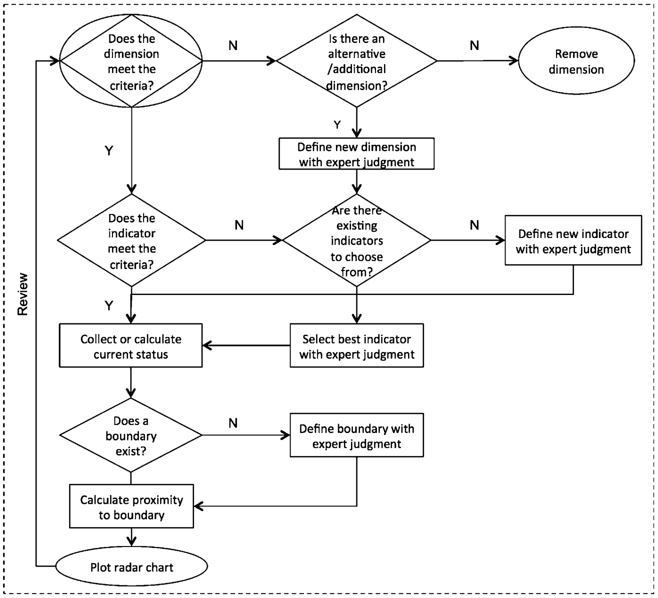


**Fig. 1.** Decision-based methodology for selecting national dimensions, indicators and boundaries for the national barometer for inclusive sustainable development.

points and in most cases this calculation had already been done in the source documents. In three cases (phosphorous, biodiversity loss, and marine harvesting) no preexisting calculation was available and was performed by the authors (details in *Supporting Information*). Environmental baselines were not used because of very limited information on preindustrial conditions.

Determining national environmental boundaries was challenging because of the novelty of defining local equivalents to planetary boundaries, the uncertainty in the data, and because ideally safe boundaries should combine expert scientific opinion and societal acceptance. We identified three types of environmental boundaries, which arise from differences in the nature of the biophysical dimensions. The first type (Type A) is used for dimensions that are inherently global in nature: climate change and ozone depletion. Boundaries are based on global biophysical thresholds but necessarily incorporate some measure of multilateral political agreement to ensure that they take differences in national capability and responsibility into account. They can either be internationally agreed targets that set out national actions (Type A1), which is the case for ozone depletion, or national interpretations of a globally accepted threshold in the absence of agreed targets (Type A2), which is the case for climate change. The second type of boundary (Type B) represents national limits for land and freshwater resources. These can be purely natural limits (Type B1) or natural limits combined with human intervention, such as infrastructure, technology, and imports (Type B2). The third type (Type C) combines local biophysical thresholds and a national safe boundary based on established research and expert judgment. These can be based on a single local biophysical threshold (Type C1), such as phosphorous concentrations in freshwater, or aggregations of biophysical thresholds of different components (Type C2), such as ecosystem types for biodiversity loss.

***Type A: Global boundaries—climate change and ozone depletion.*** Global $CO_2$ and stratospheric ozone concentrations cannot be disaggregated to the national scale; however, emissions are reported at the national scale. The Montreal Protocol contains internationally agreed phasing out schedules for the production and consumption of 96 ozone-depleting (ODP) substances. South Africa has phased out all ODP substances except hydrochlorofluorocarbons (HCFCs) (62), producing 262 ODPt in 2013 (63). Our indicator "Annual HCFC consumption," has a boundary based on the government's commitment to freeze HCFC consumption and limit it to the baseline of 370 ODPt by 2013 (64). South Africa is 29% below its ODP boundary. Although no internationally agreed $CO_2$ emissions targets exist, South Africa has committed to reduce its emissions by 30–40% by 2050 from 2003 levels, after peaking at 650 $MtCO_2$ in 2020, based on the long-term mitigation scenarios (65). Our indicator, "Annual direct $CO_2$ emissions," had a status of 461 $MtCO_2$ in 2010 (66) and we based our boundary on the emissions trajectory of the "Required by Science" scenario in the long-term mitigation scenarios, which sets the 2010 target at 451 $MtCO_2$. South Africa exceeds its climate change boundary by 2%.

***Type B: National limits—freshwater use and arable land use.*** Freshwater and land are limited natural resources. We estimated that freshwater use in South Africa was 18,895 $Mm^3 \cdot yr^{-1}$ in 2013 based on the Department of Water Affairs (DWA) Water Authorization and Registration Management System database (67), and used this as our indicator. The DWA (68, 69) calculate that the country has 14,319 $Mm^3 \cdot yr^{-1}$ total available yield for human use, which accounts for the "ecological reserve," the minimum in stream flow needed to support ecological functioning (70), and assurance of supply. We used this as our safe boundary, which was exceeded by 34%, showing that human freshwater use is given priority over the ecological reserve. Although Rockström et al. (12, 13) focused on land-use change, land cover in South Africa has been stable since 1961 (71). Instead we used "rain-fed arable land converted to cropland" (11.9% in 2005) (72) as our indicator, because South Africa is a largely semiarid country with limited land capable of supporting sustainable crop production. Only 12.1% is classified as rain-fed arable land (73); hence, South Africa is 2% below its land use boundary.

***Type C: Local thresholds.***

***Nutrient cycles.*** Although nitrogen (N) and phosphorous (P) cycles (essential for food production) are global in scale, the local negative impacts of N and P use pose the main challenge. Eutrophication of freshwater resources is widespread in South Africa and is a national concern (74), with P levels in major reservoirs used as a national indicator. We obtained the latest data from the National Eutrophication Monitoring Program to calculate the current status of 0.098 mg/L in 2013 (75) and used Oberholster and Ashton's (76) critical threshold of 0.10 mg/L P in freshwater as the safe boundary. South Africa is 2% below its P loading boundary. The negative impact on the N cycle in South Africa is largely through N removed from the soil by crop production, despite fertilizers being applied. Maize production uses nearly two-thirds of N (77) and is the staple crop. On average, maize removes 27 kg N from the soil per ton of marketable product (78), thus in 2011/2012 an estimated 102 kg N/ha were removed from the soil. The average maize N application rate (our indicator) was 85 kg N/ha in 2012 (77), indicating that N is not being fully replaced. Rockström et al. (12, 13) identified the overapplication of N as the main global concern and we therefore used Brentrup and Palliere's (79) N use efficiency threshold of 70%, which would translate to an N application rate of 144 kg N/ha for maize in South Africa, as our safe boundary. South Africa is 41% below its N boundary.

***Biodiversity loss.*** Although Rockström et al. (12, 13) used rate of extinction to measure biodiversity loss, the more common indicator is threat of extinction (80). South Africa has undertaken biodiversity assessments since 1980 and in 2004 expanded from a species approach to an ecosystem approach. The 2011 National Biodiversity Assessment (56) reported the ecosystem threat status of 1,763 ecosystem types across six categories: terrestrial, rivers, wetlands, estuaries, coastal and inshore, and offshore. The assessment has four threat status classes: critically endangered, endangered, vulnerable, and least threatened, which incorporate biophysical thresholds. Our indicator, "endangered and critically endangered ecosystems" (37% in 2011), is based on expert opinion and our safe boundary is set at zero (i.e., no ecosystems should be endangered or critically endangered). South Africa exceeds its biodiversity loss boundary by 37%.

***Marine harvesting.*** South Africa is at a very early stage in understanding ocean acidification (81) and the national priority for oceans is the sustainability of marine resources. Although the biodiversity-loss dimension measures marine ecosystem stress, marine harvesting is better measured by the stock status of commercial fisheries. Seventeen fishery sectors and 45 species (or subspecies) are reported in the *Status of South African Marine Fishery Resources 2012* (82), published by the Department of Agriculture, Forestry, and Fisheries (DAFF). Stock status is based on the present biomass level (population size) and the biomass level at which maximum sustainable yield (the target for optimal utilization) is obtained. Our indicator, the "depleted marine fisheries stocks" (45% in 2011), is based on expert judgment and our safe boundary was set at zero (i.e., no marine fisheries are depleted). South Africa exceeds its marine harvesting boundary by 45%.

***Air pollution.*** Aerosol loading, a driver of regional climate change, is not a major concern in South Africa; hence, we changed the dimension to address the national issue of air pollution that affects human health. The government (83) has identified particulate matter ($PM_{10}$) and $SO_2$ as problem pollutants at a national scale, and uses the annual average concentration of each to calculate a National Air Quality Indicator. The latest "State of Air" results for 2012 (83) show that $PM_{10}$ is the "greatest national cause for concern in terms of air quality"; hence, we chose $PM_{10}$ concentration as our indicator (46.9 $\mu g/m^3$ in 2012) and the government's $PM_{10}$ threshold of 50 $\mu g/m^3$ as our safe boundary. South Africa is 6% below its air pollution boundary.

***Chemical pollution.*** Similarly to Rockström et al. (12, 13), we did not identify an indicator for this dimension because of the lack of detailed and accurate data. Although South Africa's National Waste Information Baseline Report (84) provides an estimated baseline of over 1.3 Mt of hazardous waste (most of which is landfilled), reporting is voluntary and measurement is incomplete.

**Social Deprivation.** We used the South African Index of Multiple Deprivation (SAIMD) (85, 86), developed by the national Department of Social Development, the Human Sciences Research Council and Oxford University, and the annual Development Indicators report (87), published by the Presidency, as guidelines for selecting social dimensions and indicators. Both have been informed by international good practice and adapted to South African conditions, and the latter uses aggregate data from a range of sources covering the post-Apartheid period (1994–2013) and supplied most of the data for our barometer. Where it did not contain the required data, we used the latest General Household Survey (GHS) (88). We grouped the dimensions into four domains—basic services, public goods, livelihoods, and living standards—to facilitate the analysis.

We made a number of changes to the original Raworth (30) dimensions. Water and sanitation were separated into individual dimensions; housing, household goods, and safety were added; and resilience, social equity, and sex equality were removed. The experts we consulted saw resilience as a cumulative effect that is dependent on the other dimensions, and therefore an indirect measure. Experts also felt that both social equity and sex inequality should be incorporated into the other dimensions, as they are cross-cutting. The Gini coefficient only measures income inequality and Palma (57) argues that it hides the homogeneity in the middle half of the population and the great heterogeneity between the top 10% and the bottom 40% of the population. As the five indicators of the UN's Sex Inequality Index (89) shows, sex equality could be addressed under the dimensions of health, education, voice, and employment. Ideally, social equity and sex equality should be measured for all of the dimensions of the barometer in future iterations.

We had to choose social boundaries from three types of indicator sets. The first type (Type 1) represents a range of levels of deprivation, which are commonly found in household surveys. For example, choosing "access to piped water within 200 m of the dwelling" rather than "access to piped water in the dwelling" sets a lower boundary. The second type of indicator set (Type 2) is a range of definitions of the same indicator. For example, unemployment can be defined as narrow or broad, which includes discouraged jobseekers. The third type (Type 3) is a diverse set of indicators that represent different aspects of a dimension. For example, material deprivation can be measured by ownership of a range of household goods, such as a refrigerator or television.

### Basic Services: Energy Access, Water Access, Sanitation, and Housing

Household access to electricity, piped water, adequate sanitation, and formal housing are all national priorities in South Africa. The GHS records seven levels of access to piped water (based on distance from the dwelling) and eight levels of sanitation. The official water target is "25*l* of potable water per person per day without interruption for more than 7 d within 200m of the dwelling," known as the Reconstruction and Development Programme (RDP) standard (87), and the official sanitation indicator is "access to at least a ventilated pit latrine on site." In 2011/2012, 23.5% of households were deprived of electricity access, 4.5% were deprived of piped water access (RDP standard), 16.6% were deprived of adequate sanitation, and 22.3% were deprived of formal housing.

### Public Goods: Education, Health Care, and Voice

There are numerous indicators to choose from when measuring education and health care. We did not use Raworth's (30) MDG indicators because South Africa has achieved the MDG target of universal access to primary school, and there is no data for "access to essential medicines." We chose the SAIMD education indicator "adults with no secondary schooling," the adult illiteracy rate in Development Indicators, which was 19.3% in 2011. The only health care (rather than health) indicator in Development Indicators is "infant immunization coverage" (90.8% in 2011), which we used. Raworth did not define an indicator for voice and experts recommended that voice should measure public participation in decision-making, which does not appear in Development Indicators. We chose to keep the dimension without a national indicator, with further research required.

### Livelihoods: Jobs and Income

Poverty, unemployment, and inequality make up South Africa's "triple challenge" (90) and little progress has been seen since 1994. We chose the broad unemployment rate (36.3% in 2012) as our jobs indicator, with the potential for incorporating Raworth's (30) indicator for sex equality, "the employment gap in waged work (excluding agriculture)," if the data becomes available. The official national poverty lines used in South Africa are a food poverty line of R305 per person per month (pppm), a lower-bound poverty line of R416 pppm, and an upper-bound poverty line of R577 pppm in 2011 Rands (87). We used the latter as our income indicator, with a deprivation status of 52.3% in 2011.

### Living Standards: Food Security, Household Goods, and Safety

Food security, household goods, and safety are important measures of living standards in South Africa. The only regularly reported national measure of hunger and food access is provided in the GHS, and we used the "households without adequate food" as our food security indicator, with a deprivation status of 23.1% in 2013. The SAIMD uses the indicators "ownership of a refrigerator" and "ownership of a radio and/or landline telephone" to measure material deprivation. We selected the former as our household goods indicator (28.1% in 2013) because radio and landlines are being replaced by cell phones (88). Safety is a complex dimension to measure, as crime statistics do not compare well across jurisdictions, except murder. Our choice of indicator was limited because most indicators measure rates and not proportions of the population; hence, we chose "households that feel unsafe walking alone at night in their area," which was 63.5% in 2011.



### Summary of National Barometer Results

The results of our case study are presented as two radar charts, environmental stress in Fig. 2*A* and social deprivation in Fig. 2*B*, which together form a barometer for inclusive sustainable development in South Africa. Four dimensions—climate change, freshwater use, marine harvesting, and biodiversity loss—have exceeded their boundaries by 2%, 34%, 45%, and 37%, respectively; whereas arable land use, phosphorous loading, and air pollution are within 10% of exceeding their boundaries. Depri-

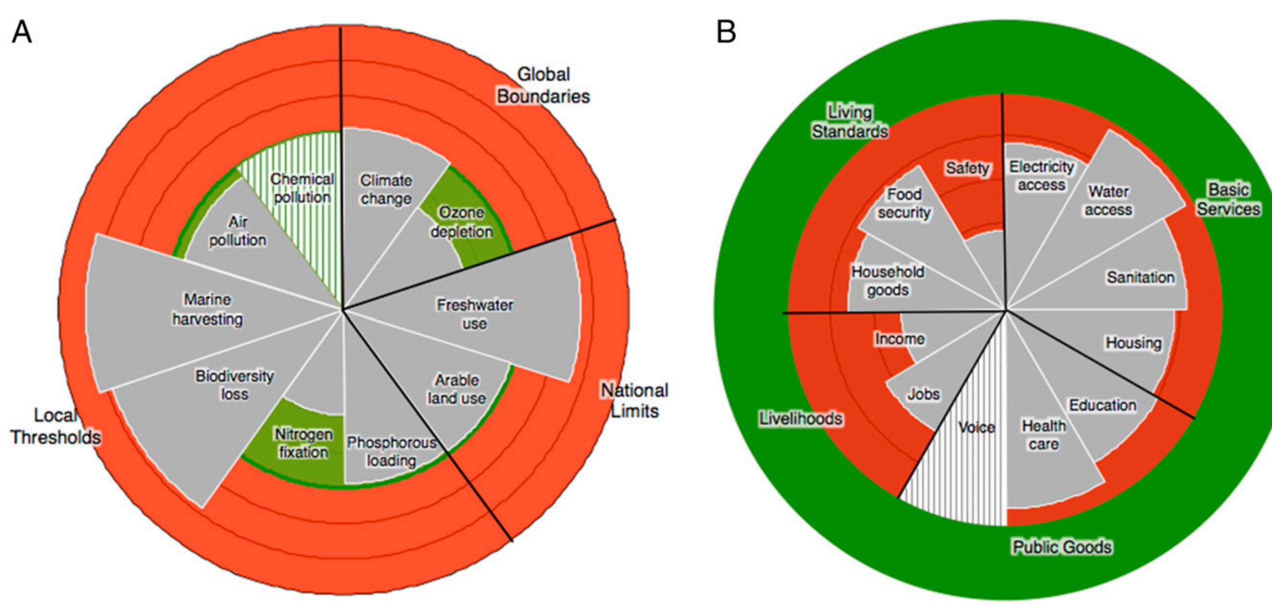


**Fig. 2.** A national barometer for inclusive sustainable development in South Africa. The green areas represent the safe and just space, beyond which is excessive environmental stress (*A*) and social deprivation (*B*), shown in red. The gray wedges measure the national status for each dimension compared to its boundary as a percentage (0% at the centre, 100% at the boundary), striped wedges show indicators still to be determined, the black dividing lines delineate the three types of environmental boundaries (*A*) or the four social domains (*B*).

vation was most widespread regarding safety (63.5%), income (52.5%), and jobs (36.3%) and least prevalent in basic services, such as electricity and water access. Tables 1 and 2 summarize the details of the dimensions and Fig. 3 shows trends in the indicators since 1990. Trends in environmental stress are difficult to analyze for five dimensions because of multiyear gaps between data points (land, water, biodiversity, nitrogen), a change in methodology (biodiversity), or a recent start to current data reporting (marine harvesting). Climate change and freshwater use have been moving toward or beyond the safe boundary, and recent progress away from the boundary can been seen for ozone depletion and air pollution. Social deprivation has decreased in all dimensions (ranging from 33.8% in water access to 0.8% in food security) except safety and income, where deprivation has increased by 19.5% and 2.0%, respectively. When the barometer's environmental dimensions are framed in terms of national policy applications (Table 3), it is clear that exceeding the environmental boundaries has implications for energy security, food security, water security, job security, and human health; these in turn have the potential to affect the national economy and bilateral trade agreements, highlighting that decisions on socio-economic development need to take environmental boundaries into account.

## Discussion

**Utility of the Barometer.** The main aim of this case study was to evaluate the applicability of the SJS framework at the national level. The findings show that it is possible to maintain the original design and concept of the framework while making it meaningful in the national context. In interviews we conducted, there was consensus among experts that a "national barometer for inclusive sustainable development" could be a very useful tool in South Africa, and this view is supported by the National Development Plan, which recognizes the need to measure and monitor progress on important social and environmental indicators (58). If the barometer were adopted nationally, the indicators would need to be further developed iteratively over time in a dialogue between scientists, civil society, and government (as indicated in the flowchart shown in Fig. 1).

SDIs are not new and are regularly used in "state of environment" or "environment outlook" reports (e.g., ref. 91) and made more visually appealing in maps, such as the Dashboard of Sustainability (92), and quantified metaphors, such as footprints (11). The novelty of the barometer is twofold. First, it presents a visual snapshot of the state of a broad but manageable set of environmental and social indicators in relation to national priorities and realities that goes beyond color-coding or single figures. Our trend charts provide additional information about progress (or lack thereof) over time that aid decision-making, and the combination of environmental and social dimensions highlights the dual nature of the sustainability challenge. Second, it goes beyond being merely a measure of the current status and highlights the country's proximity to its environmental boundaries and its acceptable level of social well-being. It is aimed at a national audience first and an international audience second, to encourage national action, and is science-based. Specific uses identified by the experts interviewed were that it removes intersectoral barriers, communicates a complex set of indicators in a relatively simple way, identifies gaps in the underlying knowledge base, and raises new questions in the discourse on social deprivation and environmental sustainability. Inclusion of

**Table 1. Dimensions and indicators of environmental stress for South Africa (using the most recent data available)**

| | | State | | | | Boundary | | | |
|---|---|---|---|---|---|---|---|---|---|
| Dimension | Indicator | Value | Year | Data source | Level of confidence | Value | Source | Proximity to Boundary (%) | Type* of Boundary |
| Climate change | Annual direct $CO_2$ emissions | 460.1 $MtCO_2$ | 2010 | UN 2013 (66) | High | 451 $MtCO_2$ | Scenario Building Team 2007 (65) | 102 | Type A2 |
| Ozone depletion | Annual HCFC consumption | 262.0 ODPt | 2013 | UN 2014 (63) | High | 369.7 OPDt | NEDLAC 2012 (64) | 71 | Type A1 |
| Freshwater use | Consumption of available freshwater resources | 18,895 $Mm^3/yr$ | 2013 | DWA 2014 (67) | Low | 14,196 $Mm^3/yr$ | DWA 2004 (68), 2013 (69) | 134 | Type B2 |
| Arable land use | Rain-fed arable land converted to cropland | 11.9% | 2005 | Schoeman et al., 2013 (72) | Medium | 12.1% | Collett 2013 (73) | 98 | Type B1 |
| Nutrient cycle | Total phosphorous concentration in dams | 0.098 mg/L | 2012 | DWA 2013 (75) | Medium | 0.10 mg/L | Oberholster and Ashton 2008 (76) | 98 | Type C1 |
| | Nitrogen application rate for maize production | 85 kg N/ha | 2012 | FSSA 2013 (78) | Low | 144 kg N/ha | Brentrup and Palliere 2010 (79) | 59 | Type C1 |
| Biodiversity loss | Endangered and critically endangered ecosystems | 37% | 2011 | Driver et al., 2012 (56) | Medium | 0% | Expert judgment | 137 | Type C2 |
| Marine harvesting | Depleted marine fisheries stocks | 45% | 2011 | DAFF 2012 (82) | Medium | 0% | Expert judgment | 145 | Type C2 |
| Air pollution | Annual average PM10 concentration | 46.9 $\mu g/m^3$ | 2012 | DEA 2013 (83) | High | 50.0 $\mu g/m^3$ | DEA 2013 (83) | 94 | Type C1 |
| Chemical pollution | To be determined | | | | | | | | |

*Type A1: global boundary with internationally agreed target; Type A2: global boundary with national target; Type B1: national resource limit without human intervention; Type B2: national resource limit with human intervention; Type C1: single local biophysical threshold; Type C2: aggregate local biophysical threshold.

Table 2. Dimensions and indicators of social deprivation in South Africa

| Dimension of well-being | Indicator of deprivation | Current status of deprivation (%) | Year | Change since 1994* | Source | Type of Indicator Set† | Domain |
|---|---|---|---|---|---|---|---|
| Energy | Households without access to electricity | 23.5 | 2012 | −25.6% (1995) | DPME 2013 (87) | Type 1 | Basic services |
| Water | Households without access to piped water within 200m (≥ RDP standard) | 4.5 | 2012 | −33.8% | DPME 2013 (87) | Type 1 | |
| Sanitation | Households without a toilet or ventilated pit latrines | 16.6 | 2012 | −32.5% | DPME 2013 (87) | Type 1 | |
| Housing | Households without formal dwellings | 22.3 | 2011 | −13.7% (1996) | DPME 2013 (87) | Type 1 | |
| Education | Adults (≥20 y old) without more than 7 y of schooling (adult illiteracy) | 19.3 | 2011 | −11.1% (1995) | DPME 2013 (87) | Type 3 | Public goods |
| Health care | Infant (<1 y) immunization coverage | 9.2 | 2011 | −27.8% (1998) | DPME 2013 (87) | Type 3 | |
| Voice | To be determined | | | | | | |
| Jobs | Broad unofficial unemployment rate (adults aged 15–64 available to work) | 36.3 | 2012 | −1.4% (2001) | DPME 2013 (87) | Type 2 | Livelihoods |
| Income | Population living below the national poverty line (R577/mo in 2011 Rands) | 52.5 | 2011 | +2.0% | DPME 2013 (87) | Type 2 | |
| Household goods | Household does not own a refrigerator | 28.1 | 2012 | −20.9% (2001) | StatsSA 2014 (88) | Type 3 | Living standards |
| Food security | Households without adequate food | 23.1 | 2013 | −0.8% (2010) | StatsSA 2014 (88) | Type 3 | |
| Safety | Households feel unsafe walking alone in their area at night | 63.5 | 2011 | +19.5% (1998) | DPME 2013 (87) | Type 3 | |

*Or since start of measurements, year given in brackets. Negative value represents reduction in deprivation; positive value represents increase in deprivation.
†Type 1: range of levels of deprivation; Type 2: range of definitions of the same indicator; Type 3: diverse set of indicators that represent different aspects of a dimension.

the barometer in national reports, such as the State of Environment Report, was suggested as being highly beneficial.

It is recognized, however, that indicators are limited and can oversimplify complexities, making them better suited to conveying broad messages and encouraging discourse (93). Indeed, a criticism of the barometer from some experts was that it hides the complexity of the local scale (i.e., the geography of social deprivation and environmental stress), which was also a critique of the planetary boundaries. Biophysical thresholds vary spatially (e.g., from dry to wet regions), therefore the issue of scale is an important consideration in acting on national barometer results at subnational scales. Specific subnational analysis is needed to investigate if and how national thresholds could be determined that incorporate and do not mask this heterogeneity. Analysis at the subnational level would also reveal inequalities in access to and use of resources, where both the ecological and political-economic borders are important. Nevertheless, broad sustainability indicators can provide substantial momentum to a more detailed debate, as the evidence from the MDGs shows, and can serve as first-order proxies for inclusive development.

**National-Regional-Global Links.** As a nation's political borders seldom match borders of biophysical systems, the national state of environmental stress has local, regional, and global components. Similarly, perceived social and economic benefits lead to regional migration into South Africa, which affects overall national social well-being. The fact that South Africa has exceeded or is close to exceeding almost all of its environmental boundaries highlights its own vulnerability, as well as that of its neighbors, and raises the importance of international and regional cooperation. The proximity to Type A "global boundaries" is likely to result in international pressure for South Africa to act, as seen in climate negotiations. The proximity to Type B "national limits" indicates that neighboring countries may be called on to provide water and arable land for regional food production, already evidenced by the DWA assessment of crop production potential in the region (94). The proximity to Type C "local biophysical thresholds" will probably result in pressure from local civil society.

International pressure will highlight the respective national contributions to the pressure on the planetary boundaries. South Africa has roughly 0.7% of the world's people (3) and 0.9% of its land area (95). It contributed 1.4% of global $CO_2$ emissions in 2010 (96), 4.4% of HCFC consumption in 2013 (63), 0.5% of global freshwater use (based on ref. 13), and 0.4% of global nitrogen fertilizer consumption in 2010 (97). South Africa is therefore not a big contributor to the global pressure on the planetary boundaries. It is, however, the main contributor on the African continent, and as a member of the BRICS group, is closely associated with countries that do have a significant global impact; this provides impetus to act, but also raises the issue of how national environmental boundaries are determined.

Table 3. Links between environmental stress and national policy applications in South Africa

| Environmental dimension | Energy security | Water security | Food security | Job security | Human health |
|---|---|---|---|---|---|
| Climate change | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ozone depletion | | | | | ✓ |
| Freshwater use | | ✓ | ✓ | | |
| Land use change | | | ✓ | ✓ | |
| Nutrient loading | | ✓ | ✓ | | ✓ |
| Biodiversity loss | | ✓ | ✓ | | ✓ |
| Marine harvesting | | | ✓ | ✓ | |
| Air pollution | | | | | ✓ |

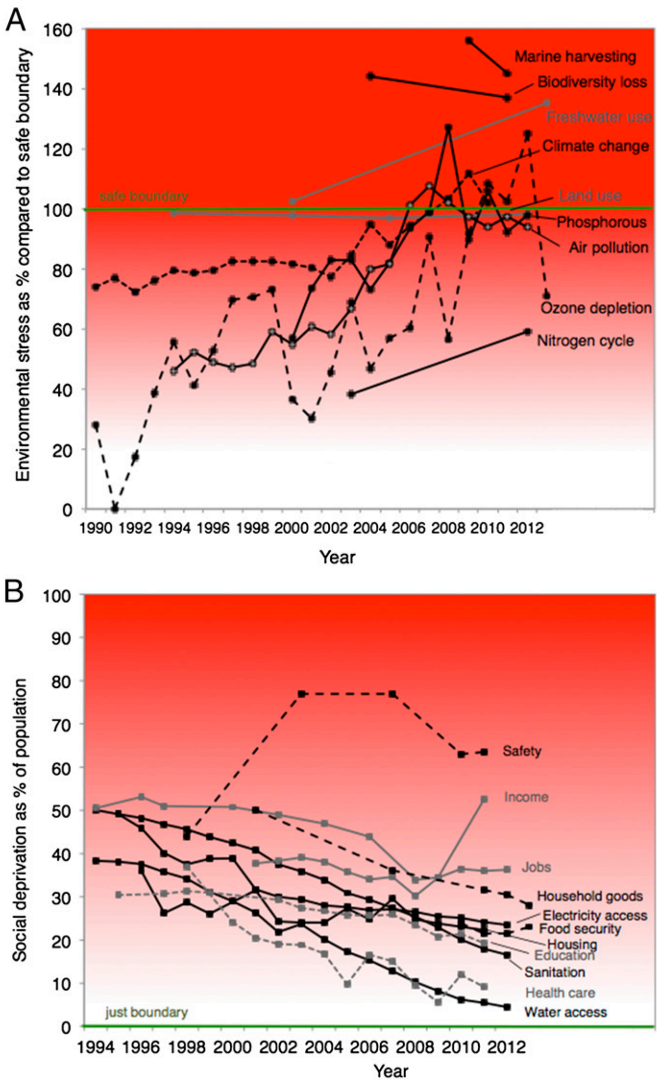


**Fig. 3.** (*A*) Change in environmental stress indicators in South Africa from 1990 to 2013 (Data sources in Table 1). Darker red shading indicates direction of increasing environmental stress. Black dotted lines are Type A boundaries (climate change, ozone depletion), gray solid lines are Type B boundaries (freshwater use, land use), black solid lines are Type C boundaries (phosphorous, nitrogen, biodiversity loss, marine harvesting, air pollution). (*B*) Change in social deprivation in South Africa from 1994 to 2013 (Data sources in Table 2). Darker red shading indicates increasing social deprivation. Black solid lines are basic services (electricity, water, sanitation, housing) gray dotted lines are public goods (education, health care), gray solid lines are livelihoods (income, employment), black dotted lines are living standards (food security, household goods, safety).

Different boundaries could lead to different levels of international pressure and different national policy decisions. For example, Nykvist et al.'s (36) equal per capita share approach results in South Africa exceeding a global boundary for climate change by 335%, whereas our study (which uses nationally defined boundaries) puts the figure at 2%. The very large difference is because of the latter incorporating the UNFCCC principle of common but differentiated responsibilities and respective capabilities, which is arguably more realistic as no climate deal is likely to be agreed without it. Globally defined boundaries also fall short for other dimensions, where national resource limits and local thresholds are arguably more appropriate. For example, Rockström et al.'s (12) 15% cropland boundary is inappropriate in South Africa, as only 12% of the land is capable of supporting rain-fed crop production. Caution is also needed with comparing social deprivation across countries if different social boundaries, which need to be appropriate to the country's current level of development and able to adapt to changing circumstances, are used. For example, according to the MDG indicator for water access, 8.8% of South Africans are deprived; however, according to the more stringent SAIMD indicator (piped water inside the dwelling or yard), 26.6% of South Africans are deprived. South Africa's latest MDG Country Report (98) includes 69 "domesticated indicators" that were developed by "adjusting the MDGS to reflect the local situation while ensuring that the globally designed targets and indicators are in line with local reality" through a stakeholder consultation process. Indicators that are inappropriate in the national context were identified and new targets and indicators required to fully reflect the local context were created. Although the government supports the MDGs, viewing them as an integral part of the development agenda (98), the global indicators are used for international comparison and the domestic equivalents are used for monitoring national development. South Africa is likely to take the same approach to the SDGs. This adoption of multiple indicators for different purposes could be taken if we were to upscale a set of national barometers to the global scale. Each dimension could have a national and global indicator to meet the needs of both audiences.

The downscaling of the global SJS framework is not only complex for setting boundaries but also in calculating the current status. The social dimensions are relatively straightforward to calculate at different scales, as they are all aggregations of individual people or households, although care must be taken to ensure consistency when using either household or individual data and adjusting for changes to political boundaries over time. The status of each environmental dimension is more difficult to calculate because they occur naturally at different scales. Despite the unavoidable complexity, each is based on local data sources and can therefore be scaled up to the national level, and possibly to the global level to recalculate Rockström et al.'s original planetary boundaries (12, 13). The methodology for this would be similar to the one we have used for turning local data into national values for South Africa. Some dimensions would be simpler than others; for example, $CO_2$ emissions and ODP substances are already aggregated to regional and global levels in UN databases. Although land and water use are also aggregated in global databases, the figures do not take into account national boundaries and need to be adjusted accordingly. The ecosystem level dimensions, such as biodiversity loss and phosphorous loading, could in principle be up-scaled through simple aggregation. One significant challenge is obtaining data for the same indicators across many countries, and additional indicators could be developed for each dimension to ensure there is some overlap. For example, marine harvesting could be changed to aquatic harvesting to incorporate a second indicator on freshwater fisheries to accommodate landlocked countries.

**Gaps in the Data and Science.** Our report has provided a methodology for other countries to use to develop their own national barometers. We chose South Africa for this case study partly because it has a wealth of good data and research. Other developing countries may struggle to find the appropriate data to populate their own national barometer, as the levels of research and monitoring are often much lower than that of South Africa. This is likely to also be the case with the implementation of the SDGs. Perhaps instead of this being seen as a barrier, it should be used as an opportunity for data-poor countries to begin an efficient targeted collection of specific data needed to address these global and national challenges. This has been one of the positive outcomes of the MDGs: that new longitudinal data have been collected in developing countries, aiding national governments in making more informed policy decisions (99). For now, the second-best solution (100)—where existing constraints prevent the first-best solution from being obtained—is to use existing data and proxies and to refine the barometer over time as more data are gathered. We note that the approach we have taken is supported by UN Environment Programme recommendations in limiting the number of indicators, using existing data and proxies, being sensitive to scale, and engaging stakeholders early on (101).

According to the Rio+20 outcome document, the SDGs must be "action-oriented, concise and easy to communicate, limited in number, aspirational, global in nature and universally applicable to all countries, while taking into account different national realities, capacities and levels of development and respecting national policies and priorities" (102). Our barometer meets the first four of these five criteria and attempts to address the last and toughest criteria of global applicability and national relevance, which is a challenge given the significant socio-economic differences between the 193 countries in the UN. As we have shown, some of the MDG indicators do not suit the South African context and there is disagreement over the sharing of responsibilities for addressing environmental stress, especially climate change.

Based on the Zero Draft (103) from the Open Working Group on SDGs (established by the UN General Assembly in January 2013), all of the dimensions in the barometer are likely to appear in the SDGs. The proposal has 17 goals (*Supporting Information*, section D), which together have 148 targets. No indicators have been developed as yet, but there are likely to be more than 200 and therefore intrinsically difficult to communicate with ease. Our barometer seeks a balance between simplicity and complexity, and although countries will have to measure and report on all of the SDGs in time, it makes sense to highlight some of the more important indicators and ensure that the necessary data are gathered early on in the process. It is likely that social indicators will be more readily available than environmental indicators, and multiyear research projects will be required to fill in the data gaps.

Apart from the data challenges, there are also gaps in the science on defining environmental boundaries, at both global and subglobal scales. Considerable effort is currently being put into investigating both the causes of tipping points in Earth systems and uncovering indicators of the proximity to critical thresholds (104). Schellnhuber (105) argues that the tipping elements issue "probably poses one of the toughest challenges for contemporary science" and highlights "social tipping elements" as an important research area. Similarly, Galaz (106) believes that "social connectors," which can lead to tipping points that would not otherwise occur, need to be researched. Although different scientific perspectives can lead to different national boundaries and indicators, so indeed could different political interests. Both scientific input and a robust process that involves all stakeholders are needed.

## Conclusion

We have described a worked case study for applying Raworth's "safe and just space" (30) framework at the national scale, using South Africa as our test case. We developed a decision-based methodology for identifying and quantifying indicators and boundaries for both environmental and social dimensions, creating what is, to our knowledge, the first national barometer for inclusive sustainable development in South Africa. The barometer highlights environmental risks and unacceptable social deprivation intended to prompt public debate; indeed, similar barometers could be developed for other countries. Four dimensions—climate change, freshwater use, marine harvesting, and biodiversity loss—have exceeded their safe boundaries by 2%, 34%, 45%, and 37%, respectively, and arable land use, phosphorous loading, and air pollution are within 10% of exceeding their boundaries. Social deprivation was most widespread regarding safety (63.5%), income (52.5%), and jobs (36.3%) and least prevalent for basic services, such as water access. Trends show that environmental stress is still increasing for two dimensions (climate change and freshwater use), and social deprivation has reduced in all areas except safety and income. This case study provides insights into the challenges and complexities of developing relevant indicators and boundaries at national scales, and highlights areas where additional research is needed to refine and further develop the framework.

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1. Steffen W, et al. (2011) The anthropocene: From global change to planetary stewardship. *Ambio* 40(7):739–761.
2. Foley J (2010) Boundaries for a healthy planet. *Sci Am* 302(4):54–57.
3. UN Department of Economics and Social Affairs, Population Division (2013) *World Population Prospects: The 2012 Revision. Highlights and Advance Tables* (UN Department of Economics and Social Affairs) Working Paper No ESA/P/WP.228.
4. UN (2012) Agenda21. *United Nations Conference on Environment and Development* (United Nations, Rio de Janeiro).
5. IISD (2013) Compendium of sustainable development indicator initiatives. Available at www.iisd.org/measure/compendium/. Accessed March 7, 2013.
6. Senbel M, McDaniels T, Dowlatabadi H (2003) The ecological footprint: A non-monetary metric of human consumption applied to North America. *Glob Environ Change* 13(2):83–100.
7. Galli A, et al. (2012) Integrating ecological, carbon and water footprint into a "Footprint Family" of indicators: Definition and role in tracking human pressure on the planet. *Ecol Indic* 16(2012):100–112.
8. Moran DD, Wackernagel M, Kitzes JA, Goldfinger SH, Boutaud A (2008) Measuring sustainable development—Nation by nation. *Ecol Econ* 64(3):470–474.
9. Fredericks SE (2013) Justice in sustainability indicators and indexes. *Int J Sustain Dev* 19(6):490–499.
10. Ostrom E (2009) A general framework for analyzing sustainability of social-ecological systems. *Science* 325(5939):419–422.
11. Haines-Young R, Potschin M (2008) *England's Terrestrial Ecosystem Services and the Rationale for an Ecosystem Approach*. Overview Report, Project Code NR0107. Available at www.nottingham.ac.uk/CEM/pdf/NR107_FTR_080108.pdf. Accessed March 8, 2013.
12. Rockström J, et al. (2009) A safe operating space for humanity. *Nature* 461(7263): 472–475.
13. Rockström J, et al. (2009) Planetary boundaries: Exploring the safe operating space for humanity. *Ecol Soc* 14(2):32.
14. Galaz V, Crona B, Österblom H, Olsson P, Folke C (2012) Polycentric systems and interacting planetary boundaries—Emerging governance of climate change–ocean acidification–marine biodiversity. *Ecol Econ* 81:21–32.
15. Brook BW, Ellis EC, Perring MP, Mackay AW, Blomqvist L (2013) Does the terrestrial biosphere have planetary tipping points? *Trends Ecol Evol* 28(7):396–401.
16. Bass S (2009) Planetary boundaries: Keep off the grass. *Nat Reports Clim Chang* 3(0910):113–114.
17. Molden D (2009) Planetary boundaries: The devil is in the detail. *Nat Reports Clim Chang* 3(0910):116–117.
18. Biello D (2012) Walking the line: How to identify safe limits for human impacts on the planet. *Sci Am.* Available at www.scientificamerican.com/article.cfm?id=do-planetary-boundaries-help-humanity-manage-environmental-impacts. Accessed June 2012.
19. Lewis SL (2012) We must set planetary boundaries wisely. *Nature* 485(7399):417.
20. Molina MJ (2009) Planetary boundaries: Identifying abrupt change. *Nat Reports Clim Chang* 3(0910):115–116.
21. Running SW (2012) Ecology. A measurable planetary boundary for the biosphere. *Science* 337(6101):1458–1459.
22. Samper C (2009) Planetary boundaries: Rethinking biodiversity. *Nat Reports Clim Chang* 3(0910):118–119.
23. Schlesinger WH (2009) Planetary boundaries: Thresholds risk prolonged degradation. *Nat Reports Clim Chang* 3(0910):112–113.
24. SDSN (2013) An Action Agenda for Sustainable Development. Report for the UN Secretary-General (Sustainable Development Solutions Network, Paris).
25. Griggs D, et al. (2013) Policy: Sustainable development goals for people and planet. *Nature* 495(7441):305–307.
26. UNEP (2013) Embedding the Environment in Sustainable Development Goals. UNEP Post-2015 Discussion Paper 1 (United Nations Environment Programme, Nairobi).
27. Brito L (2012) Analysing sustainable development goals. *Science* 336:1396.
28. Brito L, Stafford Smith M (2012) State of the Planet Declaration. *Planet Under Pressure: New Knowledge Towards Solutions* (International Council for Science, London).
29. Glaser G (2012) Policy: Base sustainable development goals on science. *Nature* 491(7422):35.
30. Raworth K (2012) A safe and just space for humanity: Can we live within the doughnut? Oxfam Discussion Paper (Oxfam, Oxford).
31. Raworth K (2012) Living in the doughnut (interview). *Nature Climate Chang* 2(4): 225–226.
32. UNGA (2012) *Summary of the Special Event of the Second Committee of the UN General Assembly Conceptualizing a Set of Sustainable Development Goals* (United Nations General Assembly, New York).

33. IIED (2012) Fair Ideas: Sharing solutions for a sustainable planet (International Institute for Environment and Development, London).
34. Tearfund (2013) Briefing to Partners from the Advocacy and Media Group. Quarterly Update May 2013 (Tearfund, Teddington, United Kingdom).
35. Stewart G (2013) State of the World 2013: Is sustainability still possible? *Australas J Environ Manage* 20(3):259–260.
36. Nykvist B, et al. (2013) *National Environmental Performance on Planetary Boundaries: A study for the Swedish Environmental Protection Agency* (Stockholm Environment Institute, Stockholm).
37. Folke C, Rockström J (2009) Turbulent times. *Glob Environ Change* 19(1):1–3.
38. Folke C, Carpenter SR, Walker B, Scheffer M, Chapin T (2010) Resilience thinking: Integrating resilience, adaptability and transformability. *Ecol Soc* 15(4):20.
39. Lenton TM, et al. (2008) Tipping elements in the Earth's climate system. *Proc Natl Acad Sci USA* 105(6):1786–1793.
40. Hughes TP, Linares C, Dakos V, van de Leemput IA, van Nes EH (2013) Living dangerously on borrowed time during slow, unrecognized regime shifts. *Trends Ecol Evol* 28(3):149–155.
41. Haines-Young R, Potschin M, Cheshire D (2006) *Defining and Identifying Environmental Limits for Sustainable Development: A Scoping Study*. Final Full Technical Report (University of Nottingham, Nottingham, United Kingdom).
42. Barnosky AD, et al. (2012) Approaching a state shift in Earth's biosphere. *Nature* 486(7401):52–58.
43. Foley JA, et al. (2011) Solutions for a cultivated planet. *Nature* 478(7369):337–342.
44. IPCC (2007) *Climate Change 2007: Synthesis Report. An Assessment of the Intergovernmental Panel on Climate Change* (Intergovernmental Panel on Climate Change, Valencia, Spain).
45. Sutton M, et al. (2011) Too much of a good thing. *Nature* 472(7342):159–161.
46. Doney SC (2010) The growing human footprint on coastal and open-ocean biogeochemistry. *Science* 328(5985):1512–1516.
47. Cornell S (2012) On the system properties of the planetary boundaries. *Ecol Soc* 17(1):r2.
48. Hughes TP, Carpenter S, Rockström J, Scheffer M, Walker B (2013) Multiscale regime shifts and planetary boundaries. *Trends Ecol Evol* 28(7):389–395.
49. Sen A (2005) Human rights and capabilities. *J Hum Dev* 6(2):151–166.
50. Gasper D (1997) Sen's capability approach and Nussbaum's capabilites ethics. *J Int Dev* 9(2):281–302.
51. Townsend P (1987) Deprivation. *J Soc Policy* 16(2):125–146.
52. Parris TM, Kates RW (2003) Characterizing a sustainability transition: goals, targets, trends, and driving forces. *Proc Natl Acad Sci USA* 100(14):8068–8073.
53. Clarke M, Feeny S (2011) Old challenges and new opportunities for the MDGs: Now and beyond 2015. *J Asia Pac Econ* 16(4):509–519.
54. Sachs JD (2013) High stakes at the UN on the Sustainable Development Goals. *Lancet* 382(9897):1001–1002.
55. IMF (2012) *Regional Economic Outlook: Sub-Saharan Africa - Maintaining Growth in an Uncertain World* (International Monetary Fund, Washington, DC).
56. Driver A, et al. (2012) *National Biodiversity Assessment 2011: An Assessment of South Africa's Biodiversity and Ecosystems. Synthesis Report* (South African National Biodiversity Institute and Department of Environmental Affairs, Pretoria, South Africa).
57. Palma JG (2011) Homogeneous middles vs. heterogeneous tails, and the end of the "Inverted-U": It's all about the share of the rich. *Dev Change* 42(1):87–153.
58. National Planning Commission (2012) *National Development Plan 2030 Our Future—Make it Work* (Government of South Africa, Pretoria, South Africa), Available at: www.npconline.co.za/MediaLib/Downloads/Downloads/NDP 2030 - Our future - make it work.pdf. Accessed April 12, 2013.
59. DEA (2011) National Strategy for Sustainable Development and Action Plan (NSSD 1) 2011-2014 (Department of Environmental Affairs, Pretoria, South Africa) pp 48.
60. EDD (2011) *Green Economy Accord. New Growth Path: Accord 4* (Department of Economic Development, Government of South Africa, Pretoria, South Africa), Available at: www.economic.gov.za/communications/publications/green-economy-accord. Accessed April 25, 2013.
61. DEA (2013) *Environmental Sustainability Indicators Technical Report 2011* (Department of Environmental Affairs, Government of South Africa, Pretoria, South Africa).
62. GCIS (2011) *South Africa Yearbook 2011/12* (Government Communication and Information System, Republic of South Africa, Pretoria, South Africa), pp 191–214.
63. UNEP (2014) *UNEP Ozone Secretariat Data Access Centre*. Available at ozone.unep.org/new_site/en/ozone_data_tools_access.php. Accessed August 15, 2014.
64. NEDLAC (2012) *Hydrochlorofluorocarbons (HCFC)* Phase Out Plan for South Africa (National Economic Development and Labour Council, Ferndale, South Africa).
65. Scenario Building Team (2007) *Long Term Mitigation Scenarios Strategic Options: Technical Summary* (Department of Environment Affairs and Tourism, Pretoria, South Africa).
66. United Nations Statistical Division (2013) *Millennium Development Goals Indicators*. Available at mdgs.un.org/unsd/mdg/SeriesDetail.aspx?srid=749&crid=710. Accessed August 15, 2014.
67. DWA (2014) Water Authorisation and Registration Management System (WARMS) database (Department of Water Affairs, Government of South Africa, Pretoria, South Africa).
68. DWAF (2004) *National Water Resource Strategy* (Department of Environmental Affairs and Tourism, Government of South Africa, Pretoria, South Africa), 1st Ed.
69. DWA (2013) *National Water Resource Strategy June 2013* (Department of Water Affairs, Government of South Africa, Pretoria, South Africa), 2nd Ed.
70. Stats SA (2006) *Natural Resource Accounts: Updated Water Accounts for South Africa 2000.* Discussion document - D0405 (Statistics South Africa, Pretoria, South Africa).
71. Niedertscheider M, Gingrich S, Erb K-H (2012) Changes in land use in South Africa between 1961 and 2006: An integrated socio-ecological analysis based on the human appropriation of net primary production framework. *Reg Environ Change* 12(4):715–727.
72. Schoeman F, Newby TS, Thompson MW, Van den Berg EC (2013) South African National land-cover change map. *South African J Geomatics* 2(2):94–105.
73. Collett A (2013) The impact of effective (geo-spatial) planning on the agricultural sector. *Proceedings of the South African Surveying and Geomatics Indaba 22-24 July 2013* (South African Geomatics Institute, Kempton Park, South Africa).
74. Van Ginkel C (2011) Eutrophication: Present reality and future challenges for South Africa. *Water SA* 37(5):693–701.
75. DWA (2014) National Eutrophication Monitoring Programme (NEMP) database (Department of Water Affairs, Government of South Africa, Pretoria, South Africa).
76. Oberholster PJ, Ashton PJ (2008) *State of the Nation Report: An Overview of the Current Status of Water Quality and Eutrophication in South African Rivers and Resevoirs*: CSIR/NRE/WR/IR/2008/0075/C (Council for Scientific and Industrial Research, Pretoria, South Africa).
77. FSSA (2013) *Estimated Fertilizer Use by Crop in South Africa for the 2012 Calendar Year* (Fertiliser Society of South Africa, Pretoria, South Africa).
78. FSSA (2007) *Fertiliser Handbook* (Fertiliser Society of South Africa, Pretoria, South Africa), 6th Ed, pp 176–187.
79. Brentrup F, Palliere C (2010) in *OECD Workshop: Agri-Environmental Indicators: Lessons Learnt and Future Directions.* 23-26 March 2010. (Organisation for Economic Co-operation and Development, Leysin, Switzerland).
80. Zamin TJ, et al. (2010) National red listing beyond the 2010 target. *Conserv Biol* 24(4):1012–1020.
81. CSIR (2012) *Workshop Report: Ocean Acidification and Impacts on South African Continental Shelf Ecosystems*, 13–14 March 2012 (Council for Scientific and Industrial Research, Cape Town, South Africa).
82. DAFF (2012) *Status of the South African Marine Fishery Resources 2012* (Department of Agriculture, Forestry and Fisheries, Government of South Africa, Pretoria, South Africa).
83. DEA (2013) *2013 State of Air Summary* (Department of Environmental Affairs, Government of South Africa, Cape Town, South Africa).
84. DEA (2012) *National Waste Information Baseline Report. Draft* (Department of Environmental Affairs, Government of South Africa, Pretoria, South Africa).
85. Noble M, et al. (2009) *The South African Index of Multiple Deprivation 2001 at Datazone Level* (Department of Social Development, Pretoria, South Africa).
86. Wright G, Noble M (2009) *The South African Index of Multiple Deprivation 2007 at Municipality Level* (Department of Social Development, Pretoria, South Africa).
87. DPME (2013) *Development Indicators 2012* (Department of Performance Monitoring and Evaluation, Government of South Africa, Pretoria, South Africa).
88. StatsSA (2014) General Household Survey 2013. Statistical release P0318 (Statistics South Africa, Pretoria, South Africa).
89. UNDP (2013) *Human Development Report 2013. The Rise of the South: Human Progress in a Diverse World*, ed Malik K (United Nations Development Programme, New York).
90. Government of South Africa (2014) State of the Nation 2014. Text of the speech given by President Jacob G Zuma, President of the Republic of South Africa, on the occasion of the Joint Sitting Of Parliament, 13 February 2014 (The Presidency, Government of South Africa, Pretoria, South Africa).
91. UNEP (2006) *Africa Environment Outlook 2. Our Environment, Our Wealth. Executive Summary* (United Nations Environment Programme, Nairobi).
92. IISD (2007) Dashboard of Sustainability. Available at www.iisd.org/cgsdi/dashboard.asp. Accessed March 7, 2013.
93. Molle F, Mollinga P (2003) Water poverty indicators: Conceptual problems and policy issues. *Water Policy* 5(6):529–544.
94. Rutherford R (2010) *An Assessment of Rain-fed Crop Production Potential in South Africa's Neighbouring Countries* (Department of Water Affairs, Pretoria, South Africa).
95. World Bank (2013) *World Development Indicators 2012* (The World Bank, Washington, DC).
96. World Resources Institute (2013) Climate Analysis Indicators Tool (CAIT) 2.0. Washington, DC. 1. Available at cait2.wri.org. Accessed August 15, 2014.
97. FAO (2013) FAOStat. *Fertilizers.* Available at faostat.fao.org/site/575/DesktopDefault.aspx?PageID=575#ancor. Accessed August 15, 2014.
98. StatsSA (2013) *Millennium Development Goals Country Report 2013* (Statistics South Africa, Pretoria, South Africa).
99. Sachs JD (2012) From millennium development goals to sustainable development goals. *Lancet* 379(9832):2206–2211.
100. Lipsey RG, Lancaster K (1956) The general theory of second best. *Rev Econ Stud* 24(1):11–32.
101. UNEP-WCMC (2011) *Developing Ecosystem Service Indicators: Experiences and Lessons Learned from Sub-Global Assessments and Other Initiatives*. Secretariat of the Convention on Biological Diversity, Technical Series No. 58 (United Nations Environment Programme, Montreal).
102. UN General Assembly (2012) *The Future We Want: Resolution Adopted by the General Assembly* (United Nations, Rio de Janeiro).
103. UN Open Working Group on SDGs (2014) Zero Draft rev 1. Introduction and proposed goals and targets on sustainable development for the post 2015 development agenda (United Nations Open Working Group on Sustainable Development Goals, New York).
104. Scheffer M, et al. (2012) Anticipating critical transitions. *Science* 338(6105):344–348.
105. Schellnhuber HJ (2009) Tipping elements in the Earth System. *Proc Natl Acad Sci USA* 106(49):20561–20563.
106. Galaz V (2013) A Planet without Humans? Two Short Reflections on "Does the terrestrial biosphere have planetary tipping points?" Resilience Science blog. 28 February 2013. Available at rs.resalliance.org/2013/02/28/a-planet-without-humans-two-short-reflections-on-does-the-terrestrial-biosphere-have-planetary-tipping-points/. Accessed March 5, 2013.