Stockholm Resilience Centre

Report

October 2018

Transformation is feasible

How to achieve the Sustainable Development Goals within Planetary Boundaries

A report to the Club of Rome, for its 50 years anniversary 17 October 2018

A report to the Club of Rome by: Jorgen Randers, Johan Rockström, Per Espen Stoknes, Ulrich Golüke, David Collste and Sarah Cornell

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Global Challenges Foundation

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Preface:

The Grand Ambition

The dual adoption of the UN Sustainable Development Goals (SDGs) together with the Paris Climate Agreement, both in 2015, represents a global turning point. We have never before had such a universal development plan for people and planet. For the first time in human history the world has agreed on a democratically adopted roadmap for humanity's future, which aims at attaining socially inclusive and highly aspirational socio-economic development goals, within globally defined environmental targets.

Humanity's grand ambition is surely to aim at an inclusive and prosperous world development within a stable and resilient Earth system. This human quest is to attain as many of the SDGs as possible by 2030, and then continue following a sustainable global trajectory well beyond the next 12 years. This report has identified one such possible, smarter pathway to success through five transformative and synergistic actions.

But we are running out of time. There is now overwhelming scientific evidence that humanity poses such pressures on Earth that we can no longer exclude destabilizing the entire Earth system, undermining possibilities for future prosperity. Already at 1.1 °C of global warming above pre-industrial temperatures, we have hit the ceiling of the maximum average temperature on Earth since exiting the last Ice Age, some 12,000 years ago. We are also seeing earlier than predicted major social and economic impacts on human livelihoods, social stability, and economic development. We are complicit in the 6th mass extinction of species on Earth, triggered in large by deforestation, land use change, nutrient overload and chemical loading. On this pathway, we are rapidly reaching a juncture of existential peril for humanity's future on Earth.

The scientific message to humanity is clear: We have entered a new geological epoch, the Anthropocene, where our modern world constitutes the largest driver of change on Earth. And the message is truly sinking in. But science also provides additional support – through the IPCC, IPBES, and integrative frameworks like the planetary boundaries – for the need now to take an even longer-view than "only" 2030. Therefore, policymakers must look beyond 2050 as the roadmap for the SDGs is drawn out. In a nutshell we want to attain the SDGs within planetary boundaries: call it #SDGinPB.

A key challenge lies in the psychology of worldviews. While the adoption of the SDGs is such a positive global act – a true turning point for the entire agenda on world development – we still remain in a world view where "Everybody knows, but nobody wants to understand" the magnitude of the transformation that is needed.

It is time to rise together to take on the grand challenge.

The SDGinPB initiative originated from Stockholm Resilience Centre at Stockholm University and BI Norwegian Business School. The project team consists of experts from Scandinavia, UK and Germany which consulted with experts from Kenya/Ethiopia, China and India. We thank all contributors and particularly the The *Global Challenges Foundation* for providing funding support.

Stockholm October 2018,
The authors

Sony Kapoor

Managing Director, Re-Define,
an International Think Tank

"As policymakers, businesses and investors start to sign up to the SDGs and efforts to deliver them are redoubled, it is more important than ever to understand the trade-offs between the different SDGs. This landmark report makes these trade-offs explicit, and shows that only a new developmental path will allow us to fulfil all the SDGs at the same time. Without a fundamentally new approach and prioritising tackling environmental constraints, gains in one or more of the SDGs will not be sustainable and will come at the cost of undermining other, equally important SDGs.

This report shows how all the SDGs can be met at the same time, and the progress sustained. "

Dr. Belay Begashaw

Director,
SDG Center for Africa

To embark on the journey towards sustainable development in Africa effectively means we have to reach the SDGs within the planetary boundaries, the call for this report. The report provides the immensely important first steps towards creating Sustainable Development Pathways that enables this. It also carries the important message that the world is currently falling behind and not only have to "try harder", but that nothing less than a transformation is what is needed.

The adverse impacts of climate change and ecosystem degradation will, if left uncontrolled, subject millions to poverty and deprive our common resources. It is already here and is showing itself on the African continent in the form of droughts. That we have to do something is unquestionable and the report's top-down perspectives effectively complements the bottom-up processes that we have started with the African Dialogues on The World In 2050. Ego-logic thinking has to diminish and give space for eco-logic thinking: we all share the one Planet.

I have chosen to summarize the report's conclusions in that we need transformed energy, sustainable food, new development models, reduced inequality and education for all – elsewise development will stall.

Agenda 2030 and conventional growth incompatible!

This new report to the Club of Rome *"Achieving the Sustainable Development Goals within Planetary Boundaries"*, by Jörgen Randers, Johan Rockström and Per-Espen Stoknes, is the forty-sixth report of its kind. Ever since Limits to Growth, the first report to the Club of Rome, the ambition within the Club has been to promote and stimulate a discussion around conventional economic growth and its implications. This report is no exception. It addresses a most important issue – the implementation of Agenda 2030 or the SDGs.

The adoption of the SDGs by the UN General Assembly in 2015 was a landmark decision. The Declaration accompanying the SDGs contains a vision statement, including "we envisage a world in which development and the application of technology are climate-sensitive, respect biodiversity and are resilient. One in which humanity lives in harmony with nature and in which wildlife and other living species are protected."

We believe that most people lend support to such a transformational vision. The problem, however, is that very little is said in Agenda 2030 about its implementation. Against this backdrop, an obvious task must be to examine the consistency of the SDGs and the modalities under which the goals will be implemented. What is really the meaning of the quoted statement? It surely relates to the three environmental SDGs, speaking in af-firmative language about urgent action needed to combat climate change (Goal 13); conserving and sustainably using the oceans, seas and marine resources (Goal 14), and protecting, restoring and promoting sustainable use of terrestrial ecosystems, ... and halting biodiversity loss (Goal 15).

Nowhere, however, is it admitted in the 2030 Agenda that the successes in reaching the eleven social and economic goals (Goals 1–11), *if done based on conventional growth policies,* would make it virtually impossible to reduce the speed of global warming, to stop overfishing in the oceans or to stop land degradation, let alone to halt biodiversity loss.

This report explores different pathways for the implementation of Agenda 2030. The report confirms that meeting the SDGs in an integrated fashion based on conventional growth policies is not possible. By accelerating growth an increasing number of the socio-economic goals may be reached but it will occur at the expense of the environmental SDGs and push planetary boundaries into high-risk zones. In other words, assuming no major changes in the way economic growth is defined and pursued, humanity would be confronted with massive trade-offs between the socio-economic and the environmental SDGs.

The only way that, according to the report, will meet most of the goals by 2030 is one built on transformational change starting now. Such a pathway rests on at least five transformational actions with systems-wide effects of the SDGs:

- Accelerated renewable energy growth
- Accelerated productivity in food chains
- New development models in the poorer countries
- Active inequality reduction
- Investments in education for all, gender equality and family planning

We find the report of great importance. Governments around the world are struggling to develop policies for an integrated approach to Agenda 2030. The findings of the report will hopefully lead the way towards a more honest debate about the measures needed for meeting the SDGs. Let us also hope that the transformational change needed will start happening in individual countries. For that to happen conventional growth must be replaced by policies that give priority to welfare and wellbeing and puts ecological and social objectives at the forefront of policymaking.

Emmedingen and Stockholm, October 2018,

Ernst von Weizsäcker, Anders Wijkman
Co-presidents of the Club of Rome

Executive Summary

Highlights & key findings

If the world's nations continue with the same efforts as in the recent decades we will not achieve SDGs by 2030, nor 2050. By 2030, in the business-as-usual scenario, the world's success score on SDGs will be only 10 out of 17, up from 9 in 2015. The main problems are that satisfying the social SDGs with conventional policy tools will lead to very large human footprints in terms of resource use and pollution outputs, and to increasing inequity. The state of the Earth's planetary boundaries (PBs) will be further in the red, high-risk zone particularly with regards to global warming, biodiversity loss, air pollution and toxic entities in nature. There is high risk for pushing the Earth's life supporting systems beyond irreversible trigger-points by 2050.

If the world accelerates economic growth in all regions to 2050, this will give more funds that can improve the world's SDG success somewhat. The score rises from 10 to 11 by 2030. But this will also worsen the high-risk conditions for many planetary boundaries.

If the world tries harder to achieve the SDGs on all fronts through intensified conventional policies to 2050, this gives better SDG success than the business-as-usual or faster economic growth scenarios. It also improves the PBs safety marginally, but not sufficiently to keep them in the low-risk, safe zone.

This is the world's first study – to our knowledge – on how to optimally achieve all SDGs within all PBs through an integrated Global System Model. We find that a piecemeal approach to attaining the goals sets up trade-offs and conflict among goals. The pursuit of each and all SDGs is necessary, but not sufficient to succeed in the longer run, and potentially even counterproductive. A transformational approach to SDG achievement is needed. The elements of this transformation are presented in our scenario 4) but further analysis and modelling are needed to support the necessary changes worldwide.

It seems necessary to implement transformational and extraordinary policy changes, in order to achieve near full success of SDGs within PBs. These policies need to go well beyond the conventional policy toolbox.

A call to action for policy makers

How can the world achieve the Sustainable Development Goals within planetary boundaries?

The following policy recommendations emerge from the project's foresight analysis:

1. *We call on world leaders, as a matter of urgency, to explore transformative change measures to increase the likelihood of meeting more SDGs by 2030 and to achieve global sustainability by 2050.* Transformative change is needed to attain the SDGs because, on the current path, the world will only achieve 10 of the 17 Sustainable Development Goals by 2030. This happens at the expense of pushing 8 of the 9 planetary boundaries out of their safe zones – with the situation worsening to 2050 and beyond.

2. *Transformative change is possible, through five strategies that seem to be powerful ways to reach most SDGs within most PBs.* The five measures are:
   1) accelerated renewable energy growth sufficient to halve carbon emissions every decade,
   2) accelerated productivity in sustainable food chains,
   3) new development models in the poor countries,
   4) unprecedented inequality reduction, and
   5) investment in education for all, gender equality, health, family planning.

   The choice is the simplest way we have found to achieve all SDGs both social and environmental. They represent five "leverage points" to intervene in the globally interconnected geo-bio-socio-economic system. Together, they are capable of shifting the global system onto a new path in the decades ahead.

3. *There is no silver bullet. Attaining the SDGs within PBs will require an integrated mix of policy levers* – as indicated by the five transformations we recommend above. The policy mix will include economic growth, technological advancements, policies in support of inclusion and social equity, and global partnerships for governance of planetary boundaries. We have calculated the scale required, but recommend further analysis of how to achieve implementation, and these need to be made on in-depth understanding of the global system and the dynamics of socio-economic-environmental transition.

4. *Behavioural transformation is also required, particularly in the rich parts of the world.* Given current trajectories, it seems very unlikely that SDGs within PBs can be attained without a shift in mind-set and values broad enough to support the acceleration of transformational actions. 2030 is only 12 years away and it is urgent that both world leaders and citizens move into a domain where everyone not only knows the information but also acknowledges the implications. Our analysis indicates that transformational change is not only necessary and possible, but also desirable, with many positive synergetic implications for people and communities.

5. *Humanity can avoid planetary breakdown by postponing consumption growth by one year.* We challenge the economic and policy community to look critically at our transformational scenario. The measures are not only necessary, possible, and generally desirable, they are also affordable. Related studies indicate that, at most, the costs of implementing the five actions would result in a global GDP in 2051 at the same level as global GDP would have been 2050. This equals postponing economic gain for 12 months. More likely it will give a huge net benefit, but – at present – we are unable in this study to fully quantify it. Most rational analysts would nevertheless say that the Earth's life-supporting systems are worth it.

1. Rising to the grand challenge

How can the world achieve the Sustainable Development Goals within Planetary Boundaries? What will it take to bring about human prosperity and equity within a safe biosphere? If the world is serious about the SDGs, and thus the need for a truly integrated prosperous and peaceful people-planet trajectory for development, what will it take to succeed? Is it at all possible to transition the world to global sustainable development as it is now defined – attaining the SDGs within Earth's planetary boundaries – through conventional means of economic development? What potential trade-offs and synergies do societies face when taking a truly systemic approach to the SDGs? And, most importantly, what are the transformational requirements to succeed in attaining human prosperity within a safe operating space on Earth?

Pathway analysis for achieving SDGs within PBs

This report presents new integrated scenario analyses of pathways to attain the SDGs within PBs. It explores all the above questions, based on a transparent, integrated and easily understandable modelling framework, which we call Earth3 (See Box 1). Earth3 calculates the effects on the 17 SDGs of major socio-economic developments for seven regions of the world, and assesses the status of global environmental pressures on the nine PBs. In essence, it is a tool to answer the question: will given policies help the world move in an inclusive direction while staying within Earth's safe operating space?

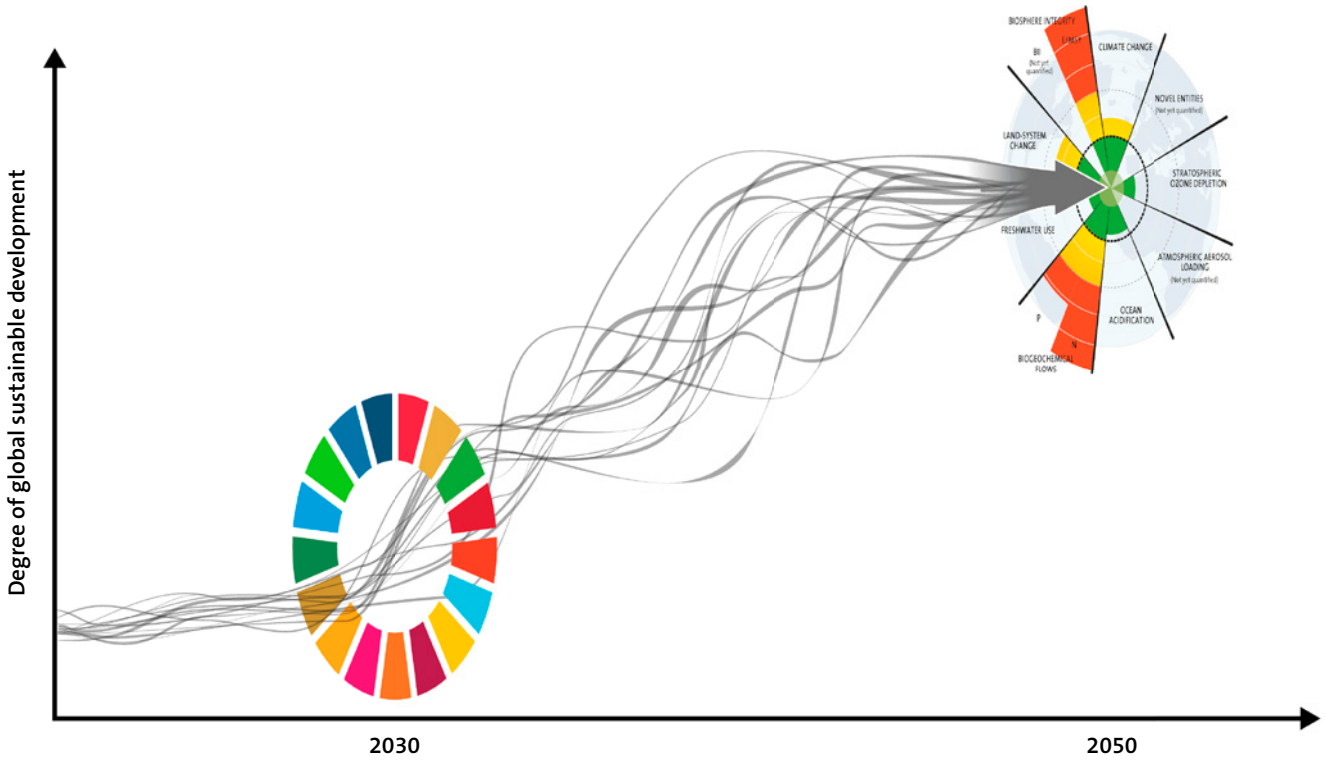


Figure 1.1 What pathways can lead to achieving the SDGs within planetary boundaries in 2050?

The SDGinPB initiative has focused on calculating the effects of policy actions needed for meeting the globally agreed aspirational goals for human development within the safe operating space of a stable planet. Earth's safe operating space is defined through the nine planetary boundaries boundaries – global quantifications of human-caused environmental changes, where continued pressure risks destabilizing the long-term dynamics of the Earth system (see figure 1.2).

Box 1: About The Earth3 model

Earth3 is a Global Systems Model linking socio-economic and biophysical processes. It builds on more than 100,000 historic and new data points, from existing databases all over the world.

Earth3 first calculates the main socio-economic developments (GDP, population, economic sectors, energy use, government spending, etc). Then it calculates estimates of how many of the 17 SDGs can be achieved by adopting certain policies in seven regions of the world. It also gives estimates of the status of global pressures on nine planetary boundaries for different world-development trajectories to 2030 and 2050.

Our modelling approach is described in appendix 1: The Earth3 model system

Data sources are described in appendix 2: The empirical basis for Earth3 model system.

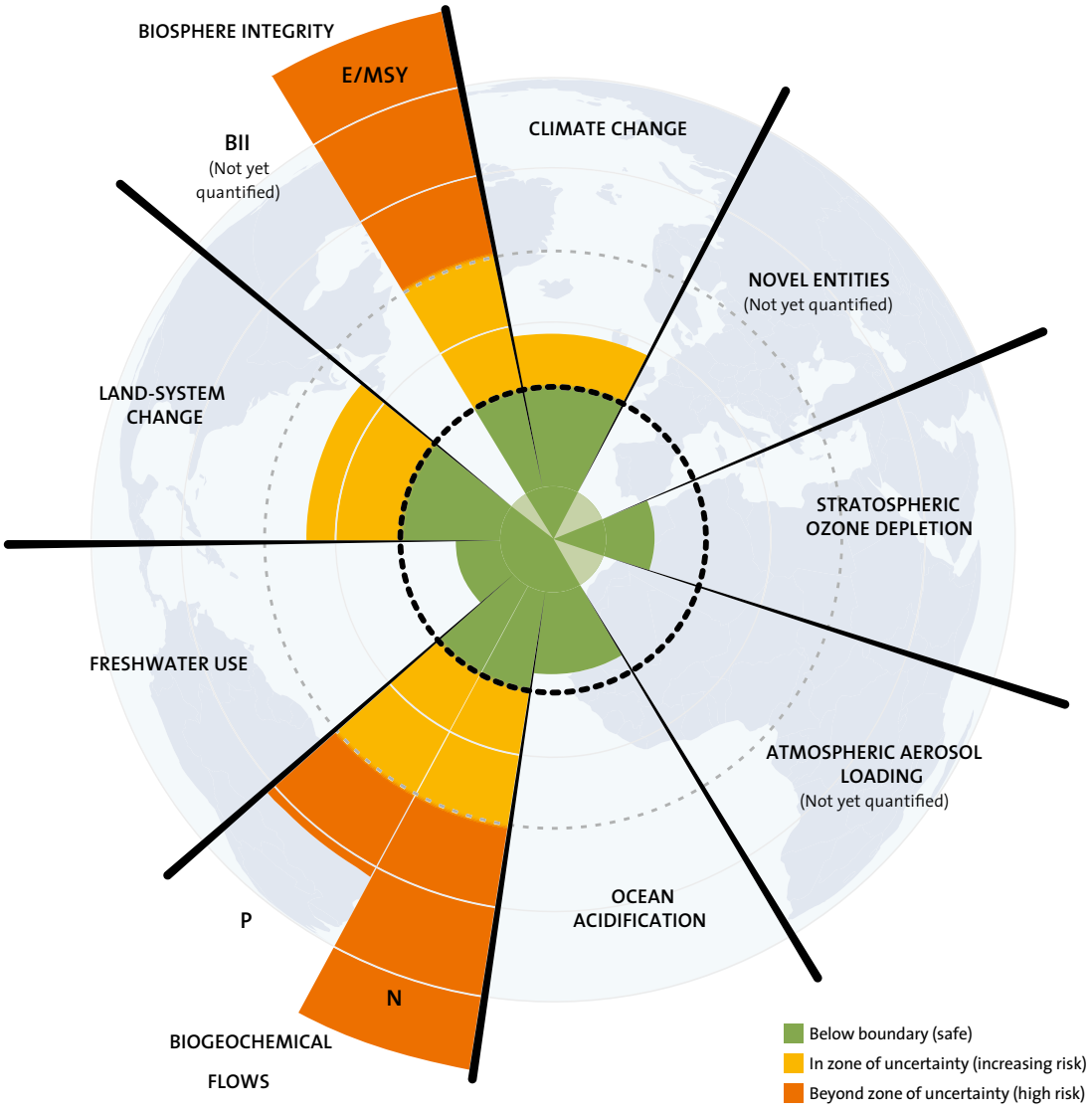


Figure 1.2 Nine planetary boundaries (PB) from Rockström et al. (2009) and Steffen et al. (2015). The dotted area represents the safe operating space. The greater the human-caused perturbation, the greater the risk of large-scale abrupt, and irreversible Earth system changes.

Figure 1.3 The UN 17 Sustainable Development Goals (SDGs), implemented by all the world's countries in 2016.

The grand ambition quantified: the SDG success score and PB safety margin

Our guiding question is: **how can the world succeed in achieving the Sustainable Development Goals within planetary boundaries?**

New studies show that currently no country meets the basic needs for its citizens at a globally sustainable level of resource use.[1]

To study the whole world's progress on the SDGs into the future, we calculate the number of SDG achieved every year, the "SDG success score".[i] The SDG success score thus goes from 0 to 17. This is done for each region in the world as well as the whole world weighted by population. We also calculate how this progress impacts the Earth's safety margin over time, to see if any SDG achievement is inside the planetary boundaries. Earth's safety margin goes from 0 to 9. If all PBs are in the safe zone (green), the safety margin is nine. If all PBs are violated (high risk = red), the safety margin is zero.

We assume that most of humanity would agree that a SDG success score of 17 with a PB safety margin of 9 is where we all want to be, whatever the population size is. The World Business Council for Sustainable Development published in 2010 a vision for 2050 formulated as "9 billion people living well on one planet"[2]. Since then the SDGs have come into force. Now, the same vision can be more precisely formulated as 9 billion people achieving 17 SDGs with Earth's 9 planetary boundaries in a safe state. To capture this vision in a shorthand we formulate it as SDGs within PBs, or #SDGinPB.

i We grade the SDG achievement in a simple way: An achieved goal (green) means 1 point. A goal that has passed the half-way target is 0,5 point (yellow). A red, ie not achieved goal is 0 points. See table 5.5 in appendix 1 for details on goals, chosen indicators and thresholds.

The #SDGinPB project approach

In short, the project answers the question by analysing the developments in all 17 SDGs, the nine planetary boundaries across seven regions of the world to 2050. To our knowledge, this is the world's first study to see if all SDGs can be reached within the PBs based on an integrated Global System Model.

The main types of input to our modelling approach are socio-economic data from 1980 to 2015 for all the world's countries. These include economic growth rates, population, education, health data, resource use and more aggregated into the regions. We use the most suitable publicly available databases to establish the historical trends (see appendix 2).

The model includes parameters that can reflect policy levers in many areas. The parameters can be seen as a "policy dashboard" for running the world model to 2050. There are levers per region to influence the expected a) Growth rates, b) Jobs, poverty and inequality levels, c) Energy use and composition, d) Food- and agriculture productivity, and finally e) Education, health and gender variables.

Based on this, the Earth3 model can then calculate the SDG Success Score for each region and the Earth's common safety margin based on the state of the planetary boundaries. This report explores four possible and plausible pathways to 2050. The exploration consists of four model simulations of how the world can respond to the grand challenge, with each scenario giving both a regional and a world SDG as well as a global PB score. It also contains a scenario narrative of how these four world futures come about. The four scenarios are all based on the same historic facts but are shaped by different policy and investment choices made in the coming decade(s).

We do not assign probability to the scenarios, which means they are not predictions. Some people may consider the first, business-as-usual scenario most likely and the fourth transformational scenario very unlikely. Others the opposite. We hope this foresight analysis will stimulate debate and create understanding about the long-term view on the SDGs, synergies between them, and how they are systemically related. But based on historic and current trends, using the best socio-economic and biophysical data available, the modelling clearly shows that only the most transformational scenario points to a sustained higher and inclusive human wellbeing, by achieving most of the SDGs while staying within most of the PBs. Thus, the results from our analysis show that only one of the four pathways actually rises to the grand challenge.

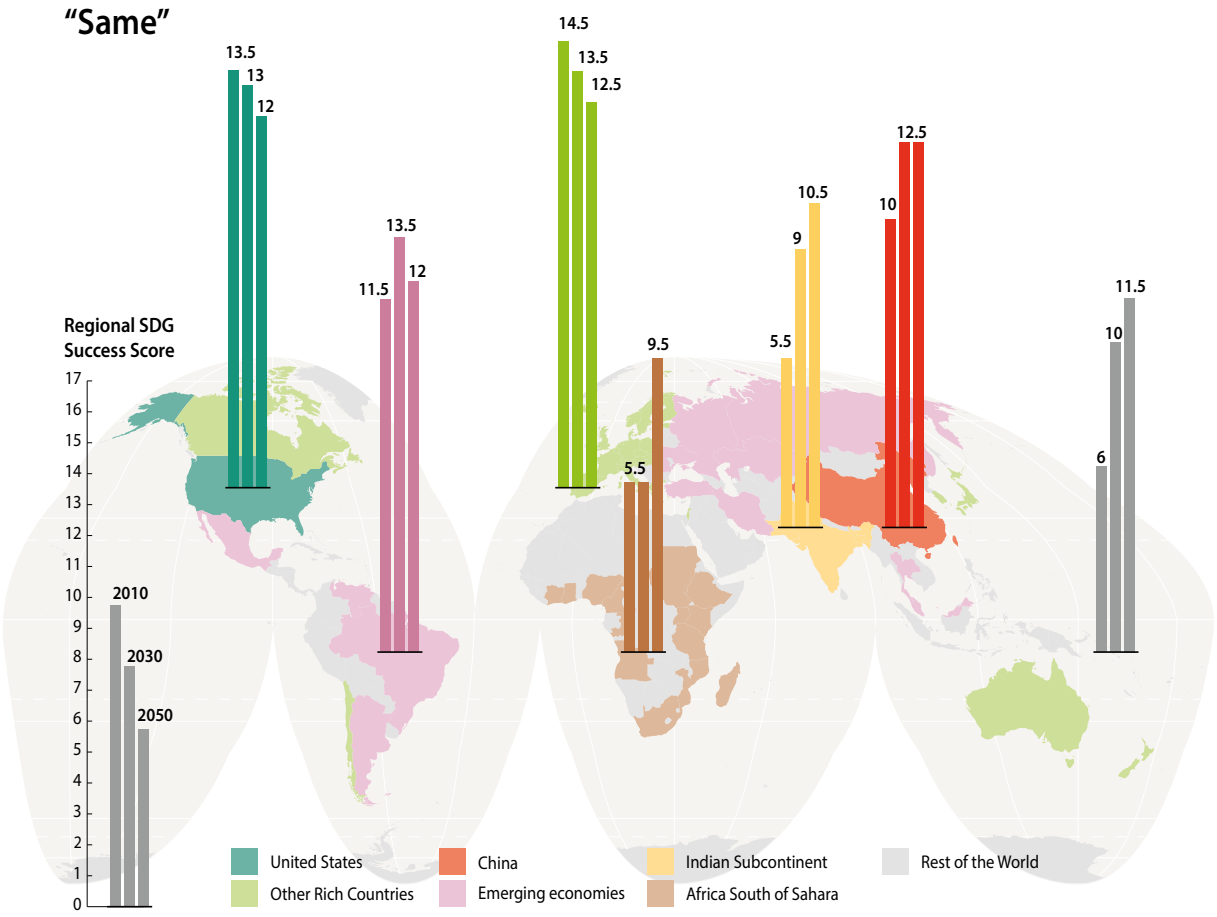


Figure 1.4 SDG success score per region in the Same scenario. Regional SDG scores for 2010, 2030 and 2050 are shown.

Four scenarios – a summary of possible futures

Through the scenarios we test four different answers to our overarching question: *"How can the world achieve the Sustainable Development Goals within planetary boundaries?"* The first answer comes from modelling how far the world will get by following business as usual to 2050. The second from simulating how far the world could get with faster economic growth. The third by pushing existing policies harder toward sustainability. The fourth by calculating the scale of key transformational actions actually needed to get there.

Scenario 1) Same: how far will business as usual take the world to 2050?

This baseline scenario explores a future where today's **Same** policies and actions are applied at the same pace into the future. Governments and industry will respond to technology, inequality and climate change in the conventional ways that the world has done over the last decades. Despite rapid technological changes, digitalisation in particular, the data from the last decades shows that most rates of socio-economic change are slow. In a more-of the-**Same** world, there is even more talk about sustainability and SDGs, but in practice nations still continue to change at the very same pace. But this pace of progress proves insufficient to deliver on the SDG targets by 2030 nor 2050. The good news is that poverty and hunger is finally eradicated by 2050, the bad news is that increased resource use and waste flows lead to more planetary boundaries in the red zone. This leaves many of Earth's life-supporting systems in a high-risk of irreversible decline, and people's prospects for wellbeing, particularly the poor, bleaker by 2050. In total, the world's SDG score only improves from 9 in 2015 to 11 in 2050. The reasons are that it is not inclusive of the poorer countries, within country inequality grows and total human footprints are too high. By responding to our new problems in the same, conventional ways, most people on Earth end up in a more precarious situation in 2050 than we are in 2018.

Scenario 2) Faster: will accelerating economic growth help?

This scenario explores what happens if governments and industry succeed with faster economic growth. Higher incomes can give extra funds to pay for more education, clean water, food, more jobs and the other SDGs for all people. The **Faster** growth scenario explores the effects of accelerated economic growth all the way to 2050. To achieve this, governments ramp up conventional policy tools, such as increasing trade, innovations and investments, keeping corporate taxes and interest rates low. We model growth rates that are +1% higher in GDP per person than the historic trend, which makes the global economy significantly larger by 2050. In this way, higher incomes are available to solve the world's problems. But this approach only delivers a little bit better on SDGs by 2050. Indeed, the planetary boundaries are more severely violated than in the **Same** scenario. Many people get very wealthy, but societies suffer even more destabilising inequality, and humanity as a whole undermines Earth's safe operating space by overexploiting nature's life-supporting systems.

Scenario 3) Harder: what if both governments and industry tries even harder to deliver on SDGs?

In this scenario, we explore where working harder for sustainability on all fronts will lead. The world's decision-makers focus real attention and energy on achievement of the SDGs. They allocate more funds to pay for more education, clean water, food, more jobs and the other SDGs for all people. In this way, governments strengthen their conventional policy tools, starting in 2018 and soon do on average 30% more rapid SDG-achievement than they did in the 1990–2015 period. Workforces and finance are redirected from current activity to projects that help achieve SDGs and/or reduce the pressure on PBs. But by delivering on the SDGs one by one in a piecemeal way, there are many trade-offs. And by 2040 the planetary boundaries are still under strong pressure, which leads to flat SDGs scores from 2030 to 2050. Many regions still struggle with destabilising inequality that undermines the sustainability policies. The **Harder** pathway leads humanity still undermines Earth's life-supporting systems, even if less so than in **Same** or **Faster**.

Scenario 4) Smarter: what if governments and industry actually choose transformational actions?

This scenario explores five bold transformations in our societies and economies to see whether these can bring the human world to a desired future on Earth. This is a challenge-and-response scenario which describes the extent of what is needed to "hit target". Rather than repeating the Same conventional solutions, growing Faster or trying Harder, this scenario explores what could happen if five bold, extra-ordinary actions were taken by decision- and policymakers in all regions. The Smarter scenario assumes that the world's countries and their leaders together become aware of the massive scale of the challenge ahead, and that the changes in mind-sets spread worldwide. Then, they rise to the challenge by implementing five turnarounds:

1. Rapid renewable energy growth – sufficient to halve carbon emissions every decade from 2020.
2. Accelerated productivity in food chains – improving productivity by +1%/year.
3. New development models in the poorer countries – following models such as China, Scandinavia, Ethiopia or Costa Rica.
4. Active inequality reduction – ensuring that the richest 10% take no more than 40% of income.
5. Investment in education for all, gender equality, health, family planning – stabilising the world's population.

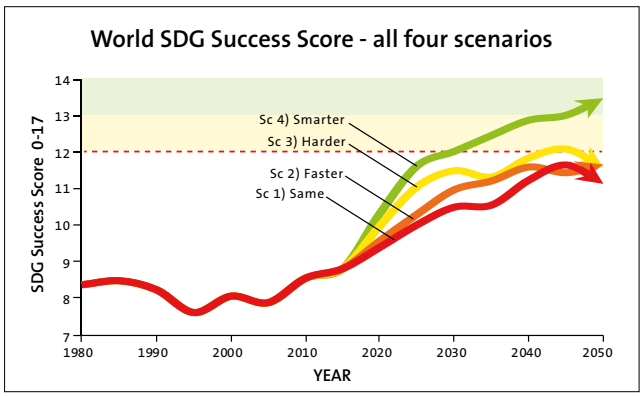


Figure 1.5 The world's SDG Success Score for each scenario. The score is calculated as the sum of the regional success indices, weighted by population, for each scenario.

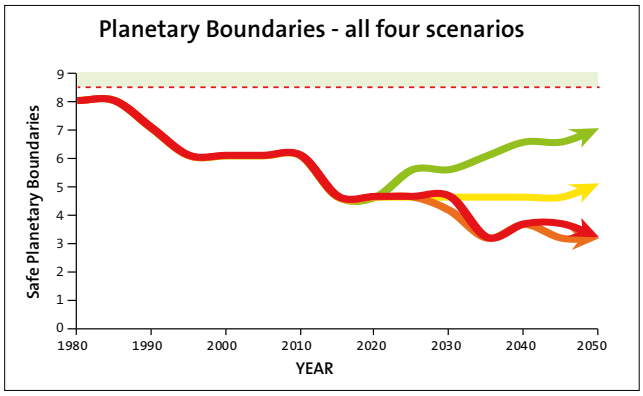


Figure 1.6 The four scenarios' impact on the Earth's safety margin. The safety margin is determined as the number of the 9 Planetary Boundaries that are within their safe operating space.

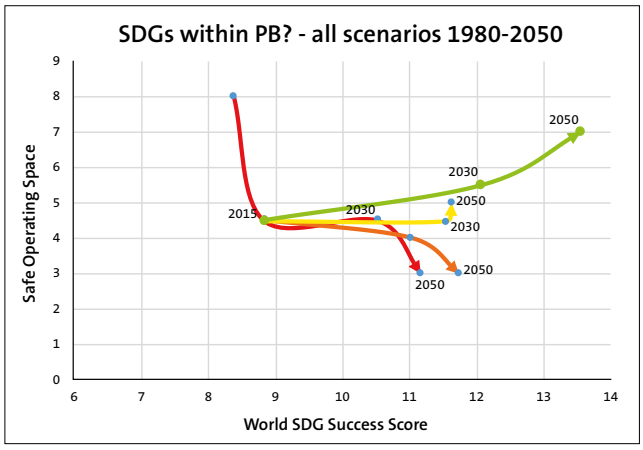


Figure 1.7 Achieving the SDGs within PBs: Only one of the four scenarios achieves the grand challenge of improving the world's SDG Success Score, without eroding Earth's Safety Margin.

Despite criticisms for being too radical, in the **Smarter** scenario these five transformative efforts are widely adopted, accelerated, and scaled over the coming decade. The scenario model runs indicate that these actions together create synergies that are capable of attaining (nearly) all SDGs while staying within (nearly all) planetary boundaries.

Will we achieve the SDGs within PBs by 2050?

The scenarios are described in detail over the next chapters but numerical answers to the main question are summarized in figures 1.5, 1.6 and 1.7. They show that while the scenarios Same, Faster and Harder can improve somewhat on the world's SDG achievement, they tend to do that at high cost to the stability and risk level of Earth's life supporting systems.

In summary, the analysis shows that – of the four scenarios – only the five actions in the **Smarter** scenario can keep developing the economy in an inclusive manner while staying within planetary boundaries. This type of transformative development seems to be able to secure a safe operating space for all of humanity before mid-century so that the world's societies can continue to flourish into the future beyond 2050 with safe(r) life-supporting systems on Earth.

The set of four scenarios together shows the necessity to consider global transformations if we are serious about attaining the SDGs within a stable Earth system.

Before delving into the scenarios, we would like to give two caveats: First, the Earth3 model system has not been developed to analyse and simulate what happens in a dynamic socio-economic transformation at the more detailed levels of real-world decision-making. It has too simple representation of the complex socio-economic feedbacks, such as rising inequality, debt, the long term effects of education and social responses to crises. A more elaborate global system model for informing decision makers would also include structures linking socio-economics more explicitly with water use, food use, unused biocapacity and emissions, and other resource systems.

Our second caveat: the Earth3 model system is not a comprehensive model of the Earth system. It has simplified representations of the complex environmental feedbacks between physical and living systems. Some of these feedbacks themselves are changing, such as greenhouse gas emissions from permafrost, ice sheet melting, forest dieback and more. If Earth3 underestimates these effects, then it could mean that failure to meet the SDGs within PBs may have even larger negative environmental social and economic impacts than illustrated in the scenarios, and thus lead to failure in reaching the SDGs at all.

2. Four possible pathways to 2050

With near universal acclaim from 193 countries, the 17 Sustainable Development Goals came into force in early 2016. For the first time in human history, the entire international community now has a shared plan and common goals for development to 2030. On this basis, there is a widespread sense of optimism and hope for the future. With such a clear plan as a shared foundation, the joint attention of governments and intergovernmental bodies becomes set on trying to attain all SDGs by 2030.

In this chapter we describe four alternative and different narratives of how this plays out in the coming decades. Each scenario narrative builds on the same 35 years of historic data input since 1980, and then explores how the world's seven main regions develop from 2018 to 2050.

Why did we choose these four scenarios? In the project we identified some key uncertainties that will determine which pathways to 2050 that we follow (for most countries and regions, on average): Will world societies mainly chose *conventional* or *extraordinary* efforts in order to achieve the SDGs? And if conventional policies are continued, will there be the same rates of growth, or will there be accelerated economic growth? And if extraordinary efforts are embarked on, will those be the same type of policies that we have seen, just stronger and trying harder? Or will societies embark on new types of transformational strategies and actions?

The three key bifurcations which give us the four scenarios are shown in figure 2.1.

Here, the pathway at the bottom of the page represents our first, business-as-usual scenario, in which the model replicates the **Same** tempo of change that the world has gone through in the previous 35 years. This continuation of the conventional policies and efforts is useful as a baseline scenario.

Then, in the second scenario (**Faster** *economic growth*), we explore the effect of higher rates of conventional economic growth. The reason is that many people view more economic

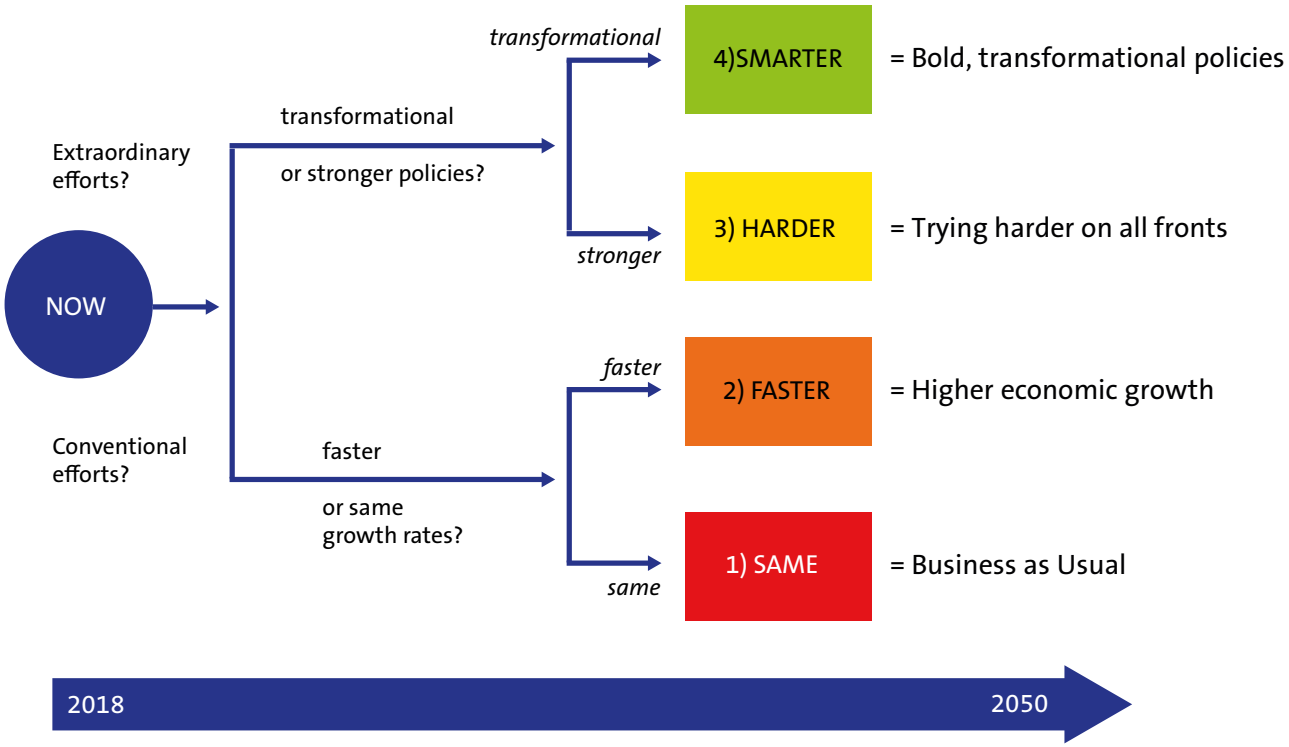


Figure 2.1 The "scenario logic" that determines the main characteristics of each scenario.

growth as the obvious way out of the current crises of poverty, hunger, education and environmental decline.

In the third scenario, we explore extraordinary efforts in the scenario of trying **Harder** on all fronts. This is because that another way to improve the SDGs is to focus more directly on the achievement of each goal. This means that government and industry reallocate and distribute funds and workforce to best practices that aim to improve the delivery on each SDG.

The fourth scenario explores the scaling up of extraordinary efforts. Not by trying harder at conventional solutions, but by working **Smarter**. Transformational actions are introduced and followed through. These key actions are chosen because they have systemic effects impacting several SDGs as part of the transformation, and have already been proven to work in certain model countries.

The table below summarises the main policy levers that are applied in each scenario.

The Earth3-model system can estimate the effects of the different policies per region. When aggregated for all regions, weighted by population, we can find the global SDG score per scenario. Earth3 also calculates the impacts on Earth's safety margin and average human well-being.

Scenario—> Main Policy Levers:	**Same** Business as usual	**Faster** Higher growth	**Harder** Stronger efforts – on all fronts	**Smarter** Extraordinary transformation
Growth	Average 2–3% GDP/yr "As is": (higher in poor countries, slower in rich countries)	3–4% GDP/yr	2–3% GDP/yr (= Same)	2–3% GDP/yr (differentiated: higher growth in poor countries)
Poverty, unemployment & inequality	"As is": Maintain current aid and unemployment benefit levels	= Same	+30% effort in fighting poverty, unemployment, inequality	active redistribution until 10% richest control <40% income
Energy	"As is" (current trends continue)	= Same	+30% effort in clean energy access, clean cities	rapid growth rates in renewables (wind & solar) and electrification
Food	"As is" (historic trends continue)	= Same	+30% effort in no hunger, safe water,	rapid shift to sustainable food chain (+1%/yr higher productivity)
Education & gender	"As is" (historic trends continue)	= Same	+30% effort in gender equality, education of women, family planning	investment in education to all, gender equality, health, family planning, (financed by redistribution)

Table 2.1 The main characteristics of each scenarios policy-portfolio.

Scenario 1: *Same* – business as usual

Same describes a pathway to 2050 where the world's countries officially commit to deliver on all Sustainable Development Goals, including no poverty nor hunger, as well as protecting the planet from degradation. To finance this, most countries draw on existing and well-established policies, with a focus on first growing their economies.

But no extraordinary policy effort or social measures are applied in reality. In large, business as usual is continued. Governments come and go. Most bold attempts at sustainability fall apart after an election period or two. At best, it's "two steps forward, one step back", which results in the same rates of change as in 1980–2015.

Overall, many poorer regions experience periods with higher economic growth, while richer countries see declining growth rates. Increasing inequalities cause social unrest, political crises, and derail fulfilment of SDG delivery towards 2050. Continuing 20th-century policies doesn't deliver in the 21st century.

Overall development in Same

In the **Same** scenario, it turns out that both politicians and business are generally better at talking about "sustainability", than implementing real action on it. The Sustainable Development Goals are for some years on everyone's lips (like the Millennium Development Goals were), but during the 2020s, interest starts to wane.

Many politicians, governments, companies, NGOs, philanthropists, and networks nevertheless make a sincere and committed effort. In sum, they keep pushing the world forward. Many millions of poor are lifted out of poverty. Many new technologies are developed and commercialised. In particular, there is rapid digitalisation and robotisation in industry and many services. There are also quite a few initiatives under way to establish processes and structures to measure and motivate SDG progress. Worldwide these efforts amount to continuation of the same rates of change in policy and economic development as in the 1980–2015 period through the 2020s and onwards.

Same policies: increase economic growth to deliver on SDGs

The governments in both rich and poor countries start to make national implementation plans by integrating SDGs into their existing polices and strategies. Already in May 2017 the UN General Assembly underlined the transformative potential of science, innovation, and technology. Accordingly, new technology solutions draw a lot of interest and funds in the 2020s. This builds on the widely shared perception that new technologies, like better renewable energy, cheap sensors, digitalisation, blockchain, robotisation, Internet of Things and 3D printing, along with open markets, can both boost the economy to solve poverty and malnutrition on the one hand, and cut pollution of Earth systems on the other. "Growth first, then sustainability" is the mantra.

Thus, to eradicate poverty, efforts are made to increase economic-growth rates in poor countries, particularly by more foreign direct investment and World Bank loans. All over the world, governments coordinate their initiatives, in their work to achieve the elimination of poverty (SDG 1), no hunger (2), better health (3), education (4), decent work (8) and less inequality (10). The really good news is that *all the world's regions succeed in eliminating poverty and hunger while improving longevity by 2050*. There are also great improvements in education and access to safe water. But often, each SDG initiative fights for funds among the others silos and governmental ministries, so trade-offs abound.

To fund even more SDG achievement, governments look for growth opportunities. They tend to follow conventional economic recommendations, such as those from the World Bank,[3] including stimulating the level of investments, keeping interest rates low, more public funds for infrastructure, digitalisation and wireless technologies. Through such policies and measures, mostly supply-side stimulus, the economies of many poorer countries start to grow briskly, some near 6% GDP increase per year. Many richer countries grow too, but much more slowly. The world average declines from 3,8 % per year in the decades before 2015, towards 2,8 % annual growth in global GDP in the 2018–2050 period.

On energy and climate, countries gradually inch their Intended Nationally Determined Contributions up every five years in order to comply with the Paris agreement. Some countries are much more ambitious than others. But the world average does not improve rapidly and the accumulated

Figure 2.1.1:The gist of the Same - Business as usual scenario: Keep pushing at same speed

emissions to 2050 give a temperature rise of already 1.9°C by 2050. The bad news is that the temperature trend is still pointing upwards beyond 2050. Some progress is also made on regional carbon-emissions pricing, with a patchwork of emission-trading systems spreading throughout the 2030s. Carbon productivity is improving slowly at around the same annual rates seen in the 1980–2015 period (3.4 % per year change in $/t$CO_{2e}$)

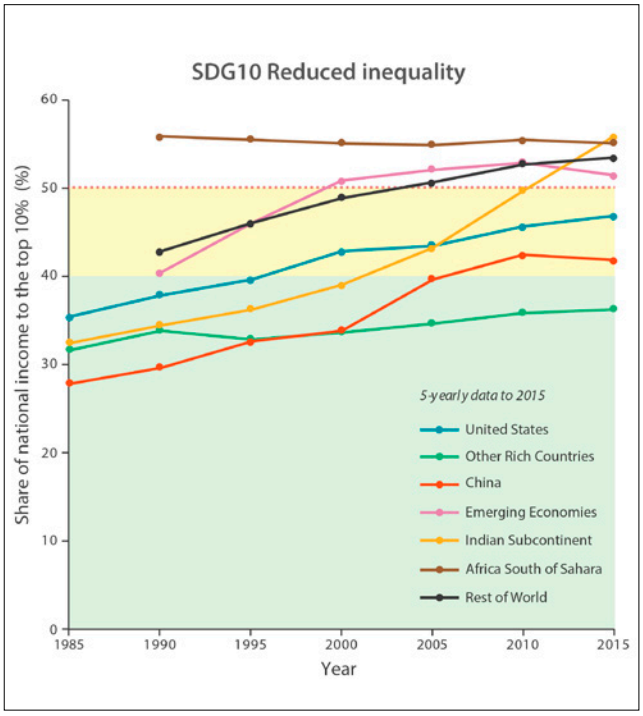


Figure 2.1.2 In the 1985-2015 period, most regions have seen increasing, not reduced, inequality as measured by income to the top 10%. Only ORC is still in green territory. Particularly EE, India and China have seen high increases in inequality. Source: World Inequality Report (2018)

Why more of the Same is not enough

On the path to 2030, however, several unintended consequences crop up. First, social inequality (see figure 2.1.2) within countries continues to worsen along historic trends because most of the wealth created accrues to the already wealthy.[4] Among the causes are financial sector wealth concentration and more middle-income jobs being hollowed out by rapid digitalisation and robotisation in almost all countries. Also in some areas, increased foreign direct investment in automation actually results in net job loss. The resulting inequality tends to weaken economic growth rates.[5]

Second, environmental decline – with air and freshwater pollution, along with worsening droughts, freshwater shortages, heatwaves and wildfires due to global warming – contributes to more urban crises, migration waves and even civil wars. These crises, thirdly, put severe pressure on often already weakened public institutions, as they lose taxes from a dwindling middle-class workforce. There is an increase in failed cities and states. Debt-ridden governments struggle with public poverty and private wealth, as gains are privatised but losses are consistently socialised. Capital investments seek out the stable areas, increasingly making a split world with some progressive growth zones and other areas falling behind.

In food and agriculture, historical trends continue, which gives annual productivity improvements in the food value chains of around +1% per year from soil to table. But as this

productivity improvement is not by itself enough to meet the world's growing food demand, thus ever more pristine land and forests are converted to monocultures. During the 2020s, rising pressure on arable land and freshwater push even more biodiversity and ecosystems into high-risk zones of irreversible decline. This particularly hits the marginalised poor who depend the most on the ecosystem services, further escalating inequality.

Region by region, from 1980 to 2050

The United States (US): The strong economic growth of USA started already in the 1950s. By 1980 it already had the conditions in place to deliver on most SDGs (poverty, hunger, health, education, water, energy, etc). This wealth is maintained up to the 2030s and beyond but with slowing growth rates – since it is considerably more difficult to have high growth rates per year, when the GDP per person is already above USD 60,000 (2011 USD). Towards 2050, however, due to growing inequality, sluggish jobs' growth and worsening global conditions on the planetary boundaries of climate, life on land and ocean acidity, etc, even the US's SDG scores are pointing downwards.

Other Rich Countries (ORC)[ii]: Many OECD countries in this group see the same socio-economic trajectory as the US. On the basis of their strong economic growth starting before 1980, their economies continue to deliver high income per person. These countries had already in 2015 a high SDG score of 13.5 (out of 17), and maintain this level in the following decades. But here, too, global warming and life below water show declining states towards the 2040s. By 2050 they have a sinking trend on their SDG score.

China displayed exceptionally strong economic growth and SDG performance in the 2000 to 2015 period. During the 2020s China continues to experience some of the highest economic growth rates around, and reinforces its position as the largest economy in the world all the way to 2050. But as China's economy booms, so does inequality. For a while inequality grows to high levels in China (>40% to the 10% richest), but through anti-corruption and redistribution measures, China follows through on what it has said (President Xi[7]), and gradually turns that ratio downwards again to around 40%. But in spite of electrification, many Chinese cities continue to struggle with air pollution – not just from coal, but also traffic, and climate emissions remain high to beyond 2040.

Emerging Economies (EE)[iii]: Like China, EE countries see strong economic development and improvement in SDG scores for 2000–2020, but also see even more rapid increases

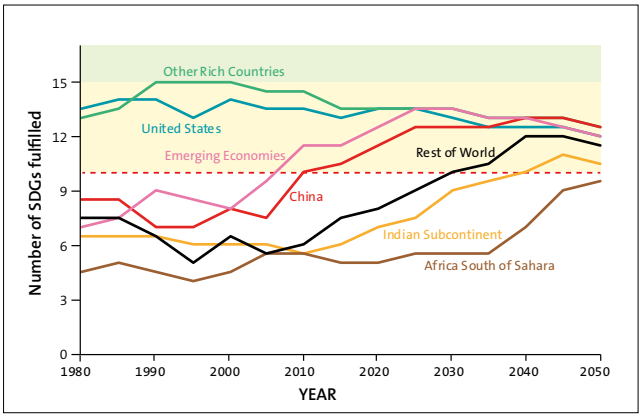


Figure 2.1.3 SDG success score per region 1980–2050 in scenario ***Same***.

in inequality. Most cities, too, grow bigger quicker than they get cleaner. They only start getting cleaner slowly towards 2050 in this scenario. Climate action is also rather weak in these countries, and in sum this region still has very high emissions by 2050.

The Indian subcontinent (India, Bangladesh, Pakistan) has by far the biggest population, at over 2 billion people by around 2030 and grows strongly in the 2020–2040 period. The rest-of-the-world region follows India time wise. Both these start to catch up with other regions from around 2030, particularly looking to China for trade and support. But here too, inequality, cities and climate are among the SDGs that are far from being achieved, leaving many people at lower wellbeing levels.

Africa South of Sahara is the final large region to get strong growth, particularly in the 2030–2050 period. In this region, by 2050 there is good progress on poverty, hunger, health, gender equality and decent jobs. But several SDGs are still in the red zone by 2050: inequality, air pollution, climate action, governance and partnerships.

In summary, economic development proves, at best, to be uneven in all regions, due to inadequate handling of the issues of inequality, urban overexpansion and pollution, corruption, intergovernmental bureaucratese and inertia, increasing protectionism and many nation-state (near-) failures.

In this **Same** world, no further, ambitious government policies are implemented to secure SDG success by 2030 as intended. As the 2020s pass, it becomes increasingly apparent to all that full SDG achievement is far away. As 2030 eventually arrives the world SDG success score is only up from 9 in 2015 to 10,5 in 2030. Recognizing this, politicians chose to postpone the timeline for delivery on SDGs to the 2050 horizon.

ii These are: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Israel, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, UK. See section 3.3 for details.

iii EE countries are: Argentina, Brazil, Iran, Kazakhstan, Malaysia, Mexico, Russia, Romania, Thailand, Turkey, Ukraine, Venezuela.

Accordingly, at the UN General Assembly in 2030, the SDGs are adjusted and revised but mainly kept in place. Conclusions are drawn that there is nothing wrong with the SDGs themselves, nor with the growth-first-then-trickle-down approach. Rather, countries just need to get more effective at implementing the existing strategies and known solutions. Some SDG progress is after all being made. Nation states declare intentions to cooperate and trade more freely with less regulation, to reignite higher growth rates. So the same strategies are adjusted, measures fine-tuned and more global collaboration and trade promised. But the follow-up and follow-through is patchy. The world mainly continues to try with the same old solutions.

From 2030 to 2050: why conventional solutions still fail to achieve more goals

As the **Same** world approaches 2050, it becomes more and more apparent that several planetary boundaries are under pressure and in a red zone state. Critical voices have long doubted the realism of achieving both the environmental and social SDGs without coordinated policies.

By 2050 they are unfortunately proven right: due to more and more problems with air pollution, nutrient overuse and frequent extreme weather events, this draws an ever higher share of public funds into repairs and rebuilding from disasters, and infrastructure maintenance. Private funds seek higher short-term return on investment opportunities. Thus, too much of the investments go into unproductive areas of the financial economy, leaving too little for education, gender equality, innovation, health, clean urban development and investment in natural capital.

The underlying problems with the red-state planetary boundaries (see figure 2.1.4) are not solved mainly because governments do not raise enough funds (through taxation) and transfer these to people to do the jobs that need to be done and thus stimulate demand. Since per capita GDP growth slows as countries get richer, there is also lower economic growth in spite of increased attempts to reignite economic performance in these richer countries.

The situation in 2050

The **Same** world in 2050 will thus be one of huge regional and class inequality, with a very small Earth safety margin. Population growth slows down and peaks at 8.7 billion people before 2050. With fewer children and more elderly, nearly all people live in urban centres and ever more interaction happens

Scenario SAME overview

Main policies (2020–2040)	- keep investments at historic levels - more trade, competition, foreign direct investments - maintain unemployment and health benefit levels at same levels - no further policies to reduce inequality, - underfunded public services, private wealth
Unintended obstacles & challenges (2025–2050)	- increasing economic inequality - political instability, nationalism, anti-globalisation and conflicts - weakening public institutions and government - severe global warming and costly extreme weather events - social instability, some cities fail
Outcomes & consequences (2050 –>)	- world SDG success score of 11,3 (out of 17) in 2050 - Safety margin of 3: PB in 'green' is: Ozone depletion (1pt) In 'yellow' are: Ocean acidification, freshwater, nutrient overload, forest degradation. (0,5 pts each) In 'red': Global warming, biodiversity loss, air pollution, toxics.

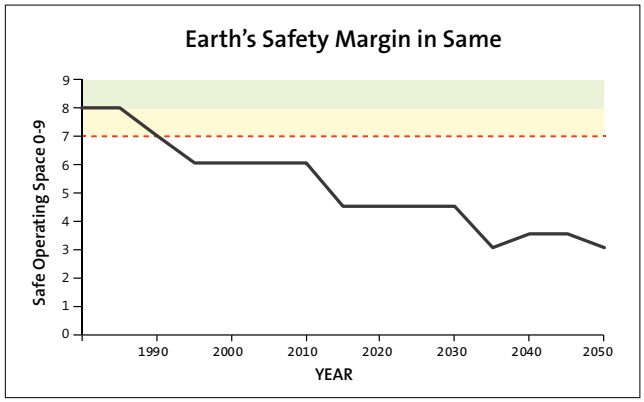


Figure 2.1.4 The Earth's safety margin as a sum of planetary boundaries (0= all in high risk, 9 = all safe).

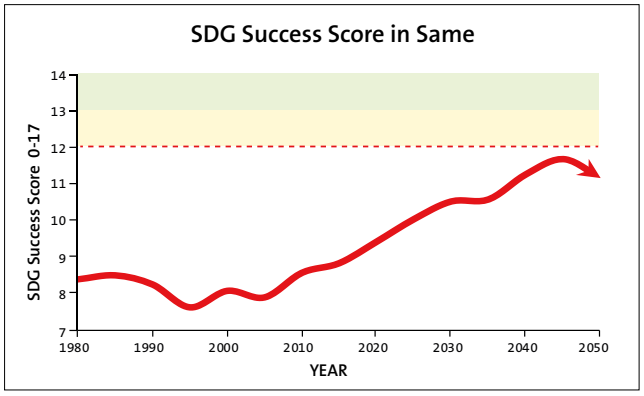


Figure 2.1.5 The whole world's SDG success score for scenario 1 Same, aggregated from regions and weighted by population (0-17).

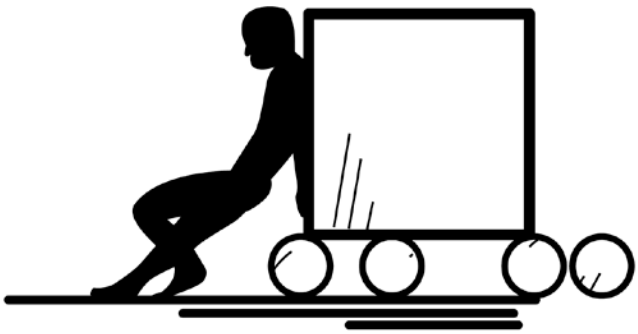
in virtual spaces. The good news is that poverty and hunger is eradicated. The bad news is that Earth's safety margin is in deep red, risk zone (with a score of just 3 out of 9)[iv].

The world economy is two and a half times bigger in 2050 than in 2018 (from 94 trillion US dollars to 251 trillion[v]). But the wealth goes mainly to the richest in the wealthy areas of the world. The 10% richest take more than 52% of the world's incomes (up from 32% in 1980 and 49% in 2015). This is perceived as unfair and sparks increasing social friction, tougher border protection measures, and even terrorism and armed conflict. Most poor people are much better off in absolute terms in 2050 than in 2018 with poverty and hunger mainly solved. But due to rising relative inequality, urban fragmentation and natural degradation their wellbeing often suffers.

In sum: despite following the established advice and "best-practice" recommendations from the conventional economic development toolbox, going forward from 2020 in this same manner, the world falls short when the SDGs are combined with planetary boundaries. Dangerous climate impacts and collapses in ecosystems (like ocean corals, fisheries, wildfire-prone forests) start overwhelming early gains in SDGs. In this **Same** world, the rising trend in SDG scores has therefore peaked and turned around by 2050, and points firmly downhill into the second half of the century.

iv When the Earth's Safety margin is 3, this is due to the following: Only one PB in the 'green': Ozone depletion (gives 1point) Four are in 'yellow': Ocean acidification, freshwater, nutrient overload, forest degradation. (adds 0,5 pts each). The four in 'red' are: Global warming, biodiversity loss, air pollution, toxics contamination from novel entities (0 pts).

v 1 trillion $ = 1 T$ = 1000 G$ = 1000 billion dollars. With "$" we, in this report, always refer to 2011-USD at purchasing-power-parity, in short: 2011ppp $.



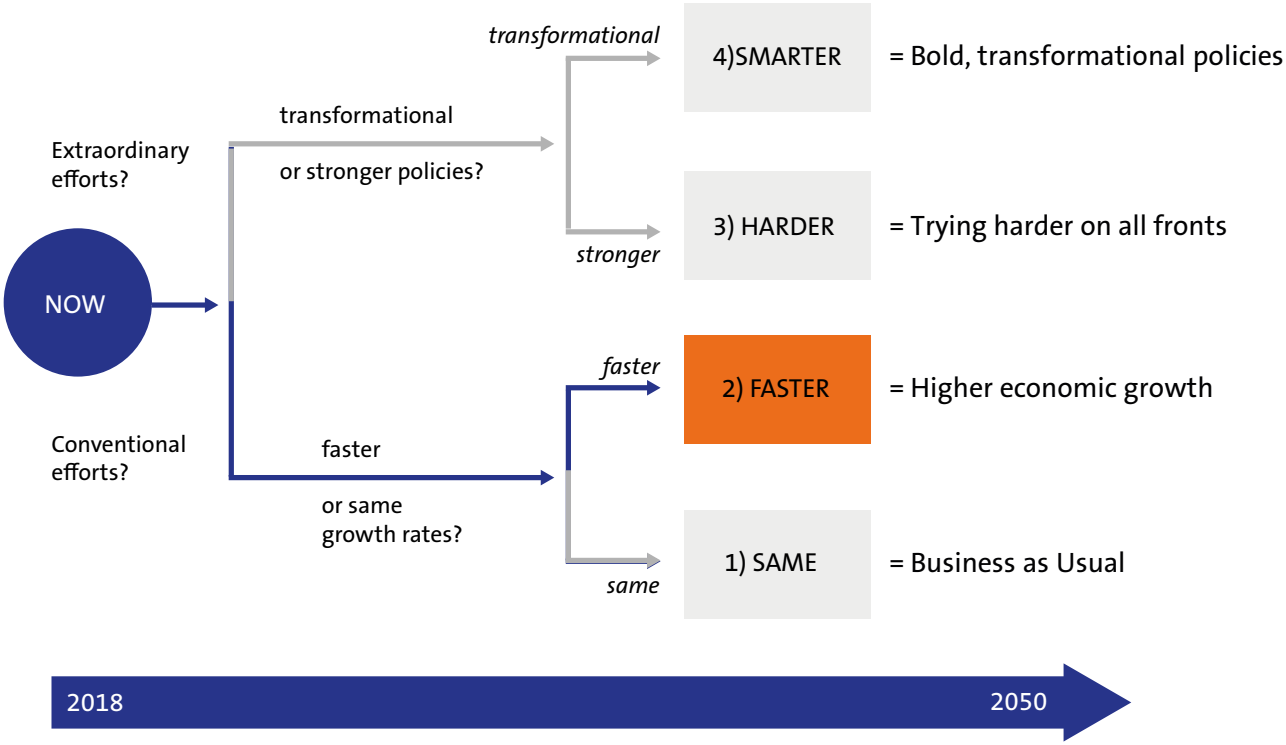
Scenario 2: *Faster* – accelerating economic growth

The **Faster** scenario is similar to the **Same** scenario, except that governments here try – and succeed – in raising economic-growth rates to substantially higher levels. On average, the world increases its growth rates by an extra 1% of GDP *per person* per year from 2018 to 2050. This gives an increase in the average global economic growth rate from 2018 to 2050 from 2.8 %/y to 3.5%/y. The reason why global GDP grows less than 1 %/y is because of the compensating feedbacks in the system – specifically both lower GDP-growth- and birth rates as people get richer and better educated. As regions get richer, the rate of change in annual growth per person tends to decline, following the empirically observed global guideline (the bottom guideline labeled Same in figure 2.2.1).[8] This results in a slightly less GDPpp and fewer people over time and hence a little less (than +1% per year increase in) total GDP growth to 2050.

Faster describes a pathway to 2050 where all the world's countries make a concerted effort to grow their economies even quicker. The dominant idea is that with faster growth, all the Sustainable Development Goals can be financed, fixing poverty, hunger, climate and environmental damage, and providing better health and education.

Most countries intensify conventional pro-growth policies, primarily by increasing trade, investment levels and new technology development.

At first this goes well. On average from 2018 to 2050 the annual growth rates are +1% GDP per person higher than in the Same scenario. But speeding up average growth rates also increases social inequalities. Furthermore ramping up high-growth 20th-century policies in the 21st century causes an even larger ecological footprint, which weakens responsible consumption, worsens climate, and harms life below water and life on land.



The key uncertainties for the pathway that leads to Scenario Faster.

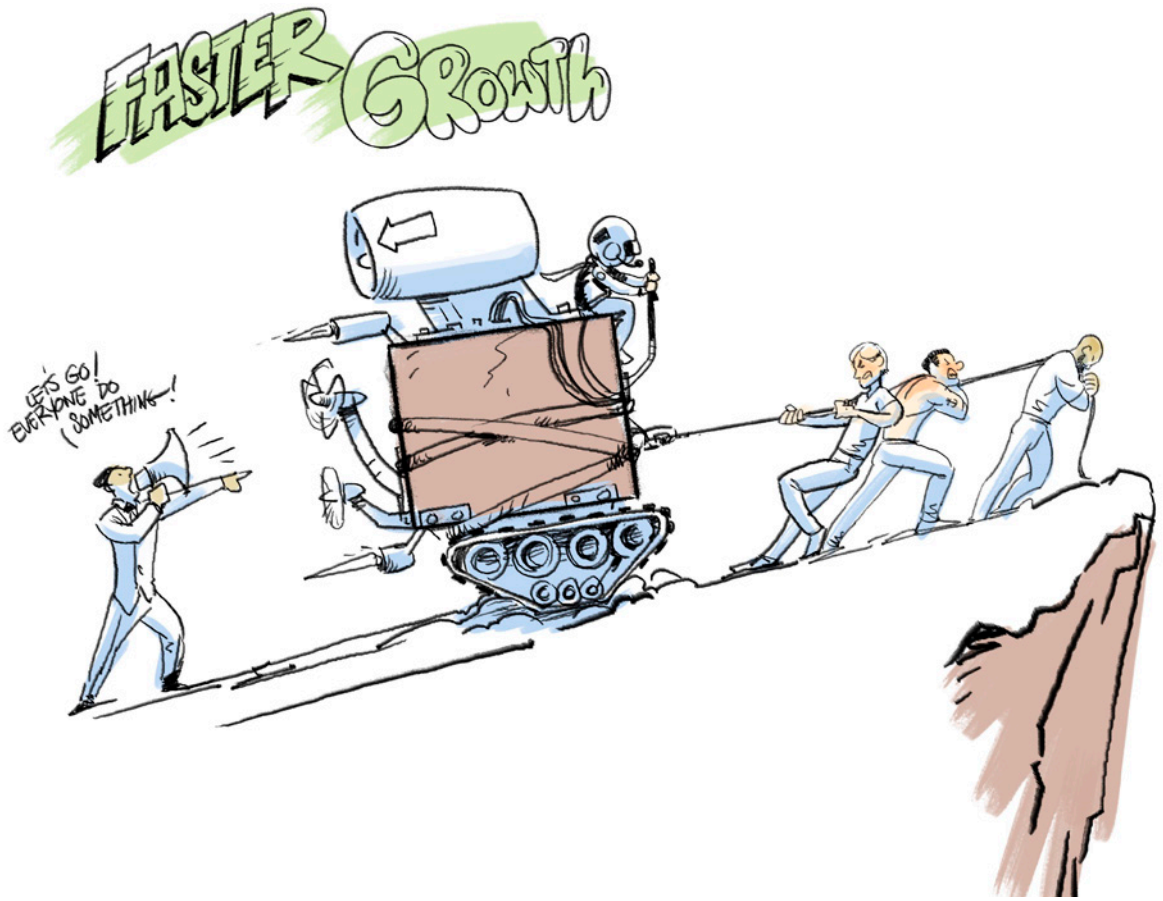


Figure 2.2.2 The gist of scenario 2; Going **Faster**, speeding up economic growth as first priority, as much as possible.

During the 2020s many countries attempt raising growth through the prescriptions of the "Washington consensus": the basic idea is that by attracting more investment in open markets and generating economic growth, there will be enough of the proceeds from economic growth to reduce inequalities by redistribution, without anyone's standard of living having to be lowered by taxation. This message is popular with the already wealthy and powerful, and is so successfully pushed that it wins politically in most regions.[9]

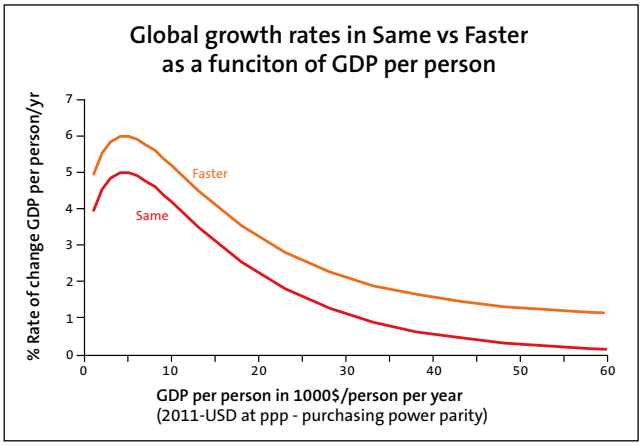


Figure 2.2.1: Regional GDP per person growth rates (on vertical axis) in Faster vs. Same shows how a 1 % faster economic growth rate per year plays out as countries get richer in terms of a higher absolute GDP per person.

All over the world, governments compete during the 2020s and onward to achieve higher growth for their citizens. To raise growth rates, governments apply conventional economic recommendations, such as those from the World Bank.[10] This includes:

- increasing the level of investments to above 25% of GDP, with public investment in infrastructure accounting for 5–7% or more of GDP. Digitalisation and wireless technologies are prioritised;
- more technology transfer, particularly in affordable, low-carbon and renewable energy (SDG7). Foreign direct investments are coupled with know-how transfer and best-available technologies, enabling leap-frogging in finance, logistics, energy;
- increasing investments in the health, education and skills of the people – the human capital;
- enhancing competition and structural change in markets, while protecting people – not outdated jobs – with some unemployment insurance, retraining and access to health care;
- export promotion and industrial policy for increased trade;
- seeking macroeconomic stability in terms of price level, the exchange rate and low interest rates

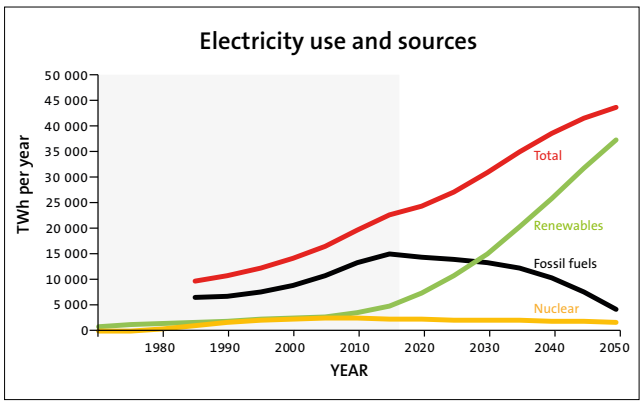


Figure 2.2.3: The energy transition in **Faster**: Renewables are outcompeting fossil fuels for electricity generation.

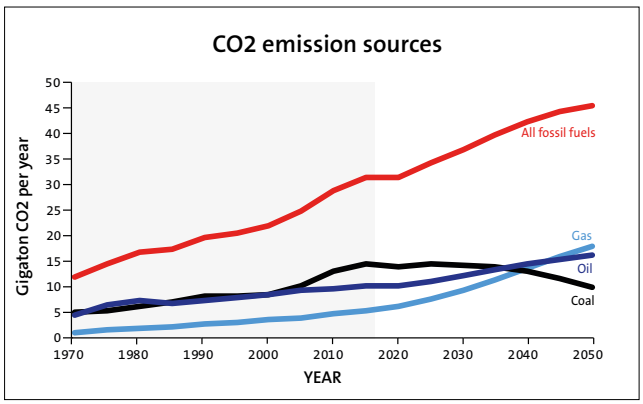


Figure 2.2.4: The rise in the direct use of oil and particularly gas, keeps pushing CO2 emissions despite cleaner electricity generation. The total use of fossil fuels in **Faster** is 18,000 Mtoe/year in 2050 relative to 12,000 Mtoe/year in **Same**.

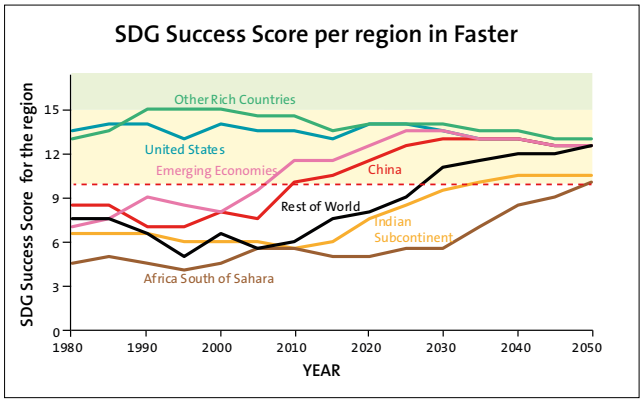


Figure 2.2.5 The SDG success score per region from 1980 to 2050 in scenario **Faster**.

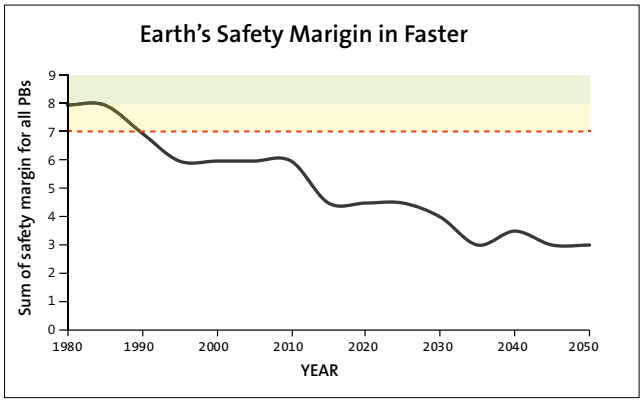


Figure 2.2.6: The Earth's safety margin is declining from 1980 all the way to 2050.

– lowering tax burden and increasing domestic savings;
– establishing new processes and structures to measure economic and SDG progress.

Through such policies and measures, mostly supply-side stimulus, the poorer countries all over the world start to grow briskly. Some poorer regions achieve near 6% annual GDP growth. And, as developing countries get richer, the strength of the new global middle class starts to surprise everyone by 2030: The purchasing power of this new, mostly urban, middle class in Asia, Africa and Latin America stimulates demand-side growth as well. Satisfying middle class demand in burgeoning cities through digitalisation and new services in smart cities, make them into powerful economic hothouses. This is the main impetus about the +1% annual increase in GDP per person in this scenario to 2050.

The world also sees brisk growth in renewable energy, even more than in **Same**, as there is demand for ever more electricity and renewables get cheaper. There is rapid take-over of the electricity supply by renewables. But the direct use of fossil fuels, particularly gas in other sectors than power generation, also keep increasing. There is no concerted effort at electrification of industry, heating and transport. This keeps emissions from fossil fuels high and pushes them above 45 $GtCO_2$/year in 2050. This furthermore drives the global warming past +1.9 C average surface temperature rise already by 2050.

All this energy use and economic growth does however, deliver more funds that trickle down in various degrees to eliminate poverty (SDG 1), fight hunger (2), give better health (3), education (4), more energy (7) and more decent work (8). This is visible in figure 2.2.5, particularly for India, Africa south of the Sahara and the rest-of-the-world region. Also better technology will be able to both grow the economy while delivering on cheaper, cleaner energy to reduce the pressure (relative to the size of the economy) on biodiversity in water and on land.

Regional development, from 1980 to 2050

The US: The extra 1% average growth rate raises USA's GDP per person from 50,000 dollars per year in 2018 to over 72,000 in 2050. USA is still the world's richest region measured in GDP per person in 2050, but nevertheless represents a much smaller part of the world economy.

China is the world's largest economy (in PPP terms) all the way to 2050. By 2050 China's economy represents more than one fifth of the global economy. It is almost three times the size of USA's (68,000 billion dollars vs USA's 24,000 billion dollars). The two region's SDG success scores are very even from 2030 and onwards.

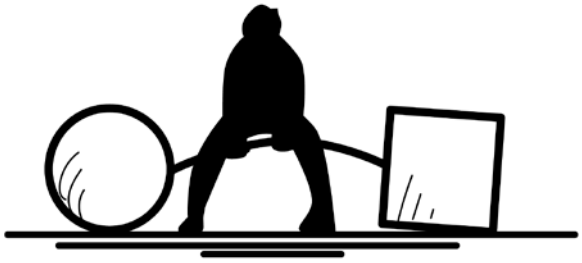
The most important difference in this scenario compared to **Same** is that growth in poorer regions, particularly Africa, India and the rest of the world, comes at an earlier period. Since this funds improvement in hunger, poverty and other social SDGs, their success score rises earlier than in **Same**, but do not keep rising to 2050. By then, with still growing consumption, the environmental SDGs (12–15) start to decline. This is clearly reflected in the state of the planetary boundaries, see figure 2.2.6.

The situation in 2050

In a **Faster** world, there will be fewer children and more elderly by 2050, and nearly all people live in urban centres and ever more interaction happens in virtual spaces. The world economy is more than three times bigger in 2050 than in 2018 (from 100 trillion dollars to 320 trillion dollars).

The extra economic growth reduces absolute poverty earlier in most regions, wherever the poorest can gain some increase in living standards from the nation's growth. In this **Faster** scenario however, it does not reduce the *relative* poverty, ie. inequality. This is partly because faster economic growth creates the best opportunities for those who are highly skilled and educated. Also the world's economies are creating fewer industry jobs due to robotisation and increased number of part-time, flexible service sector jobs, with typically lower wages. In this scenario, the rate of return on capital is higher than the rate of growth in general (even higher than in **Same**). Hence, as there is – in this scenario – little political will to fight inequality by redistribution, the wealth accrues mainly to the richest in the wealthy areas of the world; the 10% richest take more than 55% of the world's total incomes by 2050. This frequently leads to political crises, instability, crime and – by 2050 – threaten to reverse societal progress on SDGs (declining success scores).

Thus a **Faster** world, even more so than in **Same**, will be one of huge regional and class inequality, as there are insufficient policies to counteract the tendency of financial markets to accumulate income and wealth to capital owners relative to the poor. Despite increasing efficiency in the wealthier economy, the size of the total economy pushes the human footprint higher than in **Same**. Therefore, the safety margin on the nine planetary boundaries is greatly reduced, having gone down to just 3 (out of 9) for the 2035 to 2050 period. This makes further SDG achievement increasingly more difficult due to increasing severity of weather catastrophes, migration and natural resource decline. The outlook from 2050 into the second half of century looks bleak for the majority of people, in spite of an ever wealthier world.



Scenario 3: *Harder* – stronger efforts on all fronts

Most reports that are delivered to the 2020 UN General Assembly clearly show that trying to achieve the SDGs mainly through conventional economic growth, will surely fail.[11] There is widespread agreement during the 2020s that a sustainable future trajectory can only be achieved through really intensified efforts to harness a *new model* for economic growth that can deliver on both the social SDGs and a sustainable use of global natural resources and pollution sinks. Everyone agrees that the old 20th-century economic model has to shift to a green and sustainable growth model.

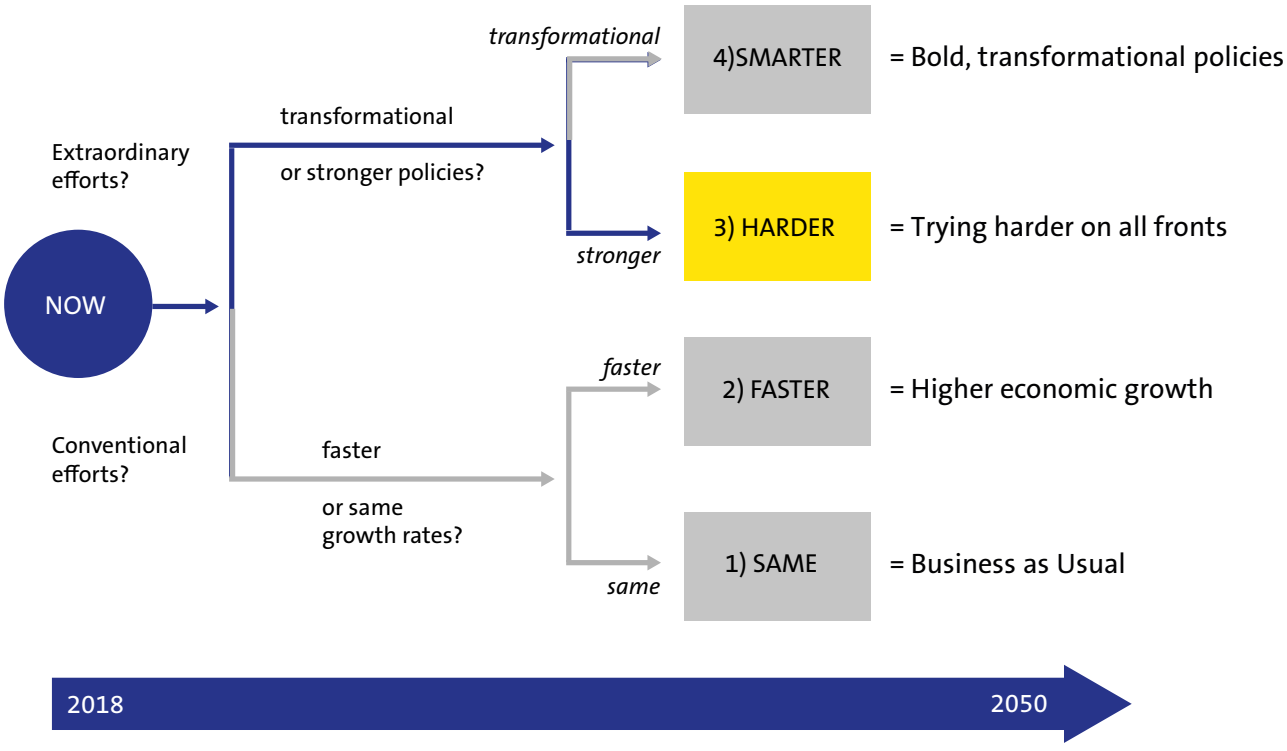
Trying harder at green and inclusive growth

By 2020, sustainable development therefore requires stronger policy focus in the **Harder** world. Revised and ambitious action plans are put in place in many countries. These include huge green stimulus packages, aiming for scaling investments in carbon productivity as well as water and land productivity

Harder describes a pathway to 2050 where the world's countries pull themselves together. The sustainability talk is followed up by working harder on all fronts, engaging governments, business and civil society. Yet, each SDG is lifted separately, and in many situations there are trade-offs, with one goal pitted against the other. One period money is cut off for sustainable agriculture to support education, or stimulus abruptly switched from clean energy to support freshwater, etc.

The conventional and well-known policies from 2000 to 2015 are still applied, just with, on average, 30–50% more effort than previously. People hope this will be enough to bring about SDG achievement quicker.

With more social and financial resources devoted to the grand challenge, more of the goals are reached by 2030, particularly in poor areas. Earth's natural resources are somewhat better managed, and more progress is made on responding to climate change. But it is clear that the world's societies will still push many planetary boundaries out to high-risk zones by 2050.



The key uncertainties for the pathway that leads to Scenario Harder.

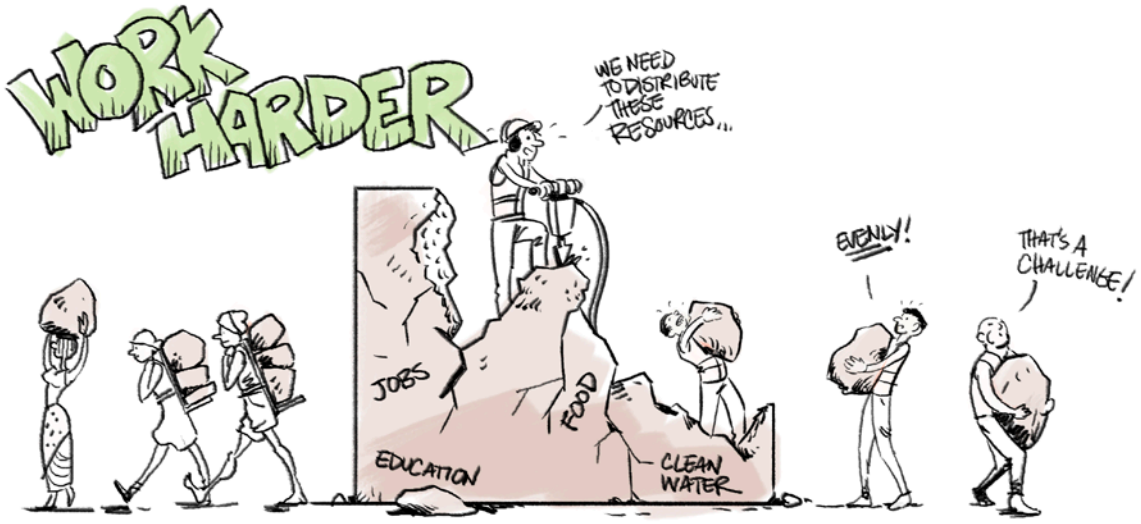


Figure 2.3.1 The gist of scenario 3 – Harder; stronger focus on all SDGs through better policies and industry efforts, each SDG being approached separately (by different ministries, industries, sectors, regulatory silos, separate budgets, single-issue groups etc).

in agriculture. These policy packages also aim to rapidly electrify the world using more solar and wind energy with power storage, further accelerating the dramatically falling costs in these technologies. They equally entail strengthening education, appropriate nutrition, unemployment and health benefits. In short, inequalities are lessened through better welfare policies, and technological change is rapid and directed towards more circular economy and environmentally-friendly processes.

Large-scale green growth policy and social activism

The ambition of transitioning to a green(er) economy is given ever more solid economic, scientific and social backing in the years up to 2030. Most regions see a strengthened political will to act harder. This arises from the recognition that the conventional market-based growth approach has insufficient incentives to protect social welfare and the "global commons"[12] of Earth's shared natural resources. Most governments, after much handwringing, succeed in ramping up efforts with 30–50% on:

- levelling the playing field for greener products by phasing out harmful subsidies;
- reforming climate policies and using "carbon clubs" for carbon pricing through import tariffs and border tax adjustments[13]
- redesigning market infrastructure and oversight to stimulate a circular economy;
- shifting taxation from labour to resource use;
- redistribution efforts such as more progressive taxation, cash transfers to low-income families, and other welfare benefits
- improving disaster management and emergency preparedness
- prioritising electrification and decarbonisation in the green stimulus packages;
- redirecting public investment and greening public procurement;
- discouraging investments in fossil-fuel extraction and removing subsidies for fossil-fuel use;
- reducing deforestation.

All these policies are greatly debated and fought against by special interest-groups that defend the status quo. Thus, progress is incremental at first. Yet, ultimately, the ambitious policies and harder efforts to deliver on SDGs mostly prevail on all fronts. There is real and substantial change in the direction of stronger focus on SDG delivery in all regions of the world. By 2020 they are significantly higher compared to the 1980–2015 period. Many politicians in the 2020s declare that a sustainability breakthrough has finally arrived. Others counter that it is too little, too late.

Therefore, the world also sees unprecedented levels of civil activism in the years up to 2030: people form new groups and institutions to push harder for private and public action, driven by the ease of digital transparency and international coordination. Anyone with a smartphone now easily accesses almost all the world's information, available anywhere at any time. Compared to previous decades, the case for governments engaging strongly with the private sector has broader support. More billionaire philanthropists also join forces to invest in global health, education and economic inequality. This helps give a boost to public-private cooperation on issues such as:

- supplying family planning, and education and empowerment of women everywhere;
- engaging more women in leadership;
- social entrepreneurship.

To improve conditions for food production, freshwater and land ecosystems, countries speed up the transition to sustainable agriculture aiming at:

- improvement in water productivity by 2030;
- reduction of nitrogen and phosphorus losses into the environment;
- halving of agricultural land-use expansion leading up to 2030.

For business and the private sector, the extra efforts involves taking advantage of opportunities[14] arising from global green growth serving the needs of 5 billion urbanites by 2030, mostly in megacities where the economic output is the highest. Many cities and states also start to levy taxes on polluting products (such as single-use plastic and fossil-fuel cars), while stimulating demand for green products, such as plant-based meats, solar panels, electric vehicles, public transport and bikes.

Despite trying even harder, surprising side-effects keep emerging

As the world gets nearer to 2030, there are many results to celebrate. Poverty reduction, hunger, education, gender equality and access to clean water (SDGs 1–6) are all improving. Yet, income inequality also grows drastically as the wealth created mostly accrues to the already wealthy. New jobs are created, but these are mostly high- or low-paying jobs. Middle-income jobs are hollowed out by rapid digitalisation and robotisation in almost all countries, and there are not enough new jobs to compensate for these losses.

Despite historically rapid developments in new greener technologies, the total human footprint on climate and ecosystems does not go down sufficiently. Global warming causes severe weather events to come ever more frequently. Hurricanes, heat waves, droughts and floods make many areas almost uninhabitable. Fisheries are weakened by ocean eutrophication, surface heating and acidification. This hits the poor disproportionately hard and contributes to more migration, and more failed states and cities. As a counter-reaction to rising international migration, more walls are erected and protectionist measures are buttressed in richer countries. It becomes overwhelmingly clear by 2030 that the SDGs pertaining to the life-supporting systems of climate, cities, ocean and land (SDGs 6, 11, 13–15) are failing severely, despite great progress being made on energy efficiency, renewables and smart mobility.

From 2030 to 2050: neither more technology nor trying harder nails it

In response to worsening environmental conditions affecting the global commons, most countries agree on multi-lateral collaboration. New accords and agreements are made to strengthen green stimulus packages, carbon-pricing, transparent and internationally coordinated taxation and environmental regulations. All pull together and try (even) harder to become sustainable, but with the same mostly non-binding, voluntary policies.

From 2030 countries have put in place more than 30% stronger efforts than historic levels, in sustainability policies such as

- improving health and unemployment benefits;
- better family planning;
- more education, particularly for women;
- green stimulus packages with support for decarbonisation and electrification;
- taxation shift from labour to resources.

By 2040 this results in both further economic growth as well as many social improvements (SDGs 1–5: poverty, hunger, health, education and gender). Also clean energy, jobs, economic growth and infrastructure show improvements (SDGs 7–9). As a consequence in the 2030s and 2040s, people's wellbeing keeps rising on average, but only gradually. Due to rising wealth inequalities there is social unrest, increasing violence and corruption in many areas. These social concerns tend to take priority over environmental issues, except for the most local and immediate problems. There is less focus on guarding the global environmental commons. The world's progress on SDGs stalls by 2040, and starts to decline towards 2050.

As 2050 approaches, although living standards are improving in many cities, the overall improvement in human

Scenario HARDER overview

Main policies (2020–2040)	30–50% increase in: - unemployment and health benefits; - family planning and education of women; - green stimulus packages; - support for decarbonisation, electrification, water productivity; - taxation shift from labour to resources.
Unintended obstacles & challenges (2025–2050)	- continued global warming and costly extreme weather events; - still growing economic inequality; - beliefs in techno-fixes and slow linear ecosystem change remain pervasive; - weakening public institutions and government.
Outcomes & consequences (2050 –>)	- world SDG success score of 12 (out of 17); - safety margin of 5 (6 out of 9 PBs are in red/high-risk state).

wellbeing is stagnating because environmental problems rapidly worsen. The main reasons are that too many planetary boundaries are pushed into the red, high-risk zones, with ecosystems entering irreversible decline after long-term pressure. Even rapid efficiency and productivity improvements haven't brought down environmental footprints sufficiently. This causes increasing costs in repairs and maintenance of infrastructure after extreme weather, droughts, heatwaves, failing crops and harvests, which in turn cause escalating social unrest, crime, conflicts and migrations. This further weakens the goals for peace, and stronger institutions and partnership (SDGs 16 and 17).

The total human footprint is still triggering a possibly irreversible decline of planetary health, with the SDGs relating to water, climate, ocean and life on land in severe decline (6, 13–15). The good news in this world where everyone tries **Harder** is that the world's SDG success score is higher in 2050 than in 2015 (from 9 up to almost 12). But the bad news is that both the SDG success score and safety margin trend is flat from 2030 up to 2050. And it is not significantly better than simply the **Same**, business as usual, or **Faster** growth.

This is especially due to the pressures on the planetary boundaries global warming and ocean acidification (SDGs 6, 13–15) which all worsen in the 2030-2050 period. The small uptick from 2045 to 2050 is caused by better handling of toxics and novel entities (+0,5 points) and less atmospheric aerosols (+0.5 points). However, in that same period ocean acidity gets worse and passes the threshold to higher risk (-0,5). Two steps forward, and one back. Thus the net improvement is just 0,5 up on the safety margin.

The main conclusion from scenario **Harder** is that simply trying harder on all fronts separately helps SDG achievement somewhat, but does not secure a safe operating space by 2050.

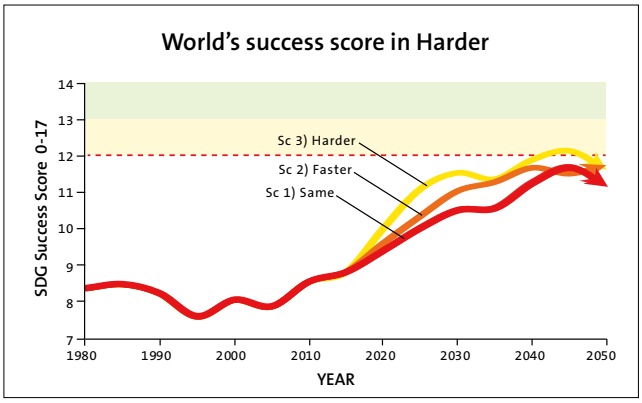


Figure 2.3.2 The whole world's SDG success score for scenario 3 **Harder**, relative to scenario 1 **Same** and scenario 2 **Faster**.

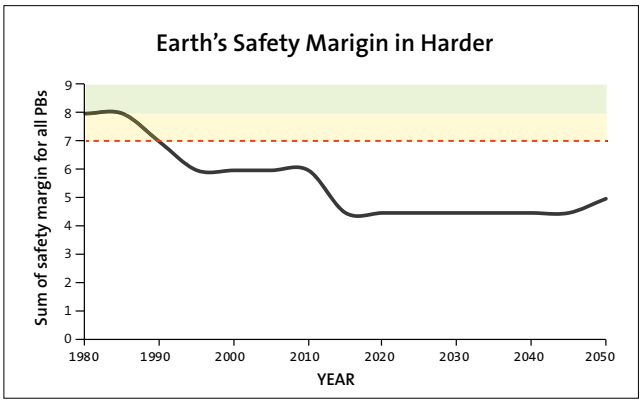


Figure 2.3.3 The Earth's safety margin (number of PBs in the green, safe zone), keeps declining from 2010 to 2050, but with some improvement from 2045 to 2050. This gives the safety margin in Harder of just 5 out of 9, but somewhat better than in **Same** or **Faster**.

Scenario 4:
Smarter – transformational change

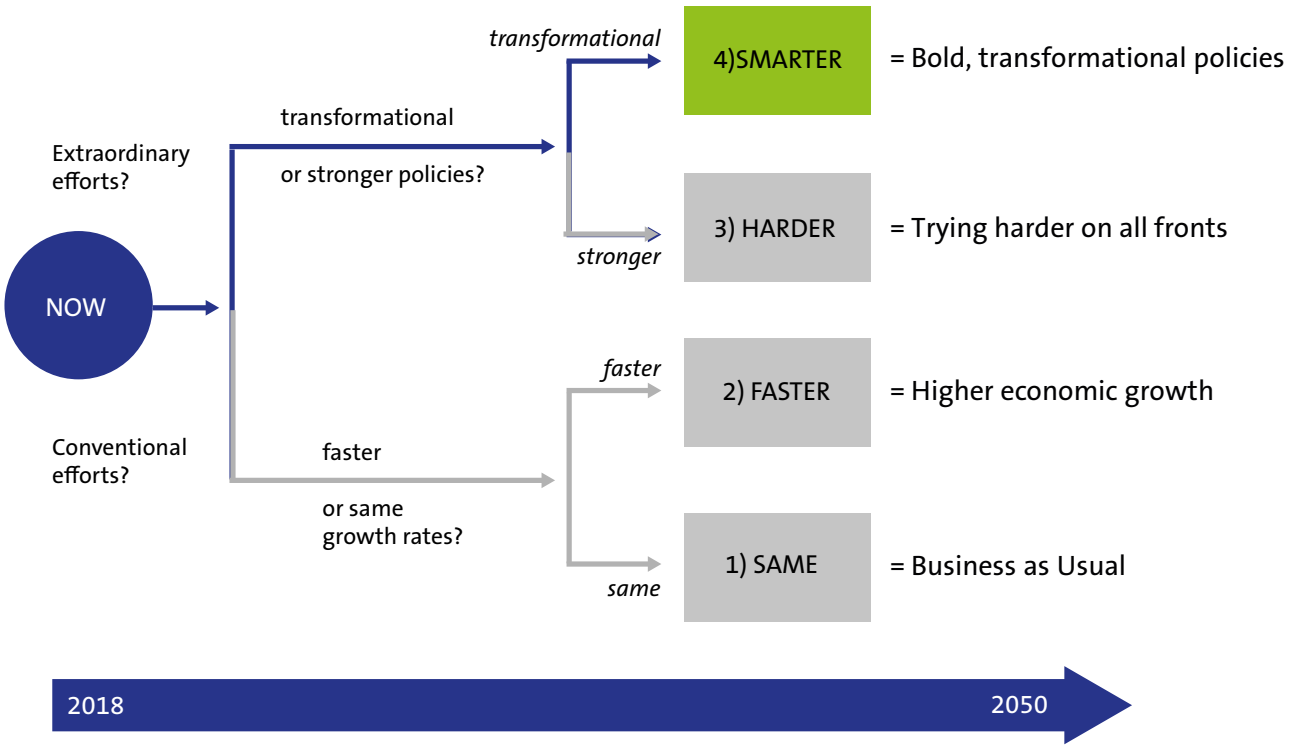
Smarter progress by focusing on human wellbeing

After a long time in the coming, intergovernmental bodies and most governments accept that maximising GDP as a first priority is not the best way to achieve sustainable human wellbeing. The EU's work on "Beyond GDP"[15], OECD's work on wellbeing[16] and China's work on *héxié shèhuì*[17] (a harmonious society) and the China dream, all reflect a deeper value shift in many societies. In the **Smarter** world, the broader objectives of society are seen as better defined by the first generally agreed sustainability framework signed up to by the majority of the world's nations back in 2016: achieving all SDGs without endangering planetary ecosystem. This proved – in retrospect – a paradigm shift for global development, when the move away from a sectorial approach to dealing separately with social, economic and environmental issues to a model of mutual leverage.

Smarter describes a pathway to 2050 where the world's countries choose bold and transformational policies. From 2020 there is no more "just talk", but determined, concerted action in most nations, taking most observers by surprise.

Transformational change is introduced through five leverage points that have a synergetic effect on the SDGs: a) accelerated renewable energy growth to halve carbon emissions every decade, b) accelerated sustainable food chain productivity, c) rolling out new development models in the poor countries, d) unprecedented action for inequity reduction, and e) step changes in education, gender equality and family planning.

The world SDG success score goes up to 13 in 2030 and 15 in 2050. The Earth's safety margin is by 2050 moving in a safer direction, as if coming back from the brink.



The key uncertainties for the pathway that leads to Scenario Smarter.

Recognising the deep transformation required, more governments explicitly shift their long term purpose to *maximising human wellbeing and freedom*. They acknowledge that a conventional market-based growth approach has weak incentives to achieve SDGs; and none at all for protecting the commons, social welfare or any other non-economic values. In national decision-making, the wellbeing measure is accordingly widened from the previous function of just consumption, to also include decent public services, equity and good environmental quality.

Executing five transformational policies

Rather than pushing for faster growth or incrementally harder work at each SDG separately, the **Smarter** approach happens through a systems transformation where five main policy initiatives start to create synergies between the SDGs.

1) Energy: Accelerated renewables growth

A worldwide rapid electrification in power, transport, as well as heating and cooling, is rolled out. This happens by scaling up mainly solar and wind power, distributed energy storage, electric vehicles, heat pumps and necessary distribution infrastructure, all digitised and integrated in smart grids to replace fossil fuels. Nearly all investments in fossil fuels (a historical average of 1.5%–2% of GDP per year[18]) are shifted to renewables and power infrastructure during the 2020s. The higher investments are driven both by a combination of demand-side pull as renewables start delivering higher profitability than fossils, and a government push through tougher regulations. This results in a doubling of the annual growth rates in wind, solar and other renewables during the 2020s.

Most countries also put bans in place on any new fossil-fuel-capacity investments, including announcements during the 2020s of upcoming bans on sales of new fossil-fuel cars. Most regions adopt some form of the "Carbon Law"[19]: That means halving carbon emissions every decade, starting in 2020. This rapidly reduces global carbon emissions and at the same time eliminates human suffering by spreading affordable electricity to cities, slums and remote areas. In this field China takes the global lead, with policies for transforming coal-reliance to low-cost distributed renewables and electric mobility that make it profitable for other countries to follow. The direct use of fossil fuels and in buildings are replaced with electrification and smart system redesign. In this **Smarter** scenario, global carbon emissions fall from over 30 $GtCO_2$ in 2015 to 20 in 2030, and just 6 in 2050.

The effect of this energy system transformation is that it starts to wean the world off fossil fuels and hits the nail on the clean energy goal (SDG7). Giving most people access to safe and clean energy creates a true energy democracy, which improves the development of many other SDGs (1, 2, 6, 8, 9, 11–13). It provides better access to lighting, education, clean water and communications. In addition to reducing climate change (13) it also helps fight poverty (1) and make more jobs (8). It makes innovations and infrastructure (9) more available, reduces food-waste and hunger by access to refrigeration, and helps making city air cleaner (11) by replacing combustion. In sum, cheap and clean electricity changes everything!

2) Food: Accelerated shift to sustainable food chains

In the **Smarter** scenario, the world accelerates the transformation to sustainable agriculture, linking production to better logistics that drives down food waste, as well as nutrient and pesticide overuse. People shift their diets to more plant-rich foods which lowers the share of meat per person (particularly in richer countries).[20] The food system gets more direct links between food producers and consumers, i.e. direct delivery of easily available, affordable and nutritious foods that people actually need and want. This brings down food waste.

New technology builds on the rapid development of digitalisation, cheap sensors, satellite monitoring and the Internet of Things to make real-time big data available to monitor the state of each field, river, crop and shop. Through better water management, total water use is brought within planetary boundaries. Intelligence embedded in water pipelines helps stop water loss from leakages, and secures good water management in all river basins. It makes fresh-water pricing more accurate and feasible, giving incentives for better water efficiency. Biogas and composting replace landfills and surface run-off to the oceans, creating the capacity to recapture nitrogen and phosphorus and circulate these nutrients within bioregions.

These kinds of both low-tech and high-tech solutions enable agriculture to produce more food without any further land expansion, and with rapidly sinking bioactive nitrogen release. Climate-smart agriculture becomes a net carbon sink and draws down one billion tons of carbon into the soil per year from 2040.

A less waste-full more productive food system will also increase people's health as they get more nourishing and affordable food. With recycling of nutrients it also improves clean water (SDG6), responsible consumption (SDG12), and reduces the pressure on climate change, life on land and life below water (SDG 13–15). In sum, all these improvements lower the footprint of the food chain by an extra 1% per year, relative to **Same**.

3) Growth: Rolling out new development models in the poor countries

A higher growth rate is achieved in the world's poorest countries by increasing investment, strengthening institutions and allowing favourable trade arrangements in the early stages of industry development. The liberal market ideal is supplemented with various planned developments where certain industries that are of national interest are cultivated – inspired by role models of countries such as China, South Korea, Ethiopia, Scandinavia and Costa Rica. First Japan, then South Korea, Singapore and China have already quadrupled the GDP per person over thirty years. As other poor countries

Figure 2.4.1. The gist of the **Smarter** scenario: Collaborating on the transformation of societies to fit within one Earth system; investing and rebuilding the economy for one planet living. .

repeat these feats, they start providing each citizen with a reasonable standard of living. China has achieved an unprecedented duration of sustained economic growth and lifted hundreds of millions of people out of poverty in the process. (See box 2, on "the Chinese model".)

The Chinese model is preferred by many such countries over the Washington Consensus, which prescribes policies such as macroeconomic stabilisation, rapid economic opening with respect to both trade, finance and investment, and the expansion of market forces within the domestic economy. During the 2020s many of the world's poorer countries thus roll out forward-looking protectionist policies too, to raise standards of living by allowing their economies to catch up, and protect infant industries, without full immediate exposure to competition with advanced global industries in their home market in the beginning stages.[21] The effects in these countries are more rapid economic growth that lifts many millions more out of poverty quicker, and also delivers on hunger, jobs growth, clean water, better health, education, infrastructure (SDGs 2, 3, 4, 8, 9).

4) Active inequality reduction

Increasingly both rich and poor countries face the need to reduce growing unemployment and inequity. During the early years of the 2020s there is a series of political crises which are fed by broad protests and discontent among the public about the extreme unfairness of wealth inequality. A push for fairer wages and more progressive taxation succeeds at redistributing total output. Many developing countries intensify the domestic resource mobilisation by improving

Box 2: What do we mean with "the Chinese model"?

"The Chinese model" is often equated with authoritarian capitalism – single-party rule combined with extensive state ownership and control over the economy. Others call it a political meritocracy[22] in contrast to democracy.

Rather than just authoritarianism dominating over markets and people, it seems there were many factors stimulating China's dynamism in the latest decades. Key factors were the introduction of some democratic qualities through bureaucratic reforms according to *long-term plans*, and Beijing's willingness to allow and direct local improvisation. In her research, Yuen Yuen Ang found that under Deng's rule: "Instead of trying to command their way to rapid industrialisation and growth, reformers focused on creating the right conditions for lower-level officials to kick-start development in their own communities using local resources."[23] Instead of only top-down commands, the country often leveraged local knowledge and resources, promoted diversity, and motivated and incentivised people to step up efforts and share ideas.

In short, with "the Chinese model", we refer in this report to the characteristics and conditions under which certain newer historic experiences in China – and in several other countries such as Ethiopia and Costa Rica – may have high relevance and serve as inspiration for the development of other countries. No such model is a perfect ideal to copy-paste; and each should be seen in the light of the other transformational strategies (further rapid transition from coal to renewables, reduction of inequality, etc). The rapid, intentional and positive change these models have delivered substantiate our claim that this kind of transformation is possible, and shows how it can be done.

their tax systems. As a result, there are funds for better service delivery and development for the majority.[24] There is, also in richer countries, growing accept of the recommendations from IMF[25] and OECD[26] to reduce inequality to enhance growth and wellbeing. By shortening the work-year for everyone, it becomes possible to create and share more jobs, even in regions and sectors where there is low or no per capita GDP growth (for example, due to work automation).

There is broad and growing recognition among voters that it is in the interest of national stability to ensure that the 10% richest take no more than 40% of income. Redistribution of wealth, work, and incomes through policies such as higher unemployment benefits and a shorter working year is the best way for businesses and banks to guarantee a stable economic future in the developed world, because it will put more money into the pockets of the poor. It allows the less well-off to spend more, which also improves conditions for business, investors, and the banking sector.

The funds raised by progressive taxation of income and wealth are also used to stimulate and deliver better well-being through SDG achievement: particularly health, education, infrastructure, sustainable cities and responsible consumption (SDGs 3, 4, 9 and 11). Extensive redistribution efforts through more progressive taxation and unemployment benefits are stepped up in most countries during the 2020s. The historic trend of a falling median incomes since the 1980s is reversed starting in the 2020s. This proves conducive to regain more trust in government and stability in politics, which strengthens institutions (16) and partnerships for the goals across national borders (17).

5) *Investment in education for all, gender equality, health, family planning:*

Global funds that focus on education, especially for all women, are strengthened. This gives women broader opportunities for autonomy and work. In addition, better family planning and urbanisation give women more freedom to choose the kind of life they want. The more female leaders the world gets, the more women become empowered to take positions of leadership, a self-reinforcing loop.

While women worldwide were closing the gender gap before 2018 in critical sectors such as health and education, significant gender inequality persists in the workforce and in politics. The rate of progress for women starts slow, too. Between 2006 and 2016, the proportion of female leaders increased by only 2%.[27] But when women are better represented in leadership roles, more women are hired across the board. This picks up speed from 2025 and onwards, when the world recognises that to encourage more female leadership is one of the levers for increasing gender equality in the entire workforce. Results speak for themselves, and by the 2030s it is becoming increasingly clear that a good gender balance is much smarter and more profitable[28] (SDGs 5, 8, 16) than the conventional male-dominated networks.

This also results in women choosing freely to have lower average birth rates. In many countries, these five factors (education, urbanisation, job opportunities, family-planning and reproductive health) combine to give better wellbeing for both women and children.

Smarter, but there's still widespread resistance to transformation …

Regardless of good progress and smarter policies, environmental stresses – air pollution, water, heatwaves, wildfires – have been building up and worsening for many decades. These cause more urban crises and waves of migration, in the decades up to 2040 relative to 2015, and contribute to conflicts, and sometimes civil wars. These put severe pressure on many fragile institutional structures. Political crises, corruption and distrust of interventionist government cause an outspoken opposition to the active planning and government roles key to rolling out the transformative actions. The increased progressive taxation to reduce inequality is also a hotly contested topic for decades.

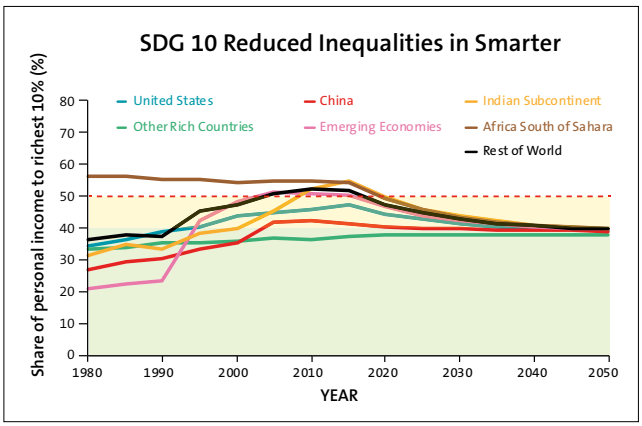


Figure 2.4.2. In **Smarter**, in an overall richer world by 2050, the regions gradually succeed in reducing income inequality to the before-1990 levels, at which the top 10% richest take <40% of total incomes.

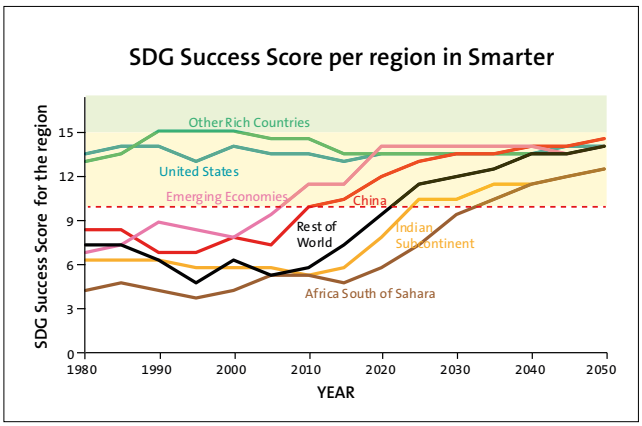


Figure 2.4.3 In this scenario, the poorest catch up earlier than in Same, Faster or Harder. This is the result of the five transformational actions having systemic effects on several SDGs The world's total success score also goes higher.

But with better redistribution measures in place that large majority groups benefit from, a stronger taxation base, and an international commitment to peace and partnership that remains resilient and responds rapidly, the worst crises are dealt with before descending into full collapse of cities or more failed states.

Despite such obstacles, there is growing acceptance of the evidence that effective and smarter – rather than just bloated and bigger – governments are a huge boon to all market economies, of whatever culture and ideology. And there is evidence that their functions are indispensable for social stability by reducing inequity, in addition to maintaining law and order. Overall, there is also a growing willingness to invest public funds in repairs and rebuilding of infrastructure. Government oversight also helps to account for the material flows through the economy in real-time. The data is used for optimising a circular economy and resource productivity so that total resource use does not threaten the safe operating space of both local ecosystems and global natural commons.

From 2030 to 2050: Smarter delivers results

Increasingly, the financial sector and capital markets start connecting corporate activity to positive Environment, Social and Governance criteria (ESG) for investment. From a feeble start around 2015, ever more of the world's funds start to actively *apply* the Principles of Responsible Investment (PRI). The strength of this connection is priced into security and capital markets, and investors include these considerations in their day-to-day operations. Rather than just subscribing to PRI but doing little in practice (as in **Same**), in the **Smarter** scenario the talk becomes reality, and more than half of the world's wealth gets invested in line with effective PRI and ESG guidelines. This has a large direct effect on how businesses join governments' concern for achieving the SDGs inside Earth's safe operating space.

As 2050 approaches, the **Smarter** world sees a rapid trend to job-sharing, fairer wages and extensive redistribution reversing the trend of worsening inequity from the three decades that led up to 2020. More regions also manage to provide equitable access to natural resources and ecosystem services. Both these give a net positive impact on GDP/capita growth, the first by stimulating demand, the second by better resource use.

Population stabilises more quickly as more women get radically better opportunities for education, jobs, economic autonomy, reproductive health and security, particularly in cities.

Among investors and private companies, there is a growing realisation that business cannot succeed in societies that fail. The corollary is also true: societies striving for sustainability require the many opportunities that business can provide. The rationale for broad business engagement with the SDGs could not be plainer[29]: the smarter solution is when government and businesses mutually reinforce markets and regulations to deliver on the goals that they are (or should be) designed for. The new conventional wisdom in the 2030s is that delivering on the SDGs can happen only if business, governments, and civil society work together; and this is rapidly put into action in transformative ways.

By 2050, most regions of the world are delivering on nearly all SDGs. Both India and Africa South of Sahara has shown tremendous progress (from a 5.5 regional SDG-success score in 2010 to 12.5 in 2050, see figure 2.4.4). This **Smarter** pathway seems to point the world's economy in a prosperous direction within the Earth's safe operating space by 2100.

Scenario SMARTER overview

Main policies (2020–2040)	- Accelerated renewable energy growth, sufficient to halve carbon emissions every decade from 2020. - Accelerated productivity in food chains, improving by extra +1%/year. - New development models in the poorer countries, following models such as South Korea, China, Scandinavia, Ethiopia or Costa Rica. - Active inequality reduction, ensuring that the richest 10% take no more than 40% of income. - Investment in education for all, gender equality, health, family planning, stabilising the world's population.
Unintended obstacles & challenges (2025–2050)	- Distrust of central government roles - More nationalism that discredits global cooperation - Ideological opposition to redistribution, particularly in Anglosphere - Market fundamentalism that opposes government work on market design.
Outcomes & consequences (2050 –>)	- World SDG success score of 12 (out of 17) - Safety margin of 7: Zero PBs are in high-risk zones, and four in yellow: Global warming, forest degradation, air pollution, toxics.

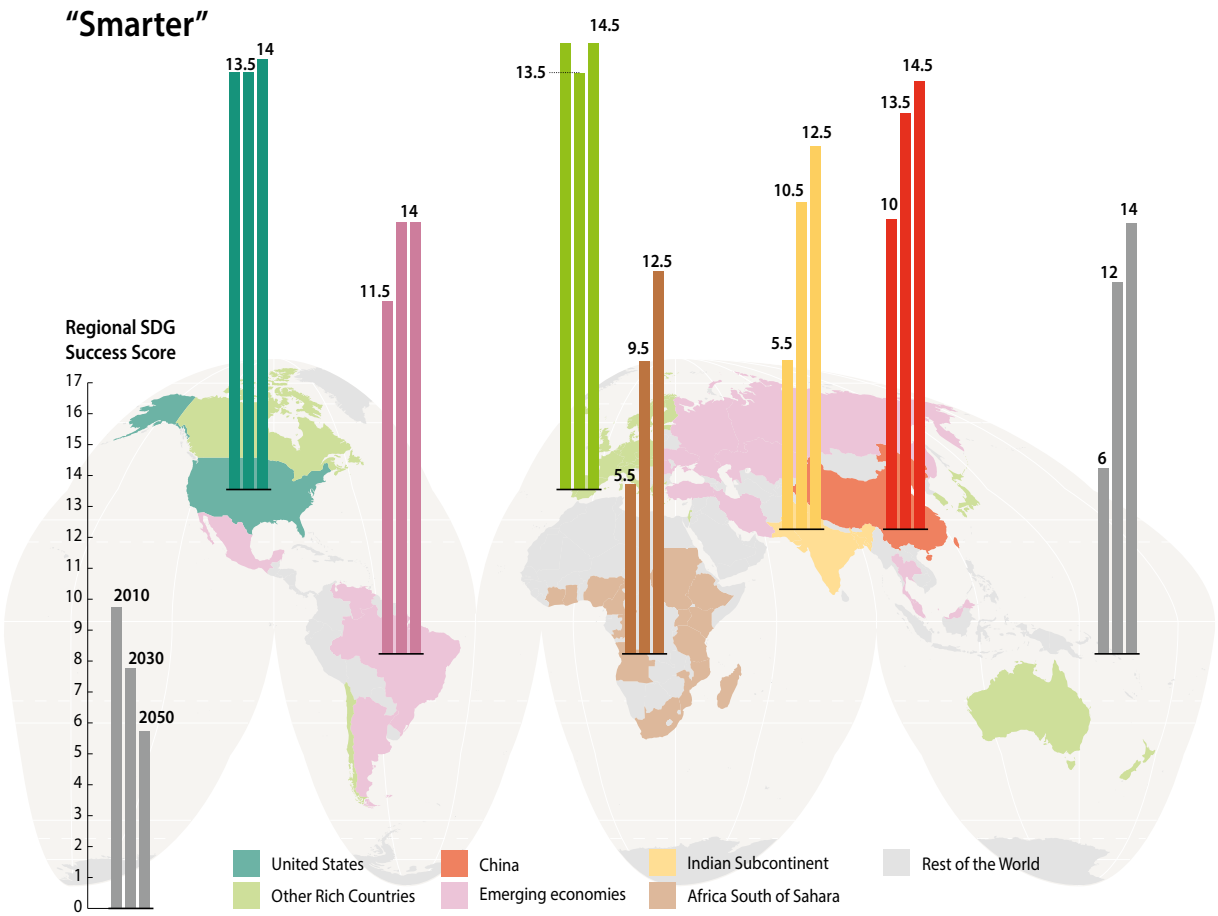


Figure 2.4.4: SDG success score per region in the **Smarter** scenario. Regional SDG scores for 2010, 2030 and 2050 are shown.

3. Discussion: New findings and old dilemmas on the path to 2050

Humanity has ushered in a new geological epoch, the Anthropocene, where our modern world constitutes the largest driver of change on Earth. We, particularly the richest, most resource-consuming countries, have pushed climate, biodiversity, parts of the ocean into conditions and high-risk zones that are fully unchartered territory.

Yet, the adoption of the UN SDGs together with the Paris Climate Agreement, both in 2015, were a potential global turning point in setting a new course. For the first time in human history on Earth, the world has agreed on a democratically adopted roadmap for humanity's future that in principle aligns the economy with the Earth's life supporting systems. We have never before had such a universal development plan for people and planet. The SDGs point out a roadmap that is clearly a worthwhile pursuit and purpose. Now the grand challenge must surely be to figure out the smartest way of achieving the SDGs within a safe operating space.

How can it be done?
Based on the four scenarios described in the previous chapter, and on the model runs supporting them, we can now address some important questions about the future of SDG achievement:

1) How far can future economic growth assist us in achieving the SDGs?
2) How far can improved and strengthened policies take us?
3) To what extent can there be a piecemeal approach to SDGs and PBs, or is a systemic approach needed?
4) What insights arise from modelling SDG achievement in the Earth3 system?
5) Are the five transformational strategies feasible? Or too costly?

3.1 Scenario comparison: revisiting the economic growth dilemma

The first scenario, **Same**, gives a specific answer to the Question 1 above: *How far can future economic growth assist us in achieving the SDGs?* If we continue with current trend lines of economic growth, the world will deliver on such important SDGs as the eradication of poverty, hunger with good life expectancy to the world's humanity – not by 2030 – but by 2050. In 2030, however, the world's total SDG success score is only up to 10.5 from 9 in 2015. This is very far from the ambitions of the UN Agenda 2030.

The second scenario, **Faster**, goes further in answering the same question. It shows how far we can get in SDG achievement through the relatively large step-up of +1% GDP per person per year of economic growth all the way from 2018 to 2050. But this huge impetus which grows the world economy by an extra 28% by 2050 (from 250 trillion $ in **Same** to 320 trillion $ in **Faster**, see table 3.1.2, does not deliver substantially more SDGs across the world's regions. The SDG success score moves from 9 in 2015 to 11 in 2030 and then only 11.5 in 2050, see figure 3.1.1. And the two scenarios give almost the same dismal result when it comes to keeping the planetary boundaries in a safe condition. If the goal is to achieve the SDGs, then maximizing economic growth as the main (or sole) strategy does not seem a very effective choice in the longer run.

How far can improved and strengthened policies take us? The scenario **Harder** delivers the answer that we can directly deliver more of the SDGs than in **Same** *without faster economic growth*. Reallocating resources and workforce to improve the speed of SDG delivery will take us closer to target. But if it is done within the conventional approaches and separate structures as it was done in the 1980-2015 period, then it does not lift the regional nor world scores enough. The improvements also stalls during the 2030s, and starts to decline in the 2040s.

The **Smarter** scenario illustrates what a genuine green growth approach can give us.[30] Here we see a rise in GDP per person by 129% from 2015 to 2050 combined with a 80% decline in greenhouse gas emissions. There is enough food within (most) planetary boundaries, and reduced inequality (which stimulates economic growth per person) along with better gender equality. The calculations of this scenario illustrate that another type of growth model is

Scenario—> Main Policy Levers:	Same Business as usual	Faster Higher growth	Harder Stronger efforts – on all fronts	Smarter Extraordinary transformation
Growth	Average 2–3% GDP/yr "As is": (higher in poor countries, slower in rich countries)	3–4% GDP/yr	2–3% GDP/yr (= Same)	2–3% GDP/yr (differentiated: higher growth in poor countries)
Poverty, unemployment & inequality	"As is": Maintain current aid and unemployment benefit levels	= Same	+30% effort in fighting poverty, unemployment, inequality	active redistribution until 10% richest control <40% income
Energy	"As is" (current trends continue)	= Same	+30% effort in clean energy access, clean cities	rapid growth rates in renewables (wind & solar) and electrification
Food	"As is" (historic trends continue)	= Same	+30% effort in no hunger, safe water,	rapid shift to sustainable food chain (+1%/yr higher productivity)
Education & gender	"As is" (historic trends continue)	= Same	+30% effort in gender equality, education of women, family planning	investment in education to all, gender equality, health, family planning, (financed by redistribution)

Table 3.1.1: Main policies and strategies in each scenario.

possible, where there is an improvement in the carbon (greenhouse gas) productivity of 5–7% annually in the years from 2015 to 2050. This results in keeping global warming at 1.4C relative to pre-industrial levels in 2050.

So, what really is the role of future economic growth in achieving the SDGs? In one sentence, the answer from our study is: It is humanity's footprint growth that is the problem, not the growth in GDP per person. With a genuine green growth model for the economy, then economic growth is essential to achieve the SDGs within planetary boundaries for all people by 2050.

Table 3.1.1 summarises the main policy levers that are applied in each scenario. The effects of the main policies are calculated by the Earth3-model per region, and summed up to the world score, weighted by population. Figure 3.1.1 shows these SDG success scores for the four scenarios. Sceanrios 1, 2 and 3 see very little improvement from 2030 to 2050.

The main reason for the stagnation in improvement and the falling trend from 2040 to 2050 is the violation of the planetary boundaries (PB), of which three are very similar to SDGs 13–15. Conversely, achieving the SDGs 13–15 is an essential step towards living within PBs.[vi]

Finally, it is possible to combine the SDG score for the world as a whole with the estimates of the Earth's safety margin, to visualise the interplay between the two measures. See figure 3.1.2. This chart plots each scenario's progress along the world's SDG success score on the horizontal axis, spanning from 0 to 17. On the vertical axis we plot the number of

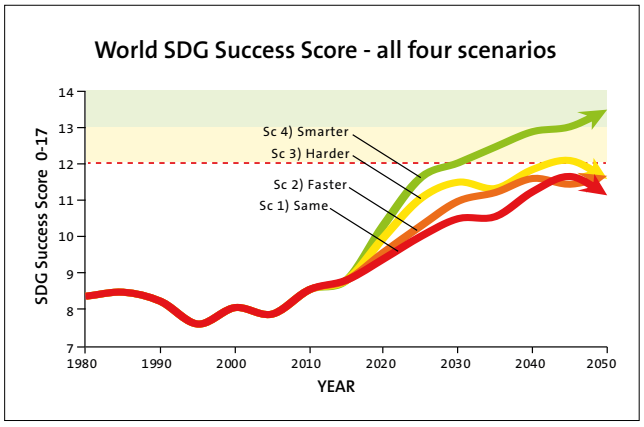


Figure 3.1.1: The World's SDG success score in all four scenarios

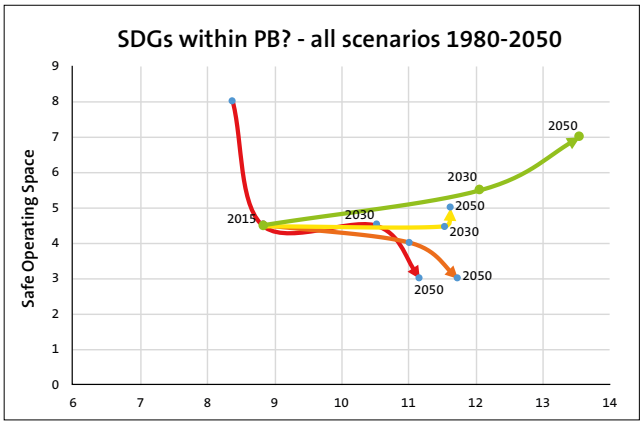


Figure 3.1.2: Achieving the SDGs within planetary boundaries. Showing the performance of both SDG success and planetary boundary states in all four scenarios

vi As SDGs 13-15 (climate, life on land, life below water), are closely related to PBs 1,3,4 (global warming, biosphere integrity, ocean acidification), there will be some correlation between world SDG score and Earth's safety margin, which describes the Earth's safe operating space. We do not see this as a problem for our analysis, as it is quite common that there are multiple interconnections in any complex system. Furthermore, these SDGs and PBs operate on different timeframes, so it is useful to include both in our analysis

Key global figures – all scenarios		In 2015	In 2050:			
			Same	Faster	Harder	Smarter
Global GDP (in trillion USD, i.e. T$)		94	251	320	251	227
Total anthropogenic GHG emission (GtCO2e/y)		50	42	57	33	11
Temperature rise (Temp surface anomaly compared to 1850 degC)		1,1	1,9	1,9	1,8	1,4
GHG productivity (GDP / kgCO2e)		1,89	6,00	5,63	7,69	21,09
Green Growth Rate (rate of change in GHG-productivity/year, scenario average 2015-2050)		3,6 %*	3,4 %	3,2 %	4,1 %	7,1 %
			2050			
Population (million people)		**2015**	**Same**	**Faster**	**Harder**	**Smarter**
	US	324	335	335	335	307
	ORC	748	714	714	714	653
	China	1 428	1 431	1 428	1 431	1 300
	EE	890	957	956	957	874
	India	1 660	2 084	2 059	2 084	1 814
	ASoS	746	1 202	1 180	1 202	1 002
	Row-120	1 539	1 973	1 958	1 973	1 763
	World	7 334	8 697	8 630	8 697	7 713
			2050			
GDP per person (2011ppp k$/person-year)		**2015**	**Same**	**Faster**	**Harder**	**Smarter**
	US	49	53	72	53	53
	ORC	36	46	61	46	46
	China	11	38	48	38	38
	EE	17	38	48	38	38
	India	4	21	26	21	21
	ASoS	3	13	16	13	14
	Row-120	7	26	33	26	27
	World	13	29	37	29	29
			2050			
Share of income to top 10% richest (%)		**2015**	**Same**	**Faster**	**Harder**	**Smarter**
	US	47	54	54	54	39
	ORC	38	39	39	39	38
	China	41	41	41	41	39
	EE	51	54	54	52	40
	India	55	58	58	52	40
	ASoS	54	57	57	52	40
	Row-120	52	54	54	52	40
	World	49	52	52	49	40
Ecological footprint pp (gha/p)		**2015**	**Same**	**Faster**	**Harder**	**Smarter**
	US	8	5	6	5	5
	ORC	5	3	3	3	3
	China	3	4	4	4	4
	EE	4	4	4	4	4
	India	1	2	2	2	2
	ASoS	1	1	2	1	2
	Row-120	2	3	3	3	3
	World	3	3	3	3	3

Table 3.1.2: Key global figures all scenarios.
* The Green growth rate in 2015 of 3.6%, refers to annual change in the 1980-2015 period. Above 5% per year is needed for achieving <2C global warming goal. > 7% per year is needed to achieve the 1.5C goal, as illustrated by scenario **Smarter**

planetary boundaries that are in safe territory, from 0 (unsafe) up to 9 (safe). We can then see how – depending on humanity's shared choices in the coming decades – we can bend downwards towards the unsafe territory, or upwards and right towards a more flourishing territory. Upper right corner is where SDGs and PBs can mutually reinforce each other.

Table 3.1.2 shows the key factors of population, GDP per person, income inequality and ecological footprint per sector, with the historic data for 2015, and then the values for the four scenarios in 2050.

3.2 A piecemeal or systemic approach to SDGs and PBs?

The 17 goals lay out a clear plan of where humanity wants to go by 2030 (or 2050). But not much on *how* to get there. The four scenarios show that in order to succeed the plan cannot be implemented in a conventional way nor in a piecemeal way, picking SDGs to realize at whim as if from a smorgasbord.

For instance, achieving good jobs and growth (SDG8) with zero hunger (2) longer lives to all (3) and better education (4) can easily imply that life below water (14) and life on land (15) deteriorates even quicker than today. Similarly, hitting target on reduced poverty (SDG2) in the conventional ways, can lead to higher resource consumption (12) with more cars and fossil energy use (7) weakening the achievement of clean cities (11) and climate action (13).

More consumption will strain infrastructure (9) to move more goods around, will put strains on available energy (7), clean water and sewage disposal (6), and to safely handle waste (12). Think of the challenge India faces.[31]

That is why it's essential to see all 17 SDGs as part of a system, that is is interconnected and inter-dependent. Among the deeper, more general interdependencies we've found are: If we fail on poverty and social equity we will risk failing on stable governance over time. Without stable governance we risk failiing on climate and biodiversity. If we fail on climate and biodiversity, then we will risk failing on food and poverty (more heatwaves with no rain, or no pollinators, give less crops and food security).

At best, a systemic analysis can make the SDG achievement more robust: Investment in measures to realize some SDGs can also enhance others. A piecemeal approach can easily end with trade-offs and conflict among the goals (if we increase funding for quality education, there will be less for safe water). Rather than piecemeal we can cultivate positive synergies between the SDGs as well as with Earth's life-supporting systems. We must recognise that even the most honest attempt within business-as-usual, is not proving sufficient. Good will, faster growth, or harder work, within the current trajectory are unlikely to succeed.

So what does a systemic and dynamic approach to SDG achievement look like?

What is needed – at least according to the simplified runs of the Earth3 model – is, first, a doubling of the renewable energy growth rates and investment in electrification compared to business as usual. This weans the world off fossil fuels and hits the nail on the clean energy goal (SDG7). Giving all people access to safe and clean energy creates a true energy democracy, which improves the development of many SDGs (1, 2, 6, 8, 11-13, 16).

Second, encouraging differentiated growth rates where poorer countries have higher rates than richer. The development model that China – like several other countries – has used since 1990, to slash poverty, can be broadly applied by other poor countries. When scenario 4 is run in Earth3, this happens particularly in African countries, and lifts many millions quicker out of poverty.

Third, a rapid shift toward sustainable use of the world's agricultural land, forests, and oceans. At least 1% extra resource use improvement per year is required in the whole food chain from soil to table. This is technologically and economically feasible today, given sufficient funding.

Fourth, a radical increase in more education, health, access to work, and family planning services – particularly for women all over the world – will bring about several immediate benefits like gender equality (5), longer lives (3) and reduced inequality (10), while also slowing population growth, easing pressure on how to survive and prosper economically (8) and wage-race-to-the bottom competition in burgeoning cities (11).

Fifth, making sure that the 10% richest don't capture more than 40% of each nation's income. Reforming taxation in this direction, will reduce inequalities (SDG10) but also provide societies with funding to better achieve a number of the SDGs (1-12).

The good news is that these five policy levers, holds the promise of achieving (nearly) all 17 SDGs within (nearly all) the 9 PBs by 2050, although it takes some time before the Earth's safety margin is back at acceptable levels, from its low of 4.5 in 2015.

3.3 Insights from the #SDGinPB modelling work

Our scenario analysis using the Earth3 model allows us to develop several well-characterised insights about future pathways as the world's regions put Agenda 2030 into practice:

1. *If global society continues on its current path, the world will only achieve 10 of the 17 SDGs by 2030*, and exceed 5 of the 9 planetary boundaries. The world will be moving deeper into the high-risk zone by 2050. These developments are clearly analysed and quantified in Scenario 1: *Same* – business as usual.

2. *If global society tries to achieve the SDGs* simply by increasing the rate of economic growth – in an attempt to use economic development as the sole strategy to pay for higher goal satisfaction – the result will be mixed. Global society will do a little better on a number of social and

economic SDGs by 2030: 11 instead of 10, and 12 by 2050. But at the same time humanity will put even more rapid and severe pressure on the PBs. In other words, the achievement will not be sustainable, with a high risk of irreversible, destructive feedbacks (such as increased droughts, floods, disease, heatwaves, eutrophication, eco-system or species collapse) undermining social and economic SDG achievements. See Scenario 2: *Faster*.

3. *If global society makes harder efforts to achieve the SDGs,* but sticks to conventional policy tools within available budget restrictions, the SDG achievement will be better than in Scenario 2. More SDGs will be reached: 12 of 17. But humanity will still pressure the same number of PBs into unsafe zones by 2030: 5 of 9. See Scenario 3: *Harder* – stronger efforts on all fronts. The major challenge proves to be in satisfying social SDGs in the remaining areas while keeping within the planetary boundaries.

4. *If the world wants to achieve all the SDGs within the planetary boundaries*, this will require more than "higher economic growth rates" or "a dedicated conventional effort". Achieving the SDGs within the PBs and in reasonable time (certainly before 2030, but even before 2050) will require transformative change. This means unconventional policy and unconventional funding, implemented in a thoughtful, transparent, collaborative and well-prepared manner.

   The good news is that it seems possible to reach these ambitious and inspiring goals. The challenging news is that it will require fundamental change – a marked break with the traditional approach, with the way things are normally done. A major challenge will be to get democratic support for such transformative change – it will require a longer perspective in the electorate. A second challenge is to handle the restructuring costs – in terms of jobs and turnover – that unavoidably follow from a change in the way things are done. A third is to sustain public and political support for progressive redistribution measures that are unpopular among the wealthy and powerful. Luckily, the financial cost of the transformative change is surprisingly low. Jobs and turnover will grow in the green sectors, which will transform into being the new normal sectors, as they take over from the traditional ways of doing things.

5. *As an example of what it will take to satisfy the SDGs within the PBs before 2050*, we have done some first attempts to calculate the effects of implementing a package of five possible measures:
   a) Rapid decarbonisation of the global energy supply.
   b) Active redistribution of income, within and (ideally) among countries.
   c) Shift towards sustainable use of the world's agricultural land, forests and oceans.
   d) New "planning based" development model for poor countries.
   e) Population stabilisation, through more education, health and contraception.

These five broad, strategic actions are further described above in section 2.4, on Scenario 4: *Smarter* – transformational change.

This set of transformational changes is capable of pushing the SDG success score to 13,5 and the safety margin to 7, and to even better values towards the end of the 21st century. But it is not possible, it seems, to reach complete SDG success within a totally safe planet in the time span analysed.

This raises the question of whether our scenario 4, **Smarter**, is not transformational enough? Maybe future work should consider making a fifth scenario, possibly called "**Bliss**"? The challenge for this scenario, of course, is to be able to describe a plausible pathway that includes reversing acidification of the oceans and global warming. So far in the project, we have decided that "Bliss" is outside the current realm of modelling and plausibility that we can analyse.

3.4 Are the five transformational actions feasible? Too costly?

What are the costs?

The transformation that many speak about as something almost insurmountable, may not be such a big deal. There have been historic policy shifts of larger magnitude before; under the world wars, the handling of the great recession. The Earth3 model does not include a cost analysis of the transformational actions. Nevertheless, the expected income or GDP per person is expected to be a little higher in **Smarter** than in **Same**. So the transformation comes at no net loss to economic welfare or wealth per person.

When looking at recent and related studies, the *New Climate Economy Report* (NCER 2018) finds that there is actually a net benefit of 26 trillion dollars in the 2018- 2030 period from transitioning from the business-as-usual trajectory to a low carbon economy. What they call a decisive shift to a low-carbon economy, is similar to our transformational action number one of rapid scaling of renewable energy and electrification. They state that "We know that we are grossly under-estimating the benefits of this new growth story. Current economic models are deeply inadequate in capturing the opportunities of such a transformational shift, or the grave dangers of climate inaction. We need a new class of economic models that can capture the powerful dynamics at play, including transformative technological advances, preservation of essential natural capital, and the full health benefits of

cleaner air and a safer climate".[32] Their findings in this respect confirm some results from our study.

Another study, from the *Business & Sustainable Development Commission*, finds business opportunities in the implementation of the SDGs in four systems – food, cities, energy and health – could be worth more than US$12 trillion annually for the private sector in 2030 (representing 10 percent of forecasted global output in that year). The investment required to achieve these opportunities is around US$4 trillion per year.[33] A third study, by DNV GL's Energy Transition Outlook, indicates that shifting 2-3% of GDP in 2050 will get us to a low-carbon economy by 2050.[34] This is equivalent to postponing consumption growth by 12 months. Factoring in the total costs of transformation will mean that the GDP per person will be the same in 2051, as it could have been in 2050 – but with the added benefit of a healthy planet, and with societies in a safer and more just operating mode.

What are the barriers?

Whatever the economic costs may be, the five transformations we have analysed may still – and will be – debated on an ideological basis. The main obstacles to the type of transformational policies that are illustrated in **Smarter**, are found in widespread public and political perceptions. In large areas of the world there is a deep scepticism and distrust of ("big") government. With each scandal of corrupt politicians, the idea that more tax revenue, stimulus and transfers should pass through government coffers, for whatever good purpose, meets with ever-less enthusiasm. With each local economic or environment crisis there also arises the opportunity to blame "the others" or "the global elites" for interference. Then different forms of nationalism can be levered to discredit global cooperation or national contributions to the global commons. Others have a perception that "free markets" work best when there is next to no government oversight or regulation.

In order to get a better grasp of barriers, costs and benefits from SDG achievement and hence the feasibility of the transformational actions, further studies are needed. We describe planned next steps in section 4.3 below.

4. Main conclusions from the #SDGinPB project

4.1 The world in 2050: Will the world have achieved the SDGs within Planetary Boundaries?

In short: the odds seem stacked against it. Not just because of the current geopolitical instability, political conflicts or trade wars. But there are deeper driving forces working against achieving the SDGs within planetary boundaries. These can be found not in least social, institutional and corporate inertia, existing physical infrastructure, vested interests by incumbents, outdated ideas along with short-sightedness in individuals, capitalism and democratic four-year horizons.

Yet, there are many drivers that point in the direction of social and ecological sustainability:

- the rapid eradication of poverty and hunger
- the rapid expansion of new renewables and clean energy
- the shift from resource-intensive sectors (agriculture and industry) to more dematerialized sectors (service, digital) as economies mature and average incomes increase
- better gender balance in education
- the rapid urbanisation
- the mobilisation of civil sector organisations working for transformation (NGOs)
- the slow-down in population growth, with "peak child" already happened.

When all such factors are considered into one integrated Global System Model such as Earth3, some conclusions can be drawn and answers found from the analysis and quantification of the four scenarios in the project. Here the main lessons from each scenario are summarized:

Scenario 1: Same – business as usual takes a realistic while pragmatic approach to the future. Here, the world's countries officially take an ambitious approach to the SDGs, the Paris Agreement and other multi-lateral development commitments. But they do not do anything more than what they conventionally have done since the Rio Earth Summit global conference in 1992. The scenario shows why the world will neither reach the social and economic SDGs, nor global environmental targets by 2030, and much less, planetary boundaries by 2050. A traditional, incremental, piecemeal, goal-by-goal approach to the SDGs will undermine the possibilities of meeting fundamental social and economic needs, aspirations and rights for coming generations, and jeopardise the life-support systems on Earth.

The baseline scenario shows that it is urgent and imperative that nations, communities and businesses across the world understand that the SDGs constitute a universal and socially inclusive development agenda for people and planet, which will require more than the conventional effort to succeed. From this scenario it becomes evident that an extraordinary effort is necessary. Or put plain negatively: With this pathway, the world will *not* achieve the SDGs within PBs (just up from 9 SDG score in 2015 to 10.5 in 2030).

Scenario 2: Faster – accelerating economic growth shows what will happen if global society tries to solve the challenge through accelerated growth in GDP, based on the conventional assumptions that simply more economic muscle will trickle down into solutions of the SDGs. While an increasing number of social and economic SDGs may be reached by 2030 (i.e., short-term delivery on some goals), it will occur at the expense of environmental SDGs and push planetary boundaries deeper into high-risk, red zones by 2050. This will undermine human development in the long term. Uncontrolled, exponential technological and economic growth (even if willed) is likely to result in rebound effects that accelerate humanity's journey towards destabilising the planet with declining natural life-support systems. It is not possible to attain the SDGs by investing solely in accelerated economic growth. A more thoughtful, guided effort is necessary. So again, the answer is no.

Will it help with a harder, global effort? What if everyone increases their direct efforts to achieve the SDGs by 30% harder work that starts ramping up in 2020. The third answer is given in **Scenario 3: Harder – stronger efforts on all fronts.** In this pathway the situation improves somewhat, but still does not lead to achievement of all the SDGs by 2030 – unless one makes unrealistic assumptions about how fast global society is willing to shift its priorities and institutions.

So far, we have learnt that neither conventional approaches, faster growth nor harder efforts are sufficient to realize the grand ambition. *Which leaves us with a very clear answer: Don't work harder, work smarter. The world needs transformative change to achieve the SDGs within the PBs – even if the deadline is postponed from 2030 to 2050.*

The preliminary modelling of Scenario 4: Smarter – transformational change indicates that the most attractive way for humanity to attain most SDGs by 2030 within planetary boundaries beyond 2050 is through transformational change

starting now. Whether we like it or not, unconventional, collaborative measures that rapidly – in one generation – enable the world to shift gears from exponential development in the direction of rising environmental risks and deepened social inequality to sustainable and inclusive development.

The five transformational actions with systems-wide effects on SDGs seem to be:

1. Accelerated renewable energy growth – sufficient to halve carbon emissions every decade from 2020.
2. Accelerated productivity in food chains – improving productivity by +1%/year.
3. New development models in the poorer countries – following models such as South Korea, China, Scandinavia, Ethiopia or Costa Rica.
4. Active inequality reduction – ensuring that the richest 10% take no more than 40 % of income.
5. Investment in education for all, gender equality, health, family planning – stabilising the world's population.

To analyse the full, dynamic impacts of these five actions, however, on the world's bio-socio-economic system lies beyond the capabilities of the current Earth3 model. Therefore, we want and plan to develop a next-generation model, Earth4, that can deepen our understanding of the systemic nature of the transformation to SDG-within-PB success.

4.2 What we learnt in the process

What is new in the Earth3-model approach? The below are key learning points from our scenario and modelling exercise:

We have identified surprisingly stable and well-behaved correlations in historical data between socio-economic indicators and GDP per person (either total, or in primary and secondary sectors) and have used them for forecasting.

We have also identified surprisingly stable and well-behaved correlations in historical data between ecological footprint data (the non-energy footprint per person, various forms of emissions per person) and GDP per person in primary and secondary sectors and have used them for forecasting.

We utilise the surprisingly stable and well-behaved correlations in historical data between macroeconomic variables (growth rate in GDPpp, share of GDP in primary, secondary and tertiary sectors, share of GDP in consumption and in government spending) and the GDP per person (either total, or in primary and secondary sectors) and have used them for forecasting.

We have successfully constructed and run an integrated Global Systems Model in which the main socio-economic variables (in Earth3-core) are combined with the main environmental biogeochemical variables (in ESCIMO) in a way that is transparent and consistent. See appendix 1 for details.

The model describes most of the well researched Earth potential "tipping points" – in the form of potentially self-reinforcing mechanisms in ESCIMO (such as arctic ice melting, permafrost thawing, tropical forest dieback and more).

We track the development over time, instead of studying the effect on an equilibrium which lies far into the future (100 to 1,000 years in the climate subsystem).

We include both gases that are missing in most greenhouse gas calculations: a) CO2 from the burning and rotting of biomass, and b) the Montreal gases – in addition to the six Kyoto gases.

We present a logically consistent causal model of the development over time of "global biocapacity" (the same as the annual production of biomass) and of the remaining "old-growth-forest area" (an approximate measure of remaining biodiversity).

We have discovered how useful it is to distinguish between the full GDP and the GDP in the primary and secondary sectors, when analysing the effects of GDP growth.

We have discovered how useful it is to split "energy use" into a) electricity use (in TWh/y) and b) direct use of fossil fuels (in Mtoe/y) – that is in electricity and heat.

4.3 What's next? Future work from Earth3 to Earth4

Based on the learning points above, the authors see both high value and a clear need to continue to improve on the model system, the indicators, the underlying correlations and the thresholds for each indicator.

We have discovered several areas of improvement potential while running the model scenarios on Earth3. Prominent among them are to:

a) improve the age structure in the population sector,
b) introduce capital and debt as a level in the economy sector to better study inequality and its relationship to growth, governance, partnership etc
c) reformulate the energy sector into stocks for electricity and direct fossil capacity,
d) introduce food use,
e) improve the model structure on water use, emissions and unused biocapacity,
f) improve representation of costs and benefits of the transformational actions

We see significant benefits to developing a next generation "Earth4 model". On the technical front, this involves converting the Earth3-spreadsheet model into a complete system-dynamics model. This would entail closing the remaining system loops, so that the whole model is upgraded to a fully integrated Global System Model that can run experiments on any computer through a user-friendly web interface. This resulting generic model of a modern socio-economy in a finite environment would also be usable for study conventional policy in a region on a 20-year horizon. It could be run on both country and regional level. This would give us a much clearer picture of the transformation needed, in a more detailed, consistent and inspirational way forward.

5 Appendix 1: The Earth3 model system

A paper (Randers et al. 2018) that describes the Earth3 model system in scientific terms, can be found and downloaded at doi.org/10.31223/osf.io/xwevb. Supplemental information including the full Earth3model can be downloaded, too. In this appendix, we give an introduction to the model system with a description of how the four scenarios are parameterised and implemented in the Earth3 model.[vii]

5.1 Earth3 model structure – the basis of the SDGs within PBs report

In order to make sure that our scenarios are internally consistent, and that the future they depict actually does arise from the assumptions we make about how the world operates, we use a system of computer models. See Figure 5.1 which shows the components of the model system and the flow of data among them. The parameter values we use and the causal assumptions we make are all drawn from publicly available information – both numerical and qualitative.

Earth3-core

The core of the system is the **Earth3-core spreadsheet model**, which tracks history from 1980 to 2015, and generates consistent scenarios for the period 2015 to 2050. Earth3-core does so for the world split into seven 'regions' or country clusters. Not all clustered countries ('Rest of world' and 'Other rich countries') are in the same geographic region. But they share other characteristics, see section 6.3 for a full listing. Scenarios for the whole world are achieved by adding up the seven regional scenarios. Figure 5.2 gives an aggregate list of the main variables in the Earth3-core model – the full list numbers nearly 100 variables for each of the 7 regions.

Figure 5.3 shows an example of the output from Earth3-core: the development from 1980 to 2050 of global population, GDP, GDP per person, inequity, government spending, fossil energy use, electricity use, greenhouse-gas (GHG) emissions, non-energy ecological footprint, freshwater use, aerosol concentration, and lead (Pb) release. There is one future for each of our four scenarios, including Scenario 1, which portrays the consequences of continued business as usual. Similar graphs exist for each of the seven regions.

An overall check of model quality has been made by comparing the output of Earth3-core with two major global modelling efforts: DNV-GL's Energy Transition Outlook 2017[35]and the IIASA's global population model.[36]

vii The whole Earth3 model system can also be downloaded for free from http://www.2052.info/earth3. It can be run with MS Excel and Vensim software.

ESCIMO (Earth System Climate Interpretable MOdel)

The descriptions of the future produced with the Earth3-core model are used as inputs for the second model in our model system, the **ESCIMO system dynamics model**. The ESCIMO model calculates the impact on the global ecosystem of the anthropogenic "drivers" that are the outputs from Earth3-core. The model includes most well-known Earth "tipping points" – in the form of potentially self-reinforcing mechanisms. The output from ESCIMO has been compared with the major Earth-system models of the literature.[37]

It is important to keep in mind that ESCIMO is a global model, calculating global averages for the variables involved (like global warming and sea-level rise). ESCIMO does not produce regionalised results. Both Earth3 and ESCIMO are based on a dynamic perspective of the world, viewing it as a causal mechanism, where the current situation and external drivers create the future (in a big system of non-linear differential equations that are solved through simulation).[viii]

Figure 5.4 shows the effect on global warming, ocean acidity and old-growth-forest area over the period 1980 to 2050, for Scenario 1 – *Same*. This is just an example of the outputs from ESCIMO, which produces a large number of other indicators of the status of the global ecosystem. Different forecasts for the future of the global ecosystem will result from different human-caused drivers.

17 Sustainable Development Goals – the SDG module

Once the two models (Earth3-core and ESCIMO) have produced a quantitative picture of both the socioeconomic and environmental outcomes for a scenario of the world to 2050, we use this information to provide a reasoned answer to the basic question motivating our study: to what extent will the 17 SDGs be achieved in this future – in this scenario?

The basic reason why we believe we can make reasoned forecasts of SDG achievement is that there is a strong correlation between past achievement of sustainability objectives and past values of GDP per person. This is not only true for the world at large, but also by region. On this basis, we have assumed that we can forecast future satisfaction of the SDGs in a region by forecasting future values of GDP per person in

viii The detailed assumptions underlying the Earth-3 core spreadsheet model and the ESCIMO system dynamics model are available in the form of equation listings (in Excel and Vensim respectively – please contact goluke@blue-way.net). Descriptions of the numerous assumptions made are available in Randers (2012) 2052 A Global Forecast for the Next Forty Years on Earth3-core and Randers, Goluke, Wenstøp, Wenstøp (2015) on ESCIMO.

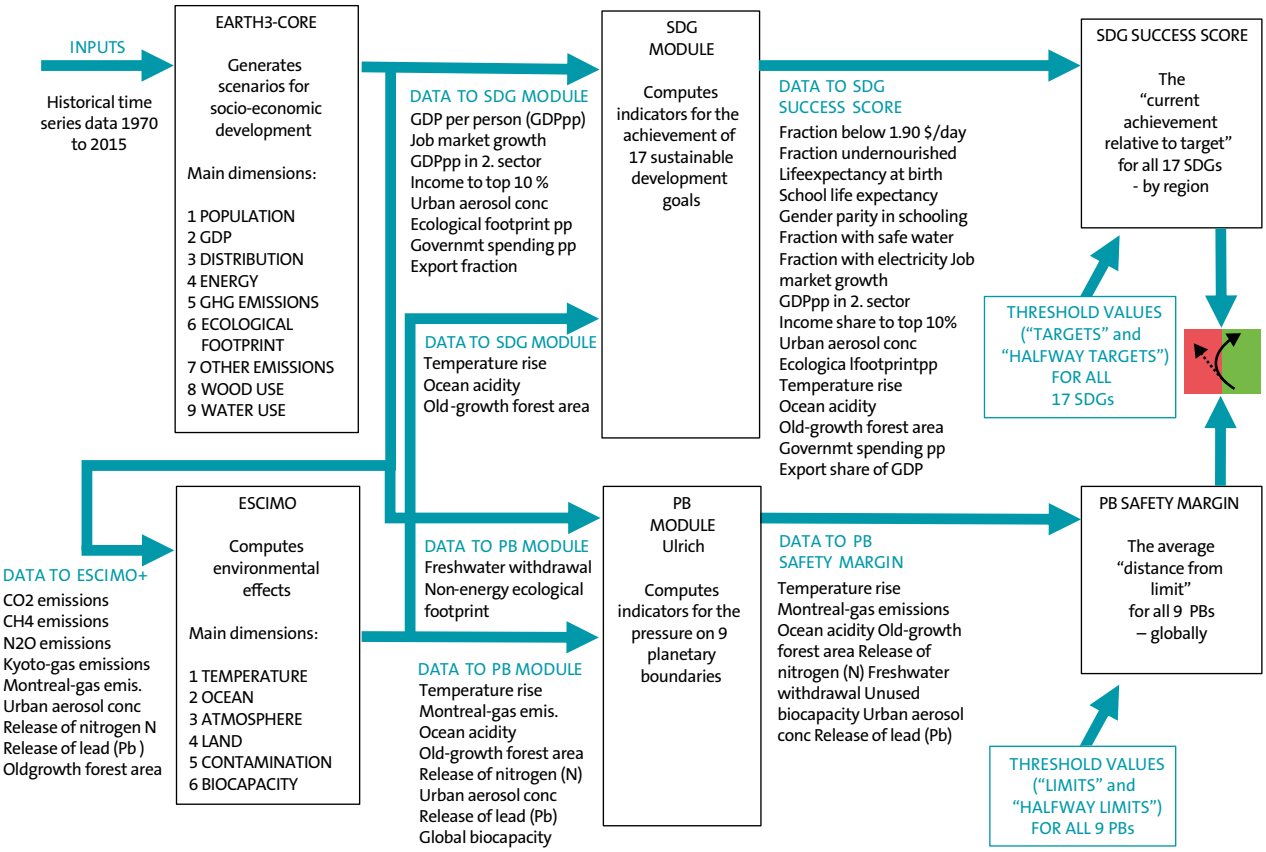


Figure 5.1 Overview of the Earth3-model system, showing the flow of variables among the model elements.

the region (which is exactly what Earth3 does). This forecasting is done in the "SDG Module".

In order to quantify our response, we had to choose a numerical indicator for each of the 17 SDGs. We had to decide on what constitutes full achievement of the goal (the "target") and what we see as half-way achievement (the "half-way target"). Figure 5.5 shows our selection of SDG indicators, units, targets and half-way targets.

The empirical data sources and the reasons for our choices are mentioned in Appendix 2, and further documented in Collste (2018) a forthcoming scientific article on the empirical basis for the Earth3 model. This publication also documents the strength of the correlations we found with GDP per person (measured in 2011 PPP US$ per person per year) for 9 of the (social) SDGs.[ix]

Nine planetary boundaries – the PB module

Once we know to what extent the sustainable development goals will be achieved in a given scenario, we need to answer the other question motivating our study, namely: to what extent will this achievement lead to further pressure on, and higher risk of pushing the planetary boundaries beyond points of irreversible change.

ix In some cases, we had to use other drivers than GDP per person, because we did not find strong correlations with GDP per person. See section 6 for introduction to the empirical basis for our correlations.

1 POPULATION
– total, births, deaths

2 GDP
– total, growth rate, per person, by sector, by end-user

3 DISTRIBUTION
– income to top 10%, government spending per person

4 ENERGY USE
– electricity use, direct fossil-fuel use, by type and fuel, renewable fraction

5 **GREENHOUSE GAS EMISSIONS**
– CO_2 from energy and cement, CH_4 and N_2O from agriculture

6 ECOLOGICAL FOOTPRINT
– non-energy ecological footprint, biocapacity, unused biocapacity

7 OTHER EMISSIONS
– release of nitrogen (N) and lead (Pb), urban aerosol concentration

8 WATER USE
– freshwater withdrawal

9 WOOD USE
– remaining old-growth-forest area

Figure 5.2 Variables in the Earth3-core model. More detail in Randers et al (2018) Achieving the SDGs within PBs

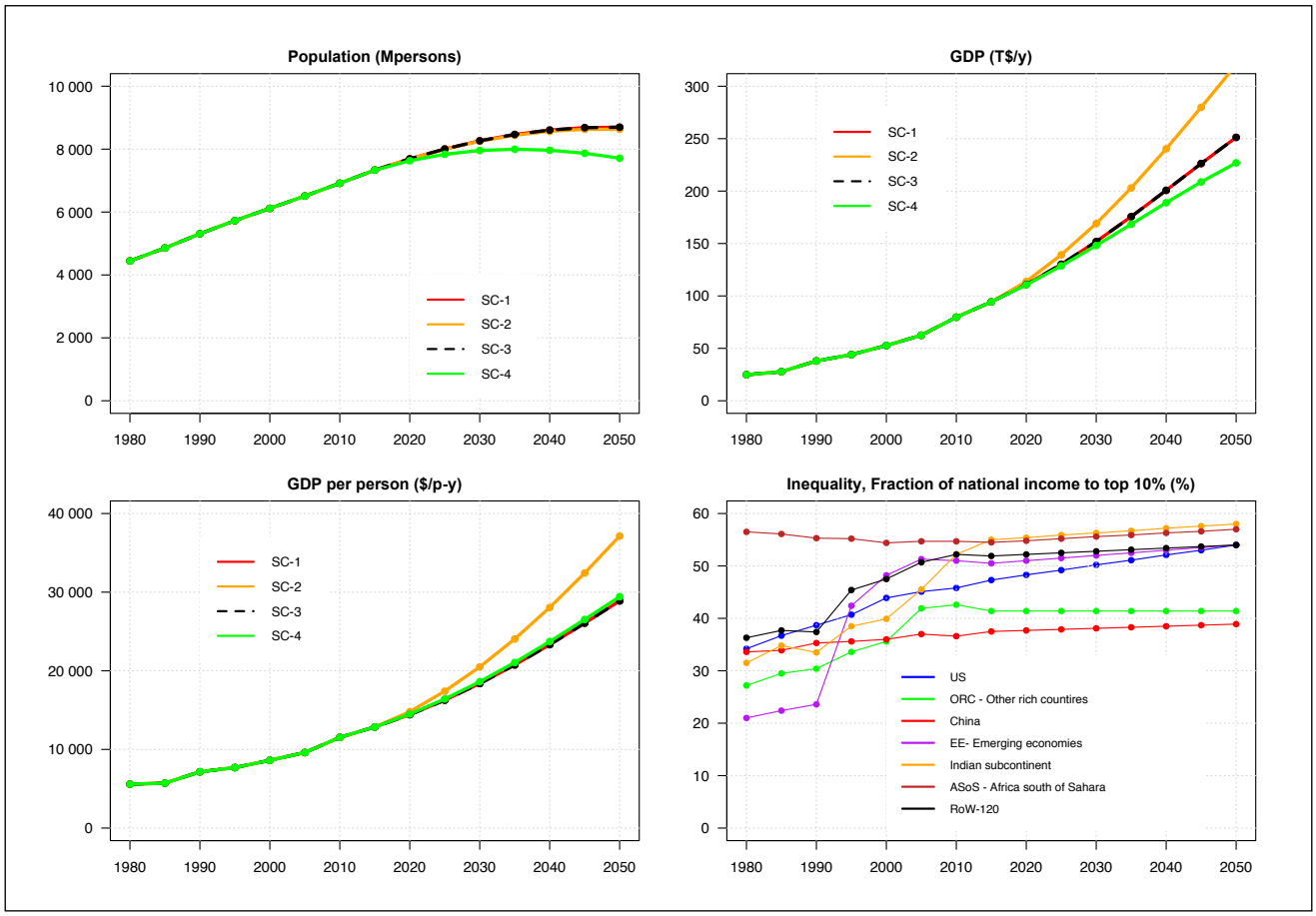


Figure 5.3a Output from Earth3-core model – the development over time from 1980 to 2050 of four variables, in different scenarios.

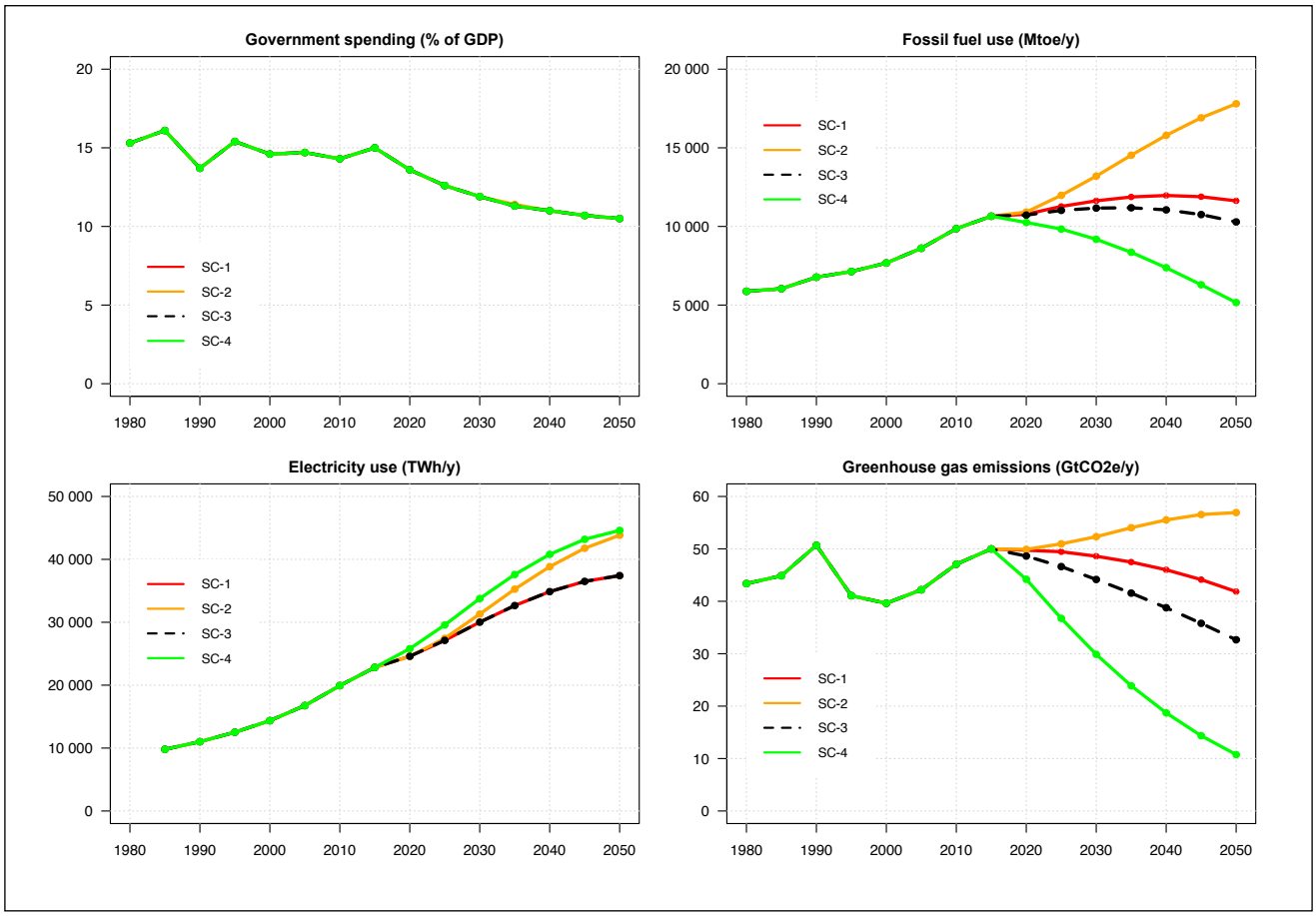


Figure 5.3b Output from Earth3-core model – the development over time from 1980 to 2050 of four variables, in different scenarios.

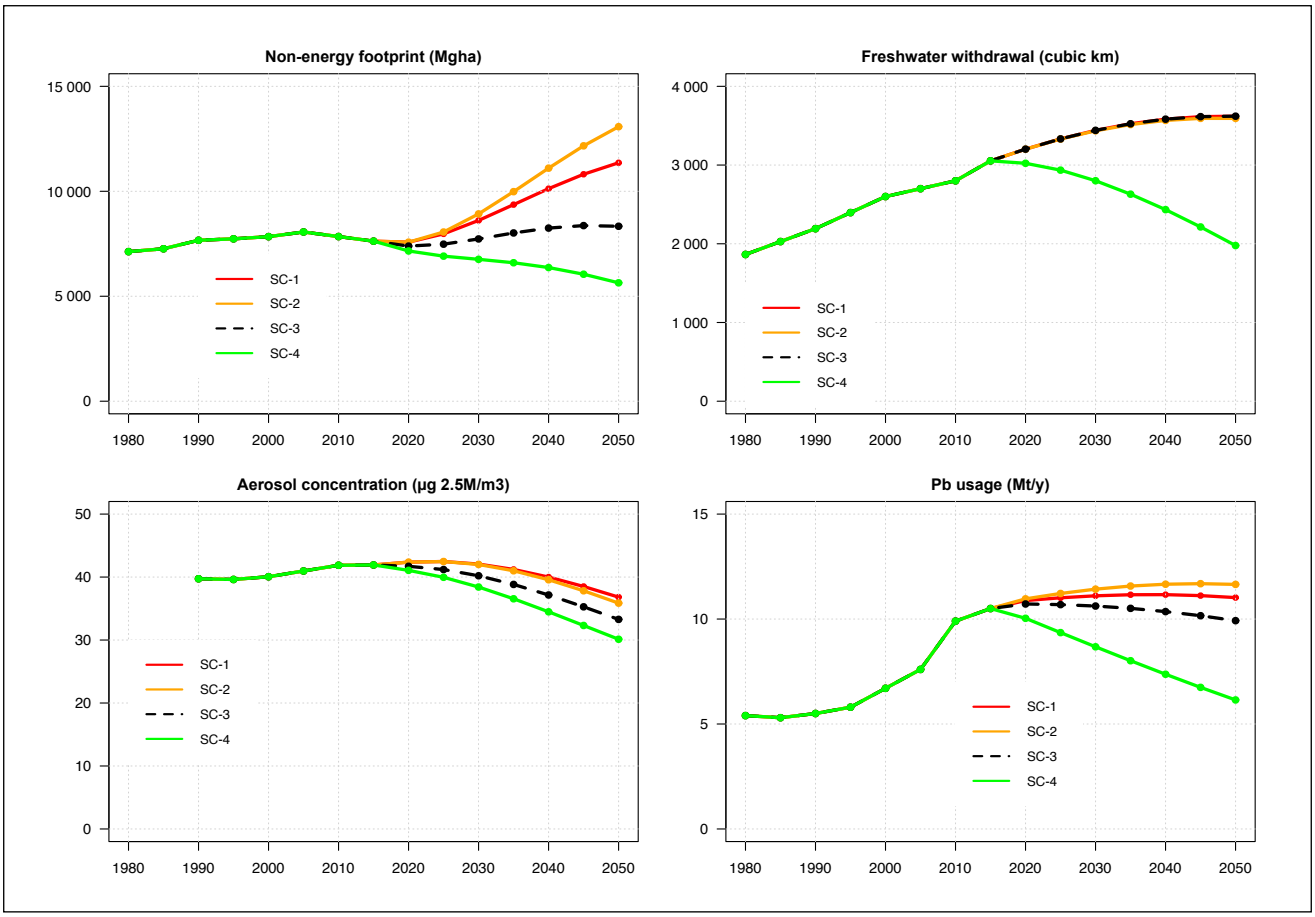


Figure 5.3c Output from Earth3-core model – the development over time from 1980 to 2050 of four variables, in different scenarios.

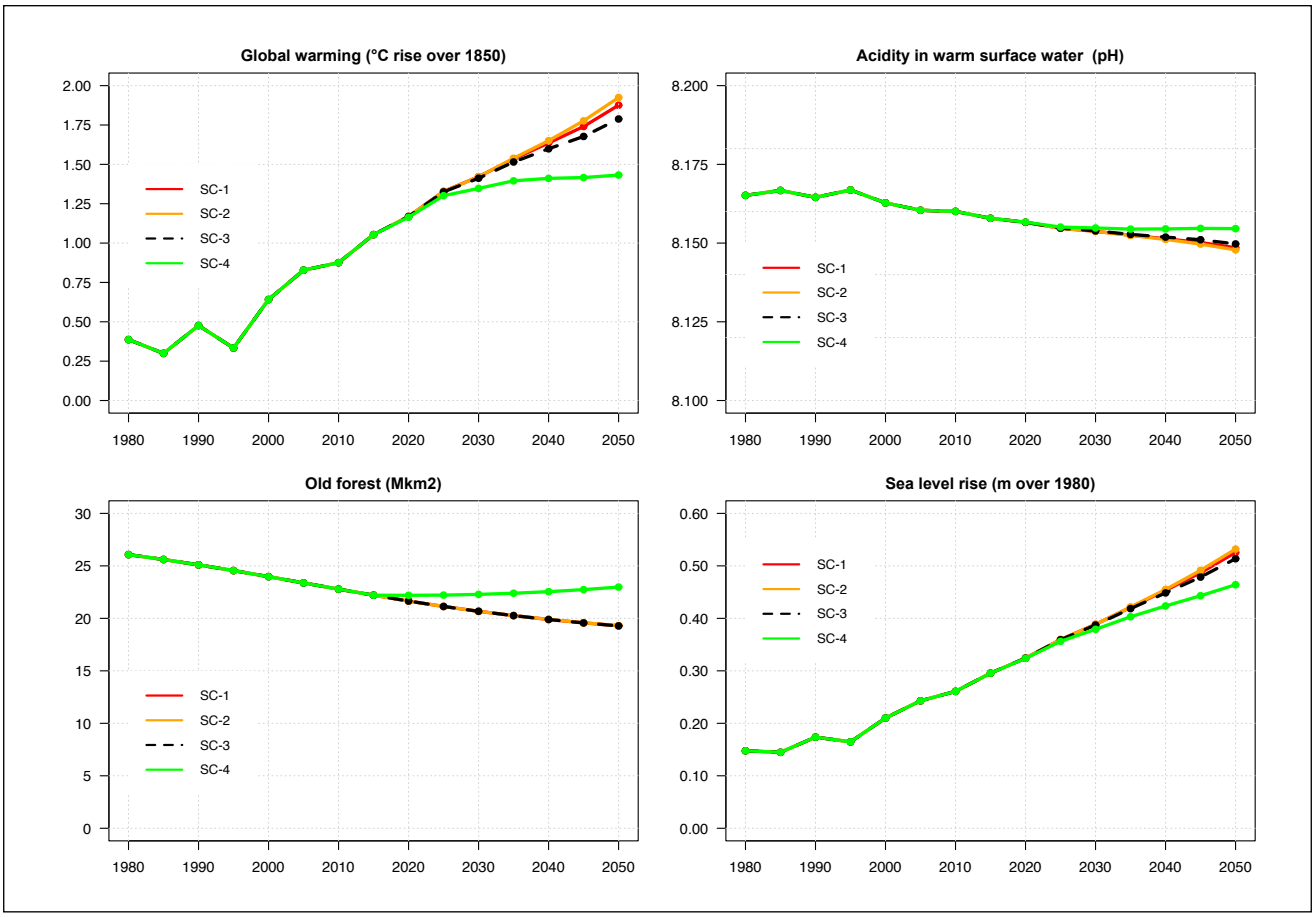


Figure 5.4 Output from ESCIMO – the development over time from 1980 to 2050 of four variables – in different scenarios (page 1 of 1).

SDG		Indicator	Target	Halfway-target
The 17 goals for humanity agreed by the UN in 2015		*Indicator for the achievement of each sustainable development goal*	*Threshold value for "green"*	*Threshold value for "yellow"*
1	No poverty	Fraction of population living below 1.90$ per day (%)	< 2 %	< 13 %
2	Zero hunger	Fraction of population undernourished (%)	< 7 %	< 15 %
3	Good health	Life expectancy at birth (years)	> 75 years	> 70 years
4	Quality education	School life expectancy (years)	> 12 years	> 10 years
5	Gender equality	Gender parity in schooling (1)	> 0.95	> 0.8
6	Safe water	Fraction of population with access to safe water (%)	> 98 %	> 80 %
7	Enough energy	Fraction of population with access to electricity (%)	> 98 %	> 80 %
8	Decent jobs	Job market growth (%/y)	> 1 % / year	> 0 % / year
9	Industrial output	GDP per person in manufacturing & construction (2011 PPP US$/p-y)	>6.000 2011 PPP $/p-y	>4.000 2011 PPP $/p-y
10	Reduced inequality	Share of national income to richest 10 % (%)	< 40 %	< 50 %
11	Clean cities	Urban aerosol concentration (µg 2.5M /m3)	< 10 µg 2.5M /m^3	< 20 µg 2.5M /m^3
12	Responsible consumption	Ecological footprint per person (gha/p)	< 1.4 gha/p	< 2 gha/p
13	Climate action	Temperature rise (deg C above 1850)	< 1 deg C	< 1.5 deg C
14	Life below water	Acidity of ocean surface water (pH)	> pH 8.15	> pH 8.1
15	Life on land	Old-growth forest area (Mkm2)	>25	>19
16	Good governance	Government spending per person (2011 PPP US$/p-y)	>3.000 2011 PPP $/p-y	>2.000 2011 PPP $/ p-y
17	More partnership	Exports as fraction of GDP (%)	> 15 %	> 10 %

Figure 5.5 The 17 UN Sustainable Development Goals – indicators, units, and threshold values. More detail in Appendix 2, and Collste et al (2018)

Planetary boundary		Indicator	Safe zone	High-risk zone
Man-made processes that threaten to exceed a planetary boundary in 21st century		*Indicator of the current pressure on each planetary boundary*	*Green zone*	*Red zone*
1	Global warming	Temperature rise (deg C above 1850)	< 1 deg C	>= 1,5 deg C in 2050, 2.0 in 2100.
2	Ozone depletion	Montreal-gas emissions (Mt/y)	< 0,25 Mt/y	>= 2 Mt/y
3	Ocean acidification	Acidity of ocean surface water (pH)	> pH 8.15	<= pH 8.1
4	Forest degradation	Old-growth forest area (Mkm^2)	> 25 Mkm^2	<= 19 Mkm^2
5	Nutrient overloading	a) Release of bioactive N (Mt/y) b) Release of bioactive P (Mt/y)	< 100 N Mt/y < 10 Mt/y	>=200 Mt/y not set yet
6	Freshwater overuse	Freshwater withdrawal (km3/y)	< 3.000 km^3/y	>= 4.000 km^3/y
7	Biodiversity loss	Unused biocapacity (% of biocapacity)	> 25 %	<= 12 %
8	Air pollution	Urban aerosol concentration (µg 2.5M/m^3)	< 10 µg 2.5M/m^3	>= 35 µg 2.5 M/m^3
9	Toxics contamination	Release of Pb (Mt/y)	< 5 Mt/y	>= 10 Mt/y

Figure 5.6 Nine planetary boundaries – indicators, units, and threshold values. More detail in Appendix 2 and in Collste et al (2018)

Region	**Symbol**	**Population** million persons	**GDP** billion US$ per year	**GDP per person** US$ per person-year	**Share of world population** %
1. United States	USA	330	16 700	51 100	5
2. Other rich countries	ORC	750	28 100	37 500	10
3. Emerging economies	EE	890	15 400	17 300	12
4. China	CHINA	1 430	18 500	13 000	20
5. Indian subcontinent	IND	1 660	8 100	4 900	23
6. Africa south of Sahara	ASoS	750	2 800	3 800	10
7. Rest of the world	RoW	1 540	11 500	7 500	20
World total	World	7 350	101 100	13 800	100

Figure 5.7 The seven regions used in the Earth3-model system. More detail in 6.3.

In order to quantify our response, we had to choose the one numerical indicator for each of the nine planetary boundaries we see as most relevant – and, importantly, indicators for which there exist historical data and for which we can make forecasts using Earth3-core and ESCIMO. We also had to decide on what constitutes for each boundary the limit of the safe operating zone for human activity (the boundary between the green and the red zone) and what constitutes the limit to the danger zone (the limit between the yellow and the red zone). This work was based primarily on Rockström et al. (2009) and later updates (Steffen, 2015).

We use the indicators to measure the extent to which the different SDGs are achieved as shown in figure 5.5.

Figure 5.6 shows our selection of planetary boundaries, with pressure indicators, units, threshold values for the safe or "green" and high-risk "red" zones. The risk refers to the boundary conditions beyond which irreversible decline may start in the Earth life-supporting systems. For further detail, see Appendix 2 and the supplemental information available from the links.

Seven regions – our world map

The Earth3-model system sees the world as consisting of seven regions[x]. Figure 2.7 (a table showing the following numbers for the seven regions) shows the regions, their population (in million persons), GDP (in billion PPP US$ per year), and the GDP per person (in 1000 PPP US$ per person per year), all around 2015. The complete list of nations aggregated into the seven regions is shown in Appendix 2, section 6.3.

The outcome performance measures: SDG success score and safety margin

To summarise: we use the two models (Earth3-core and ESCIMO) to produce a quantitative picture of one scenario for the world to 2050. Then we use the SDG module to calculate our estimate of the extent to which the 17 SDGs will be achieved in that scenario. And then we use the PB module to estimate the resulting pressure on planetary boundaries.

The information challenge is that this leads to 17 conclusions for 7 regions, plus 9 conclusions for the world as a whole. That is 128 numbers in total, and much too much for an effective discussion of global policy. Thus we have to define two aggregate measures of system performance, to make it simpler to discuss the relative merit of different scenarios and different policy interventions. The two measures are the SDG success score (by region) and the safety margin (for the planet as a whole).

The **SDG success score** measures the extent to which the sustainable development goals (SDGs) are achieved, on a scale from 0 (no achievement at all) to 17 (full achievement of all goals). We calculate the SDG success score for every year from 1970 to 2050, for each of the seven regions, and also compute a global average score, weighing the regions by population.

The **safety margin** measures the gap between man-made pressure on the ecosystem and our estimate of the sustainable carrying capacity of the planet. The safety margin is given on a scale from 9 (little pressure on all of the 9 planetary boundaries, and hence "full" safety margin) to 0 (when the human pressure has pushed the boundary to red, high-risk zone for all 9 of them, so there is "zero" safety margin). The safety margin should be thought of as the margin of safety between current human pressure on the planet and the maximum pressure that can be handled by the planet in a sustainable manner. If it is 9, Earth's systems are in safe operating space (as stable as they were during the Holocene). If it is 0, Earth is operating in very high-risk zone for serious impacts or destabilisation of life-supporting systems, and hence high risk for human societies.

x To make the group averages more meaningful, we have disregarded an "8th region" consisting of a small number of super-rich nations outside the OECD, with ca 50 million people (less than 1% of the world's population). These small super-rich nations are Qatar, Saudi Arabia, Singapore and UAE.

5.2 Our four scenarios in the Earth3-model system – the quantitative backbone

We use the method described above to produce four consistent quantitative scenarios from 1980 to 2050 and use the result to calculate the SDG success score and the safety margin in each of the scenarios. All calculations are made at the regional level, and then aggregated into global figures when desired. The exception is the safety margin, which is only calculated at the global level.

These results constitute the consistent quantitative backbone for the four scenario narratives presented in chapter 2.

Scenario 1: Same – business as usual.

Scenario 1 describes the most likely development towards 2050 if global society continues to respond to emerging problems in the conventional way, that is, without taking any significant extra action relative to the historic average efforts. We run the model with all policy levers in neutral. Scenario 1 could therefore be named the "baseline case" of the Earth3-model system. It describes a smooth continuation of the normal, very gradual, institutional development that we expect will occur in response to emerging realties when governance operates in "default mode".

Therefore, the model system is parameterised in the manner which best tracks the general trends in historical data from 1980 to 2018, and furthermore embodies the overall assumption that the decision-makers of the world continue to perceive and respond to emerging challenges in the same way as they have done during the last several decades.

Scenario 2: Faster – accelerating economic growth

What if **Same** underestimates the economic growth in the coming decades, particularly when the poor countries get into catch-up mode? This scenario describes what we believe will be the result if the whole world tries and succeeds in achieving more SDGs by increasing the rate of economic growth per person in all regions. These extra funds are to a certain extent (the same as the last 30 years) used to finance the accelerated move towards higher goal satisfaction. Scenario 2 assumes that the regions continue to use conventional policy tools in the effort, but helped by both supply-side and demand-side efforts, particularly a much bigger middle-class in Asia, Africa and Latin America, succeed in higher growth rates than in Scenario 1, **Same**.

Scenario 2, **Faster**, is achieved by increasing (exogenously, from 2018) the growth rate in GDP per person by 1% per year – in USA, other rich countries, China, emerging economies, Indian subcontinent, Africa south of Sahara, and rest of the world. In sum the exogenous change amounts to increasing the global growth rate in GDP from around 2.8 to 3.5 %/y in 2020 to 2050.

Otherwise we make no policy lever changes in the model.

The positive result is that more SDGs are achieved than in Scenario 1. But the faster growth increases pressure on the planetary boundaries. Thus there are more PBs in deeper high-risk, red zone and lower safety margins than in **Same**.

Scenario 3: Harder – stronger efforts on all fronts

Scenario 3 describes what we believe will be the result if the world increases its effort to achieve the SDGs, in the sense that more manpower and more money are spent on goal achievement. Scenario Harder reflects a future where the world's decision-makers focus real attention and energy on achievement of the SDGs. That is, they shift manpower and finance from current activity to projects that help achieve SDGs and/or reduce the pressure on PBs.

Scenario 3 also assumes an extra effort to reduce the footprint per unit of consumption – in an attempt to keep within the planetary boundaries. In both cases keeping within conventional policy tools.

Scenario 3 is simulated in the model by i) an exogenous increase in the speed at which each SDG indicator moves towards its target value when income (GDP per person) increases, and ii) by an exogenous, gradual decrease in the footprint intensity (resource use and emission per unit of GDP).

i) Scenario 3 is achieved in Earth3 by reducing by 30–50% the time it takes to reach the targets for those SDGs that can be attained without fundamental change of the capitalist, liberal, market and consumption-based world order – that is, without fundamental redistribution of income or wealth. These SDGs are:

SDG	Indicator and target
1 No poverty	Fraction of population living below 1.90$ per day (%)
2 Zero hunger	Fraction of population undernourished (%)
3 Good health	Life expectancy at birth (years)
4 Quality education	School life expectancy (years)
5 Gender equality	Gender parity in schooling (1)
6 Safe water	Fraction of population with access to safe water (%)
7 Enough energy	Fraction of population with access to electricity (%)

ii) Scenario 3 furthermore assumes a very gradual reduction (0.5% per year) in per capita greenhouse-gas emissions and in the non-energy footprint – over and beyond the reduction that takes place in Scenario 1. This has direct effects on the four environmental SDGs:

12 Responsible consumption	Ecological footprint per person (gha/p)
13 Climate action	Temperature rise (deg C above 1850)
14 Life below water	Acidity of ocean surface water (pH)
15 Life on land	Old-growth-forest area (Mkm2)

In addition, Scenario 3 assumes that the world's decision-makers place real attention and energy on keeping within the PBs. But only to the extent of reducing the footprint intensity ("cutting emissions" and "reducing resource use" per unit of GDP) for urgent planetary boundaries. In other words, Scenario 3 does **not** assume a real move away from consumption growth as the main societal objective, **nor** a large-scale shift towards green values (sustainability) in agriculture and land use.

The result of the extraordinary increase in effort in Scenario 3 are described in section 2.3. All these efforts improve the situation somewhat, but it does not achieve the grand ambition. More SDGs are achieved by 2030 (11.5 compared to 11 in scenario 2, and 10.5 in scenario 1), but no further increase by 2050. This is because global society is still exceeding several planetary boundaries, not only in 2030, but increasingly to 2050. The safety margin stays low (at 4,5 in 2030, compared to 4 in scenario 2) and improves only very slightly to 2050.

In other words, it will take much more than working **Harder** to achieve (nearly all of the) 17 SDGs within (nearly all of the) 9 PBs by 2050.

The caveat regarding modelling of scenario 4

The above three scenarios are well fitted to be simulated in the current structure of the Earth3 model. They are therefore described in further detail in a separate scientifically peer-review paper (Randers et al 2018). The scientific paper does not include Scenario 4 because it could be objected that the model runs seem to push the simulation outside the capabilities of Earth3. After identifying the five transformative actions that seem to have the greatest leverage, we recognized that the Earth3 model system has limited capacity to describe the transformation in an integrated and dynamic manner. We have still – with great reluctance and caution – tried to quantify them in the existing model system, "bending the rules" beyond the safe zone for the model, so to speak. And used the experience to learn more about what a next-generation model will have to be able to solve, to give a more in-depth understanding of the transformation in systems terms. Any further critiques from fellow modellers, scientists or other critics to the authors are most welcome.

Scenario 4: Smarter – transformational change

Scenario 4 describes what it will take to achieve (nearly) all the SDGs within (nearly all) PBs by 2050. Scenarios 1, 2 and 3 show that it is not enough to continue business as usual, nor to accelerate GDP growth, nor to focus societal attention on the SDGs. In short it is not enough to implement conventional policy. There is need for transformational change: unconventional measures and unconventional funding, implemented in a thoughtful manner. Scenario 4 includes five examples of transformational measures – grounded in knowledge, technologies and political options that already exist – which we believe could lead to the achievement of (nearly) all SDGs by 2050 - or maybe a few decades later.

Scenario 4 is generated by *direct intervention into the logic of the Earth3-model system*, in such a manner that decarbonisation takes place even if it may not always be profitable; redistribution takes place even if there may be insufficient political or democratic support; food waste and land use is done more sustainably even if the benefits may appear a generation later; poor countries (particularly African) successfully copy aspects of China's, Ethiopia's or Scandinavia's system of governance; and birth rates are allowed to fall in response to better conditions for mothers.

This is how we tested the five strategies of transformational change in the model system:

a) Rapid decarbonisation of the global energy supply

This is achieved in Earth3 by increasing (exogenously) the speed at which renewable electricity capacity is added to the system. An extra 40% of fossil fuels are replaced by electricity by 2050, with the final result that fossil-fuel use is 5,000 Mtoe/y in 2050, compared to 11.500 Mtoe/y in Scenario 1 **Same**.

This has direct positive effects on the climate situation (SDGs 13, 14 and 15), on availability of electricity (SDG 7), and on the ecological footprint (SDG 12).

The indirect effects of more clean energy on some other SDGs are not yet included in the model. Nor is the cost of this acceleration – namely the cost of doubling the annual investment in new renewables (which would amount to an increase from 0.3 in 2018 to 0.6 trillion USD each year from 2010 – or about 1% of the rich world's GDP).

Accelerated decarbonisation helps greatly towards solving the climate problem (keeping within PB 1 Global warming and PB3 Ocean acidification).

b) Active redistribution of income, within and (ideally) among countries

This is achieved in Earth3 by reducing exogenously the share of national income that accrues to the top 10%. The share is lowered to 39% in 2020 in those regions that have a share higher than that in 2018. The proceeds are used to finance government spending on achieving the social SDGs (1–12).

Active redistribution has many positive effects for the majority in the regions involved (just like Scenario 3). The negative wellbeing effect on the richest 10% of the population – who lose money and power – is not modelled. But neither is the fact that they get a more socially stable (and hence more sustainable) society in return. The two effects on rich person wellbeing could be hoped to balance each other.

Active redistribution helps satisfy more SDGs within the same footprint but does not in itself reduce the pressure on the PBs (at least not in the current version of Earth3).

c) Shift toward sustainable use of the world's agricultural land, forests and oceans

This transformation is meant to mimic a large-scale transition to sustainable agriculture, forestry and land use. This is achieved in Earth3 by exogenously reducing by 1%/y the footprint intensities (resource use and emissions per unit of GDP in primary and secondary sector) and by reducing forest cut in tropical and northern forests. Nutrient release (N) are cut by 1.4%/y, from 160 Mt/y of Nitrogen to just below 100 Mt/y, freshwater use, urban aerosols and the release of toxics (Pb) (from 160 Mt/year of Nitrogen.

In sum these changes lead to reduced pressure on PB 4 Forest degradation, PB 5 Nutrient overloading, PB 6 Freshwater overuse, PB 7 Biodiversity loss, PB 8 Air pollution, and PB 9 Toxics contamination.

Some of the boundaries will still be temporarily exceeded in the period towards 2100.

d) New "plan-based collective" development model for poor countries

This transformation is meant to mimic the adoption of the Chinese development model in the poor nations of the world, (see box 2, "The Chinese Model", in section 2.4)

This is achieved in Earth3 by increasing (exogenously) the growth rate in GDP per person to Chinese levels, for levels of income below 10.000 USD per person per year. And at the same time increasing the speed at which the SDG indicators move towards their target, also to Chinese levels.

The effect is to accelerate the satisfaction of many SDGs, but also accelerate the load on many PBs.

e) Investing in more education, health and contraception, stabilising population growth

This is achieved in Earth 3 by reducing the birth rates (by halving the time it takes to reduce them in Scenario 1).

Slowing population growth has little effect in the short term. But it works over time to reduce the total human footprint (fewer people, but at the same footprint per person), thus lowering the pressure on all the PBs.

6. Appendix 2: The empirical basis for the Earth3-model system

A scientific paper (Collste et al. 2018) with technical notes that describes the empirical basis for the Earth3 model system, can be found and downloaded at doi: 10.31223/osf.io/ephsf. In this appendix, we give an overview of our approach with a description of data sources and basic methods for how we arrived at the set of correlations that are the foundation for the Earth3 model.[xi]

6.1 Data selection, sources, analysis and forecasting methods

Our starting point is the 17 Sustainable Development Goals agreed by the UN in 2015. Table 5.5 lists the modelled indicators we have used to track the degree to which the 17 SDGs are achieved, by region. The indicators were chosen based on goal formulations in the resolution , data availability and compatibility with the processes in our model system, the SDG Index and Dashboards Report 2016 and 2017, and further modified by the project team. Details on the correlations on each SDG are presented in a separate publication Collste et al (2018).

The 9 planetary boundaries are listed in figure 5.6 above. We use the seven world regions as specified in section 6.3, and weight by population size when aggregating (the primary) national data to regional levels.

In general, the following procedure has been followed with some differences for the different SDGs as specified under each goal:

- We present the historical data as a function of GDP per person (GDPpp, measured in 2011 PPP US$ with data from the Penn World Tables). Country data has been averaged over five-year periods. As there are shortages of historical data for many countries, we have averaged the numbers based on the population sizes of countries where data is available, as part of the respective regions.
- We have then regressed the indicator (y) on GDP per person (x) – fitting the curve by using a suitable mathematical form based on soft knowledge and the data analysed. Normally the formula is y=a+b*exp(-cx). The reasoning behind this functional form is that we assume that social and economic indicators of progress will initially improve fast as GDPpp grows. Eventually, however, this effect will be balanced by different forms of saturations such as that the whole population has been lifted out of poverty (SDG1) or that electricity access is approaching 100% (SDG7).
- We use the resulting regression equations to forecast future values of the indicators.
- In most cases, we use different functions for the seven different regions. We do this based on the assumption that there are characteristics of the regions, such as institutions and distribution, that have been stable over time and will continue to coevolve with GDP per person in a similar way.

For more information on the detailed data for SDG indicators, we refer to Collste (2018) doi: 10.31223/osf.io/ephsf.

6.2 Defining the Planetary boundaries

We measure the different effects of human activities on the nine planetary boundaries in terms of the production and consumption activities that are included in the Earth3-core module, supported by the environmental system dynamics model ESCIMO (full high-level description, model equations and documentation and input data available at www.2052.info/ESCIMO).

We have used the planetary boundaries processes as presented in Steffen et al. (2015)[40] and Rockström et al. (2009)[41]. Where possible, we retain their indicators. In some cases, we have had to use other indicators for which historical data are available back to 1980. For these, we have chosen indicators that have widespread real-world application, especially in policy contexts, and that are sensitive to changes over the time frame to 2050. In setting the safe and high-risk zones for these indicators, we have focused on the points where scientific assessment coincides with multilateral and international policy concern about large-scale systemic environmental change.

For more information on the data and details about the planetary boundaries together with a rationale behind our thresholds and graphs, see Collste (2018) doi: 10.31223/osf.io/ephsf

xi The whole model system can be downloaded for free from http://www.2052.info/earth3. It can be run with Excel and Vensim software.

6.3 Specification of the seven regions

We have divided the world's countries into economic regions. The source of the national economic data we have used is the Penn World Tables, version 9[42] available for download at www.ggdc.net/pwt. All GDP data are in 2011 PPP $, in the table below 2011 PPP G$/y. (1 G$ = 1 billion $ = 1000 million $.) Population data is from UN Population Division: https://esa.un.org/unpd/wpp/DataQuery/

We have used seven regions for our analysis: United States, Other Rich Countries, Emerging Economies, China, Indian Subcontinent, Africa South of Sahara and Rest of World. The sequence of the sectors below reflects an order of descending GDPpp per region average.

We have disregarded "region 8", which consists of a few super-rich countries outside the OECD. This cluster of countries is small (<1% of world population), and they are statistical outliers that distort the analysis. The global messages about SDG implementation from our analysis nevertheless also apply to these countries.

REGION	Country	Population	GDP	GDPpp
		2015	2015	2015
		Mp	G$/y	$/p-y
		UN	PWT	(=D/C)
1. United States (USA)				
	US, Including Puerto Rico and US Virgin Islands			
		327	16 705	51 100
	SUM USA	**327**	**16 705**	**51 100**
2. Other Rich Countries (ORC)	Australia	23,8	1 017	42 700
	Austria	8,7	407	46 800
	Belgium	11,3	490	43 400
	Canada	36,0	1 507	41 900
	Chile	17,8	383	21 500
	Czech Republic	10,6	336	31 700
	Denmark	5,7	254	44 600
	Estonia	1,3	38	29 200
	Finland	5,5	221	40 200
	France	64,5	2 603	40 400
	Germany	81,7	3 707	45 400
	Greece	11,2	286	25 500
	Hungary	9,8	256	26 100
	Iceland	0,3	14	46 700
	Israel	8,1	264	32 600
	Italy	59,5	2 141	36 000
	Japan	128,0	4 483	35 000
	Luxembourg	0,6	53	88 300
	Netherlands	16,9	797	47 200
	New Zealand	4,6	156	33 900
	Norway	5,2	331	63 700
	Poland	38,3	972	25 400
	Portugal	10,4	296	28 500
	Slovakia	5,4	155	28 700
	Slovenia	2,1	63	30 000
	South Korea	50,6	1 758	34 700
	Spain	46,4	1 567	33 800
	Sweden	9,8	433	44 200
	Switzerland	8,3	480	57 800
	UK	65,4	2 589	39 600
	SUM ORC	**748**	**28 057**	**37 500**

REGION	Country	Population	GDP	GDPpp
3. Emerging Economies (EE)				
Characteristic: big mid-income countries				
	Argentina	43,4	869	20 000
	Brazil	206,0	3 064	14 900
	Iran	79,4	1 215	15 300
	Kazakhstan	17,8	407	22 900
	Malaysia	30,7	692	22 500
	Mexico	125,9	1 988	15 800
	Russia	143,9	3 448	24 000
	Romania	19,9	409	20 600
	Thailand	68,7	946	13 800
	Turkey	78,3	1 491	19 000
	Ukraine	44,7	465	10 400
	Venezuela	31,2	434	13 900
	SUM EE	**890**	**15 428**	**17 300**
4. China				
	Taiwan	23,5	1 039	44 200
	China	1 397,0	17 080	12 200
	Hong Kong	7,3	374	51 200
	SUM CHINA	**1 428**	**18 493**	**13 000**
5. Indian Subcontinent				
Characteristic: poor and populous				
	Bangladesh	161,2	459	2 800
	India	1309,0	6 767	5 200
	Pakistan	189,4	860	4 500
	SUM INDIAN SC	**1 660**	**8 086**	**4 900**
6. Africa South of Sahara (ASoS)				
Characteristic: poor and resource rich				
	Angola	27,9	193	6 900
	Cameroon	22,8	61	2 700
	Congo	76,2	91	1 200
	Cote d'Ivoire	23,1	74	3 200
	Ethiopia	99,9	128	1 300
	Ghana	27,6	96	3 500
	Kenya	47,3	124	2 600
	Madagascar	24,2	29	1 200
	Mozambique	28,0	31	1 100
	Nigeria	181,2	976	5 400
	Sudan	38,6	190	4 900
	South Africa	55,3	655	11 800
	Tanzania	53,9	112	2 100
	Uganda	40,1	69	1 700
	SUM AFRICA SoS	**746**	**2 829**	**3 800**

REGION	Country	Population	GDP	GDPpp
7. Rest of the World – 120 (RoW)				
Sum world (from other data)		7 383	103 866	14 100
		5 847	92 380	15 800
	SUM ROW 120	**1 536**	**11 486**	**7 500**
8. Super-rich outside OECD				
Characteristic: "authoritarian wealth"				
	Quatar	2,5	314	125 600
	Saudi Arabia	31,6	1 483	46 900
	Singapore	5,5	400	72 700
	UAE	9,2	585	63 600
	SUM SUPER-RICH	**49**	**2 782**	**57 000**

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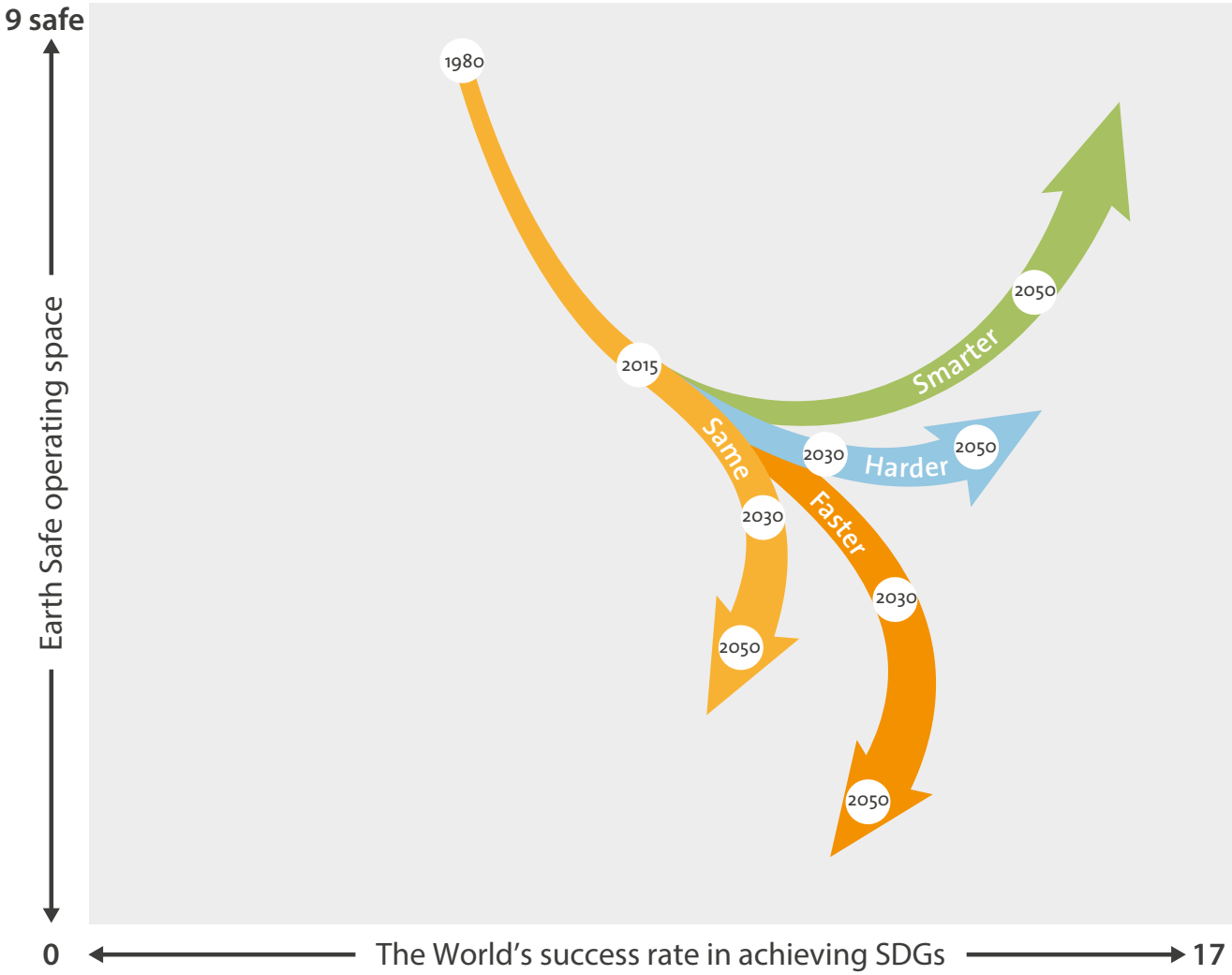
If the world's nations simply continue with business as usual, the world will not succeed in achieving the 17 UN Sustainable Development Goals (SDGs) within the 9 planetary boundaries (PBs) by 2030, nor 2050. These are findings of a world-first foresight analysis to 2050, using a Global System Model driven by historical data from 1980-2015. The report looks forward 35 years equipped with worldwide insights from data on 35 years of past links between socio-economic development and environmental change. One out of four scenarios to 2050 shows that the world's nations can work in a truly transformational way. This requires executing five bold and transformative changes that together can secure meeting nearly all SDGs for the world's population within Earth's safe operating space. These policies do require substantial political will. But the present cost will be moderate, and the future benefits and profits huge.
Four scenario runs, titled Same, Faster, Harder, Smarter, are illustrated in the figure below:



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