Companion for Chapter 6
Planetary Boundaries

SUMMARY

- Although some countries have achieved significant growth, none are actually on a path of sustainable development. The main problem is one of scale: the world economy has become very large relative to the finite planetary resources. To gauge the scope of human impact on the environment, we need to combine the sheer numbers of people with an increased resource use per person. In 1798, when Malthus predicted that any gain in living standards would be annihilated by population growth; he did not foresee technological advance and the demographic transition. However he was right to predict massive population growth.
- In 2009, a group of scientists came up with a list of planetary boundaries across 9 areas, and this allowed for the identification and quantification of safe operating limits for human activity. Those 9 areas were:
    1. Human-induced climate change, which threatens the global food supply, the survival of other species, and disrupts life due to more intense storms and sea level rise.
    2. Ocean acidification, which threatens marine life.
    3. Ozone depletion, which causes increased disorders such as skin cancer.
    4. Pollution from excessive nitrogen and phosphorous, which threatens estuaries with eutrophication.
    5. Overuse of freshwater resources, which is exacerbated by growing populations and changing precipitation patterns due to climate change.
    6. Land use—deforestation not only adds CO2 to the atmosphere, but destroys the habitats of other species.
    7. Biodiversity loss—we depend on biodiversity for food supply, safety from natural hazards, industrial materials, freshwater, and our ability to resist pests and pathogens.
    8. Aerosol loading—the burning of fossil fuels puts small particles into the air that are damaging to the lungs.
    9. Chemical pollution, a broad category mostly caused by industrial activities.
- Pent-up growth, the amount of growth resulting from poorer countries catching up with richer countries, would correspond approximately to tripling world output. In order to reconcile the growth that we would like to see with the ecological realities of the planet, the world economy needs to develop in a fundamentally different way in the future.
- Fossil fuels allowed the breakthrough to the era of modern economic growth, but now are a danger to the world because of the CO_2 they emit. As the economy grows, the energy use tends to grow alongside it: a doubling of the size of an economy tends to be associated with a doubling of primary energy use.
- For each $1,000 of output, we use about 0.19 tons of oil-equivalent energy, and 1 ton of oil-equivalent energy releases on average 2.4 tons of CO_2. For every 7.8 billion tons of CO_2 released, the concentration of CO_2 in the atmosphere increases by 1 part per million (ppm). In the past

100 years, the CO_2 concentration has shot straight up, breaking out of the natural range of the past 800,000 years which fluctuated around 150 to 280 ppm. We have now reached 400 ppm and are increasing concentrations at about 2 ppm per year.

- If we reach 450-500 ppm, we will be living in a world on average 2°C warmer, implying both large disruptions to the Earth climate systems (drought, floods, and storms) as well as sea level rise. We must engage in a 'deep decarbonization' of the energy system, involving energy efficiency, low-carbon electricity, and fuel switching.
- Agriculture is comparable to the energy sector in terms of its environmental impact: almost every planetary boundary is related to it. In addition, the food system gives rise to new deadly pathogens. If Malthus might have neglected the potential for technological innovations, economists neglect the environmental damage caused by modern farming. We are going to need a new farm system adapted to local ecological conditions and causing much less ecological damage.
- The more people on the planet, the more challenging it will be to reconcile the economic objectives of raising living standards per person with planetary boundaries. Many households are trapped in a demographic trap. Poor households tend to have more children, and because resources are spread over so many family members, each child is more likely to grow up poor. Reducing the fertility rates voluntarily is therefore essential to sustainable development. There are many determinants of fertility rate: age of marriage, access to modern contraception and family planning, women's role in the labor force, child survival, and types of economic activities.
- Choosing the right technologies, we can achieve continued economic growth and respect the planetary boundaries. However global markets cannot by themselves ensure that economic growth is sustainable, primarily because the planetary damages are "externalities": those who impose the damages don't pay the costs of it. The result is the overuse of the products and services that create these externalities.
- Second, the problem is intergenerational: those living today spoil the environment without having to bear the responsibility to future generations. When these externalities are ignored, we have a "tragedy of the commons." A variety of policy tools can help: taxation, permit systems, liability rules, social institutions that promote cooperation at the community scale, and public financial support to discover more sustainable technologies through directed research.
- The objective should be to decouple growth and dangerous overuse of primary resources and ecosystems. Decoupling means that growth can continue while pressures on the environment are reduced. Such decoupling is technologically feasible, but requires the right policies and incentives to achieve it.

EASY

REVIEW

Concepts and Definition

Can you define or explain the significance of these concepts?

Planetary boundary	Sixth Great Extinction
Greenhouse gases (GHGs)	Aerosol loading
Ocean acidification	Pent-up growth
pH scale	Decarbonization
Ozone layer	Malthus
Chloroflurocarbons (CFCs)	Demographic trap
Eutrophication	Tragedy of the Commons
Land use change	Externalities
Biodiversity	Decoupling

Check your numbers

1) Approximately how many times smaller was the population in the world in 1800?
2) Approximately how many times smaller was world output in 1800?
3) How many planetary boundaries did Rockstrom et al. identify?
4) What is the world output at present (around 2015)?
5) What would the world output be if pent-up growth was to occur today?
6) According to the rule of thumb of the average converging growth rate, if the US is growing at 1% per year in per capita terms, how fast would a country at $25,000 and $6,250 per capita tend to grow?
7) If we double the size of an economy, how many times bigger would energy use be?
8) On average, what quantity of CO_2 is equal to 1 ton of oil equivalent energy equal?
9) How many tons of carbon were released in 2010?
10) In order to raise the concentration of CO_2 in the atmosphere by 1 ppm, how many gigatons of CO_2 must be put into the atmosphere?
11) The accumulation of greenhouse gases (GHGs) causes global warming by letting sunlight into the atmosphere as _____. Then, when the earth re-radiates the heat back to space, the gases trap the energy in the form of outgoing _____.

Answers: 1) 7; 2) 275; 3) 9; 4) $91 trillion; 5) $275 trillion; 6) 2.4% and 5.2%; 7) Doubling; 8) 2.4 tons; 9) 31 gigatons; 10) 7.8; 11) ultraviolet radiation, infrared radiation

Review questions

What are the 9 planetary boundaries that Rockstrom et al. identified? Explain what each one entails.
What would the future look like under business as usual growth dynamics?
What is the main problem regarding our energy supply and use? How can we tackle it?
What are the negative impacts of agricultural practices on the environment?
Is Malthus' theory and prediction of any relevance to the world today? Why or why not?
How are population dynamics different in high-income and low-income countries?
What are the dynamics of a demographic trap? How can we get out of it?

What could lead to a faster transition to a replacement fertility rate in today's high fertility regions? How could we achieve continued growth within the planetary boundaries? Why don't global markets ensure this?
How can a country/world achieve decoupling?

DATA ACTIVITIES

EASY

A. Ecological Footprint

Visit the Global Footprint Network website at http://footprintnetwork.org. Learn about what the ecological footprint is and what the Earth Overshoot day is.
Under "FOOTPRINT BASICS", click on "World Footprint".

1) In 2014, when was the Earth overshoot day?
2) Under a moderate business-as-usual path, how many equivalents of the planet will we be using in 2050?
   Under "RESOURCES", click on "Living Planet Report". Enlarge the "FOOTPRINT BY COUNTRY" graph.
3) What was the value of world average biocapacity per person in 2010?
4) Which country had the highest ecological footprint and what is the main driver of the footprint in 2010?
5) What was the value of the per capita ecological footprint in the US in 2010?

Answer : 1) August 19; 2) close to 3; 3) 1.7 global hectares per person; 4) Kuwait, carbon; 5) about 7 gha

EASY

B. Environmental Performance Index (EPI)

Take a look at the global maps of EPI for 2014: http://sedac.ciesin.columbia.edu/data/set/epi-environmental-performance-index-2014/maps. You can learn more about the EPI at http://sedac.ciesin.columbia.edu/data/set/epi-environmental-performance-index-2014/docs.
First, take a look at the 2014 EPI map.

1) Which geographic areas had the highest EPI?
2) How do the poorest countries fare?

Now look at the map for "Environmental Health Objective - Air Quality."

3) Which countries are furthest from the target?

Answer : 1) NA, Chile, Japan, Western Europe, Australia and New Zealand, some countries in the gulf such Saudi Arabia, basically high-income countries; 2) they have the lowest EPI; 3) many sub-Saharan African countries, India and China

EASY

C. Water Footprint

Use the interactive tool from the Water Footprint Network website to familiarize yourself with the values of the water footprint index around the world:
http://waterfootprint.org/en/resources/interactive-tools/water-footprint-assessment-tool/.

1) What is the difference between the blue, green, and grey water footprints? (You can use the online glossary on the website.)
2) Using the geographic assessment tool, plot a bar chart of annual water footprint per country to investigate which countries have the highest water footprint in terms of agriculture, industry, or domestic water supply, and then all sectors together. Write a short summary of your findings.

MEDIUM

D. Petroleum Consumption

Go to the US Energy Information Administration's website: www.eia.gov/cfapps/ipdbproject.

1) Use the data available on this website to plot annual petroleum consumption from 1980 to 2013 for the whole world. (Download the data and use excel to plot the graph.)
2) What happened around 1980 and around 1983 that could explain what you observe?
3) What happened from 2007 to 2010 that could explain what you observe?
4) Plot crude oil proven reserves from 1980 to 2013 for the whole world.
5) Describe and explain the overall trend. How does it relate to the graph you plotted in question 1?

MEDIUM

E. CO_2 emissions

In this exercise, we will take a look at CO_2 emissions, CO_2 emissions per unit of GDP, and CO_2 emissions per capita, for high, middle and low-income countries, and for the whole world.

From the WDI database (http://data.worldbank.org/indicator/all), download as an excel document the following indicators for the whole time period available (1960 to today): CO_2 emissions (kt), CO_2 emissions (kg per 2011 PPP $ of GDP), and CO_2 emissions (metric tons per capita).

We are interested in the data for High Income (HIC), Middle Income (MIC), Low Income (LIC), and World (WLD).

1) On the same graph, plot CO_2 emissions against time for high, middle, and low-income countries, and for the whole world.
2) On the same graph, plot CO_2 emissions per capita against time for high, middle, and low-income countries, and for the whole world.
3) On the same graph, plot CO_2 emissions per unit of GDP (2011 PPP $) against time for high, middle, and low-income countries, and for the whole world.
4) Briefly discuss your findings in the context of decoupling.
5) Plot a cross section of CO_2 emissions per capita against GDP per capita for all the countries of the world in 2010. In the World Bank database, use the indicator GDP per capita, PPP (constant 2011 international $). Discuss. Do you see any interesting patterns?

HARD

F. Policy memo

Choose one of the 9 planetary boundaries. In a 3 to 5 page paper, explain how and why the chosen planetary boundary is particularly relevant to the country you live in. Suggest possible policy implications and solutions. Make sure you analyze available data to verify the extent of damages on the planetary boundary in that country. Provide appropriate maps or graphs that you have constructed using data.

DISCUSS AND DEBATE

1) Discuss the role of scientific expertise in the Planetary Boundary framework.

2) What are, in your view, humanity's chances of achieving absolute decoupling in terms of overall environmental footprint? Use two examples to support your discussion.

3) Discuss reasons to or not to believe that economic growth can be reconciled with environmental sustainability?

4) Using the case study below, discuss the role of corporate governance in achieving environmental sustainability.

CASE STUDY

Companies step ahead

There are many examples of successful public-private partnerships to develop information and reporting standards. In the area of greenhouse gas emissions, a joint effort of the World Business Council for Sustainable Development and the World Resources Institute developed the Greenhouse Gas Protocol, which is an accounting tool used by hundreds of private companies around the world to monitor, report on and manage emissions.

One of Central America's largest companies — with revenues of over $570 million in 2010 in Costa Rica — voluntarily set triple bottom line standards to measure its success by not only economic but social and environmental indicators. As water conservation is a priority in that State, the company invested and changed practices to move from 12 litres of water for every litre of beverage in previous years to 4.9 litres in 2011, setting the goal of becoming water neutral by 2012. Incentives are built into the salary of the Chief Executive Officer, as some 60 percent of it is linked to triple bottom line performance. It may have contributed to a triple win: the company achieved growth twice the industry average between 2006 and 2010.

The Carbon Disclosure Project is a platform whereby more than 3,000 organizations in some 60 countries currently measure and disclose their greenhouse gas emissions, water management and climate change strategies, helping them to set reduction targets and make performance improvements, as well as to make information available to concerned stakeholders and consumers.

Report of the Secretary General's Global Sustainability Panel. (2012). Resilient People, Resilient Planet: A Future Worth Choosing. Box 6. http://uscib.org/docs/GSPReportOverview_A4%20size.pdf

FURTHER READING

- **The global environment**

The author gives a general account of the environmental history of the twentieth century and shows how humanity has refashioned the earth's air, water, and soil, and the biosphere to a degree unprecedented in human history.
McNeill, J. R. (2000). Something new under the sun. W. W. Norton.

This UNEP report provides an analysis of the state, trends and outlook of the global environment.
UNEP report: Global Environmental Outlook 5: Summary for Policy Makers (20 pages). (2012). http://www.unep.org/geo/pdfs/GEO5_SPM_English.pdf

This article reviews the historical genesis of the phrase "Anthropocene" and suggesting that two dates (1610 and 1964) appear to conform to the criteria to mark the beginning of the Anthropocene.
Lewis, S. L., & Maslin, M. A. (2015). Defining the anthropocene. *Nature*, *519* (7542), 171-180.

- **Planetary boundaries**

Blockbuster book published by the Club of Rome that argues forcefully that continued economic growth on the prevailing economic patterns would collide with the Earth's finite resources.
Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. W. (1972). The limits to growth. New York, 102.

Seminal article in which scientists offer a visualization of planetary boundaries and argue that humanity is leaving the "safe operating conditions" for the planet.
Rockström, Johan, Will Steffen, Kevin Noone, Asa Persson, F. Stuart Chapin, Eric F. Lambin, Timothy M. Lenton et al. 2009. "A Safe Operating Space for Humanity." *Nature* 461(24): 472–475.

The authors attempt to measure the extent to which humanity lives within the regenerative capacity of the biosphere and indicate that human demand may well have exceeded the biosphere's regenerative capacity since the 1980s.
Wackernagel, M., Schulz, N. B., Deumling, D., Linares, A. C., Jenkins, M., Kapos, V., Randers, J. (2002). Tracking the ecological overshoot of the human economy. PNAS, 99 (14).

This article presents a general equilibrium model of renewable resource and population dynamics related to a predator-prey model, and describes how civilizations might have declined because of population overshooting and endogenous resource degradation.
Brander, J. A. & Taylor, M. S. (1998). The simple economics of easter island: a ricardo-malthus model of renewable resource use. American Economic Review, 88 (1).

- **Sustainability**

This document contains the recommendations and call for action from the UN high-level panel on global sustainability. It reflects on and formulate a new vision for sustainable growth and prosperity, along with mechanisms for achieving it.
Report of the Secretary General's Global Sustainability Panel. Resilient People, Resilient Planet: A Future Worth Choosing, Chapter 2: Progress Towards Sustainable Development pp. 15-27
https://en.unesco.org/system/files/GSP_Report_web_final.pdf

The authors develop and apply a theoretical framework for assessing whether economic growth is compatible with sustaining wellbeing over time.
Arrow, K. J., Dasgupta, P., Goulder, L. H., Mumford, K. J., & Oleson, K. (2012). Sustainability and the measurement of wealth. Environment and Development Economics, 17 (3).

This paper is an outgrowth of discussions among a group of ecologists and economists and attempts to reconcile conflicting intuitions about whether humanity is consuming too much.
Arrow, K., Dasgupta, P., Goulder, L., Daily, G., Ehrlich, P., Heal, G., Walker, B. (2004). Are we consuming too much? Journal of Economic Perspectives, 18 (3).

Nobel laureate Robert Solow grapples with the definition of sustainability and argues that we fail to weight enough the future generations in our present decisions.
Solow, R. M. (1991). Sustainability: an economist's perspective.
Solow, R. (2012). A few comments on 'Sustainability and the measurement of wealth'. Environment and Development Economics, 17(03), 354-355.

- **Economic growth and the Environment**

The authors review the arguments and the evidence on the position, shape and mutability of the environmental Kuznets curve to ultimately side with the optimists—with some reservations.
Dasgupta, S., Laplante, B.,Wang, H., & Wheeler, D. (2002). Confronting the environmental kuznets curve. Journal of Economic Perspectives, 16 (1).

This paper presents a critical history of the environmental Kuznets curve and attempt at disentangling the relations between development and the environment.
Stern, D. (2004). The rise and fall of the environmental kuznets curve. World Development, 32 (8).

The authors examines relationship between per capita income and various environmental indicators to find no evidence that environmental quality deteriorates steadily with economic growth.
Grossman, G., & Krueger, A. (1995). Economic growth and the environment. Quarterly Journal of Economics, 110 (2).

- **The tragedy of the commons**

In a 1968 seminal paper, Hardin lays out the basics of the tragedy of the commons and complement it in a 1998 article.

Hardin, G. (1968). The tragedy of the commons. Science, 162 (3859).

Hardin, G. (1998). Extensions of" The Tragedy of the Commons". Science,280(5364), 682-683.

- **Climate Change**

In this article, paleoclimate data is used to help assess climate sensitivity and potential human-made climate effects.

Hansen, James, and Makiko Sato. 2012. "Paleoclimate Implications for Human-Made Climate Change." In Climate Change: Inferences from Paleoclimate and Regional Aspects, ed. André Berger, Fedor Mesinger, and Djordjie Šijački, 21–48. Heidelberg: Springer.

This article argues that we can state, with a high degree of confidence, that extreme anomalies were a consequence of global warming because their likelihood in the absence of global warming was exceedingly small.

Hansen, James, Makiko Sato, and Reto Ruedy. 2012. "Perception of Climate Change." Proceedings of the National Academy of Sciences 109(37): E2415–E2423.