ENVIRONMENTAL AND NATURAL RESOURCE ECONOMICS: A CONTEMPORARY APPROACH

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ADVANCE CHAPTERS FOR FIFTH EDITION

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CHAPTER 2

Resources, Environment, and Economic Development

CHAPTER 2 FOCUS QUESTIONS

- What is the relationship between economic growth and the environment?
- What are recent economic and environmental trends?
- Will economic growth encounter ecological limits?
- How can economic development become environmentally sustainable?

2.1 OVERVIEW OF ECONOMIC GROWTH

Prior to the Industrial Revolution in the eighteenth and nineteenth centuries, the human population grew slowly and material living standards changed little. While data are limited, historical records suggest that in the 2,000 years prior to the Industrial Revolution the world population grew slowly from about 200 million to 1 billion. Average incomes changed even less during this period, from the equivalent of about $500 per person annually to only about $700.[1] In other words, economic growth was essentially non-existent prior to the Industrial Revolution.

The advent of market economies and rapid technological progress, centered in Western Europe, altered this pattern dramatically. Population in Europe entered a period of rapid growth that led the British classical economist Thomas Malthus to theorize that population would outgrow food supplies, keeping the mass of people perpetually at a subsistence standard of living.

Malthus's *Essay on the Principle of Population, as It Affects the Future Improvement of Society*, published in 1798, initiated a long and continuing debate on the relationship between population growth, technology, and natural resources. History has proved the simple **Malthusian hypothesis** wrong: Although population in Western Europe more than doubled in the 100 years following the publication of Malthus's *Essay*, economic output per person grew at an even greater rate.[2] And on a global scale, population growth up to the present has been accompanied by rising average living standards, despite significant inequality. But if we consider a more sophisticated argument—that a growing human population and economic system can eventually outrun their biophysical support systems — the debate turns out to have strong current relevance.

Malthusian hypothesis the theory proposed by Thomas Malthus in 1798 that population would eventually outgrow available food supplies.

The debate over population and economic growth is intimately intertwined with resource and environmental issues. In the twenty-first century it is unlikely that we will see major shortfalls in food supply on a global scale, although food crises resulting from rising prices have occurred, such as when average global food prices nearly doubled from 2007 to 2008.[3] But it is very likely that the environmental stresses associated with population and economic growth, in particular the impacts of global climate change, will require major policy changes with substantial effects on economic production systems.

Measuring Growth Rates

In approaching complex issues of economic growth and the environment, we first need to define how economic growth has traditionally been measured by economists. **Gross domestic product (GDP)** is defined as the market value of final goods and services produced within a country's borders over a specified time period, usually a year. A country's GDP can grow over time due to changes in two factors: population and per-capita (or per-person) GDP. In other words, we can define the GDP of a country using the simple identity:

$$GDP = (population) \times (per\ capita\ GDP)$$

We can then define this identity in terms of growth rates, to show the relationship among the **GDP growth rate**, the population growth rate, and the per capita GDP growth rate:[4]

$$GDP\ growth\ rate = (population\ growth\ rate) + (per\ capita\ GDP\ growth\ rate)$$

gross domestic product (GDP) the total market value of all final goods and services produced within a national border in a year.
GDP growth rate the annual change in GDP, expressed as a percentage.

We can use this equation to solve for one of these three variables when we know the other two. For example, suppose the population of a country increased by 10 percent during some time period, and that the country's GDP grew by 14 percent during this same period. We can then conclude that GDP per capita grew by 4 percent.

To correct for the effects of inflation, we should use **real GDP** rather than **nominal GDP** in this equation. Real per capita GDP will rise steadily provided that real GDP grows at a consistently higher rate than population. For this to occur, economic productivity must also rise steadily, based on technological improvements and capital investment. This increasing productivity is, of course, the key to escaping the Malthusian trap.

real GDP gross domestic product corrected for inflation using a price index.
nominal GDP gross domestic product measured using current dollars.

One of the reasons the Malthusian hypothesis was refuted in the 19th century is that new technologies were developed that relied on energy from coal. Increased agricultural productivity allowed the portion of the population working in farming to decrease, freeing labor for industrial development. Increased industrial productivity led to higher living standards, measured in traditional economic terms as growth in real GDP per capita. Broadly speaking, technological improvements and increased fossil fuel energy use have led to steady global economic development, although this growth has been unevenly distributed across the world.

Factors Essential to Economic Growth

How is steady growth in productivity and GDP per capita possible? Standard economic theory identifies two sources of increased productivity. First is the accumulation of capital. Recall our discussion of the standard circular flow model from Chapter 1—capital is one of the three standard factors of production, along with labor and land. With investment the stock of capital can increase over time, which tends to increase the productivity of workers. Second, technological progress raises the productivity of capital, labor, and land. Standard economic growth models place no limits on this process. Provided that investment continues at adequate rates and technology keeps improving, productivity and GDP per capita can continue rising indefinitely.

The ecological economics perspective focuses on three other factors as essential to economic growth. The first is energy supply. Europe's economic growth in the eighteenth and nineteenth centuries depended heavily on coal as an energy source, and some writers at the time expressed concern that coal supplies might run out. In the twentieth century, oil displaced coal as the prime energy source for industry and transportation.

Currently oil, natural gas, and coal (i.e., fossil fuels) provide about 80 percent of energy supplies for both developed and developing nations.[5] To a great extent, economic growth in both agriculture and industry has been a process of substituting fossil-fuel energy for human labor. This substitution has important resource and environmental implications, which in turn affect projections of future economic growth.

natural capital the available endowment of land and resources, including air, water, soil, forests, fisheries, minerals, and ecological life-support systems.

The second fundamental factor ecological economists emphasize is supplies of land and natural resources. As mentioned in Chapter 1, economists have traditionally referred to "land" to account for the productive resources of nature. Ecological economists prefer the term **natural capital** to refer more broadly to the natural endowment of land and resources, including air, water, soil, forests, minerals, and ecological life-support systems. All economic activities require some natural capital to provide raw materials, whether it is the wood to make furniture, the land to grow crops, or the fish to make a meal. When economic development is at a low level, natural capital may seem abundant. But as economic activities expand, natural capital may not be sufficient to meet all needs. This may lead to conflicts, such as when housing competes with farming for rural land, or when highways make land less suitable for residential or agricultural use. Eventually, degradation or depletion of natural capital could constrain future economic growth.

Land, of course, is fixed in supply. Except in very limited areas, such as the diked areas of the Netherlands, human technology cannot create more land. Natural resources vary in abundance, and human ingenuity may discover new resources or new uses for existing resources, but both mineral resources and the regenerative capacity of forests and other living resources have physical limits.

The third important factor emphasized by ecological economists is the **absorptive capacity of the environment** to assimilate wastes and pollution. This issue is not so critical when the scale of economic activity is small relative to the environment. But as national and global economic activity accelerates, the flow of waste products increases and may threaten to overwhelm environmental systems. Flows of solid wastes, sewage and liquid wastes, toxic and radioactive wastes, and atmospheric emissions all pose specific environmental problems that require local, regional, and global solutions.

absorptive capacity of the environment the ability of the environment to absorb and render harmless waste products.

2.2 ECONOMIC GROWTH IN RECENT DECADES

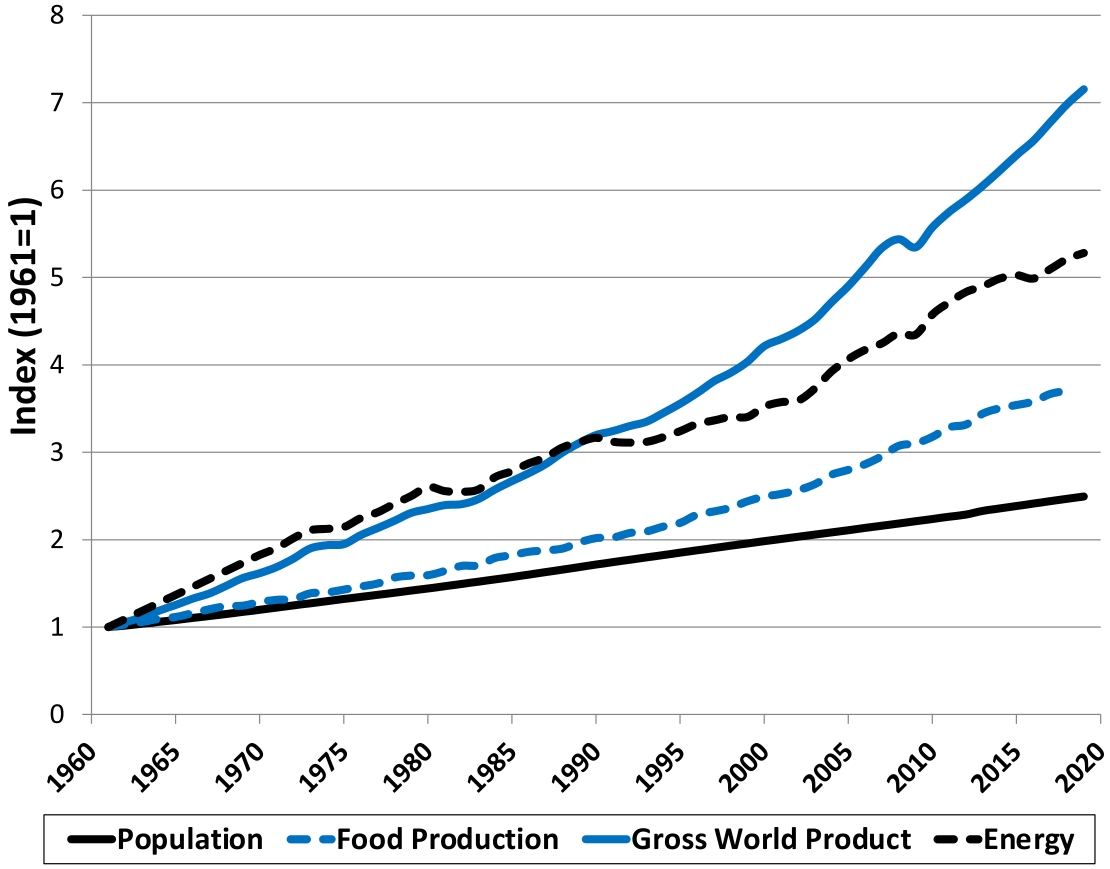
We next consider the history of economic growth, and its relation to issues of natural resources and the environment. Figure 2.1 tracks the history of several key variables since the 1960s. All variables are indexed to 1961, meaning that the value of each variable is scaled to equal 1.0 in 1961, and then the value for future years is expressed relative to the 1961 value. For example, the world population was 3.1 billion in 1961 and had risen to 6.2 billion in 2001. So the indexed population value for 2001 is 2.0, meaning it is twice as large as the 1961 value.

The trends in Figure 2.1 tell a clear story that significant economic progress has been made over the last 60 years. The growth rates for food production, economic production, and energy use have all been greater than the rate of population growth. Thus, relative to 1961 the average person has access to more food, more economic production, and more energy.

Other measures of human well-being over this time period also indicate positive global trends. For example, life expectancy increased from 53 to 72 years over this period. Literacy rates have improved, and access to clean water and adequate sanitation facilities has expanded. Thus it seems that, at least so far, resource constraints have generally not been sufficient to hamper economic progress. Figure 2.1 suggests that, at least up to the present, the Malthusian hypothesis is not valid.

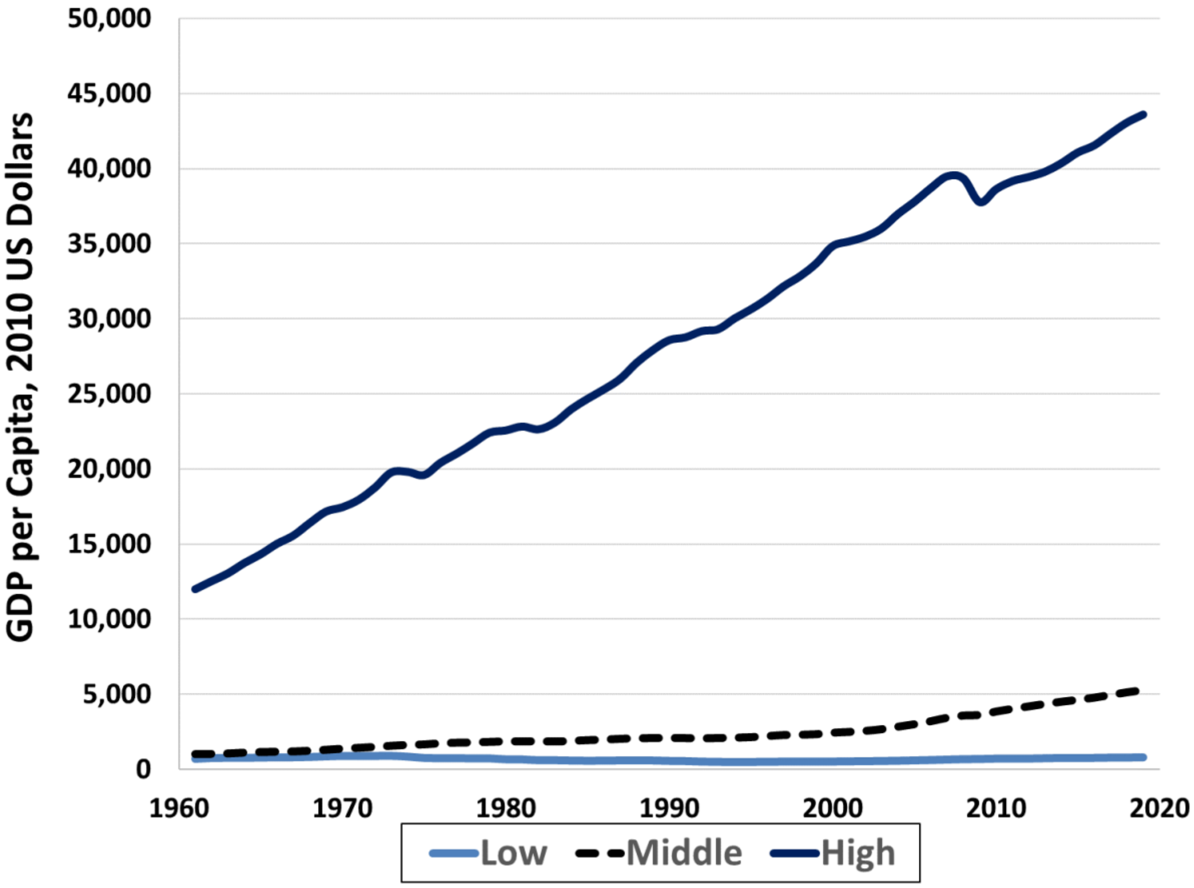
Figure 2.1 presents average results for the entire world. But economic and social conditions can vary tremendously across countries. We don't know from looking at Figure 2.1 if the overall picture of progress applies to both rich and poor countries. In Figure 2.2 we divide countries into three categories based on income levels—high, middle, and low.[6] We see that average income levels in the high-income countries have increased (after an adjustment for inflation) from about \$12,000 to \$44,000 per capita over the last several decades. Income growth measured in percentage terms has been highest in the middle-income countries, mainly due to economic growth in China and India. Averaged over all middle-income countries, incomes grew from about \$1,000 per person to more than \$5,000. But economic progress in low-income countries has been negligible. Average incomes were only about \$800 per person in 2019, essentially unchanged from the 1960s after adjusting for inflation.

Figure 2.1 Growth in Population, Food Production, Economic Production, and Energy Use, 1961–2019



Sources: Population, food production, and gross world product from the World Bank, World Development Indicators database; energy data from the U.S. Energy Information Administration, International Energy Statistics. Most recent food production data from FAO (FAOSTAT) and most recent energy data from BP (BP Statistical Review of World Energy).

Figure 2.2 Economic Growth, 1961–2019, by Country Income Category



Source: World Bank, World Development Indicators database.

The data in Figure 2.2 demonstrate the extent of global economic inequality. But the results also suggest that we may need to consider the relationship between economic development and the environment differently in developed versus developing countries. Economic growth has been substantial in high- and middle-income countries; can such growth continue without depleting important categories of natural capital or over-loading the absorptive capacity of the environment? For low-income countries, is there a relationship between their very low average growth rates and the environment?

resource curse hypothesis the theory that countries or regions with abundant natural resources actually grow more slowly than those where natural resources are scarcer.

Until recently, an abundance of natural resources was generally considered to be a key ingredient in successful economic development. But in the last few decades economists have explored the **"resource curse" hypothesis**—that countries or regions with abundant natural resources actually grow more slowly than those where natural resources are scarcer. Numerous explanations have been proposed for this effect, including the high volatility of natural resource prices, the possibility for corruption, and violence from competition for access to resources.

The resource curse hypothesis was first comprehensively tested in a 1995 paper which concluded that:

> [based on analysis of 97 countries] economies with a high ratio of natural resource exports to GDP [initially] . . . tended to have low growth rates during the subsequent period. This negative relationship holds true even after controlling for variables found to be important for economic growth, such as initial per capita income, trade policy, government efficiency, investment rates, and other variables.[7]

But the resource curse hypothesis is not universally accepted, as subsequent analyses both supported and refuted the hypothesis.[8] A 2016 **meta-analysis** reviewed 43 studies that tested the resource curve hypothesis and determined that 40% of studies found a negative relationship between economic growth and natural resource abundance, 40% found no significant relationship, and 20% found a positive relationship.[9] Thus the authors concluded that "overall support for the resource curse hypothesis is weak" and that other factors such as a nation's institutions and investment levels may be more important for explaining differences in economic growth. We will explore the relationship between economic development and the environment further toward the end of the book.

meta-analysis an analysis method based on a quantitative review of numerous existing research studies to identify the factors that produce differences in results across studies.

2.3 ENVIRONMENTAL TRENDS IN RECENT DECADES

As mentioned in Chapter 1, every few years UNEP publishes *Global Environmental Outlook (GEO)* reports that assess global environmental conditions and document trends. The most recent report when this book was written, GEO-6, published in 2019, finds that:

> … the overall condition of the global environment has continued to deteriorate since the first edition of GEO [in 1997], despite environmental policy efforts across all countries and regions. … Urgent action at an unprecedented scale is necessary to arrest and reverse this situation, thereby protecting human and environmental health and maintaining the current and future integrity of global ecosystems.[10]

In this section we draw upon the GEO reports and other sources to present an overview of environmental trends. As with our overview of economic trends, we will take a global perspective toward environmental trends, but also consider how these trends vary between high- and low-income countries.

The GEO-6 report includes separate chapters on five main categories of environmental impacts:[11]

1. Air
2. Biodiversity
3. Oceans and Coasts
4. Land and Soil
5. Freshwater

The previous GEO report, GEO-5 published in 2012, also included a chapter specifically on chemicals and wastes. As this issue remains highly important, we include it below as a sixth category in assessing environmental trends.

While we present data below on each of these six issues separately, the GEO reports emphasize that the earth is a complex system with interacting components. Further, the underlying drivers of diverse environmental impacts are related. At a simplified level, nearly all of the great acceleration of human impacts can be linked to expansion of both the human population and economic activity. Therefore, a piecemeal approach to solving separate environmental problems is generally not effective. The good news is that well-designed economic policies can address multiple environmental issues. For example, efforts to reduce fossil fuel dependence lower carbon emissions, but also reduce water pollution and habitat degradation from mining. The less-encouraging news is that such comprehensive policies tend to be more difficult to enact from a political perspective than targeted policies. We will spend considerable time throughout this text discussing policy options, including both market-based policies and other alternatives.

Air

Trends in emissions into the atmosphere can be broadly classified into two categories: those related to greenhouse gases (i.e., those that contribute to climate change) and those related to other air pollutants. GEO-6 concludes that:

> Historical and ongoing greenhouse gas emissions have committed the world to an extended period of climate change … Time is running out to prevent irreversible and dangerous impacts of climate change. Unless greenhouse gas emissions are radically reduced, the world is on course to exceed the temperature threshold set out in the Paris Agreement …[12]

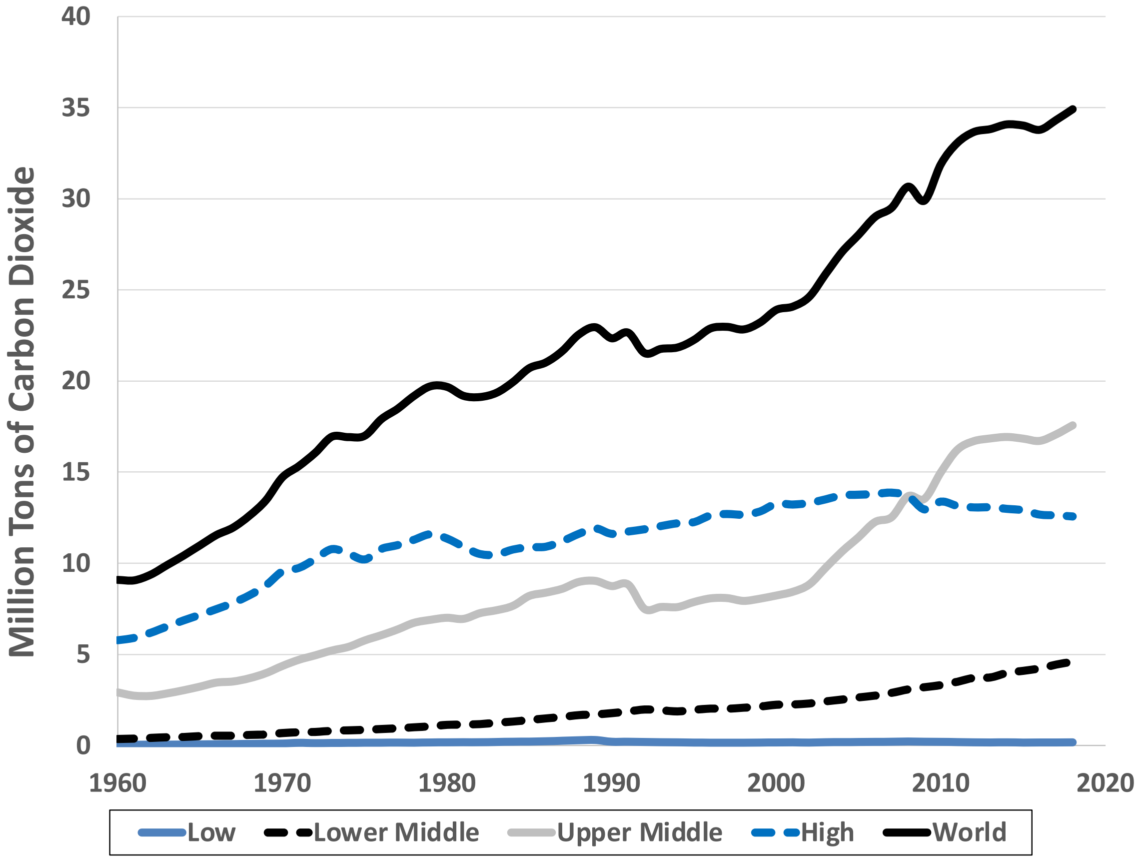
The primary greenhouse gas is carbon dioxide (CO_2). Figure 2.3 shows the global emissions of CO_2 since the 1960s, with emissions steadily rising through 2018.[13] But looking at the data in Figure 2.3 by income group tells a more informative story. First, we can see that the carbon emissions of the world's poorest countries are negligible. Second, until recently the majority of global emissions were attributed to the high-income countries. Prior to 2000 more than half of global emissions were from high-income countries. Since then, emissions from high-income countries have actually decreased, by over 5%. Third, we see the rapid increase in emissions from middle-income countries, particularly upper middle-income countries. Emissions in the upper middle-income countries, primarily China, more than doubled between 2000 and 2018.

As a result of these trends, CO_2 emissions from high-income countries now comprise only about one-third of the global total. Further, most of the projected future growth in emissions will occur in the developing world. Clearly, as we'll discuss in more detail in Chapters 12 and 13, an effective response to climate change will require a coordinated international response.

The trends for other air pollutants offer a mix of policy successes and ongoing challenges. Data on major outdoor air pollutants, including sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOC), find that global emissions increased significantly from 1940 to 1980. But from 1980 to 2010 emissions of SO_2 declined by about 20 percent, and the growth in NO_x and VOC emissions slowed.[14] Once again, the trends differ in developing and developed countries. In North America and Europe, outdoor air quality has improved over the last few decades, with further improvements projected for the future. But in both East Asia (which includes China) and South Asia (which includes India) air quality has deteriorated, especially in metropolitan areas.

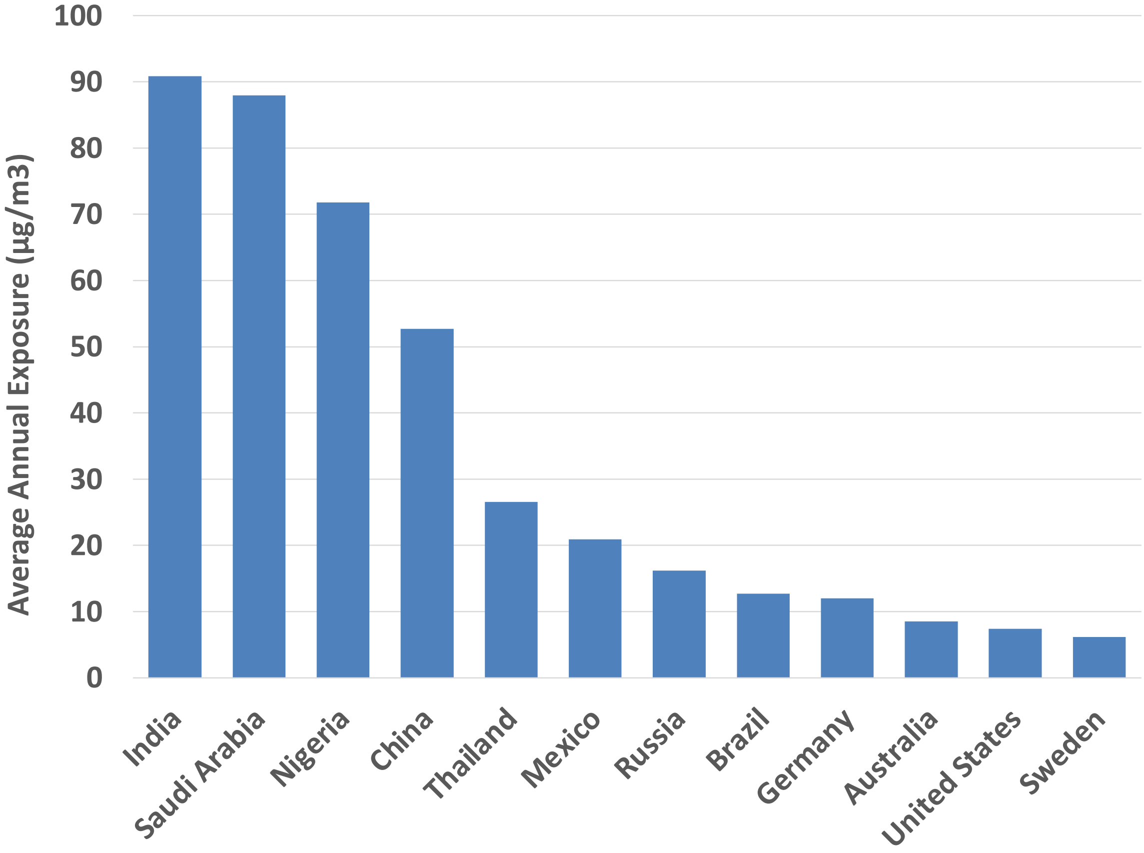
We see the differences in air quality between developed and developing countries illustrated in Figure 2.4. The World Health Organization (WHO) recommends that annual average exposure to particulate matter (PM) should be less than 10 $\mu g/m^3$ (micrograms per cubic meter of air). Particulate matter is small particles suspended in the air, such as soot, dust, and smoke, that cause negative health impacts. Figure 2.4 shows that PM concentrations meet the WHO recommendation in countries such as Australia, Sweden, and the United States. But in developing countries PM concentrations are many times higher than the WHO guideline. The WHO estimates that more than 4 million people die prematurely each year due to outdoor air pollution, with 91% of these deaths in low- and middle-income countries.[15]

Figure 2.3 Global Carbon Dioxide Emissions, 1960–2018, by Country Income Category



Sources: World Bank, World Development Indicators database (for data up to 2016); global and national data for 2017 and 2018 from the International Energy Agency, with author's estimated allocations into country income groups.

Figure 2.4 Average Exposure to Particulate Matter Air Pollution, Selected Countries, 2017



Source: World Bank, World Development Indicators database.

Indoor air pollution causes about as many deaths globally as outdoor air pollution. According to the World Health Organization nearly 4 million people per year die from indoor air pollution, with mortality rates the highest in Africa and Southeast Asia.[16] The GEO-6 report notes that women and children have higher exposure to indoor air pollutants, which are commonly emitted when biomass sources such as wood and dung are used for cooking and heating without adequate ventilation.

Two success stories stand out in reviewing the trends on air pollution. First, lead pollution has been dramatically reduced in developed nations. Lead inhalation can impede the neurological development of children and cause cardiovascular impacts, such as high blood pressure and heart disease, in adults. Mainly as a result of banning lead in gasoline, lead pollution in the United States declined by 98 percent from 1980 to 2019.[17] For another major atmospheric success story, reduction of ozone-depleting emissions, see Box 2.1 and Figure 2.5.

Box 2.1 Healing the Ozone Layer

The earth's ozone layer, located in the stratosphere about 20 to 30 kilometers above the earth, provides protection from most of the sun's ultraviolet (UV) radiation. By blocking 97–99 percent of incoming UV radiation, the ozone layer effectively reduces the damaging effects of UV rays, such as immune system suppression and skin cancer.

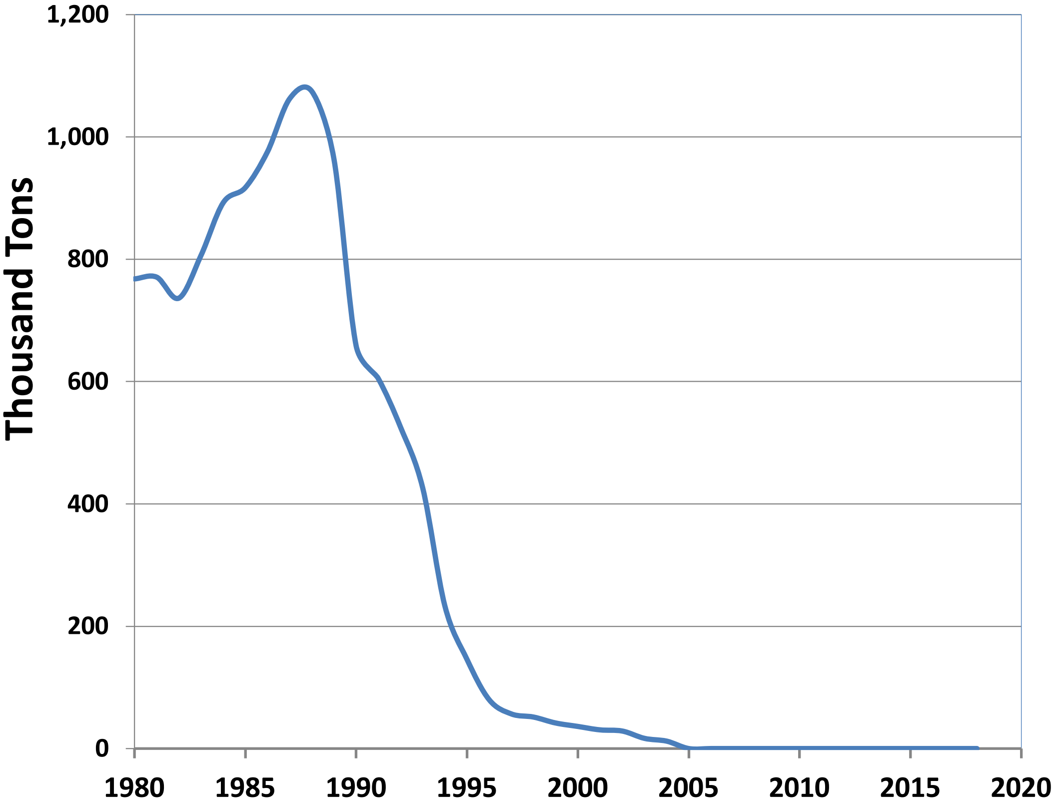
Starting in the 1970s, scientists began to assert that the emissions of various chemicals into the atmosphere could deplete the ozone layer, mainly chlorofluorocarbons (CFCs) which were used as refrigerants, in aerosol sprays, and as cleaning agents. Initially, the chemical companies producing CFCs refuted the scientific claims, arguing that their chemicals were safe. But in the mid-1980s scientists discovered an "ozone hole" over Antarctica, where concentrations of ozone had fallen far more than anticipated. This helped galvanize the call for regulation of CFCs and other ozone-depleting substances (ODSs).

In 1987 the Montreal Protocol treaty was drafted to schedule an international phase-out of CFCs and other ODSs. The Protocol eventually became the first United Nations treaty to be ratified by all member nations. Subsequent revisions to the Protocol actually increased the pace of the phase-out, particularly in developed nations. Often working in cooperation with environmental groups such as Greenpeace, chemical companies have developed alternatives to CFCs that are not harmful to the ozone layer.

As shown in Figure 2.5, global production of CFCs declined dramatically after ratification of the Montreal Protocol. By 2005, production of new CFCs had virtually ceased. Since ODSs are long-lived in the atmosphere, with some persisting for 100 years or more, the ozone layer initially continued to deteriorate despite the Montreal Protocol. A 2014 assessment by the World Meteorological Organization and the United Nations concluded that the ozone layer was relatively stable since about 2000. The study estimated that the ozone layer should fully recover before 2050 in most parts of the world, and then somewhat later for the Antarctic ozone hole.[18] Based on these results, former Secretary-General of the United Nations Kofi Annan called the Montreal Protocol "perhaps the single most successful international agreement to date."[19]

Recent progress has been partially set back, according to a 2018 study in the journal *Nature* that reported an unexpected increase in global emissions of CFC-11 since 2013.[20] A 2019 paper traced the primary source of the increased emissions to eastern China.[21] The United Nations is working to address the emissions, noting that "any illegal consumption and production of CFC-11 demands decisive action."[22]

Figure 2.5 Global Production of Chlorofluorocarbons, 1980–2018



Sources: Alternative Fluorocarbons Environmental Acceptability Study, www.afeas.org/index.html; Domonoske, 2018.

Biodiversity

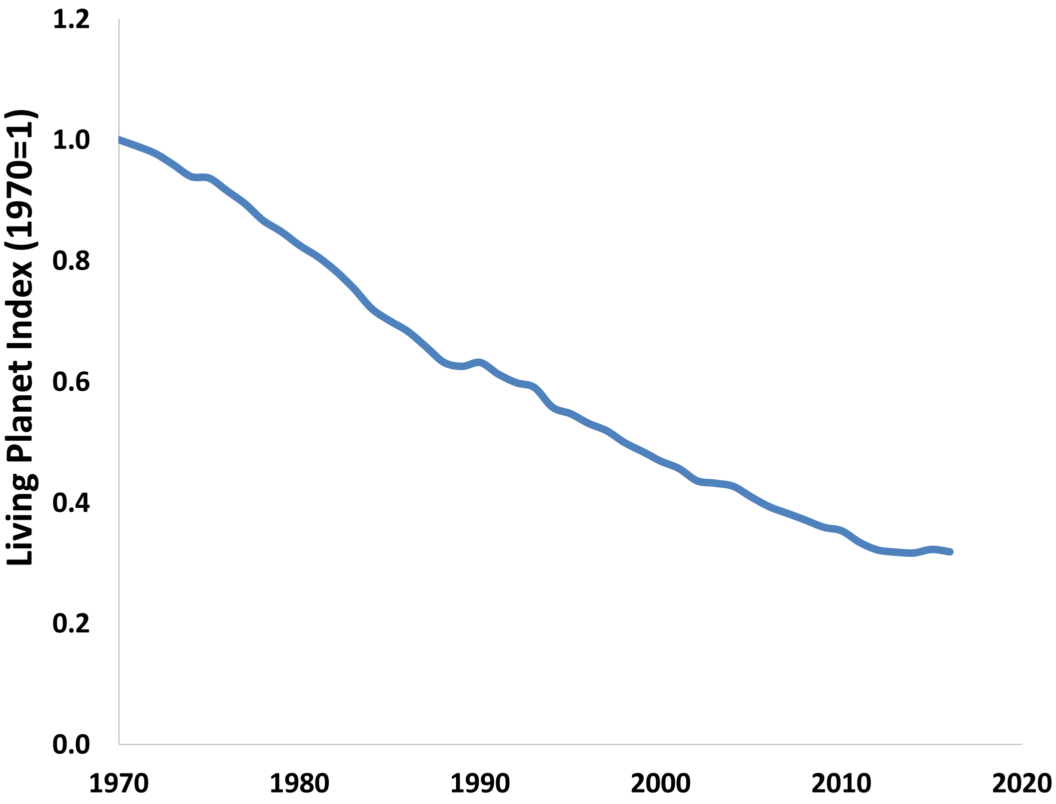
Biodiversity refers to the variety of different species in an ecological community. While some species naturally go extinct over time as ecosystems change, ecologists estimate that the current global extinction rate is 1,000 higher than the natural background rate, and comparable with previous mass extinctions, such as the one that killed off the dinosaurs 65 million years ago.[23] GEO-5 noted that:

> The state of global biodiversity is continuing to decline, with substantial and ongoing losses of populations, species and habitats. For instance, vertebrate populations have declined on average by 30 per cent since 1970, and up to two-thirds of species in some taxa are now threatened with extinction. Declines are most rapid in the tropics, in freshwater habitats and for marine species utilized by humans.[24]

biodiversity the variety of different species in an ecological community.

The declining overall state of global biodiversity is shown in Figure 2.6, which presents the Living Planet Index, an aggregate indicator produced by the environmental organization World Wildlife Fund (WWF), from 1970 to 2016. The Living Planet Index is based on the populations of over 4,000 vertebrate species, including mammals, birds, reptiles, and fish. The data indicate that the planet's biodiversity has declined by 68% since 1970, with the largest losses in South America and Africa.

Figure 2.6 Living Planet Index, 1970-2016



Source: Zoological Society of London and WWF, http://stats.livingplanetindex.org/.

GEO-6 reported progress in reducing biodiversity losses in some areas, but also that human pressure on ecosystems continues to increase. The most significant threats to biodiversity include agriculture/aquaculture, logging, and urban development. In the future these threats are likely to be overtaken by the impacts of climate change. According to one analysis in the prestigious scientific journal *Nature*, under a mid-range climate scenario 15–37 percent of species would be "committed to extinction" by 2050.[25] A 2015 paper finds that the percentage of species that will become extinct due to climate change would be 5 percent if average temperature increase is no more than 2°C,, but 16 percent under a business-as-usual scenario.[26]

GEO-6 calls for increased investment in global conservation efforts. The report finds that an adequate global response to biodiversity loss must also include reducing extreme poverty, gender inequality, and corruption.

Oceans and Coasts

Oceans cover over 70% of the earth's surface, and about two billion people live in coastal areas. GEO-6 reports that human pressure on ocean health continues to increase as the population increases and people exploit more ocean resources. The GEO-6 chapter on oceans focuses on three major issues:

1. tropical coral reefs
2. ocean fishing
3. marine debris.

Coral reefs are diverse ecosystems, containing about 30% of all marine biodiversity. The relationship between climate change and the health of tropical coral reefs is well documented. Coral reefs are adversely affected by both warmer water temperatures and the acidity that results from an increased concentration of carbon in the oceans. Scientists estimate that at least 70% of the world's coral reefs have already been impacted by climate change, with impacts accelerating since 2015 when record ocean warm was recorded.

There is a time lag of about 30 years between the time carbon emissions occur and the resulting impacts on coral reefs. Thus the negative impacts that we're currently observing are linked to carbon emissions from the 1990s. Of course, global carbon emissions have increased since then, meaning that significant future negative impacts on coral reefs are largely unavoidable. Many reefs are unlikely to survive the 21st century. A 2012 analysis found that preserving more than 10 percent of the world's coral reefs would require limiting global warming to no more than 1.5°C above pre-industrial levels.[27] But as we'll discuss in Chapter 13, current commitments by nations to address climate change suggest an eventual warming of nearly double this amount.[28]

Fish products are an important source of protein and other nutrients for about half of the world's population. The health of most of the world's fisheries is declining. As we'll see in Chapter 18, an increasing share of the world's fisheries are being over-harvested. Chapter 4 will introduce the economic theory of common property resources, which helps us understand why fisheries are commonly over-exploited. But we will also review the economic policies that can be used to promote more sustainable fishery management. GEO-6 reports that many countries have instituted successful fishery policies, noting that in countries "where capacity and political will exist to assess stock status and fishing mortality, and implement monitoring, control and surveillance measures, trends from 1990 to the present indicate that overfishing is usually avoided."[29]

Finally, the build-up of marine litter is an area of increasing concern. About three-quarters of marine litter is plastics, often less than 5 mm in size, which can cause negative health effects when ingested by marine species. Many plastics also release toxic chemicals as they break-down over time.

As a result of ocean currents, plastic litter concentrates in several ocean regions. Perhaps the most well-known example of this is the Great Pacific Garbage Patch, an area three times the size of France located between California and Hawaii. According to a 2018 article, this area contains about 2 trillion pieces of plastic, with the amount increasing at exponential rates.[30] While recycling can reduce the amount of plastic waste entering the world's oceans, the longevity of plastic litter suggests that reducing the production of plastic is more important. This can be done by shifting to sustainable materials and simply using less material in production processes and packaging.

Land and Soil

In summarizing recent human impacts on land resources, GEO-5 took a perspective that aligns with our expanded circular flow model from Chapter 1. The report noted that:

> many terrestrial ecosystems are being seriously degraded because land-use decisions often fail to recognize noneconomic ecosystem functions and biophysical limits to productivity. For example, deforestation and forest degradation alone are likely to cost the global economy more than the losses of the 2008 financial crisis. The current economic system, built on the idea of perpetual growth, sits uneasily within an ecological system that is bound by biophysical limits.[31]

According to a 2002 analysis, the impacts of humans are evident on 83 percent of the world's total land area, and 98 percent of the land area where it is possible to grow major crops.[32] The two largest categories of human land impacts are agriculture and forestry.

Nearly 5 billion hectares of land (about 40 percent of the world's total land area) are devoted to growing crops or providing pastureland for animals. Total global agricultural area has remained relatively constant since the 1960s, but crop production has increased by a factor of 3.7.[33] In other words, the same amount of agricultural land produces, on average, nearly four times the harvest as it did 50 years ago. The increase in crop production has been greatest in middle-income countries, where yields have grown by a factor of 5.3. Agricultural gains have also been substantial in low-income countries.

As we saw in Chapter 1, the human population is projected to grow to nearly 10 billion by 2050. Can agricultural yields be expanded even further? A 2010 analysis concludes that there is considerable potential to increase yields.[34] The current production efficiency of wheat is estimated to be only 64 percent of its global potential. The efficiency of corn production is even lower—only 50 percent of its potential. But efforts to boost agricultural productivity through increased use of fertilizers, pesticides, and irrigation water, can have negative environmental consequences. As GEO-6 notes:

> Current land management cannot [meet food demand in 2050] while preserving ecosystem services, [preventing] the loss of natural capital, combating climate change, addressing energy and water security, and promoting gender and social equality. … [M]onocultural farming systems, sometimes assumed to be more productive and profitable, are often associated with environmental degradation and biodiversity loss.[35]

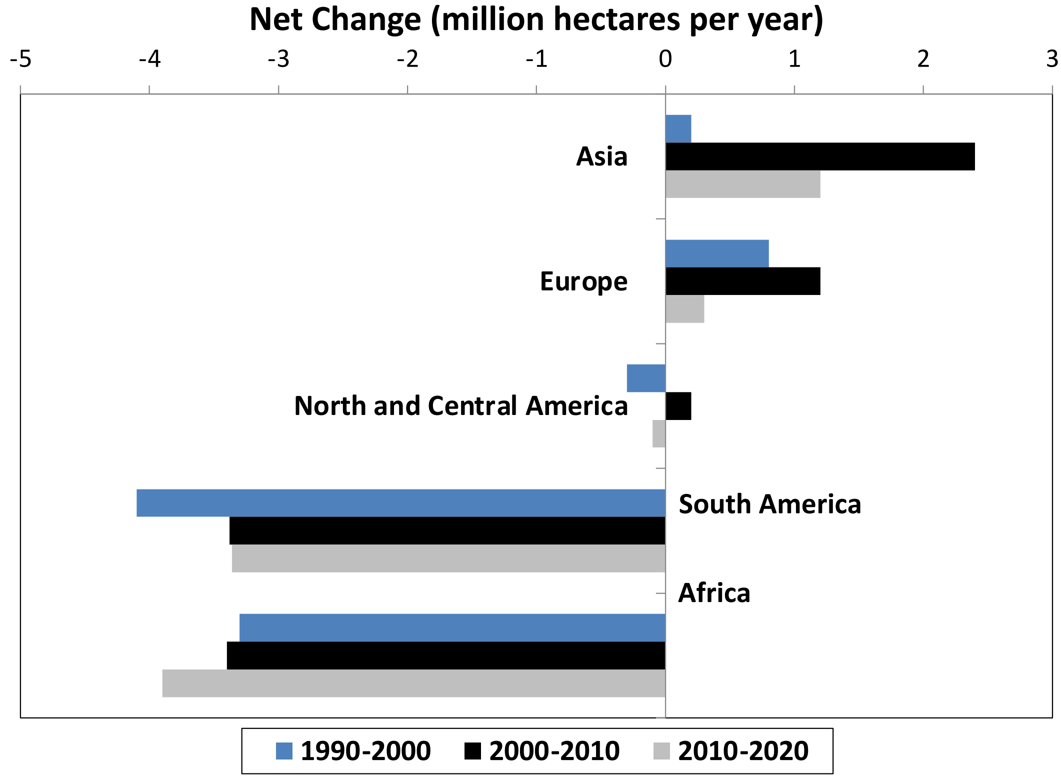
It is possible that agroecological techniques may hold the key to both increasing productivity and regenerating farming ecosystems; we will discuss these issues in detail in Chapter 16.

Compared to previous GEO reports, GEO-6 places a particular emphasis on sustainable soils management. Soil contamination occurs in developed and developing countries from industrial sites, agriculture, and waste disposal. Particularly in the Middle East and North Africa soil contamination from oil production and mining is increasing. A second soils issue discussed in the report is soil salinization – an accumulation of salt that reduces agricultural productivity. Declining productivity from salinization is evident on an estimated one-third of irrigated agricultural lands worldwide, with yield losses approaching 50% for some grain crops.

Sustainable soils management is also an important tool to mitigate climate change. The amount of carbon that is stored in soils can be increased with agricultural policies such as limiting soil tillage, letting crop residues decompose rather than burning them, and planting crops with extensive root systems that store carbon. Finally, an estimated half of the world's soils have been lost in the last 150 years due to erosion.[36] Soil erosion not only reduces agricultural productivity, it also increases flooding damages and leads to sedimentation in rivers that harms aquatic species. Many of the same agricultural practices that increase soil carbon sequestration also reduce erosion.

Environmental issues associated with forested land are also crucial. Forests cover 31 percent of the world's land area. The rate of global deforestation has slowed since the 1990s, with annual net forest loss declining from 8 million to 5 million hectares. But as Figure 2.7 shows, forest trends vary dramatically in different parts of the world. The figure shows the annual net change in total forest area in different regions over three time periods: 1990–2000, 2000–2010, and 2010–2020. In Europe and Asia forest area increased during all three time periods. The large increase in forest area in Asia during the 2000s was primarily due to a massive forest planting effort in China.[37] Significant deforestation is occurring in South America (including the Amazon Forest in Brazil) and Africa. While net deforestation is slowing in South America, it is increasing in Africa. We will discuss forestry issues in more detail in Chapter 19.

Figure 2.7 Net Change in Forest Area, by World Region and Time Period



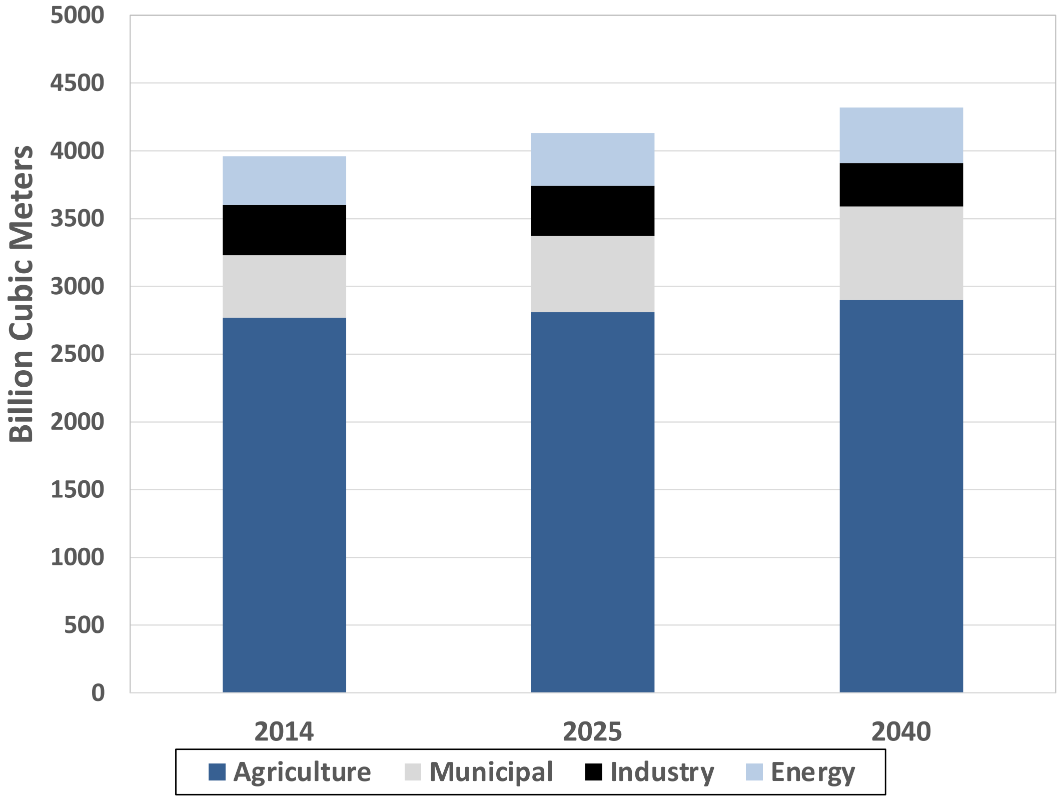
Source: FAO, 2020.

Freshwater

While water is a resource that is renewed through natural processes, only a limited amount is available for human use at one time. Freshwater availability can decline over time, such as when glaciers are lost due to global warming. Pollution can make a water source unusable for a particular activity, such as drinking or fishing. The availability of water varies significantly across the world—while water is abundant in some areas, it is quite scarce in others. The number of people living in water-scarce areas is expected to increase from nearly 2 billion in the mid-2010s to potentially more than 3 billion in 2050.[38]

Global water use increased by a factor of 6 in the last 100 years.[39] Water demand is projected to continue increasing the future, as shown in Figure 2.8. We also see that most of the world's water use, about 70%, is for agricultural purposes including irrigating crops and raising livestock.

Figure 2.8 World Water Withdrawals, Actual and Projected, by Sector



Source: IEA and OECD, 2016.

Many countries are becoming increasingly dependent upon groundwater, which is essentially a nonrenewable resource. For example, India has increased its groundwater withdrawals by a factor of 10 since 1960, and China has also significantly expanded its use of groundwater.[40] Some countries in the Middle East, including Qatar, Saudi Arabia, and the United Arab Emirates, obtain 95 percent or more of their total water supply from groundwater.[41] In most places of the world, extraction of groundwater is essentially unregulated, meaning that farmers and other users are able to pump all they want.In summarizing freshwater issues, GEO-6 finds that:

> The per capita availability of freshwater in the global water cycle is decreasing with population growth, coupled with the associated agricultural, industrial and energy requirements, while the continents are becoming drier in many places due to climate change impacts. Increasing numbers of people are at risk of 'slow-onset disasters' such as water scarcity, droughts and famine. Such events sometimes lead to increased migration and social conflicts. … Freshwater ecosystems are disappearing rapidly,

representing a high rate of loss of biodiversity and ecosystem services.[42] The key to addressing the world's freshwater challenges is to increase the efficiency of water use, particularly in agriculture. Economists often find that water is under-priced, or not priced at all, which encourages inefficient use. As we will see in more detail in Chapter 20, water pricing can be an effective tool to motivate conservation.

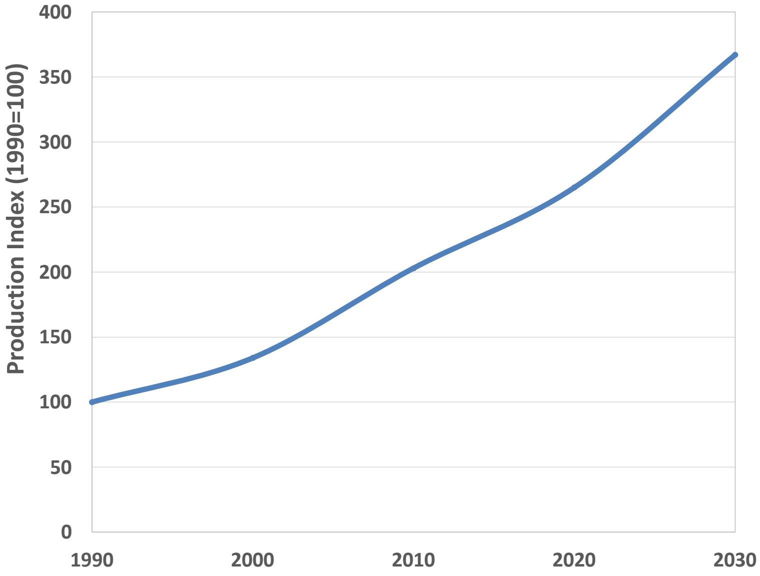
Chemicals and Waste

Of the six impacts we are summarizing in this chapter, the impacts of chemicals and waste on the environment are perhaps the least understood. According to GEO-5:

> There is an extensive but incomplete body of scientific knowledge on the impacts of chemicals and wastes on humans and the environment, with particular information and data gaps on the uses, emissions, exposure pathways and effects of chemicals. Global understanding of the complexity of properties and environmental impact of chemicals and wastes is therefore markedly deficient.[43]

The global chemicals industry has expanded significantly in recent decades, with annual production growing from less than $200 billion in 1970 to more than $5 trillion by 2016.[44] As seen in Figure 2.9, global production of basic chemicals increased by a factor of 2.5 between 1990 and 2019, and is projected to grow a further 40% by 2030. Prior to 2000, chemicals production took place primarily in developed nations. But since then production has shifted to developing countries, with China now being the world's largest producer. Some data suggest that chemicals use is slightly declining in developed countries, although trends vary across countries.[45]

Figure 2.9 Growth of Global Chemicals Production, 1990–2019, with projection to 2030



Source: UN Environment, 2019c.
Note: Chart based on global production of basic petrochemical building blocks, including ethylene, propylene, butadiene, benzene, toluene and xylenes.

Approximately 250,000 chemicals are commercially available, but little data are available on the environmental impacts of the vast majority of chemicals. We do know that chemicals are widely distributed throughout ecosystems—for example, more than 90 percent of water and fish samples worldwide show evidence of pesticides. Estimates of human health impacts from chemicals exposure are incomplete, particularly in developing countries. Those living in poverty are often subjected to more exposure to chemicals; children are particularly vulnerable.

The generation of waste is also increasing significantly. According to the World Bank, the amount of municipal waste generated per-person doubled worldwide from 2002 to 2012, with further increases projected for the future.[46] Waste generation is generally higher in richer countries. But once again, projections suggest that most of the increase in waste in the future will be a result of economic development in low- and middle-income countries. About half of all waste generated worldwide is disposed of in landfills. Close to 20 percent of waste is recycled, and 15 percent is incinerated to produce energy. The disposal of waste is a major public health concern in many low- and middle-income countries where wastes are discarded in open dumps near slums. People who then pick through these dumps for valuable items are often exposed to medical and hazardous wastes. A growing concern in recent years is exposure to electronic waste—see Box 2.2 for more on this issue. We discuss waste and recycling further in Chapter 17.

Box 2.2 E-waste

The global generation of electronic waste (e-waste), including computers, cell phones, small and large appliances, and televisions, is increasing exponentially, especially in developing countries. For example, the number of cell phones sold worldwide increased from about 120 million in 2007 to over 1.5 billion in 2020.[47]

The disposal of e-waste is of particular concern because these products contain small amounts of commercially valuable metals, including silver, palladium, and gold, along with dangerous substances such as lead and dioxin. Thus, when scavengers access e-waste they may expose themselves to toxins in the process of extracting the salable components. Also, toxic chemicals can leach into water supplies or be released into the air. The health effects of e-waste disproportionally affect children in developing countries because they frequently perform the work of picking through e-waste and because toxins such as lead are more damaging during children's developmental years.

According to the United Nations, of the 54 million tons of e-waste generated globally in 2019, only 17% was properly collected and recycled. The amount of e-waste generated annually is expected to increase by 40% by 2030, or an average of about 20 pounds per person.[48] The majority of e-waste is generated in developed nations, but much of this waste is exported—often illegally—to developing countries. One of the world's largest e-waste dump sites is the Agbogbloshie site in Ghana. It is estimated that 40,000 people in the area are being exposed to toxic chemicals. Soil samples in the area contained lead levels over 18,000 parts per million (ppm) while the allowable level of lead in soil in the United States is only 400 ppm.[49]

Efforts are underway to ensure that e-waste is properly recycled or safely disposed of. As of 2019, 78 countries had enacted legislation governing e-waste, up from 44 countries in 2014.[50] In 2014 the European Union instituted a new directive on waste for electrical and electronic equipment. The goal of this legislation is to increase the portion of e-waste that is properly treated. Shops selling electronic products are required to accept smaller e-waste items, while manufacturers are required to accept larger items for recycling. Other provisions encourage the reuse of products and design improvements that avoid the use of toxic chemicals.[51]

2.4 OPTIMISTS AND PESSIMISTS

What can we conclude from our brief overview of economic and environmental trends? Do these trends provide a reason to be optimistic or pessimistic about the future?

There are no simple, clear-cut answers to these questions. One may reach an optimistic conclusion based upon the evidence of continued, although unequal, economic and human development, with increasing per capita food consumption and living standards refuting the simple Malthusian hypothesis. But on the other hand, negative environmental impacts have generally increased, including global impacts such as climate change, species loss, and ocean pollution, as well as local and regional impacts such as deforestation, depletion and pollution of water supplies, and build-up of toxic wastes. And looking ahead, climate change presents humanity with perhaps its greatest, and most complex, environmental challenge.

Debate is ongoing concerning the resource and environmental factors that contribute to, and could eventually limit, economic growth. In 1972 a Massachusetts Institute of Technology research team published a study titled *The Limits to Growth*, which used computer modeling to estimate future global trends for five key variables: pollution, industrial output, population, food, and resources. The model's basic conclusion was that continuing along a business-as-usual path, without major policy or behavioral changes, would deplete available resources, leading to a significant decline in industrial output and food supplies, starting around 2020, followed by a declining population.

The authors revised their model in 2004, reaching the same conclusion of eventual global collapse under a business-as-usual scenario but pushing back the onset by a decade or two. Their model predicts that by the middle of the twenty-first century the world will witness a reduction in food production, industrial output, and population, with further declines later in the century. The authors emphasized that collapse is avoidable if modest limits are put on material production and society invests heavily in sustainable technologies. A 2012 book by one of the original authors of *The Limits to Growth*, Jorgan Randers, looks ahead 40 years to 2052,projecting that resources such as food and energy will generally be sufficient, but that global GDP growth will slow and the effects of climate change will become more severe in the latter half of the 21st century.[52]

The results of *The Limits to Growth* models have been criticized as overly pessimistic, akin to the original Malthusian hypothesis which under-estimated the potential of technological improvements.[53] Critics also contend that while nonrenewable resources are being depleted in an absolute sense, new discoveries and more efficient use of resources mean that resource depletion is insufficient to cause a Malthusian crash in the foreseeable future. Supporters of the limits-to-growth model emphasize that the actual data have generally tracked the projections of the business-as-usual model.[54] They also note that the critical point is not whether new resources can be discovered but whether resources can be extracted and consumed at a rate sufficient to meet growing demands without unacceptable environmental damage. Probably the most far-reaching environmental impact of increased consumption is climate change, together with the other issues of biodiversity loss, water shortages, forest loss, soil depletion, and chemical pollution that we have reviewed.

In this text we do not offer a definitive opinion on future trends, but later chapters will provide extensive information to develop informed opinions about the future. The focus of this book is on assessing policy options, rather than promoting a particular viewpoint. While analysts differ greatly regarding appropriate policy responses, few dispute the importance of global environmental and resource issues. As we will see, both a market-oriented approach stressing economic system adaptability and an ecological approach stressing biophysical systems and constraints have important roles to play in devising policy responses.

2.5 SUSTAINABLE DEVELOPMENT

Rather than approaching environmental questions as a secondary issue after we have dealt with the basic economic issues of production, employment, and output growth, both environmental and ecological economists recognize that economic production is ultimately linked to the quality of the environment and the availability of natural resources. This becomes only more evident as the scale of economic production increases. While environmental and ecological economists may define sustainable development differently, both assert that policy changes are necessary in order to achieve truly sustainable outcomes. We now turn to a more detailed discussion of sustainable development, and what its policy implications are for various environmental issues.

Recall that the standard view of economic growth is defined in terms of per capita GDP, meaning that total GDP must grow faster than population. Sustainable development, for both environmental and ecological economists, is about more than simply keeping GDP, or GDP growth rates, above a particular level. Thus, we need new measures of human and ecological well-being in order to determine whether outcomes are sustainable. Environmental economists emphasize the maintenance of human well-being—something that is dependent on more than GDP, such as the quality of the environment, the availability of leisure time, and the fairness of political systems. Ecological economists emphasize the maintenance of the ecological base of the economy—fertile soils, natural ecosystems, forests, fisheries, and water systems—factors that are generally excluded from GDP. As we will see in Chapter 10, various metrics have been developed that either adjust GDP or provide an alternative. These new measures can help in assessing progress toward sustainability.

Incorporating sustainability into both traditional environmental economics and ecological economics suggests significant policy changes in many areas, including the following:

- Current agricultural practices generally seek to maximize short-term food production by relying heavily on chemical inputs. A focus on sustainability will require consideration of the impact of industrialized agriculture on soil health, ecosystems, water quality, and climate change.
- Fisheries have been mostly unregulated in the past, often leading to severe exploitation. A focus on sustainability would ensure that harvest levels are set to maintain the health of fisheries. The impact of fishing on the health of non-target species also needs to be considered.
- Forests have been similarly historically managed to maximize short-term profits at the expense of forest and ecosystem health. Sustainable forest management would not only set harvest levels that are sustainable for the long term, but also maintain or improve biodiversity and water quality. Sustainable forest management can also be a powerful tool against climate change as trees are a significant carbon sink.
- Current energy policies often seek to obtain energy at the lowest overall cost. Sustainable energy policies consider costs more broadly, incorporating the current and long-term environmental impacts such as air pollution, land degradation from mining, and climate change. While the world currently receives most of its energy from fossil fuels, sustainable energy policies require a transition towards renewables and energy conservation.
- Current production processes often involve the introduction of artificial chemicals and plastics into the environment. Sustainable production implies the use of recyclable or biodegradable materials, with drastic limitation on the emission of wastes and pollutants to the environment.

2.6 A LOOK AHEAD

We will cover these issues, and many others, in more detail in Chapters 11-20. We will discuss further reasons for both optimism and pessimism. But regardless of whether you lean more toward the optimistic or pessimistic viewpoint, we hope you will see that economic analysis can be a powerful tool in progressing toward a more sustainable world. We will discover numerous examples where economists (both traditional and ecological) recommend policy reforms that consider human well-being, future generations and ecosystem health.

SUMMARY

Economic growth over time reflects both population and per capita GDP growth. This growth depends on increases in capital stock and technological progress, as well as increased supplies of energy, natural resources, and the capacity of the environment to absorb waste. While predictions by the British classical economist Thomas Malthus that population would outgrow food supplies have not proved accurate, population and economic growth have imposed increasing strains on the environment.

Since 1960, unprecedented rates of growth have more than doubled population, more than tripled world agricultural production, increased energy use five-fold and economic production by a factor of seven. A review of global environmental trends in six areas—air, biodiversity, oceans, land and soils, freshwater, and chemicals and waste—reveals a mix of successes and ongoing challenges. For example, the ozone layer is healing due to the phaseout of CFCs and other chemicals. However, current global climate commitments are insufficient to limit warming to below 2 degrees Celsius.

While the Limits to Growth models have predicted that unrestrained growth would lead to ecological and economic collapse, so far technological progress and some policy responses have prevented the worst predictions from occurring. While natural resources are unlikely to run out, issues of unequal distribution and ecological impacts such as biodiversity loss and climate change are central in modern debates about the Malthusian hypothesis.

The concept of sustainable development attempts to combine economic and environmental goals. Sustainable techniques and policies for agricultural production, forest and fishery management, energy use, and industrial production have significant potential but have yet to be widely adopted. The question of the sustainability of economic activity has already become a major issue and will be even more important in coming decades.

KEY TERMS AND CONCEPTS

absorptive capacity of the environment
biodiversity
GDP growth rate
gross domestic product (GDP)
Malthusian hypothesis
meta-analysis
natural capital
nominal GDP
real GDP
resource curse hypothesis

DISCUSSION QUESTIONS

1. Can we safely say that history has refuted the Malthusian hypothesis? What main factors have worked against Malthus's perspective? Do you identify similarities between the original Malthusian hypothesis and current environmental issues?
2. What are the major environmental issues that are of overriding concern in the twenty-first century? Considering air, water, land, biodiversity, and pollution issues, which do you think pose the greatest threat to human prosperity and ecological systems?
3. How do you think we need to approach environmental issues differently in developed and developing countries? What do you see as the main environmental challenges in each?

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1. **www.iisd.org**. The homepage for the International Institute for Sustainable Development, an organization that conducts policy research toward the goal of integrating environmental stewardship and economic development.
2. **www.epa.gov/economics/**. The web site for the U.S. Environmental Protection Agency's information on environmental economics. The site includes links to many research reports.
3. **https://sites.tufts.edu/gdae/**. The homepage for the Global Development and Environment Institute at Tufts University, including links to many research publications on land, energy, climate, and sustainable economics.
4. **www.wri.org**. The World Resources Institute web site offers the biennial publication *World Resources* as well as extensive reports and data on global resource and environmental issues.

NOTES

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[1] Data from the Maddison Project, University of Groningen, Groningen Growth and Development Centre, http://www.ggdc.net/maddison/maddison-project/data.htm.

[2] Ibid.

[3] Based on the Food and Agriculture Organization (FAO) world food price index, which rose from 135 in January 2007 to 220 in March 2008.

[4] This relationship is derived from the mathematical rule of natural logarithms stating that if $A = BC$, then $\ln(A) = \ln(B) + \ln(C)$. The rates of growth of B and C can be expressed in terms of natural logarithms, and when added together, they give the rate of growth of A.

[5] International Energy Agency, 2019; OECD, 2020.

[6] The income categories are determined annually by the World Bank. In 2020 the classifications, based on average per-person income levels, were: high income = greater than $12,535, middle income = $1,036 to $12,535, low income = less than $1,036.

[7] Sachs and Warner, 1995, p. 2.

[8] For a study in support of the resource curse hypothesis, see Papyrakis and Gerlagh, 2007. For a study refuting the hypothesis, see Philippot, 2010.

[9] Havranek *et al*., 2016.

[10] UN Environment, 2019a, p. 4.

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[11] UN Environment, 2019b.

[12] UN Environment, 2019b, pp. 6-7.

[13] According to the International Energy Agency global CO_2 emissions declined slightly (less than 1%) in 2019, and preliminary data at the time of writing (late 2020) suggest a global decline in emissions of 8% in 2020, driven by the impact of the COVID-19 pandemic.

[14] HTAP, 2010.

[15] WHO, 2018.

[16] World Health Organization, https://www.who.int/gho/phe/indoor_air_pollution/burden/en/.

[17] U.S. Environmental Protection Agency, Lead Trends, https://www.epa.gov/air-trends/lead-trends.

[18] World Meteorological Organization and United Nations Environment Programme, 2014.

[19] United Nations, International Day for the Preservation of the Ozone Layer web site, http://www.un.org/en/events/ozoneday/background.shtml.

[20] Montzka *et al.*, 2018.

[21] Rigby *et al.*, 2019.

[22] Ozone Secretariat, UN Environment. 2018.

[23] See, for example, Kolbert, 2014.

[24] UNEP, 2012, p. 134.

[25] Thomas *et al.*, 2004.

[26] Urban, 2015.

[27] Frieler *et al.*, 2012.

[28] See climateactiontracker.org, which as of November 2020 estimates a 2.7°C temperature increase if nations meet their current commitments.

[29] UN Environment, 2019b, p. 182.

[30] Lebreton *et al.*, 2018.

[31] UNEP, 2012, p. 66.

[32] Sanderson *et al.*, 2002.

[33] Crop production index and land data from the World Bank's World Development Indicators database.

[34] Neumann *et al.*, 2010.

[35] UN Environment, 2019b, p. 202.

[36] WWF, https://www.worldwildlife.org/threats/soil-erosion-and-degradation.

[37] Anonymous, 2014.

[38] Boretti and Rosa, 2019.

[39] UNESCO and UN Water, 2020.

[40] Shah, 2007.

[41] National Groundwater Association, 2015.

[42] UN Environment, 2019b, p. 236.

[43] UNEP, 2012, p. 168.

[44] UNEP, 2013; UN Environment, 2019c.

[45] OECD, 2008.

[46] World Bank, 2012.

[47] Statista, https://www.statista.com/statistics/263437/global-smartphone-sales-to-end-users-since-2007/.

[48] Forti *et al.*, 2020.

[49] Caravanos *et al.*, 2011.

[50] Forti *et al.*, 2020.

[51] BBC, 2012.

[52] Randers, 2012.

[53] See, for example, Nordhaus, 1992.

[54] Turner, 2014.