

SACRIFICING THE EARTH FOR THE ECONOMY

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Introduction¹

Climate change is an extreme emergency

There is ample evidence that if the international community does not act immediately and effectively to reduce greenhouse gas emissions and to replace fossil fuels with renewable energy, tipping points will be passed, after which feedback loops will take over, making human efforts to avoid catastrophic climate change useless. Some examples of feedback loops are the albedo effect, the methane hydrate feedback loop, and forest drying and fires.

Record temperature extremes in Europe

In the United Kingdom, on July 19, 2022, the nation's first ever temperature above 40 degrees Celsius was experienced. The UK government also issued its first ever red heat alert. Hospitals in the UK cancelled operations because operating theatres were too hot. Londoners were advised not to use the city's transport network because of the heat.

During the same week, record-breaking extreme temperatures killed very many people in Europe. In Spain, some municipalities, temperatures up to 45 degrees C were recorded. In Portugal, where temperatures reached 46.7 degrees C, health authorities reported that 659 people had died from heat-related causes. In Spain, 829 heat-related deaths were recorded, according to the health ministry.

In France, Spain and Portugal, firefighters battle large numbers of out-of-control fires caused by a combination of high temperatures and drought. Wildfires are raging not only in France, Spain and Portugal, but also in Croatia, Greece and Turkey. The French government has already evacuated 25,000 people from fire-struck regions.

Record temperatures and wildfires in the United States

Record high temperatures and out-of-control wildfires are not only being experienced in Europe, North Africa and China, but also in the United States, especially in the nation's south-west region. For example, in New Mexico,

¹This book draws heavily on chapters that I have previously published in various books, but a considerable amount of new material has also been added.

the huge Hermit's Peak/Calf Canyon fire is destroying everything in its path. One hopes that temperature records and wildfires will make the American public more aware of the existential dangers of climate change.

Water scarcity

According to UNICEF, *"Four billion people - almost two thirds of the worlds population - experience severe water scarcity for at least one month each year. Over two billion people live in countries where water supply is inadequate. Half of the worlds population could be living in areas facing water scarcity by as early as 2025."*

Of course, climate change is responsible for increasing water scarcity, and the continued use of fossil fuels is responsible for climate change.

UN Secretary General Antonio Guterres pleads for international action on climate.

"We have a choice, collective action or collective suicide", Guterres told diplomats from 40 countries gathered for a three-day climate conference, "It is in our hands". The Secretary General also said that the Paris conference goal of limiting global warming to 1.5 degrees C "is on life support", and he continued, "Greenhouse gas concentrations, sea level rise, and ocean heat have broken new records. Half of humanity is in the danger zone from floods, droughts, extreme storms, and wildfires. No nation is immune. And yet we continue to feed our fossil fuel addiction..."

"Nations continue to play the blame game instead of taking responsibility for our collective future, We cannot continue this way. We must rebuild trust and come together - to keep 1.5 alive and to build climate-resilient communities..."

"We need to demonstrate at COP27 that a renewables revolution is underway. There is enormous potential for a just energy transition that accelerates coal phase-out with a corresponding deployment of renewables."

The United States is uniquely bad on climate action

According to an index developed by Yale and Colombia universities, the United States ranks 43rd among nations on environmental issues. What is the reason for this extremely bad performance? One reason is that during

Donald Trump's presidency, he claimed that climate change was a hoax, and acted accordingly to destroy existing environmental legislation. His last act as president was to pack the Supreme Court with right-wing extremist judges. This rogue Supreme Court recently ruled that the Environmental Protection Agency may not restrict the emission of greenhouse gasses.

The current president of the United States, Joe Biden, is not as bad as Trump. Indeed it would be hard to find anyone as bad as Trump! But Biden has failed miserably to carry out his campaign promises of climate action. He has authorized drilling for new oil wells off-shore, on public lands, and in Alaska. In his recent visit to Saudi Arabia, one of Biden's aims was to ask Saudi Arabia to increase its production of oil, in order to reduce gasoline prices in the US and thus to increase his own political popularity.

Sacrificing the earth on the altar of economics.

Not only the United States, but most other countries as well, seem to place a healthy economy ahead of the existential need to save the world from catastrophic climate change. This explains the failure of last year's Glasgow climate conference to produce any real progress. The future of the earth, our only home, is being sacrificed for the sake of present comforts, and for the sake of corporate profits.

What will happen if we fail?

If we fail to control catastrophic climate change, then in the long run, most parts of the world will become uninhabitable, and very many plant and animal species will become extinct. The population of humans will be greatly reduced, and the struggle to survive will lead to violent conflicts. However, the human species will not necessarily become extinct, since there will be parts of the earth where survival will still be possible.

We need popular action now!

The people of the world must wake up to the dangers of catastrophic climate change. All of us must put as much pressure on our governments as possible to stop sacrificing the earth on the altar of economics, and to embrace the Green New Deal, creating both renewable energy infrastructure and new jobs.

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Chapter 1

THE TRANSITION TO 100% RENEWABLE ENERGY

1.1 Quick action is needed to save the long-term future

The worst effects of catastrophic climate change lie in the distant future, a century or even many centuries from the present; but disaster can only be avoided if quick action is taken. The nations of the world must act immediately to reduce and eventually stop the use of fossil fuels and the destruction of forests. If decisive action is not taken within the next few decades, feedback loops will make human intervention useless. These feedback loops include the albedo effect, the methane hydrate feedback loop, and the fact as tropical forests become drier, they become vulnerable to fires ignited by lightning. These fires accelerate the drying, and thus a feed-back loop is formed.

As time passes, and as the disastrous consequences of climate change become more apparent, the political will required for action will increase; but by that time it may be too late. We are rapidly approaching several crucial tipping points.

At present, the average global rate of use of primary energy is roughly 2 kW_t per person. In North America, the rate is 12 kW_t per capita, while in Europe, the figure is 6 kW_t . In Bangladesh, it is only 0.2 kW_t . This wide variation implies that considerable energy savings are possible, through changes in lifestyle, and through energy efficiency.

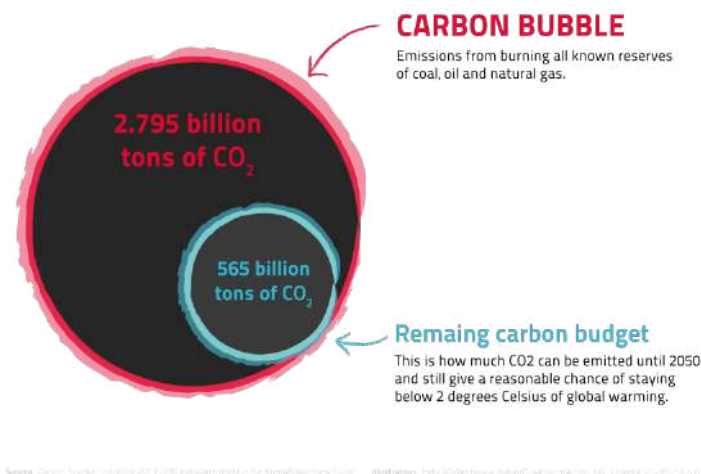


Figure 1.1: The Carbon Bubble according to data by the Carbon Tracker Initiative 2013. Uploaded by Mueller Felix. [CC BY-SA 3.0], Wikimedia Commons. In order to avoid tipping points that will make human attempts to avoid catastrophic climate change useless, we must leave most of the known fossil fuel reserves in the ground!

1.2 Is the transition to 100% renewable energy possible?

If we ask whether the transition to 100% renewable energy is possible, the answer is very simple: It is not only possible; it is inevitable! This is because the supply of fossil fuels is finite, and at the present rate of use they will be exhausted in less than a century. While the transition to 100% renewables is inevitable, the vitally important point to remember is that if we are to avoid disaster, the transition must come quickly.

In this book, we will use kilowatts (kW), megawatts (MW) and terawatts (TW) as the units in which we discuss the rate of use of energy. A megawatt is equal to a thousand kilowatts or a million watts. A terawatt is equal to a thousand megawatts, or a million kilowatts or a billion (1,000,000,000) watts. A citizen of the European Union uses energy at the rate of about 6 kilowatts, while in North America, the rate of energy use is double that amount. The global average rate of energy use is a little over 2 kilowatts. Since there are now 8 billion people in the world, our present rate of energy use is roughly 16 terawatts,

The total available energy from fossil fuels can be measured in terawatt.years (TWy). Rough estimates of global coal reserves of coal, oil and natural gas are given by the table shown below.

The present rate of use of fossil fuels is greater than the 2005 rate shown in the table, and the remaining reserves are smaller than those shown. It is assumed that as oil becomes exhausted, coal will be converted into liquid fuels, as was done in Germany during World

War II.

A second table, shown below, illustrates the historical and projected total global energy demand as a function of time between 1980 and 2030. In this slightly out-of-date table, the last year using historical data is 2003, later years being estimates based on projections.

Remaining reserves and rates of use of fossil fuels

	Reserves	2005 rate of use	Years remaining
Coal	780 TW _y	3.5 TW	217 years
Oil	250 TW _y	6.0 TW	42 years
Natural gas	250 TW _y	3.7 TW	68 years
Total	1260 TW _y	13.2 TW	(95 years)

Year	Demand	Population	Per Capita
1980	9.48 TW	4.45 bil.	2.13 kW
1985	10.3 TW	4.84 bil.	2.11 kW
1990	11.6 TW	5.99 bil.	2.20 kW
1995	12.3 TW	5.68 bil.	2.16 kW
2003	14.1 TW	6.30 bil.	2.23 kW
2010	17.1 TW	6.84 bil.	2.50 kW
2015	18.9 TW	7.23 bil.	2.58 kW
2020	20.5 TW	7.61 bil.	2.70 kW
2025	22.3 TW	7.91 bil.	2.82 kW
2030	24.2 TW	8.30 bil.	2.93 kW

Notice that the per capita energy use is almost constant. Our rapidly growing demand for energy is primarily the result of the world's rapidly growing population of humans. It would be wise to stabilize human populations because of the threat of human-caused ecological catastrophes and the danger of an extremely large-scale famine, involving billions of people rather than millions. Such a famine is threatened because growing populations require a growing food supply, climate changes threaten agriculture through droughts, melting glaciers and loss of agricultural land. The end of the fossil fuel era will also mean the end of high-yield petroleum-based agriculture.

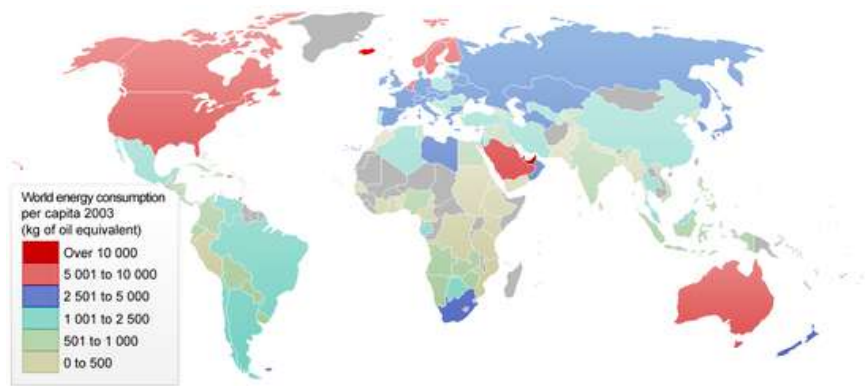


Figure 1.2: *A map of the world showing per capita rates of energy use.*

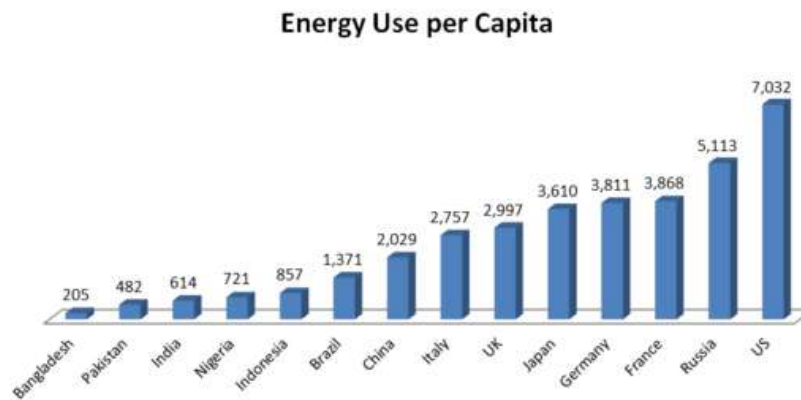


Figure 1.3: *Energy use per capita by country (World Bank data)*

The rate of growth of renewable energy

There is reason for hope that even the high energy demands show in the second table can be met by renewables. The basis of this hope can be found in the extremely high present rate of growth of renewable energy, and in the remarkable properties of exponential growth. According to figures recently released by the Earth Policy Institute, the global installed photovoltaic capacity is currently able to deliver 242,000 megawatts, and it is increasing at the rate of 27.8% per year. Wind energy can now deliver 370,000 megawatts, and it is increasing at the rate of roughly 20% per year.

Because of the astonishing properties of exponential growth, we can calculate that if these growth rates are maintained, renewable energy can give us 24.8 terawatts within only 15 years! This is far more than the world's present use of all forms of energy.

1.3 Renewables are now much cheaper than fossil fuels!

According to an article written by Megan Darby and published in *The Guardian* on 26 January, 2016, "Solar power costs are tumbling so fast the technology is likely to fast outstrip mainstream energy forecasts.

"That is the conclusion of Oxford University researchers, based on a new forecasting model published in Research Policy¹.

"Commercial prices have fallen by 58% since 2012 and by 16

"Since the 1980s, panels to generate electricity from sunshine have got 10% cheaper each year. That is likely to continue, the study said, putting solar on course to meet 20% of global energy needs by 2027.' "

Solar energy

Unlike the burning of fossil fuels, renewables like solar energy do not release pollutants into the atmosphere. In China. public opinion has shifted in favor of renewables because of air pollution in cities.

Photovoltaic cells

The price of solar photovoltaic panels has declined 99 percent over the last four decades, from \$74 a watt in 1972 to less than 70 cents a watt in 2014.

Between 2009 and 2014, solar panel prices dropped by three fourths, helping global PV installations grow 50 percent per year.

Deutsche Bank notes that as of early 2014, solar PV was already competitive with average residential, commercial or industrial electricity rates in 14 countries, and in California - even without subsidies. By late 2014 there were nearly 600,000 individual PV systems in

¹<http://www.sciencedirect.com/science/article/pii/S0048733315001699>

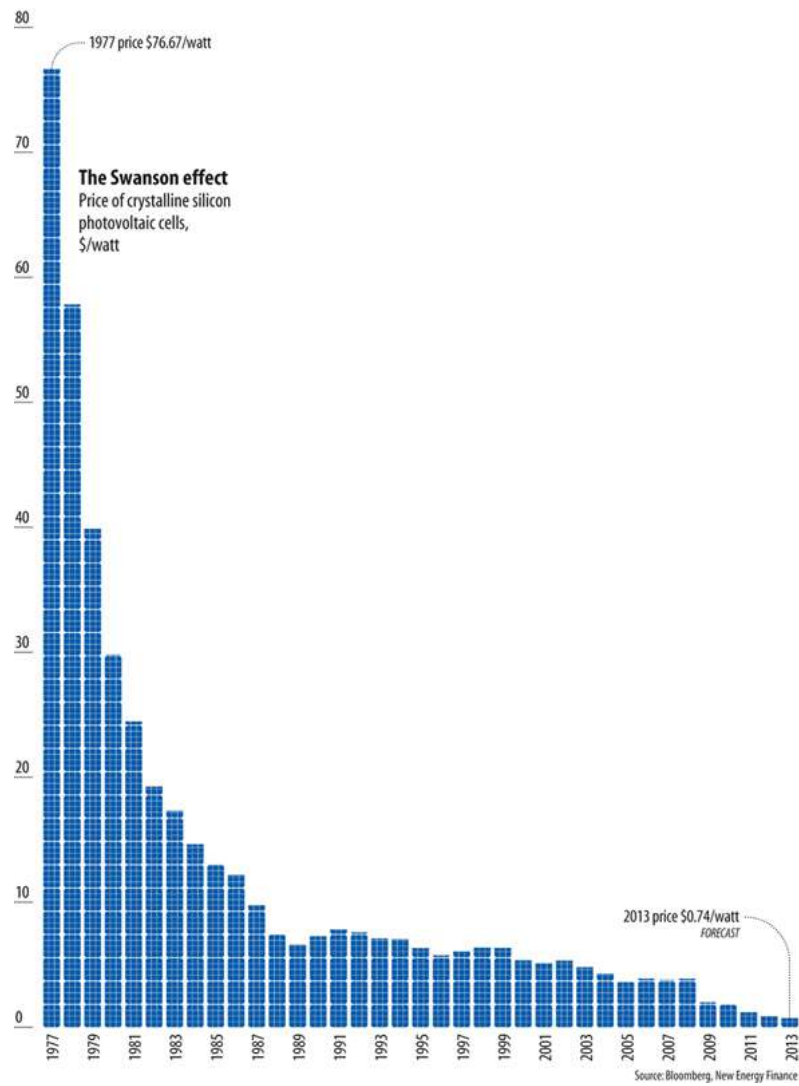


Figure 1.4: The cost of photovoltaic cell panels is falling rapidly

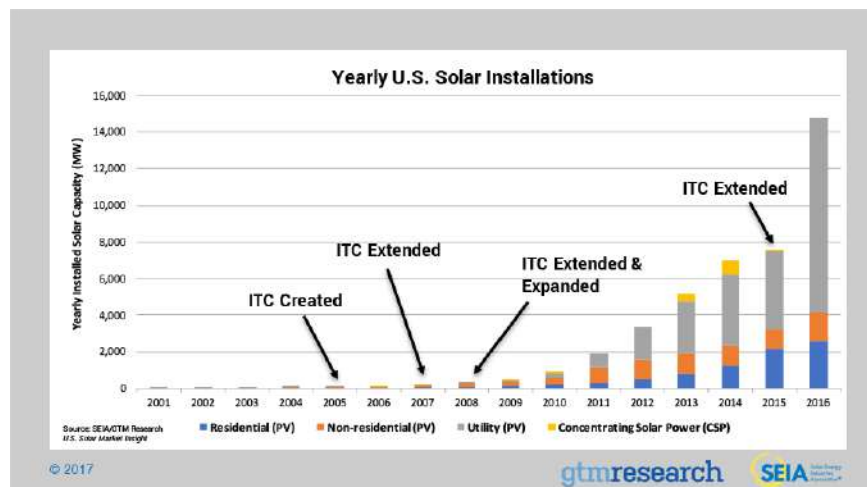


Figure 1.5: Driven by falling prices, new solar installations in the United States are increasing rapidly. The acronym ITC stands for Solar Investment Tax Credit. Commercial prices have fallen by 58% since 2012 and by 16% in the last year



Figure 1.6: Air pollution from the burning of coal has become a serious problem in China. This problem has helped to shift Chinese public opinion away from the burning of coal and towards renewables. China has now become a major manufacturer of photovoltaic cells.

the United States, almost twice as many as in 2012. This number may well pass 1 million in 2016.

In 2013, just 12 percent of U.S. homebuilders offered solar panels as an option for new single-family homes. More than half of them anticipate doing so by 2016. Four of the top five U.S. home construction firms - DR Horton, Lennar Corp, PulteGroup and KB Home - now automatically include solar panels on every new house in certain markets.

In 2007 there were only 8,000 rooftop solar installations in coal-heavy Australia; now there are over a million.

Saudi Arabia has 41,000 megawatts of solar PV operating, under construction and planned - enough to generate up to two thirds of the country's electricity.

For the roughly 1.3 billion people without access to electricity, it is now often cheaper and more efficient simply to install solar panels rooftop-by-rooftop than to build a central power plant and transmission infrastructure.

Wind energy

Over the past decade, world wind power capacity grew more than 20 percent a year, its increase driven by its many attractive features, by public policies supporting its expansion, and by falling costs.

By the end of 2014, global wind generating capacity totaled 369,000 megawatts, enough to power more than 90 million U.S. homes. Wind currently has a big lead on solar PV, which has enough worldwide capacity to power roughly 30 million U.S. homes.

China is now generating more electricity from wind farms than from nuclear plants, and should have little trouble meeting its official 2020 wind power goal of 200,000 megawatts. For perspective, that would be enough to satisfy the annual electricity needs of Brazil.

In nine U.S. states, wind provides at least 12 percent of electricity. Iowa and South Dakota are each generating more than one quarter of their electricity from wind.

In the Midwestern United States, contracts for wind power are being signed at a price of 2.5 cents per kilowatt-hour (kWh), which compares with the nationwide average grid price of 10-12 cents per kWh.

Although a wind farm can cover many square miles, turbines occupy little land. Coupled with access roads and other permanent features, a wind farm's footprint typically comes to just over 1 percent of the total land area covered by the project.

Wind energy yield per acre is off the charts. For example, a farmer in northern Iowa could plant an acre in corn that would yield enough grain to produce roughly \$1,000 worth of fuel-grade ethanol per year, or the farmer could put on that same acre a turbine that generates \$300,000 worth of electricity per year. Farmers typically receive \$3,000 to \$10,000 per turbine each year in royalties. As wind farms spread across the U.S. Great Plains, wind royalties for many ranchers will exceed their earnings from cattle sales.

The problem of intermittency

Many forms of renewable energy encounter the problem of intermittency. For example, on windy days, Denmark's windmills generate more than enough electricity to meet the needs of the country, but on days when the wind is less strong, the electrical energy generated is insufficient. Denmark solves this problem by selling surplus electrical power to Germany on windy days, and buying power from hydroelectric-rich Norway on less windy days.

The problem of intermittency can alternatively be solved by pumping water to uphill reservoirs when the wind is strong, and letting the stored water drive turbines when the wind is weak. The problem of intermittency can also be solved with lithium ion storage batteries, by splitting water into hydrogen and oxygen, or by using other types of fuel cells.

Developing countries: No need for grids

When cell phones came into general use, developing countries with no telephone networks were able to use the new technology through satellites, thus jumping over the need for country-wide telephone lines. Similarly, village solar or wind installations in the developing countries can supply power locally, bypassing the need for a grid.

1.4 An economic tipping point

Renewables are now cheaper than fossil fuels

Solar energy and wind energy have recently become cheaper than fossil fuels. Thus a tipping point has been passed. From now on, despite frantic efforts of giant fossil fuel corporations to prevent it from happening, the transition to 100% renewable energy will be driven by economic forces alone.

Subsidies to the fossil fuel industry

<http://www.imf.org/en/News/Articles/2015/09/28/04/53/sonew070215a>
<http://priceofoil.org/fossil-fuel-subsidies/>

1.5 An unprecedented investment opportunity

Investment in electric vehicles

On July 5, 2017, the Volvo Car Group made the following announcement: ²

²<https://www.media.volvocars.com/global/en-gb/media/pressreleases/210058/volvo-cars-to-go-all-electric>

“Volvo Cars, the premium car maker, has announced that every Volvo it launches from 2019 will have an electric motor, marking the historic end of cars that only have an internal combustion engine (ICE) and placing electrification at the core of its future business.

“The announcement represents one of the most significant moves by any car maker to embrace electrification and highlights how over a century after the invention of the internal combustion engine electrification is paving the way for a new chapter in automotive history.

“‘This is about the customer,’ said Håkan Samuelsson, president and chief executive. ‘People increasingly demand electrified cars and we want to respond to our customers’ current and future needs. You can now pick and choose whichever electrified Volvo you wish.’

“Volvo Cars will introduce a portfolio of electrified cars across its model range, embracing fully electric cars, plug in hybrid cars and mild hybrid cars.

“It will launch five fully electric cars between 2019 and 2021, three of which will be Volvo models and two of which will be high performance electrified cars from Polestar, Volvo Cars’ performance car arm. Full details of these models will be announced at a later date.”

The electric vehicle investment opportunity was also illustrated by the 2017 vote of Germany’s Bundesrat to ban the manufacture of internal combustion engines after 2030³.

The article announcing the vote adds that “It’s a strong statement in a nation where the auto industry is one of the largest sectors of the economy; Germany produces more automobiles than any other country in Europe and is the third largest in the world. The resolution passed by the Bundesrat calls on the European Commission (the executive arm of the European Union) to ‘evaluate the recent tax and contribution practices of Member States on their effectiveness in promoting zero-emission mobility,’ which many are taking to mean an end to the lower levels of tax currently levied on diesel fuel across Europe.”

France plans to end the sale of vehicles powered by gasoline and diesel by 2040, environment minister Nicolas Hulot announced recently.

Hulot made the announcement on Thursday, June 13, 2017, in Paris as he launched the country’s new Climate Plan to accelerate the transition to clean energy and to meet its targets under the Paris climate agreement.

To ease the transition, Hulot said the French government will offer tax incentives to replace fossil-fuel burning cars with clean alternatives.

Furthermore, the government of India has recently announced its intention to only have electric vehicles by 2030⁴. This hugely ambitious plan was announced during the 2017 Confederation of Indian Industry Annual Session. Besides the avoidance of climate change, which might make many regions of India uninhabitable, the motive for replacing 28 million combustion engine vehicles by electric ones was the severe air pollution from which India suffers. Severe air pollution also motivates efforts by the government of China to promote the transition to electric vehicles.

³<https://arstechnica.com/cars/2016/10/germanys-bundesrat-votes-to-ban-the-internal-combustion-engine-by-2030/>

⁴<https://www.greentechmedia.com/articles/read/what-country-will-become-the-first-to-ban-internal-combustion-cars>

The governments of Norway and the Netherlands have taken steps towards banning the internal combustion engine⁵. Both the upper and lower houses of the Netherlands' government voted to ban cars driven by internal combustion engines by 2025, the same year in which Norway plans to sell nothing but zero-emission vehicles.

In a report commissioned by the investment bankers Cowan & Co, managing director and senior research analyst Jeffrey Osborne, predicted that electric vehicles will cost less than gasoline-powered cars by the early- to mid-2020s due to falling battery prices as well as the costs that traditional carmakers will incur as they comply to new fuel-efficiency standards. Osbourne pointed out that a number of major car brands are hopping onto the electric bandwagon to compete in a space carved out by industry disrupter, Tesla.

"We see the competitive tides shifting in 2019 and beyond as European [car makers] roiled by the diesel scandal and loss of share to Tesla in the high margin luxury segment step on the gas and accelerate the pace of EV introductions", he wrote.

Bloomberg New Energy Finance reported similar predictions: "Falling battery costs will mean electric vehicles will also be cheaper to buy in the U.S. and Europe as soon as 2025," the report said. "Batteries currently account for about half the cost of EVs, and their prices will fall by about 77 percent between 2016 and 2030."

In October, 2017, General Motors unveiled plans to roll out 20 new entirely electric car models by 2023, with two of the new EVs coming out in the next 18 months. Meanwhile, Ford announced the creation of "Team Edison," intended to accelerate the company's EV development and partnership work. The name, is "seemingly in direct response to Elon Musk's Tesla, which recently surpassed Ford's market capitalization."

Tesla's Chairman, highly successful inventor and entrepreneur Elon Musk, has made massive investments in factories manufacturing electric vehicles, improved lithium ion storage cells, and photovoltaic panels, as will be discussed in Chapter 2.

Investment in wind turbine energy

In Denmark, the wind turbine industry contributes substantially to the country's positive balance of payments. According to Wikipedia, "The Danish wind turbine industry is the world's largest. Around 90% of the national output is exported, and Danish companies accounted for 38% of the world turbine market in 2003, when the industry employed some 20,000 people and had a turnover of around 3 billion euro."

Denmark's two largest wind turbine manufacturers are Vestas and Simiens Wind Power. Vestas employs more than 21000 people globally. In February 2016, Vestas got its largest order of 1,000 MW (278 x 3.6 MW) for the Fosen project near Trondheim in Norway. It costs DKK 11 billion, and should deliver 3.4 TWh per year.

In 2015 Siemens Wind had a combined market share of 63% of European offshore wind turbines (nearly 75% in 2009 by capacity and number). In 2011, Siemens Wind Power had 6.3% share of the world wind turbine market, and was the second largest in 2014.

⁵<http://www.prnewswire.com/news-releases/the-dutch-revolution-in-smart-charging-of-electric-vehicles-597268791.html>

In many countries, including Australia, Canada, Denmark, Germany, India, The Netherlands, United Kingdom, and United States, wind turbine cooperatives have sprung up. In these cooperatives, communities share the costs and profits of wind turbine projects. For example, the Hepburn Wind Project in Victoria, Australia, owns two 2MW wind turbines which produce enough power for 2,300 households.

Investment in solar energy

Global revenues from solar photovoltaic installations are expected to reach \$1.2 trillion between the present and 2024 according to a recent article⁶

Another article⁷ states that “The global electric power industry is evolving into a model that offers more diversity, both in terms of generation and in the ownership of generation assets, and solar PV is one technology at the head of this change. Following years of unsustainable pricing and oversupply, demand for solar PV systems has finally caught up, with 2015 expected to be the year when the global solar PV market shifts and starts to compete with other technologies. According to a recent report from Navigant Research, global revenue from solar PV installations is expected to total more than \$1.2 trillion from 2015 to 2024.”

1.6 For creating jobs, renewables beat fossil fuels

Here are some excerpts from a 2016 report issued by the Solar Foundation:

- One out of every 50 new jobs added in the United States in 2016 was created by the solar industry, representing 2 percent of all new jobs.
- Solar jobs in the United States have increased at least 20 percent per year for the past four years, and jobs have nearly tripled since the first Solar Jobs Census was released in 2010.
- Over the next 12 months, employers surveyed expect one out of every 50 new jobs added in the United States in 2016 was created by the solar industry, representing 2 percent of all new jobs.
- In 2016, the five states with the most solar jobs were California, Massachusetts, Texas, Nevada, and Florida.
- The solar industry added \$84 billion to the US GDP in 2016 to see total solar industry employment increase by 10 percent to 286,335 solar workers.
- The solar industry added \$84 billion to the US GDP in 2016.

⁶<https://cleantechnica.com/2016/01/25/global-revenue-solar-pv-installations-expected-reach-1-2-trillion/>

⁷<http://www.navigantresearch.com/newsroom/global-revenue-from-solar-pv-installations-is-expected-to-total-more-than-1-2-trillion-from-2015-to-2024>

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Chapter 2

RENEWABLE ENERGY TECHNOLOGY

2.1 Beyond the fossil fuel era

After the end of the fossil fuel era, our industrial civilization will have to rely on renewable sources to supply our energy needs. These sources include hydropower, wind and tidal power, biomass, geothermal energy and solar energy. Let us try to survey how much energy these sources can be expected to produce.

According to REN21. (Renewable Energy Policy Institute for the 21st Century), “Newly installed renewable power capacity set new records in 2016, with 161 gigawatts (GW) added, increasing the global total by almost 9% relative to 2015. Solar PV was the star performer in 2016, accounting for around 47% of the total additions, followed by wind power at 34% and hydropower at 15.5%. For the fifth consecutive year, investment in new renewable power capacity (including all hydropower) was roughly double the investment in fossil fuel generating capacity, reaching USD 249.8 billion. The world now adds more renewable power capacity annually

“2016 was the third year in a row where global energy- related CO₂ emissions from fossil fuels and industry remained stable despite a 3% growth in the global economy and an increased demand for energy. This can be attributed primarily to the decline in coal consumption, but also to the growth in renewable energy capacity and to improvements in energy efficiency. The decoupling of economic growth and CO₂ emissions is an important first step towards achieving the steep decline in emissions necessary for holding global temperature rise well below 2 degrees Celsius.”

Before the start of the industrial era, human society relied exclusively on renewable energy sources - but can we do so again, with our greatly increased population and greatly increased demands? Will we ultimately be forced to reduce the global population or our per capita use of energy, or both? Let us now try to examine these questions.

2.2 Solar energy

Biomass, wind energy, hydropower and wave power derive their energy indirectly from the sun, but in addition, various methods are available for utilizing the power of sunlight directly. These include photovoltaic panels, solar designs in architecture, solar systems for heating water and cooking, concentrating photovoltaic systems, and solar thermal power plants.

Photovoltaic cells and concentrating photovoltaic systems

Solar power was the fastest-growing source of new energy in 2016, surpassing the net growth of all other energy sources including coal, according to a new report from the International Energy Agency (IEA).

The IEA report found new solar capacity increased by 50 percent in 2016, and IEA executive director Fatih Birol hailed solar's rapid growth. "What we are witnessing is the birth of a new era in solar photovoltaics [PV]. We expect that solar PV capacity growth will be higher than any other renewable technology up to 2022."¹

The report also shows renewables as a whole accounted for two-thirds of all new energy capacity in 2016. "We see renewables growing by about 1,000 GW (gigawatts) by 2022, which equals about half of the current global capacity in coal power, which took 80 years to build," Birol said in a statement accompanying the report.²

Solar photovoltaic cells³ are thin coated wafers of a semiconducting material (usually silicon). The coatings on the two sides are respectively charge donors and charge acceptors. Cells of this type are capable of trapping solar energy and converting it into direct-current electricity. The electricity generated in this way can be used directly (as it is, for example, in pocket calculators) or it can be fed into a general power grid. Alternatively it can be used to split water into hydrogen and oxygen. The gases can then be compressed and stored, or exported for later use in fuel cells. In the future, we may see solar photovoltaic arrays in sun-rich desert areas producing hydrogen as an export product. As their petroleum reserves become exhausted, the countries of the Middle East and Africa may be able to shift to this new technology and still remain energy exporters.

It is interesting to notice that the primary process of photosynthesis in plants is closely similar to the mechanism by which solar cells separate charges and prevent the back-reaction. We can see why a back-reaction must be prevented if we consider the excitation of a single atom. An absorbed photon lifts an electron from a filled atomic orbital to an empty one, leaving a positively-charged hole in the orbital from which the electron came. However, a back-reaction occurs almost immediately: The excited electron falls back into

¹<https://www.theguardian.com/environment/2017/oct/04/solar-power-renewables-international-energy-agency>

²<https://www.iea.org/newsroom/news/2017/october/solar-pv-grew-faster-than-any-other-fuel-in-2016-opening-a-new-era-for-solar-pow.html>

³<https://www.iea.org/renewables/>

the orbital from which it came, and the absorbed energy is re-emitted. One can say that the electron and hole have recombined.

In higher plants, the back reaction is prevented because the photon is absorbed in a membrane which has a sandwich-like structure. Dye molecules (usually chlorophyll molecules) are sandwiched between a layer of charge donor molecules on one side of the membrane, and a layer of charge acceptor molecule on the other side. The electron quickly migrates to the acceptors, which are molecules with low-lying unfilled orbitals. Meanwhile the hole has quickly moved to the opposite side of the membrane, where it combines with an electron from a donor molecule. A donor molecule is a molecule whose highest filled orbital is high in energy. In this process, the back reaction is prevented. The electron and hole are on opposite sides of the membrane, and they can only recombine after they have driven the metabolism of the plant.

In a photovoltaic solar cell, the mechanism by which the back-reaction is prevented is exactly similar. It too has a sandwich-like structure, with charge donors on one side, charge-acceptors on the other, and photon absorbers in the middle. Here too, the electron and hole quickly migrate to opposite sides. They can only recombine by traveling through the external circuit, which is analogous to a plant's metabolism, and performing useful work.

The cost of manufacturing photovoltaics continues to fall rapidly. In 2017, a homeowner paid approximately \$3,360 per kilowatt to have rooftop solar panels installed. Usually photovoltaic panels are warranted for a life of 20 years, but they are commonly still operational after 30 years or more. Using the fact that there are 8760 hours in a year, and thus 175200 hours in 20 years, we can calculate that the cost of electricity to a solar-using homeowner today is about 1.92 cents per kilowatt hour. This can be compared with electricity generated from coal, which in 2011 cost 3.23 cents per kilowatt hour, while electricity generated from natural gas cost 4.51 cents per kilowatt hour. We must also remember that photovoltaics are falling rapidly in price, and that the fossil fuel costs do not include externalities, such as their contribution to climate change.

Concentrating photovoltaic systems are able to lower costs still further by combining silicon solar cells with reflectors that concentrate the sun's rays. The most inexpensive type of concentrating reflector consists of a flat piece of aluminum-covered plastic material bent into a curved shape along one of its dimensions, forming a trough-shaped surface. (Something like this shape results when we hold a piece of paper at the top and bottom with our two hands, allowing the center to sag.) The axis of the reflector can be oriented so that it points towards the North Star. A photovoltaic array placed along the focal line will then receive concentrated sunlight throughout the day.

Photovoltaic efficiency is defined as the ratio of the electrical power produced by a cell to the solar power striking its surface. For commercially available cells today, this ratio is between 9% and 14%. If we assume 5 hours of bright sunlight per day, this means that a photo cell in a desert area near to the equator (where 1 kW/m^2 of peak solar power reaches the earth's surface) can produce electrical energy at the average rate of 20-30 W_e/m^2 , the average being taken over an entire day and night. The potential power per unit area for photovoltaic systems is far greater than for biomass. However, the mix of

renewable energy sources most suitable for a particular country depends on many factors. We will see below that biomass is a promising future source of energy for Sweden, because of Sweden's low population density and high rainfall. By contrast, despite the high initial investment required, photovoltaics are undoubtedly a more promising future energy source for southerly countries with clear skies.

In comparing photovoltaics with biomass, we should be aware of the difference between electrical energy and energy contained in the chemical bonds of a primary fuel such as wood or rapeseed oil. If Sweden (for example) were to supply all its energy needs from biomass, part of the biomass would have to be burned to generate electricity. The efficiency of energy conversion in electricity generation from fuel is 20%-35%. Of course, in dual use power plants, part of the left-over heat from electrical power generation can be used to heat homes or greenhouses. However, hydropower, wind power and photovoltaics have an advantage in generating electrical power, since they do so directly and without loss, whereas generation of electricity from biomass involves a loss from the inefficiency of the conversion from fuel energy to electrical energy. Thus a rational renewable energy program for Sweden should involve a mixture of biomass for heating and direct fuel use, with hydropower and wind power for generation of electricity. Perhaps photovoltaics will also play a role in Sweden's future electricity generation, despite the country's northerly location and frequently cloudy skies.

The global market for photovoltaics is expanding at the rate of 30% per year. This development is driven by rising energy prices, subsidies to photovoltaics by governments, and the realization of the risks associated with global warming and consequent international commitments to reduce carbon emissions. The rapidly expanding markets have resulted in lowered photovoltaic production costs, and hence further expansion, still lower costs, etc. - a virtuous feedback loop.

Solar thermal power plants

Solar Parabolic Troughs can be used to heat a fluid, typically oil, in a pipe running along the focal axis. The heated fluid can then be used to generate electrical power. The liquid that is heated in this way need not be oil. In a solar thermal power plant in California, reflectors move in a manner that follows the sun's position and they concentrate solar energy onto a tower, where molten salt is heated to a temperature of 1050 degrees F (566 °C). The molten salt stores the heat, so that electricity can be generated even when the sun is not shining. The California plant generates 10 MW_e.

Solar designs in architecture

At present, the average global rate of use of primary energy is roughly 2 kW_t per person. In North America, the rate is 12 kW_t per capita, while in Europe, the figure is 6 kW_t. In Bangladesh, it is only 0.2 kW_t. This wide variation implies that considerable energy savings are possible, through changes in lifestyle, and through energy efficiency.



Figure 2.1: A rooftop array of photovoltaic cells.



Figure 2.2: A solar thermal power plant. Arrays of heliostatic reflectors concentrate the sun's rays onto molten salt in the tower. The plant produces electricity at night because the salt remains hot..



Figure 2.3: A solar cooker.



Figure 2.4: A rooftop solar thermal array for domestic water heating.

Important energy savings can be achieved through solar design in architecture. For example, insulation can be improved in walls, and insulating shutters can be closed at night.

In double envelope construction, a weatherproof shell surrounds the inner house. Between the outer shell and the house, sun-heated air circulates. A less extreme example of this principle is the construction of south-facing conservatories. The sun-heated air in the conservatories acts as a thermal buffer, and reduces heat loss from the house.

Solar design aims at making houses cool in the summer and warm in the winter. Awnings can be spread out in the summer to shade windows, and rolled together in the winter to allow sunshine to enter the house. Alternatively, deciduous trees can be planted in front of south-facing windows. During the summer, the leaves of the trees shade the windows, while in the winter, the leaves fall, allowing the sun to enter.

During daylight hours, houses can be illuminated by fiber optic light pipes, connected to a parabolic collector on the roof. The roof can also contain arrays of solar photovoltaic cells and solar water heaters.

Houses can be heated in the winter by heat pumps connected to a deeply buried network of pipes. Heat pumps function in much the same way as refrigerators or air conditioners. When they are used to warm houses in the winter, a volatile liquid such as ammonia is evaporated underground, where the temperature is relatively constant, not changing much between summer and winter. In the evaporation process, heat is absorbed from the ground. The gas is then compressed and re-liquefied within the house, and in this process, it releases the heat that was absorbed underground. Electricity is of course required to drive a heat pump, but far less electrical power is needed to do this than would be required to heat the house directly.

In general, solar design of houses and other buildings requires an initial investment, but over time, the investment is amply repaid through energy savings.

Solar systems for heating water and cooking

Solar heat collectors are already in common use to supply hot water for families or to heat swimming pools. A common form of the solar heat collector consists of a flat, blackened heat-collecting plate to which tubes containing the fluid to be heated are connected. The plate is insulated from the atmosphere by a layer of air (in some cases a partial vacuum) above which there is a sheet of glass. Water flowing through the tubes is collected in a tank whenever it is hotter than the water already there. In cases where there is a danger of freezing, the heated fluid may contain antifreeze, and it may then exchange heat with water in the collection tank. Systems of this kind can function even in climates as unfavorable as that of Northern Europe, although during winter months they must be supplemented by conventional water-heaters.

In the developing countries, wood is often used for cooking, and the result is sometimes deforestation, soil erosion and desertification. In order to supply an alternative, many designs for solar cooking have been developed. Often the designs are very simple, and

many are both easy and inexpensive to build, the starting materials being aluminum foil and cardboard boxes.

2.3 Wind energy

Wind parks in favorable locations, using modern wind turbines, are able to generate $10 \text{ MW}_e/\text{km}^2$ or $10 \text{ W}_e/\text{m}^2$. Often wind farms are placed in offshore locations. When they are on land, the area between the turbines can be utilized for other purposes, for example for pasturage. For a country like Denmark, with good wind potential but cloudy skies, wind turbines can be expected to play a more important future role than photovoltaics. Denmark is already a world leader both in manufacturing and in using wind turbines. Today, on windy days, 100% of all electricity used in Denmark is generated by wind power, and the export of wind turbines makes a major contribution to the Danish economy. The use of wind power is currently growing at the rate of 38% per year. In the United States, it is the fastest-growing form of electricity generation.

The location of wind parks is important, since the energy obtainable from wind is proportional to the cube of the wind velocity. We can understand this cubic relationship by remembering that the kinetic energy of a moving object is proportional to the square of its velocity multiplied by the mass. Since the mass of air moving past a wind turbine is proportional to the wind velocity, the result is the cubic relationship just mentioned.

Before the decision is made to locate a wind park in a particular place, the wind velocity is usually carefully measured and recorded over an entire year. For locations on land, mountain passes are often very favorable locations, since wind velocities increase with altitude, and since the wind is concentrated in the passes by the mountain barrier. Other favorable locations include shorelines and offshore locations on sand bars. This is because onshore winds result when warm air rising from land heated by the sun is replaced by cool marine air. Depending on the season, the situation may be reversed at night, and an offshore wind may be produced if the water is warmer than the land.

The cost of wind-generated electrical power is currently lower than the cost of electricity generated by burning fossil fuels.

The “energy payback ratio” of a power installation is defined as the ratio of the energy produced by the installation over its lifetime, divided by the energy required to manufacture, construct, operate and decommission the installation. For wind turbines, this ratio is 17-39, compared with 11 for coal-burning plants. The construction energy of a wind turbine is usually paid back within three months.

Besides the propeller-like design for wind turbines there are also designs where the rotors turn about a vertical shaft. One such design was patented in 1927 by the French aeronautical engineer Georges Jean Marie Darrieus. The blades of a Darrieus wind turbine are airfoils similar to the wings of an aircraft. As the rotor turns in the wind, the stream of air striking the airfoils produces a force similar to the “lift” of an airplane wing. This force pushes the rotor in the direction that it is already moving. The Darrieus design has some advantages over conventional wind turbine design, since the generator can be placed



Figure 2.5: Rows of wind turbines.



Figure 2.6: Vertical axis wind turbines.



Figure 2.7: *Wind turbines on the Danish island of Samsø. The island was the first in the world to achieve 100% renewable energy.*

at the bottom of the vertical shaft, where it may be more easily serviced. Furthermore, the vertical shaft can be lighter than the shaft needed to support a conventional wind turbine.

One problem with wind power is that it comes intermittently, and demand for electrical power does not necessarily come at times when the wind is blowing most strongly. To deal with the problem of intermittency, wind power can be combined with other electrical power sources in a grid. Alternatively, the energy generated can be stored, for example by pumped hydroelectric storage or by using hydrogen technology, as will be discussed below.

Bird lovers complain that birds are sometimes killed by rotor blades. This is true, but the number killed is small. For example, in the United States, about 70,000 birds per year are killed by turbines, but this must be compared with 57 million birds killed by automobiles and 97.5 million killed by collisions with plate glass.

The aesthetic aspects of wind turbines also come into the debate. Perhaps in the future, as wind power becomes more and more a necessity and less a matter of choice, this will be seen as a “luxury argument”.

A Danish island reaches 100% renewable energy

The Danish island of Samsø is only 112 square kilometers in size, and its population numbers only 4,300. Nevertheless, it has a unique distinction. Samsø was the first closed land area to declare its intention of relying entirely on renewable energy, and it has now achieved this aim, provided that one stretches the definitions slightly.

In 1997, the Danish Ministry of Environment and Energy decided to sponsor a renewable-energy contest. In order to enter, communities had to submit plans for how they could make a transition from fossil fuels to renewable energy. An engineer (who didn’t live

there) thought he knew how Samsø could do this, and together with the island's mayor he submitted a plan which won the contest. As a result, the islanders became interested in renewable energy. They switched from furnaces to heat pumps, and formed cooperatives for the construction of windmill parks in the sea near to the island. By 2005, Samsø was producing, from renewable sources, more energy than it was using. The islanders still had gasoline-driven automobiles, but they exported from their windmill parks an amount of electrical energy that balanced the fossil fuel energy that they imported. This is a story that can give us hope for the future, although a farming community like Samsø cannot serve as a model for the world.

2.4 Hydroelectric power

In 2015, hydroelectric power supplied 16.6% of all electrical power, and 70% of the electrical power generated from renewable energy. In the developed countries, the potential for increasing this percentage is small, because most of the suitable sites for dams are already in use. Mountainous regions of course have the greatest potential for hydroelectric power, and this correlates well with the fact that virtually all of the electricity generated in Norway comes from hydro, while in Iceland and Austria the figures are respectively 83% and 67%. Among the large hydroelectric power stations now in use are the La Grande complex in Canada (16 GW_e) and the Itapú station on the border between Brazil and Paraguay (14 GW_e). The Three Gorges Dam in China produces 18.2 GW_e .

Even in regions where the percentage of hydro in electricity generation is not so high, it plays an important role because hydropower can be used selectively at moments of peak demand. Pumping of water into reservoirs can also be used to store energy.

The creation of lakes behind new dams in developing countries often involves problems, for example relocation of people living on land that will be covered by water, and loss of the land for other purposes⁴. However the energy gain per unit area of lake can be very large - over 100 W_e/m^2 . Fish ladders can be used to enable fish to reach their spawning grounds above dams. In addition to generating electrical power, dams often play useful roles in flood control and irrigation.

At present, hydroelectric power is used in energy-intensive industrial processes, such as the production of aluminum. However, as the global energy crisis becomes more severe, we can expect that metals derived from electrolysis, such as aluminum and magnesium, will be very largely replaced by other materials, because the world will no longer be able to afford the energy needed to produce them.

⁴Over a million people were displaced by the construction of the Three Gorges Dam in China, and many sites of cultural value were lost

Table 2.1: Technical potential and utilization of hydropower. (Data from World Energy Council, 2003.)

Region	Technical potential	Annual output	Percent used
Asia	0.5814 TW _e	0.0653 TW _e	11%
S. America	0.3187 TW _e	0.0579 TW _e	18%
Europe	0.3089 TW _e	0.0832 TW _e	27%
Africa	0.2155 TW _e	0.0091 TW _e	4%
N. America	0.1904 TW _e	0.0759 TW _e	40%
Oceania	0.0265 TW _e	0.0046 TW _e	17%
World	1.6414 TW _e	0.2960 TW _e	18%



Figure 2.8: **Hydroelectric power does not suffer from the problem of intermittency, but may sometimes produce undesirable social and ecological impacts.**

2.5 Energy from the ocean

Tidal power

The twice-daily flow of the tides can be harnessed to produce electrical power. Ultimately tidal energy comes from the rotation of the earth and its interaction with the moon's gravitational field. The earth's rotation is very gradually slowing because of tidal friction, and the moon is gradually receding from the earth, but this process will take such an extremely long time that tidal energy can be thought of as renewable.

There are two basic methods for harnessing tidal power. One can build barriers that create level differences between two bodies of water, and derive hydroelectric power from the head of water thus created. Alternatively it is possible to place the blades of turbines in a tidal stream. The blades are then turned by the tidal current in much the same way that the blades of a wind turbine are turned by currents of air.

There are plans for using the second method on an extremely large scale in Cook Strait, near New Zealand. A company founded by David Beach and Chris Bathurst plans to anchor 7,000 turbines to the sea floor of Cook Strait in such a way that they will float 40 meters below the surface. Beach and Bathurst say that in this position, the turbines will be safe from the effects of earthquakes and storms. The tidal flow through Cook Strait is so great that the scheme could supply all of New Zealand's electricity if the project is completed on the scale visualized by its founders.

Choosing the proper location for tidal power stations is important, since the height of tides depends on the configuration of the land. For example, tides of 17 meters occur in the Bay of Fundy, at the upper end of the Gulf of Maine, between New Brunswick and Nova

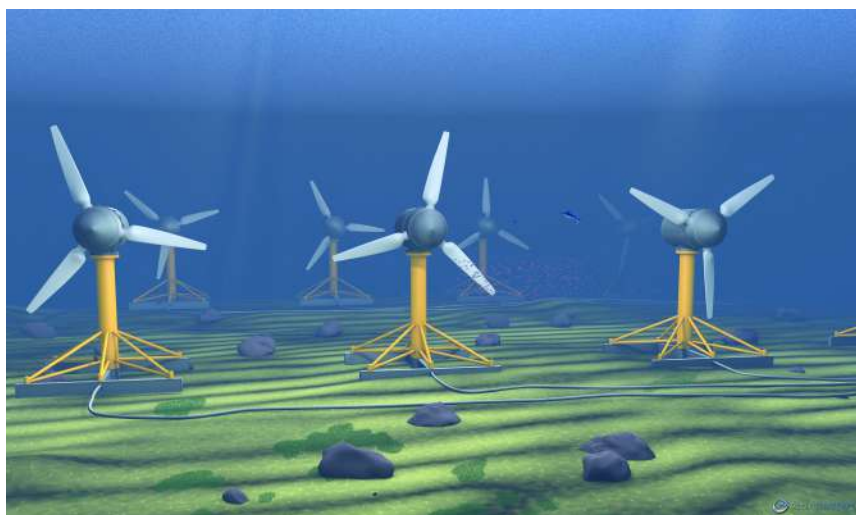


Figure 2.9: **Underwater turbines can make use of the energy of ocean currents.**

Scotia. Here tidal waves are funneled into the bay, creating a resonance that results in the world's greatest level difference between high and low tides. An 18 MW_e dam-type tidal power generation station already exists at Annapolis River, Nova Scotia, and there are proposals to increase the use of tidal power in the Bay of Fundy. Some proposals involve turbines in the tidal stream, similar to those proposed for use in the Cook Strait.

In the future, favorable locations for tidal power may be exploited to their full potentialities, even though the output of electrical energy exceeds local needs. The excess energy can be stored in the form of hydrogen (see below) and exported to regions deficient in renewable energy resources.

Wave energy

At present, the utilization of wave energy is in an experimental stage. In Portugal, there are plans for a wave farm using the Pelamis Wave Energy Converter. The Pelamis is a long floating tube with two or more rigid sections joined by hinges. The tube is tethered with its axis in the direction of wave propagation. The bending between sections resulting from passing waves is utilized to drive high pressure oil through hydraulic motors coupled to electrical generators. Each wave farm in the Portuguese project is planned to use three Pelamis converters, each capable of producing 750 kW_e. Thus the total output of each wave farm will be 2.25 MW_e.

Another experimental wave energy converter is Salter's Duck, invented in the 1970's by Prof. Stephen Salter of the University of Edinburgh, but still being developed and improved. Like the Pelamis, the Duck is also cylindrical in shape, but the axis of the cylinder is parallel to the wave front, i.e. perpendicular to the direction of wave motion. A floating cam, attached to the cylinder, rises and falls as a wave passes, driving hydraulic motors within the cylinder. Salter's Duck is capable of using as much as 65% of the wave's

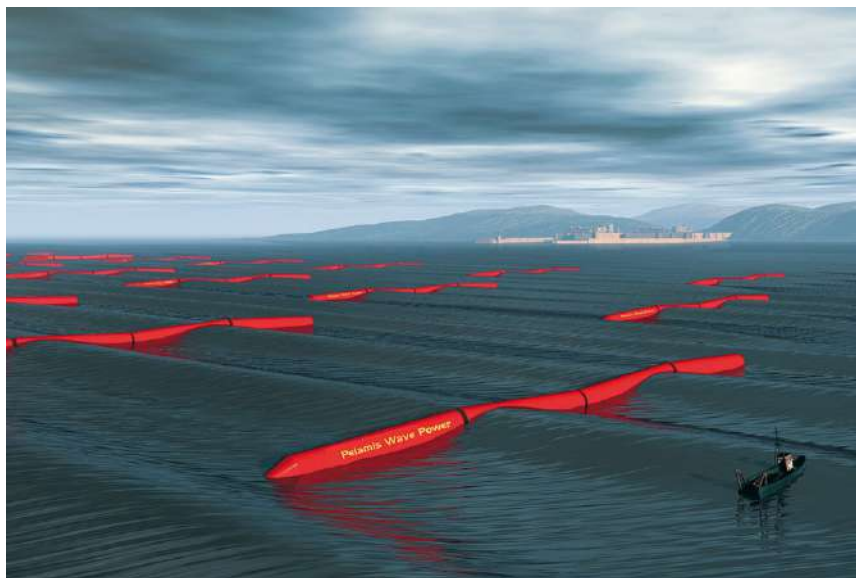


Figure 2.10: The Pelamis wave energy transformer floats on the ocean like a giant sea snake. It consists of several segments which move against each other and build up hydraulic pressure. This in turn drives a turbine. A new Pelamis generation is currently under construction.

energy.

The energy potentially available from waves is very large, amounting to as much as 100 kilowatts per meter of wave front in the best locations.

Ocean thermal energy conversion

In tropical regions, the temperature of water at the ocean floor is much colder than water at the surface. In ocean thermal energy conversion, cold water is brought to the surface from depths as great as 1 km, and a heat engine is run between deep sea water at a very low temperature and surface water at a much higher temperature.

According to thermodynamics, the maximum efficiency of a heat engine operating between a cold reservoir at the absolute temperature T_C and a hot reservoir at the absolute temperature T_H is given by $1 - T_C/T_H$. In order to convert temperature on the centigrade scale to absolute temperature (degrees Kelvin) one must add 273 degrees. Thus the maximum efficiency of a heat engine operating between water at the temperature of 25 °C and water at 5 °C is $1 - (5 + 273)/(25 + 273) = 0.067 = 6.7\%$. The efficiency of heat engines is always less than the theoretical maximum because of various losses, such as the loss due to friction. The actual overall efficiencies of existing ocean thermal energy conversion (OTEC) stations are typically 1-3%. On the other hand, the amount of energy potentially available from differences between surface and bottom ocean temperatures is extremely large.

Since 1974, OTEC research has been conducted by the United States at the Natural

Energy Laboratory of Hawaii. The Japanese government also supports OTEC research, and India has established a 1 MW_e OTEC power station floating in the ocean near to Tamil Nadu.

Renewable energy from evaporation

A September 26, 2017 article by Ahmet-Hamdi Cavusoglu et al. in *Nature Communications* points to evaporation as a future source of renewable energy. Here are some excerpts from the article:

“About 50% of the solar energy absorbed at the Earth’s surface drives evaporation, fueling the water cycle that affects various renewable energy resources, such as wind and hydropower. Recent advances demonstrate our nascent ability to convert evaporation energy into work, yet there is little understanding about the potential of this resource.

“Here we study the energy available from natural evaporation to predict the potential of this ubiquitous resource. We find that natural evaporation from open water surfaces could provide power densities comparable to current wind and solar technologies while cutting evaporative water losses by nearly half. We estimate up to 325 GW of power is potentially available in the United States. Strikingly, water’s large heat capacity is sufficient to control power output by storing excess energy when demand is low, thus reducing intermittency and improving reliability. Our findings motivate the improvement of materials and devices that convert energy from evaporation...

“Recent advances in water responsive materials and devices demonstrate the ability to convert energy from evaporation into work. These materials perform work through a cycle of absorbing and rejecting water via evaporation. These water-responsive materials can be incorporated into evaporation-driven engines that harness energy when placed above a body of evaporating water. With improvements in energy conversion efficiency, such devices could become an avenue to harvest energy via natural evaporation from water reservoirs.”

Ozgur Sahin, a biophysicist at Columbia, has developed technology that uses spores from the harmless soil-dwelling bacterium *B. subtilis* to absorb and release water when the relative humidity of the surrounding air changes. At high humidity, the spores take in water and expand, and at low humidity they release water and contract, acting like a muscle.

2.6 Biomass

Biomass is defined as any energy source based on biological materials produced by photosynthesis - for example wood, sugar beets, rapeseed oil, crop wastes, dung, urban organic wastes, processed sewage, etc. Using biomass for energy does not result in the net emission of CO₂, since the CO₂ released by burning the material had previously been absorbed from the atmosphere during photosynthesis. If the biological material had decayed instead of being burned, it would released the same amount of CO₂ as in the burning process.



Figure 2.11: **Rapeseed is grown in several countries, including Denmark and the UK. Experimental Danish buses are already running on rapeseed oil.**

The solar constant has the value $1.4 \text{ kilowatts/m}^2$. It represents the amount of solar energy per unit area⁵ that reaches the earth, before the sunlight has entered the atmosphere. Because the atmosphere reflects 6% and absorbs 16%, the peak power at sea level is reduced to 1.0 kW/m^2 . Clouds also absorb and reflect sunlight. Average cloud cover reduces the energy of sunlight a further 36%. Also, we must take into account the fact that the sun's rays do not fall perpendicularly onto the earth's surface. The angle that they make with the surface depends on the time of day, the season and the latitude.

In Sweden, which lies at a northerly latitude, the solar energy per unit of horizontal area is less than for countries nearer the equator. Nevertheless, Göran Persson, during his term as Prime Minister of Sweden, announced that his government intends to make the country independent of imported oil by 2020 through a program that includes energy from biomass.

In his thesis, *Biomass in a Sustainable Energy System*, the Swedish researcher Pål Börjesson states that of various crops grown as biomass, the largest energy yields come from short-rotation forests (*Salix viminalis*, a species of willow) and sugar beet plantations. These have an energy yield of from 160 to 170 GJ_t per hectare-year. (The subscript t means "thermal". Energy in the form of electricity is denoted by the subscript e). One can calculate that this is equivalent to about $0.5 \text{ MW}_t/\text{km}^2$, or $0.5 \text{ W}_t/\text{m}^2$. Thus, although 1.0 kW/m^2 of solar energy reaches the earth at noon at the equator, the trees growing in northerly Sweden can harvest a day-and-night and seasonal average of only 0.5 Watts of thermal energy per horizontal square meter⁶. Since Sweden's present primary energy use is approximately 0.04 TW_t , it follows that if no other sources of energy were used, a square area of *Salix* forest 290 kilometers on each side would supply Sweden's present energy needs. This corresponds to an area of $84,000 \text{ km}^2$, about 19% of Sweden's total

⁵The area is assumed to be perpendicular to the sun's rays.

⁶In tropical regions, the rate of biomass production can be more than double this amount.

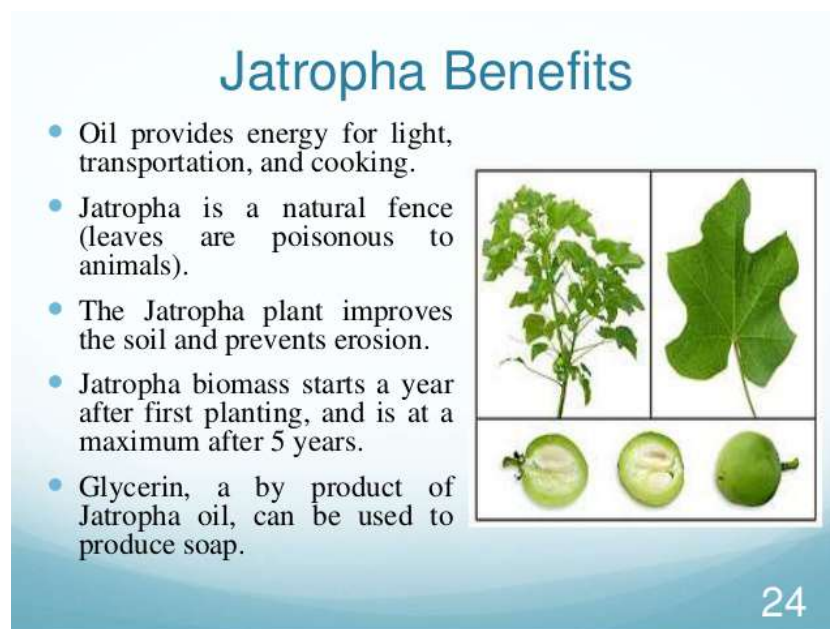


Figure 2.12: In some countries, Jatropha is a promising source of biomass..

area⁷. Of course, Sweden's renewable energy program will not rely exclusively on energy crops, but on a mixture of sources, including biomass from municipal and agricultural wastes, hydropower, wind energy and solar energy.

At present, both Sweden and Finland derive about 30% of their electricity from biomass, which is largely in the form of waste from the forestry and paper industries of these two countries.

Despite their northerly location, the countries of Scandinavia have good potentialities for developing biomass as an energy source, since they have small population densities and adequate rainfall. In Denmark, biodiesel oil derived from rapeseed has been used as fuel for experimental buses. Rapeseed fields produce oil at the rate of between 1,000 and 1,300 liters per hectare-crop. The energy yield is 3.2 units of fuel product energy for every unit of fuel energy used to plant the rapeseed, and to harvest and process the oil. After the oil has been pressed from rapeseed, two-thirds of the seed remains as a protein-rich residue which can be fed to cattle.

Miscanthus is a grassy plant found in Asia and Africa. Some forms will also grow in Northern Europe, and it is being considered as an energy crop in the United Kingdom. Miscanthus can produce up to 18 dry tonnes per hectare-year, and it has the great advantage that it can be cultivated using ordinary farm machinery. The woody stems are very suitable for burning, since their water content is low (20-30%).

For some southerly countries, honge oil, derived from the plant *Pongamia pinnata* may prove to be a promising source of biomass energy. Studies conducted by Dr. Udishi

⁷Additional land area would be needed to supply the energy required for planting, harvesting, transportation and utilization of the wood.

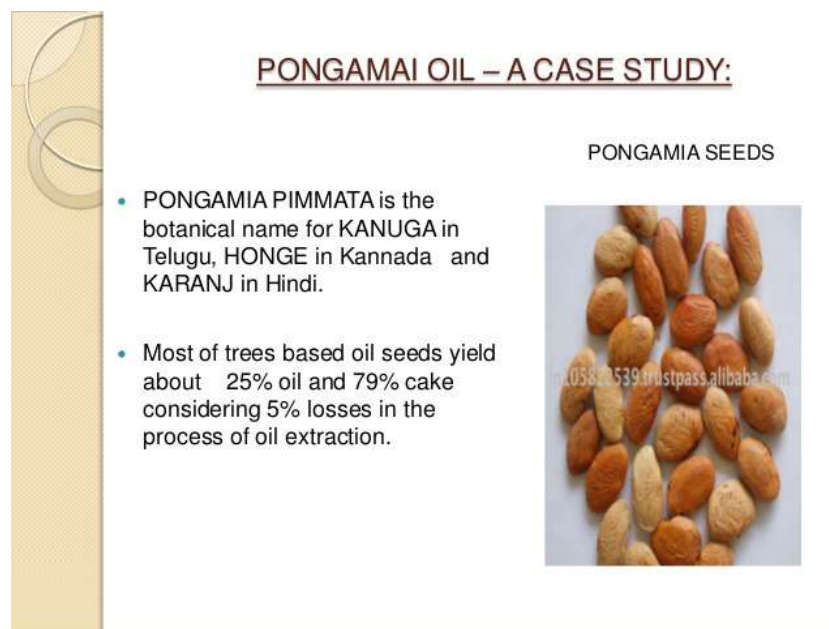


Figure 2.13: **The price of honge oil is quite competitive with other forms of oil.**

Shrinivasa at the Indian Institute of Sciences in Bangalore indicate that honge oil can be produced at the cost of \$150 per ton. This price is quite competitive when compared with other potential fuel oils.

Recent studies have also focused on a species of algae that has an oil content of up to 50%. Algae can be grown in desert areas, where cloud cover is minimal. Farm waste and excess CO₂ from factories can be used to speed the growth of the algae.

It is possible that in the future, scientists will be able to create new species of algae that use the sun's energy to generate hydrogen gas. If this proves to be possible, the hydrogen gas may then be used to generate electricity in fuel cells, as will be discussed below in the section on hydrogen technology. Promising research along this line is already in progress at the University of California, Berkeley.

Biogas is defined as the mixture of gases produced by the anaerobic digestion of organic matter. This gas, which is rich in methane (CH₄), is produced in swamps and landfills, and in the treatment of organic wastes from farms and cities. The use of biogas as a fuel is important not only because it is a valuable energy source, but also because methane is a potent greenhouse gas, which should not be allowed to reach the atmosphere. Biogas produced from farm wastes can be used locally on the farm, for cooking and heating, etc. When biogas has been sufficiently cleaned so that it can be distributed in a pipeline, it is known as "renewable natural gas". It may then be distributed in the natural gas grid, or it can be compressed and used in internal combustion engines. Renewable natural gas can also be used in fuel cells, as will be discussed below in the section on Hydrogen Technology.

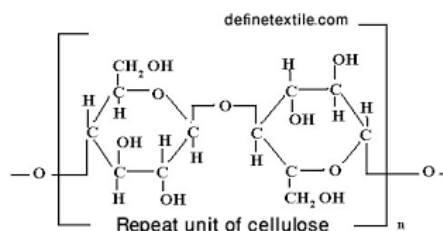


Figure 2.14: Cellulose is a polysaccharide. In other words, it is a long polymer whose subunits are sugars. The links between the sugar subunits in the chain can be broken, for example by the action of enzymes or acids. After this has been done, the resulting sugars can be fermented into alcohols, and these can be used to fuel motor vehicles or aircraft.

Cellulostic ethanol

The fact that alcohols such as ethanol can be produced from cellulose has long been known.⁸ In 1819, the French chemist Henri Braconnot demonstrated that cellulose could be broken down into sugars by treating it with sulfuric acid. The sugars thus produced could then be fermented into alcohols which could be used as liquid fuels.

In 1898, Germany built factories to commercialize this process, and shortly afterwards the same was done in the United States using a slightly different technique. These plants producing cellulostic ethanol operated during World War I, but the plants closed after the end of the war because of the cheapness and easy availability of fossil fuels. The production of cellulostic ethanol was revived during World War II.

During the last two decades, development of enzymatic techniques has supplied a better method of breaking the long cellulose polymer chain into sugars. In fact, it has recently become possible to use microbial enzymes both for this step and for the fermentation step.

In a September 9, 2008 article in the *MIT Technology Review*, Prachi Patal wrote: “New genetically modified bacteria could slash the costs of producing ethanol from cellulostic biomass, such as corn cobs and leaves, switchgrass, and paper pulp. The microbes produce ethanol at higher temperatures than are possible using yeast, which is currently employed to ferment sugar into the biofuel. The higher temperature more than halves the quantity of the costly enzymes needed to split cellulose into the sugars that the microbes can ferment. What’s more, while yeast can only ferment glucose, ‘this microorganism is good at using all the different sugars in biomass and can use them simultaneously and rapidly,’ says Lee Lynd, an engineering professor at Dartmouth College, who led the microbe’s development...

“Lynd wants to create microbes that would do it all: efficiently break down the cellulose and hemicellulose, and then ferment all the resulting sugars. Lynd, a cofounder of Mascoma, is working with colleagues at the startup, based in Cambridge, MA, to develop a simple one-step process for making cellulostic ethanol. In the combined process, a mixture of biomass and the microbes would go into a tank, and ethanol would come out.”

Cellulostic ethanol has several advantages over alcohol derived from grain;

⁸See the Wikipedia article on *Cellulostic Ethanol*

- Cellulostic ethanol avoids the food-fuel competition.
- The net greenhouse-gas-reducing effect of ethanol derived from grain is questionable.
- Cellulostic ethanol can use cardboard and paper waste as starting substances, thus reducing the quantity of trash in waste dumps.

2.7 Geothermal energy

The ultimate source of geothermal energy is the decay of radioactive nuclei in the interior of the earth. Because of the heat produced by this radioactive decay, the temperature of the earth's core is 4300 °C. The inner core is composed of solid iron, while the outer core consists of molten iron and sulfur compounds. Above the core is the mantle, which consists of a viscous liquid containing compounds of magnesium, iron, aluminum, silicon and oxygen. The temperature of the mantle gradually decreases from 3700 °C near the core to 1000 °C near the crust. The crust of the earth consists of relatively light solid rocks and it varies in thickness from 5 to 70 km.

The outward flow of heat from radioactive decay produces convection currents in the interior of the earth. These convection currents, interacting with the earth's rotation, produce patterns of flow similar to the trade winds of the atmosphere. One result of the currents of molten conducting material in the interior of the earth is the earth's magnetic field. The crust is divided into large sections called "tectonic plates", and the currents of molten material in the interior of the earth also drag the plates into collision with each other. At the boundaries, where the plates collide or split apart, volcanic activity occurs. Volcanic regions near the tectonic plate boundaries are the best sites for collection of geothermal energy.

The entire Pacific Ocean is ringed by regions of volcanic and earthquake activity, the so-called Ring of Fire. This ring extends from Tierra del Fuego at the southernmost tip of South America, northward along the western coasts of both South America and North America to Alaska. The ring then crosses the Pacific at the line formed by the Aleutian Islands, and it reaches the Kamchatka Peninsula in Russia. From there it extends southward along the Kurile Island chain and across Japan to the Philippine Islands, Indonesia and New Zealand. Many of the islands of the Pacific are volcanic in nature. Another important region of volcanic activity extends northward along the Rift Valley of Africa to Turkey, Greece and Italy. In the Central Atlantic region, two tectonic plates are splitting apart, thus producing the volcanic activity of Iceland. All of these regions are very favorable for the collection of geothermal power.

The average rate at which the energy created by radioactive decay in the interior of the earth is transported to the surface is $0.06 \text{ W}_t/\text{m}^2$. However, in volcanic regions near the boundaries of tectonic plates, the rate at which the energy is conducted to the surface is much higher - typically $0.3 \text{ W}_t/\text{m}^2$. If we insert these figures into the thermal conductivity law

$$q = K_T \frac{\Delta T}{z}$$

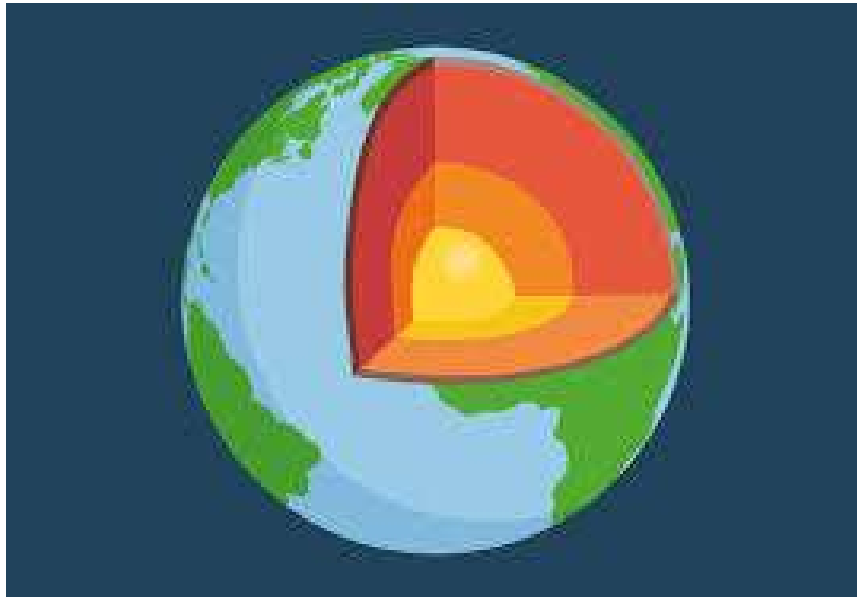


Figure 2.15: The source of geothermal energy is the radioactive decay of elements deep within the earth.



Figure 2.16: The “ring of fire” is especially favorable for geothermal energy installations. The ring follows the western coasts of South America and North America to Alaska, After crossing the Bering Sea, it runs southward past Japan and Indonesia to New Zealand. Earthquakes and volcanic activity along this ring are produced by the collision of tectonic plates. Another strip-like region very favorable for geothermal installations follows Africa’s Rift Valley northward through Turkey and Greece to Italy, while a third pass through Iceland.

we can obtain an understanding of the types of geothermal resources available throughout the world. In the thermal conductivity equation, q is the power conducted per unit area, while K_T is the thermal conductivity of the material through the energy is passing. For sandstones, limestones and most crystalline rocks, thermal conductivities are in the range 2.5-3.5 $\text{W}_t/(\text{m } ^\circ\text{C})$. Inserting these values into the thermal conductivity equation, we find that in regions near tectonic plate boundaries we can reach temperatures of 200 $^\circ\text{C}$ by drilling only 2 kilometers into rocks of the types named above. If the strata at that depth contain water, it will be in the form of highly-compressed steam. Such a geothermal resource is called a *high-enthalpy* resource⁹.

In addition to high-enthalpy geothermal resources there are *low-enthalpy* resources in nonvolcanic regions of the world, especially in basins covered by sedimentary rocks. Clays and shales have a low thermal conductivity, typically 1-2 $\text{W}_t/(\text{m } ^\circ\text{C})$. When we combine these figures with the global average geothermal power transmission, $q = 0.06 \text{ W}_t/\text{m}^2$, the thermal conduction equation tells us that $\Delta T/z = 0.04 \text{ } ^\circ\text{C}/\text{m}$. In such a region the geothermal resources may not be suitable for the generation of electrical power, but nevertheless adequate for heating buildings. The Creil district heating scheme north of Paris is an example of a project where geothermal energy from a low enthalpy resource is used for heating buildings.

The total quantity of geothermal electrical power produced in the world today is 8 GW_e , with an additional 16 GW_t used for heating houses and buildings. In the United States alone, 2.7 GW_e are derived from geothermal sources. In some countries, for example Iceland and Canada, geothermal energy is used both for electrical power generation and for heating houses.

There are three methods for obtaining geothermal power in common use today: Deep wells may yield dry steam, which can be used directly to drive turbines. Alternatively water so hot that it boils when brought to the surface may be pumped from deep wells in volcanic regions. The steam is then used to drive turbines. Finally, if the water from geothermal wells is less hot, it may be used in binary plants, where its heat is exchanged with an organic fluid which then boils. In this last method, the organic vapor drives the turbines. In all three methods, water is pumped back into the wells to be reheated. The largest dry steam field in the world is The Geysers, 145 kilometers north of San Francisco, which produces 1,000 MW_e .

There is a fourth method of obtaining geothermal energy, in which water is pumped down from the surface and is heated by hot dry rocks. In order to obtain a sufficiently large area for heat exchange the fissure systems in the rocks must be augmented, for example by pumping water down at high pressures several hundred meters away from the collection well. The European Union has established an experimental station at Soultz-sous-Forêts in the Upper Rhine to explore this technique. The experiments performed at Soultz will determine whether the “hot dry rock” method can be made economically viable. If so, it can potentially offer the world a very important source of renewable energy.

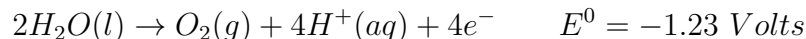
⁹Enthalpy $\equiv H \equiv U + PV$ is a thermodynamic quantity that takes into account not only the internal energy U of a gas, but also energy PV that may be obtained by allowing it to expand.

The molten lava of volcanoes also offers a potential source of geothermal energy that may become available in the future, but at present, no technology has been developed that is capable of using it.

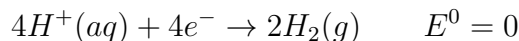
2.8 Hydrogen technologies

Electrolysis of water

When water containing a little acid is placed in a container with two electrodes and subjected to an external direct current voltage greater than 1.23 Volts, bubbles of hydrogen gas form at one electrode (the cathode), while bubbles of oxygen gas form at the other electrode (the anode). At the cathode, the half-reaction

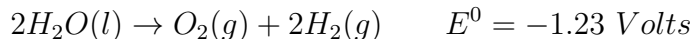


takes place, while at the anode, the half-reaction



occurs.

Half-reactions differ from ordinary chemical reactions in containing electrons either as reactants or as products. In electrochemical reactions, such as the electrolysis of water, these electrons are either supplied or removed by the external circuit. When the two half-reactions are added together, we obtain the total reaction:



Notice that $4H^+$ and $4e^-$ cancel out when the two half-reactions are added. The total reaction does not occur spontaneously, but it can be driven by an external potential E , provided that the magnitude of E is greater than 1.23 volts.

When this experiment is performed in the laboratory, platinum is often used for the electrodes, but electrolysis of water can also be performed using electrodes made of graphite.

Electrolysis of water to produce hydrogen gas has been proposed as a method for energy storage in a future renewable energy system. For example, it might be used to store energy generated by photovoltaics in desert areas of the world. Compressed hydrogen gas could then be transported to other regions and used in fuel cells. Electrolysis of water and storage of hydrogen could also be used to solve the problem of intermittency associated with wind energy or solar energy.

Half reactions

Chemical reactions in which one or more electrons are transferred are called *oxidation-reduction reactions*. Any reaction of this type can be used in a fuel cell. As an example,

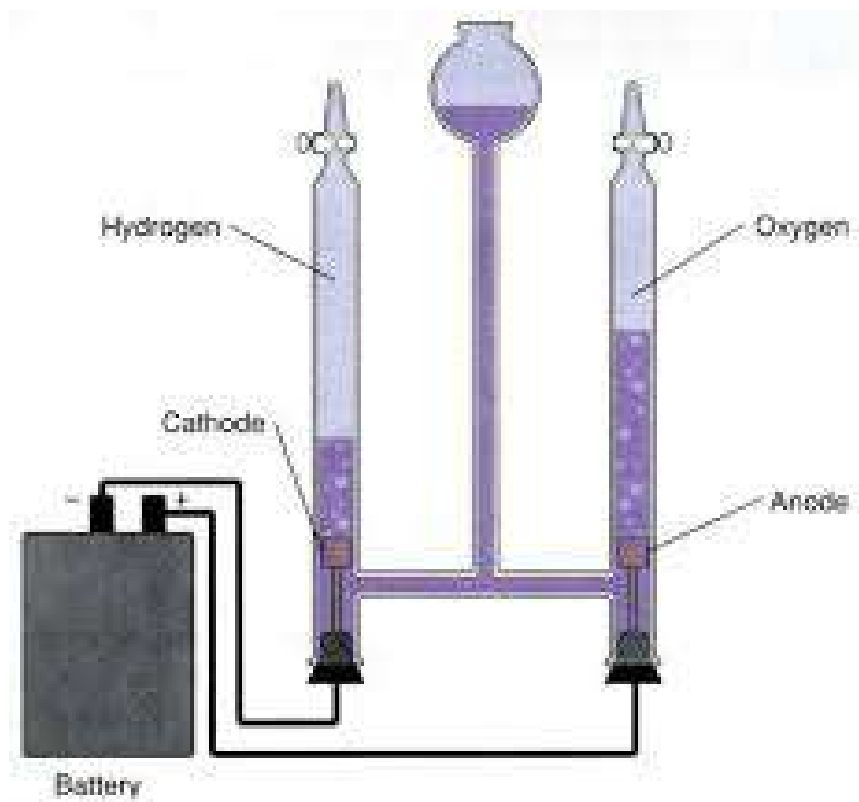


Figure 2.17: Electrolysis of water.

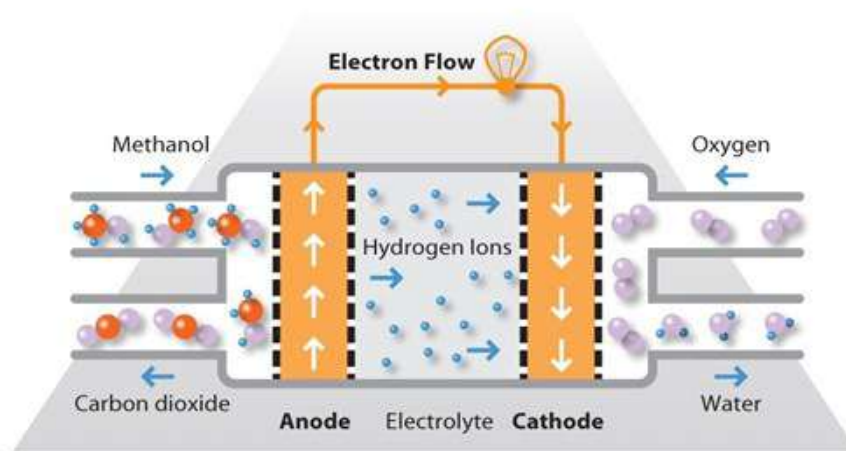
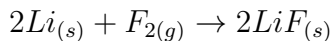


Figure 2.18: A methanol fuel cell.

we can consider the oxidation-reduction reaction in which solid lithium metal reacts with fluorine gas;



This reaction can be split into two half-reactions,



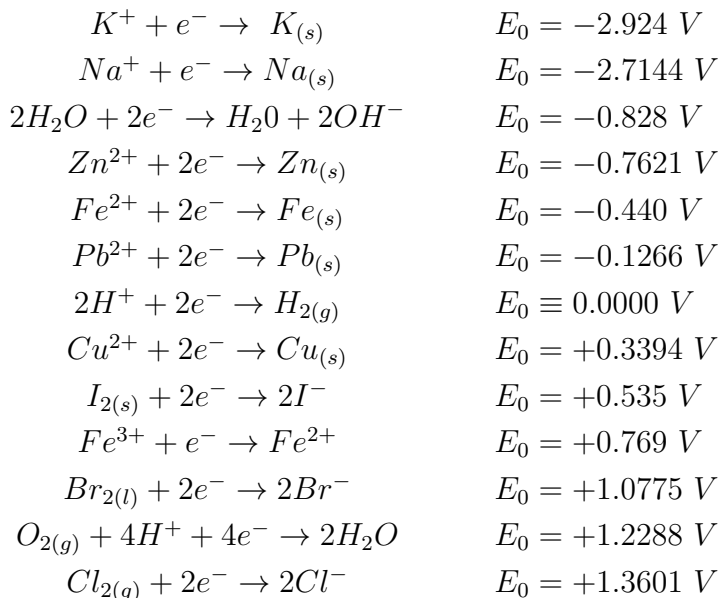
and



The quantity E_0 which characterizes these half-reactions is called *standard potential* of the half-reaction, and it is measured in Volts. If the oxidation-reduction reaction is used as the basis of a fuel cell, the voltage of the cell is the difference between the two standard potentials. In the lithium fluoride example, it is

$$2.87 \text{ V} - (-3.040 \text{ V}) = 5.91 \text{ V}$$

Here are a few more half-reactions and their standard potentials:



Fuel cells are closely related to storage batteries. Essentially, when we recharge a storage battery we are just running a fuel cell backwards, applying an electrical potential which is sufficient to make a chemical reaction run in a direction opposite to the way that it would run spontaneously. When the charged battery is afterwards used to drive a vehicle or to power an electronic device, the reaction runs in the spontaneous direction, but the energy of the reaction, instead of being dissipated as heat, drives electrons through an external circuit and performs useful work.

The next section is devoted to the renewable energy contributions of Elon Musk, and, as we shall see, he has done much to develop the technology of rechargeable batteries.

2.9 Elon Musk and renewable energy technology

Elon Reve Musk was born in 1971 in South Africa. At the age of 10, he developed an interest in computer programming, and by 12 he had invented a computer game which he sold for \$500. Just before his 18th birthday, Musk moved to Canada, obtaining citizenship through his Canadian-born mother. After studying for two years at Queens University in Kingston Ontario, Musk moved to the University of Pennsylvania, where where he obtained degrees in both science and economics.

At the age of 24, Elon Musk started Ph.D. studies in applied physics and material science at Stanford University, but he left the program (after 2 days!) to pursue his interests in the Internet-based businesses, renewable energy and outer space. He became a US citizen in 2002. In the meantime, Musk's business ventures and his inventions have made him the 80th wealthiest person in the world. In 2016 he was ranked as 21st on the Forbes list of the world's most powerful people. He has been called the new Thomas Edison.

Luckily, the transition to 100% renewable energy holds a high place in Musk's priorities, and he has applied his genius both as an inventor and as a businessman to achieving this goal. Two of the corporations led by Musk, Tesla and Solar City, are devoted to solving the problem of intermittency through improved storage batteries, replacing petroleum-driven automobiles by attractive and affordable electric cars, and harnessing solar energy.

SolarCity leases rooftop solar to customers who pay no upfront costs. In exchange, customers pay for 20 years for power generated by those panels.

Wikipedia states that "In June 2014, SolarCity announced plans to build a new manufacturing facility in Buffalo, New York, in coordination with the SUNY Polytechnic Institute after acquiring Silevo, a maker of high-efficiency solar modules. The initial manufacturing complex will be a 1.2-million-square-foot (110,000 m²) facility that will cost \$900 million and employ 1,500 workers in Buffalo and 5,000 statewide."

Speaking at the University of Paris during the recent climate talks, Elon Musk said "The important thing to appreciate is if let's say the only thing we had was solar energy, that that was the only power source, if you just took a small section of Spain, you could power all of Europe. It's a very small amount of area that's actually needed to generate the electricity we need to power civilization, or in the case of the US, a little corner of Nevada or Utah, power the entire United States."

Musk has also predicted that by 2031, solar energy will be the world's largest energy source.

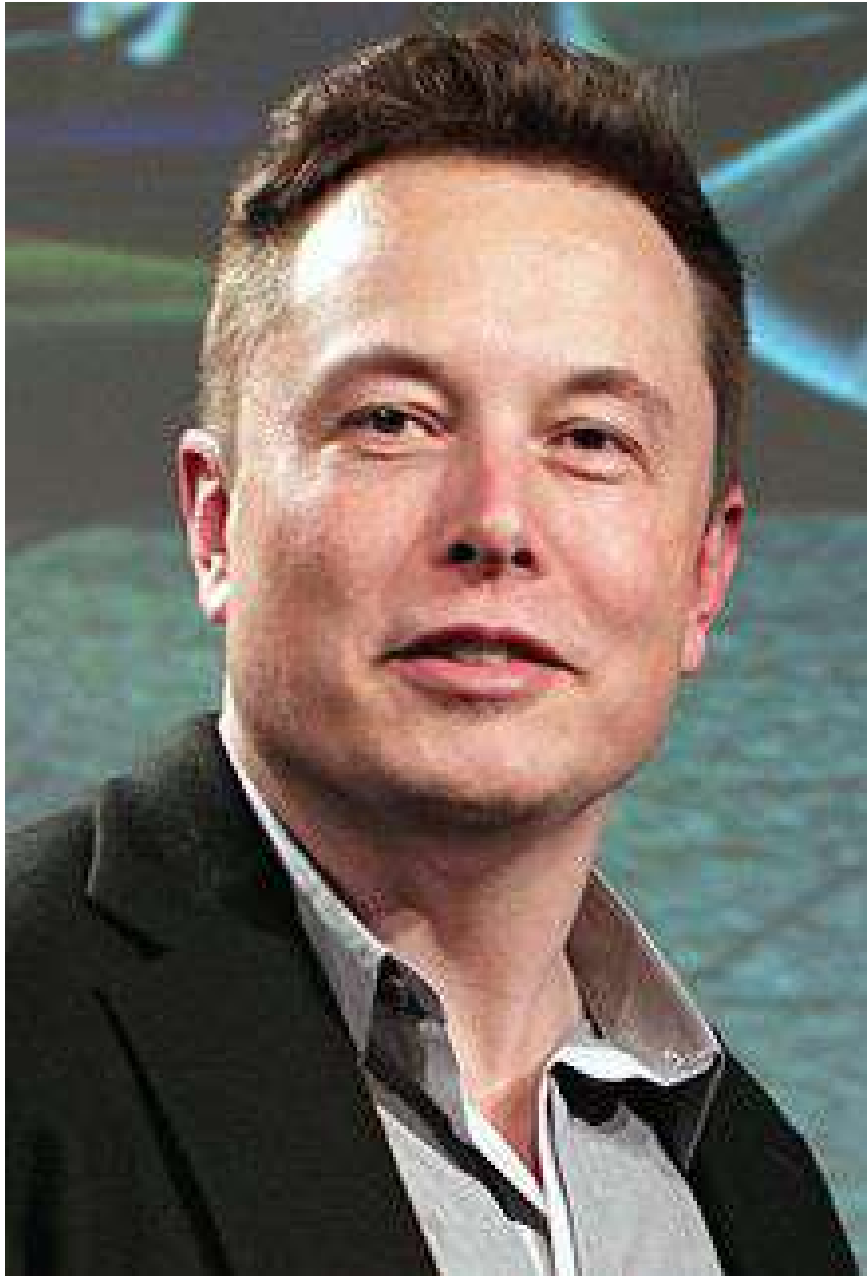


Figure 2.19: Elon Musk in 2015 (Wikipedia)



Figure 2.20: Tesla's Gigafactory 1 in Nevada produces improved lithium ion batteries. Energy for the factory is supplied by solar panels on the roof.



Figure 2.21: Gigafactory 2. SolarCity's factory in Buffalo New York produces high-efficiency solar modules. Elon Musk estimates that only 100 gigafactories would be enough to achieve a worldwide transition to 100% renewable energy.

2.10 Concluding remarks

At the start of this chapter we asked whether we will ultimately be forced by energy shortages to reduce our global population, or our per capita energy consumption, or both. In this chapter we have seen that renewable energy alternatives to fossil fuels are growing extremely rapidly, and that they offer great hope for the future.

On the other hand, the global population of humans is now increasing so rapidly that almost a billion people are added every decade. Economists continue to insist that industrial growth is necessary for “economic health”. But never-ending growth on a finite planet is a logical absurdity. Neither global population nor resource-using, pollution-producing industries can continue to grow forever. In fact, we have already exceeded the limits of sustainability.

Thus, despite the rapid growth renewable energy technology, we will be forced in the very near future to change our lifestyles, and to give culture a higher place than material goods. We will also need to devote more attention and more resources to the problem of stabilizing and ultimately reducing global population.

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Chapter 3

CONTINUED EXTRACTION OF FOSSIL FUELS

3.1 The Middle East

According to current estimates, 81.5% of the world's proven crude oil reserves are located in OPEC Member Countries, with the bulk of OPEC oil reserves in the Middle East, amounting to 65.5% of the OPEC total.

3.2 China

China's large reserves of coal lie near to the surface, and are thus very easily accessible. Mining of coal has driven the country's rapid industrial growth, but it has also produced a severe public health problem because of air pollution.

In April, 2017, China's rate of economic growth was 6.9%¹. This rate of growth, if continued, would mean that China's economy would double every ten years. and increase by a factor of 1024 every century. Obviously this is impossible. Never-ending economic growth on a finite planet is a logical absurdity. China's high economic growth rate, is driven by its use of coal, and this must quickly stop if ecological disaster is to be avoided.

3.3 India

The MIT Technology Review recently published an important article entitled *India's Energy Crisis*².

The article makes alarming reading in view of the world's urgent need to make a very rapid transition from fossil fuels to 100% renewable energy. We must make this change

¹<https://tradingeconomics.com/china/gdp-growth-annual>

²<http://www.technologyreview.com/featuredstory/542091/indias-energy-crisis/>

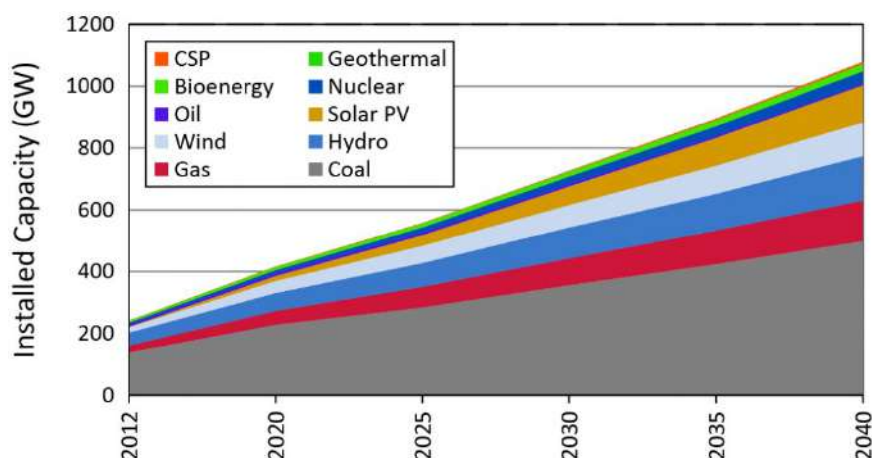


Figure 3.1: **India's installed and future energy mix, as visualized by the World Coal Association**

quickly in order to avoid a tipping point beyond which catastrophic climate change will be unavoidable.

The MIT article states that “Since he took power in May, 2014, Prime Minister Narendra Modi has made universal access to electricity a key part of his administration’s ambitions. At the same time, he has pledged to help lead international efforts to limit climate change. Among other plans, he has promised to increase India’s total power generating capacity to 175 gigawatts, including 100 gigawatts of solar, by 2022. (That’s about the total power generation of Germany.)”

However India plans to expand its industrial economy, and to do this, it is planning to very much increase its domestic production and use of coal. The MIT article continues, pointing out that

However India plans to expand its industrial economy, and to do this, it is planning to very much increase its domestic production and use of coal. The MIT article continues, pointing out that “Such growth would easily swamp efforts elsewhere in the world to curtail carbon emissions, dooming any chance to head off the dire effects of global climate change. (Overall, the world will need to reduce its current annual emissions of 40 billion tons by 40 to 70 percent between now and 2050.) By 2050, India will have roughly 20 percent of the world’s population. If those people rely heavily on fossil fuels such as coal to expand the economy and raise their living standards to the level people in the rich world have enjoyed for the last 50 years, the result will be a climate catastrophe regardless of anything the United States or even China does to decrease its emissions. Reversing these trends will require radical transformations in two main areas: how India produces electricity, and how it distributes it.”

The Indian Minister of Power, Piyush Goyal, is an enthusiastic supporter of renewable energy expansion, but he also supports, with equal enthusiasm, the large-scale expansion of domestic coal production in India.

Meanwhile, the consequences of global warming are being felt by the people of India.

For example, last May, a heat wave killed over 1,400 people and melted asphalt streets.³

Have India's economic planners really thought about the long-term future? Have they considered the fact that drastic climate change could make India completely uninhabitable?

3.4 Russia

According to Wikipedia, "The petroleum industry in Russia is one of the largest in the world. Russia has the largest reserves, and is the largest exporter, of natural gas. It has the second largest coal reserves, the eighth largest oil reserves, and is one of the largest producer of oil. It is the third largest energy user."

One of the difficulties of reducing Russia's fossil fuel production is that the Russian economy depends so heavily on its oil and gas industries. Many European countries also depend on natural gas from Russia for winter heating of homes and workplaces.

³<https://www.rt.com/news/262641-india-heat-wave-killed/>



Figure 3.2: Oil production on the shelf in the Russian Arctic.

3.5 North America

Canadian oil sands

Canada's oil-sands deposits contain an amount of carbon comparable to the world's total reserves of conventional oil. Oil is currently being extracted by methods that release four times as much carbon into the atmosphere as is contained in the refined oil from the deposits. Nevertheless, the government of Canada wholeheartedly supports extraction of oil from the tar sands.

The position of the Canadian government has been strongly criticized by leading climate scientist Professor James Hansen. A recent article in *The Guardian*⁴, reported him as saying; "To leave our children with a manageable situation, we need to leave the unconventional fuel in the ground. Canada's ministers are acting as salesmen for those people who will gain from the profits of that industry. But I don't think they are looking after the rights and wellbeing of the population as a whole.

"The thing we are facing overall is that the fossil fuel industry has so much money that they are buying off governments. Our democracies are seriously handicapped by the money that is driving decisions in Washington and other capitals."

Fracking in the United States

According to the US Department of Energy (DOE), in 2013 at least two million oil and gas wells in the US have been hydraulically fractured, and that of new wells being drilled,

⁴<https://www.theguardian.com/environment/2013/may/19/tar-sands-exploitation-climate-scientist>



Figure 3.3: **Get rich quick at the oil sands.**

up to 95% are hydraulically fractured. The output from these wells makes up 43% of the oil production and 67% of the natural gas production in the United States.

Because of earthquakes and poisoning of water supplies caused by fracking, this practice has been banned by several states in the US, and nine countries or regions in Europe: France, Bulgaria, Roumania, Germany, The Czech Republic, Luxembourg, Northern Ireland, Spain and Switzerland,

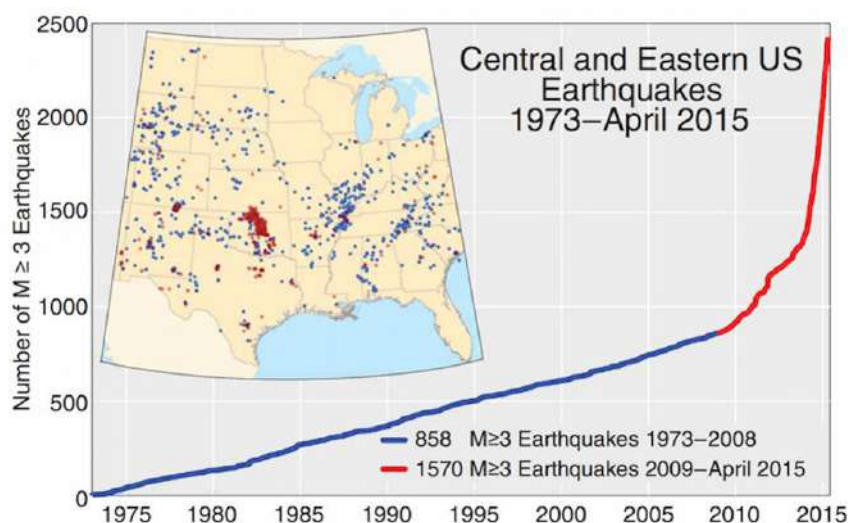


Figure 3.4: The sharply increased number of earthquakes in the United States has been linked to fracking. The use of fracking has also caused poisoning of water supplies.

3.6 Latin America

Venezuela's Belt of Tar

The Orinoco River Basin in Venezuela contains the world's largest deposit of extra-heavy oil and tar. The amount of carbon contained in this deposit is comparable to the carbon content of all the world's known reserves of conventional oil, and also larger than the carbon contained in Canada's oil sands.

The Belt of Tar follows the line of the Orinoco river. It is approximately 600 kilometers (370 mi) from east to west, and 70 kilometers (43 mi) from north to south, with an area about 55,314 square kilometers (21,357 sq mi). The Orinoco deposit is estimated to contain 1.2 trillion barrels of extra-heavy oil.

The government of Venezuela has no plans for halting extraction from the Belt of Tar. On the contrary, detailed plans have been made for expanded exploitation of the deposit⁵.

Extraction of oil in Brazil

According to a recent article in *The Guardian*⁶ "The discovery of tens of billions of barrels of oil in fields far off the coast of Rio de Janeiro was billed as one of the biggest finds of this century when it was announced in 2006.

⁵<https://en.wikipedia.org/wiki/PDVSA>

⁶<https://www.theguardian.com/environment/ng-interactive/2015/jun/25/brazils-gamble-on-deep-water-oil-guanabara-bay>



Figure 3.5: Venezuela's Belt of Tar under the Orinoco River Basin is the world's largest deposit of extra-heavy oil and tar.

“Many hoped it would deliver a bonanza for education and health and make Brazil one of world’s major economies.

“But with the country’s biggest energy company, Petrobras, mired in debt and scandal, the low price of oil and the dangers of a second Deepwater Horizon, the viability of this massive undertaking has never been under more scrutiny.”

The Brazilian offshore deposits are called “presalt oil”, since they lie under a thick layer of salt deposits.

According to the article in *The Guardian*, “Suggestions by climate campaigners that this reservoir of fossil fuel is a ‘carbon bomb’ that should be left in the ground, are dismissed as hypocrisy.”

The article quotes the geologist who discovered the off-shore fields as saying “The big countries of the world today developed without any concern for the environment. The base of US development was the oil in the Gulf of Mexico. The base of the UK’s industrial revolution was coal. How can they now say we can’t use our own pre-salt?”

3.7 The European Union

Coal in Germany and Poland

In 2016, Germany produced 176,100,000 tonnes of coal while Poland produced 131,100,000 tonnes. In the past, Poland experienced severe ecological effects from acid rain due to the burning of coal. Polish forests were destroyed by the effects of acid rain, and the facades of statues and buildings in Krakow and elsewhere were dissolved by the acid. Today the situation is improving, but the two countries are still heavily dependant on coal.

North Sea oil

According to Wikipedia, “The British and Norwegian sections hold most of the remainder of the large oil reserves. It is estimated that the Norwegian section alone contains 54% of the sea’s oil reserves and 45% of its gas reserves- More than half of the North Sea oil reserves have been extracted, according to official sources in both Norway and the UK. For Norway, the Norwegian Petroleum Directorate [28] gives a figure of 4,601 million cubic meters of oil (corresponding to 29 billion barrels) for the Norwegian North Sea alone (excluding smaller reserves in Norwegian Sea and Barents Sea) of which 2,778 million cubic meters (60%) has already been produced prior to January 2007. UK sources give a range of estimates of reserves, but even using the most optimistic ‘maximum’ estimate of ultimate recovery, 76% had been recovered at end 2010.[citation needed] Note the UK figure includes fields which are not in the North Sea (onshore, West of Shetland).

3.8 Major producers of fossil fuels

The top 20 oil-producing nations in 2016

Wikipedia's article entitles *List of countries by oil production* gives information shown in the table below. In the table, which is based on data from the International Energy Agency, production is measured in barrels of oil per day

1	Russia	10,551,497
2	Saudi Arabia	10,460,710
3	United States	8,875,817
4	Iraq	4,451,516
5	Iran	3,990,956
6	China	3,980,650
7	Canada	3,662,694
8	United Arab Emirates	3,106,077
9	Kuwait	2,923,825
10	Brazil	2,515,459
11	Venezuela	2,276,967
12	Mexico	2,186,877
13	Nigeria	1,999,885
14	Angola	1,769,615
15	Norway	1,647,975
16	Kazakhstan	1,595,199
17	Qatar	1,522,902
18	Algeria	1,348,361
19	Oman	1,006,841
20	United Kingdom	939,760

The top 10 coal producing nations in 2016

Wikipedia gives a similar list of coal producing nations. Only the top 10 are shown here, since these countries completely dominate global coal production. In the table, production is measured in millions of tonnes per year.

1	China	3411.0
2	India	692.4
3	United States	660.6
4	Australia	492.8
5	Indonesia	434.0
6	Russia	385.4
7	South Africa	251.3
8	Germany	176.1
9	Poland	131.1
10	Kazakhstan	102.4
	World	7,460.4

The world production of coal is falling. In 2014 it was 8,164.9 tonnes, in 2015, 7,861.1 tonnes, and in 2016 7,460.4 tonnes. Nevertheless, global production of coal remains worryingly high. If catastrophic climate change is to be avoided, it must stop altogether within one or two decades. At the moment the world is still producing roughly 1 tonne of coal per capita each year.

List of countries by natural gas production

Here is a similar table for natural gas. Production is measured in m³ per year. The final column indicates the date of the data.

1	United States	728,200,000,000	2014
2	Russia	578,700,000,000	2014
3	Iran	438,000,000,000	2017
4	Canada	143,100,000,000	2012
5	Qatar	133,200,000,000	2011
6	Norway	114,700,000,000	2012
7	China	107,200,000,000	2012
8	Saudi Arabia	103,200,000,000	2012
9	Algeria	82,760,000,000	2011
10	Netherlands	80,780,000,000	2012
	World	4,359,000,000,000	2010



Figure 3.6: A view of oil refineries from the Galveston Channel in Texas (Photo: Roy Luck/flick/CC)

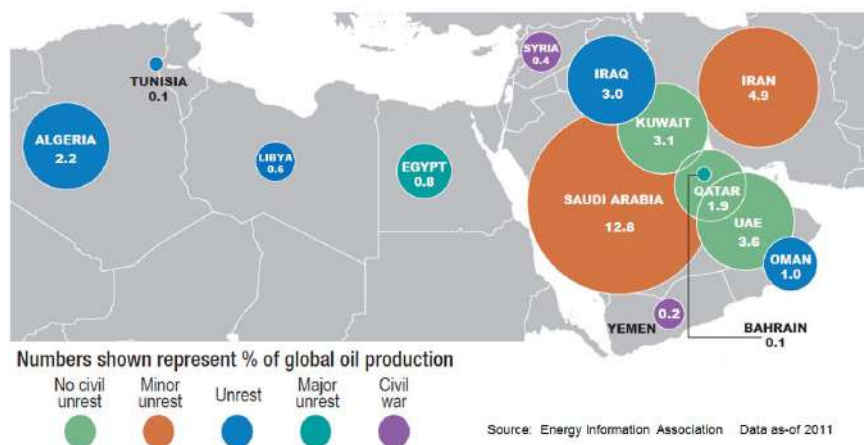


Figure 3.7: A map showing the major oil-producing countries of the Middle East and North Africa. The percent of global oil production is indicated. Many of the countries shown have some degree of civil unrest or civil war.



Figure 3.8: Burning of coal in China has contributed to rapid industrial growth, but besides being a major factor in the threat of catastrophic climate change, it has produced hundreds of thousands of deaths each year through air pollution (an estimated 366,000 in 2013).



Figure 3.9: Protests against the Keystone XL and Dakota Access pipelines which, if completed, would carry oil from the Canadian oil sands to refineries in Texas.



Figure 3.10: Protesters at the 2017 G20 meeting in Hamburg Germany.

3.9 Blood for oil

There is a close relationship between petroleum and war. James A. Paul, Executive Director of the Global Policy Forum, has described this relationship very clearly in the following words:

“Modern warfare particularly depends on oil, because virtually all weapons systems rely on oil-based fuel - tanks, trucks, armored vehicles, self-propelled artillery pieces, airplanes, and naval ships. For this reason, the governments and general staffs of powerful nations seek to ensure a steady supply of oil during wartime, to fuel oil-hungry military forces in far-flung operational theaters.”

“Just as governments like the US and UK need oil companies to secure fuel for their global war-making capacity, so the oil companies need their governments to secure control over global oilfields and transportation routes. It is no accident, then, that the world’s largest oil companies are located in the world’s most powerful countries.”

“Almost all of the world’s oil-producing countries have suffered abusive, corrupt and undemocratic governments and an absence of durable development. Indonesia, Saudi Arabia, Libya, Iraq, Iran, Angola, Colombia, Venezuela, Kuwait, Mexico, Algeria - these and many other oil producers have a sad record, which includes dictatorships installed from abroad, bloody coups engineered by foreign intelligence services, militarization of government and intolerant right-wing nationalism.”

The resource curse

The way in which the industrialized countries maintain their control over less developed nations can be illustrated by the “resource curse”, i.e. the fact that resource-rich developing countries are no better off economically than those that lack resources, but are cursed with corrupt and undemocratic governments. This is because foreign corporations extracting local resources under unfair agreements exist in a symbiotic relationship with corrupt local

officials.

One might think that taxation of foreign resource-extracting firms would provide developing countries with large incomes. However, there is at present no international law governing multinational tax arrangements. These are usually agreed to on a bilateral basis, and the industrialized countries have stronger bargaining powers in arranging the bilateral agreements.

3.10 Fossil fuel extraction must stop!

“Leave the oil in the soil! Leave the coal in the hole! Leave the gas under the grass!” That was message of protesters at the 2017 G20 meeting. But from the facts shown in this chapter, we can see that on the whole, fossil fuels are not being left in the ground, where they have to remain if an ecological disaster is to be avoided. On the contrary, the extraction of coal, oil and gas continues almost as though the climate emergency did not exist. Most politicians, with their eyes focused on the present, seem blind to future dangers. They think primarily about the jobs and living standards of their constituents, and about the next election. Meanwhile, the future of human civilization is neglected and remains in peril.⁷

The fact that historically, the highly industrialized nations were primarily responsible for atmospheric CO₂ increases does not excuse the developing countries from their responsibility for saving the future. Today China’s coal, India’s coal, Venezuela’s tar sands and Brazil’s pre-salt oil are among the greatest threats, and in these countries as elsewhere, extraction must stop.

We have to wake up! Business as usual cannot continue!

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Chapter 4

EXTINCTION EVENTS AND FEEDBACK LOOPS

Introduction

Scientists warn that if the transition to renewable energy does not happen within very few decades, there is a danger that we will reach a tipping point beyond which feedback loops, such as the albedo effect and the methane hydrate feedback loop, will take over and produce an out-of-control and fatal increase in global temperature.

In 2012, the World Bank issued a report warning that without quick action to curb CO₂ emissions, global warming is likely to reach 4 °C during the 21st century. This is dangerously close to the temperature which initiated the Permian-Triassic extinction event: 6 °C above normal. During the Permian-Triassic extinction event, which occurred 252 million years ago, 96% of all marine species were wiped out, as well as 70% of all terrestrial vertebrates.¹

4.1 A warning from the World Bank

In 2012, the World Bank issued a report warning that without quick action to curb CO₂ emissions, global warming is likely to reach 4 °C during the 21st century. This is dangerously close to the temperature which initiated the Permian-Triassic extinction event: 6 °C above normal. During the Permian-Triassic extinction event, which occurred 252 million years ago, 96% of all marine species were wiped out, as well as 70% of all terrestrial vertebrates.²

¹<http://science.nationalgeographic.com/science/prehistoric-world/permian-extinction/>
<http://www.worldbank.org/en/news/feature/2012/11/18/Climate-change-report-warns-dramatically-warmer-world-this-century>

²<http://science.nationalgeographic.com/science/prehistoric-world/permian-extinction/>
<http://www.worldbank.org/en/news/feature/2012/11/18/Climate-change-report-warns-dramatically-warmer-world-this-century>

The 4°C scenarios are devastating: the inundation of coastal cities; increasing risks for food production potentially leading to higher malnutrition rates; many dry regions becoming dryer, wet regions wetter; unprecedented heat waves in many regions, especially in the tropics; substantially exacerbated water scarcity in many regions; increased frequency of high-intensity tropical cyclones; and irreversible loss of biodiversity, including coral reef systems.

And most importantly, a 4°C world is so different from the current one that it comes with high uncertainty and new risks that threaten our ability to anticipate and plan for future adaptation needs. The lack of action on climate change not only risks putting prosperity out of reach of millions of people in the developing world, it threatens to roll back decades of sustainable development. It is clear that we already know a great deal about the threat before us. The science is unequivocal that humans are the cause of global warming, and major changes are already being observed: global mean warming is 0.8°C above pre industrial levels; oceans have warmed by 0.09°C since the 1950s and are acidifying; sea levels rose by about 20 cm since pre-industrial times and are now rising at 3.2 cm per decade; an exceptional number of extreme heat waves occurred in the last decade; major food crop growing areas are increasingly affected by drought.

Despite the global community's best intentions to keep global warming below a 2°C increase above pre-industrial climate, higher levels of warming are increasingly likely. Scientists agree that countries' current United Nations Framework Convention on Climate Change emission pledges and commitments would most likely result in 3.5 to 4°C warming. And the longer those pledges remain unmet, the more likely a 4°C world becomes.

Data and evidence drive the work of the World Bank Group. Science reports, including those produced by the Intergovernmental Panel on Climate Change, informed our decision to ramp up work on these issues, leading to, a World Development Report on climate change designed to improve our understanding of the implications of a warming planet; a Strategic Framework on Development and Climate Change, and a report on Inclusive Green Growth. The World Bank is a leading advocate for ambitious action on climate change, not only because it is a moral imperative, but because it makes good economic sense.

But what if we fail to ramp up efforts on mitigation? What are the implications of a 4°C world? We commissioned this report from the Potsdam Institute for Climate Impact Research and Climate Analytics to help us understand the state of the science and the potential impact on development in such a world.

It would be so dramatically different from today's world that it is hard to describe accurately; much relies on complex projections and interpretations. We are well aware of the uncertainty that surrounds these scenarios and we know that different scholars and studies sometimes disagree on the degree of risk. But the fact that such scenarios cannot be discarded is sufficient to justify strengthening current climate change policies. Finding ways to avoid that scenario is vital for the health and welfare of communities around the world. While every region of the world will be affected, the poor and most vulnerable would be hit hardest. A 4°C world can, and must, be avoided.

The World Bank Group will continue to be a strong advocate for international and

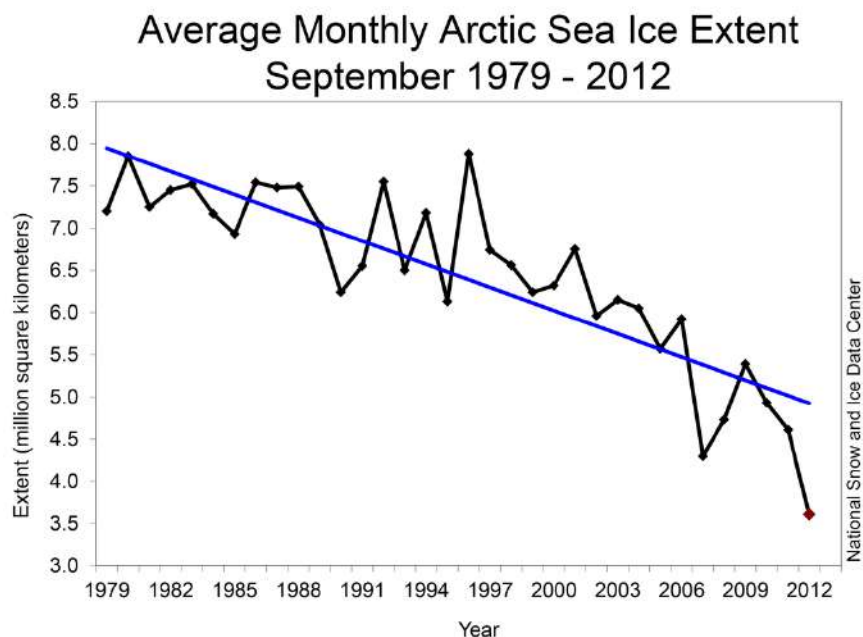


Figure 4.1: Monthly September ice extent for 1979 to 2012 shows a decline of 13.0% per decade. One can also see that the straight line does not really fit the data, which more nearly resemble a downward curve will that reach zero in the period 2016-2019. Source: National Snow and Ice Data Center. Wikimedia Commons

regional agreements and increasing climate financing. We will redouble our efforts to support fast growing national initiatives to mitigate carbon emissions and build adaptive capacity as well as support inclusive green growth and climate smart development. Our work on inclusive green growth has shown that, through more efficiency and smarter use of energy and natural resources, many opportunities exist to drastically reduce the climate impact of development, without slowing down poverty alleviation and economic growth.

This report is a stark reminder that climate change affects everything. The solutions don't lie only in climate finance or climate projects. The solutions lie in effective risk management and ensuring all our work, all our thinking, is designed with the threat of a 4°C degree world in mind. The World Bank Group will step up to the challenge.

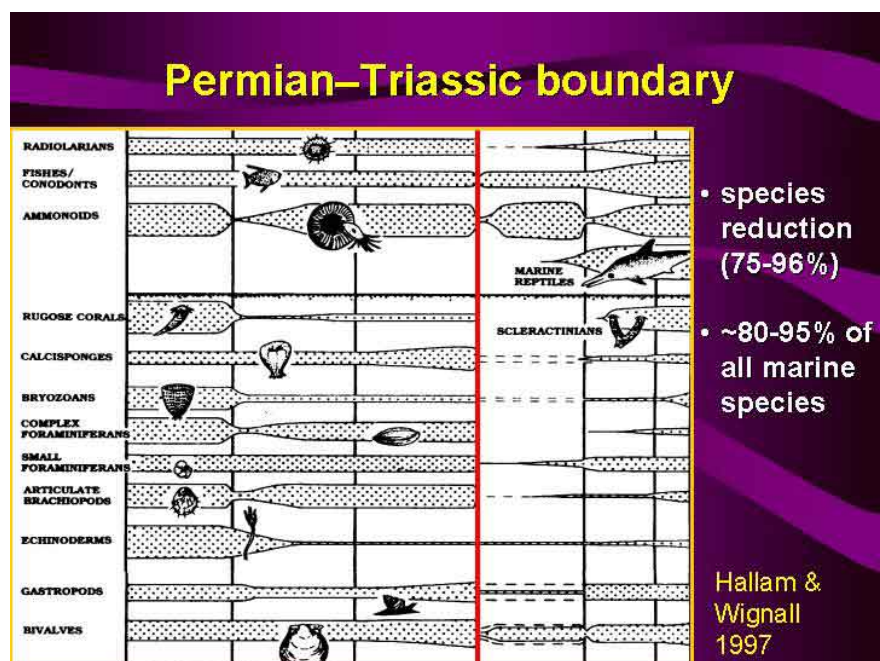


Figure 4.2: Loss of species caused by the Permian-Triassic extinction event. Unless quick steps are taken to lower our greenhouse gas emissions, we may cause a similar extinction event, which will threaten the survival of our own species. Source: Australian Frontiers of Science, www.sciencearchive.org.au

4.2 Permian-Triassic extinction event

The geological record shows five major extinction events.

- Ordovician-Silurian Extinction. around 439 million years ago.
- Late Devonian Extinction. 375-360 million years ago.
- Permian-Triassic extinction. 352 million years ago.
- Triassic-Jurassic extinction, 201 million years ago.
- Cretaceous-Paleogene extinction, 66 million years ago.

The most devastating of these was the Permian-Triassic extinction, which occurred 252 million years ago.³ In the Permian-Triassic extinction, 96% of all marine species and 76% of all terrestrial vertebrates disappeared forever. The cause of this extremely severe event is disputed, but according to one of the most plausible theories it was triggered by a massive volcanic eruption in Siberia, which released enormous amounts of CO₂ into the earth's atmosphere.

The region where massive volcanic eruptions are known to have occurred 252 million years ago called the "Siberian Traps". (The "Traps" part of the name comes from the fact that many of the volcanic rock formations in the region resemble staircases. The Swedish word for staircase is "trappe".) The eruptions continued for about a million years.

Today the area covered is about 2 million square kilometers, roughly equal to western Europe in land area. Estimates of the original coverage are as high as 7 million square kilometers. The original volume of lava is estimated to range from 1 to 4 million cubic kilometers.

The CO₂ released by the Siberian Traps eruption is believed to have caused a global temperature increase of 6°C, and this was enough to trigger the methane-hydrate feedback loop, which will be discussed below. The earth's temperature is thought to have continued to rise for 85,000 years, finally reaching 15° above normal.

4.3 The Holocene (Anthropocene) extinction

We are now living in the midst of a sixth, human-caused, mass extinction. How severe it becomes is up to us.

Recently a group of scientists stated that the scope of human impact on planet Earth is so great that the *Anthropocene* warrants a formal place in the Geological Time Scale.

³ <https://www.thomhartmann.com/bigpicture/last-hours-climate-change>
The Last Hours of Humanity: Warming the World To Extinction (book), by Thom Hartmann
<https://www.amazon.com/Last-Hours-Humanity-Warming-Extinction/dp/1629213640>
<http://www.mediaite.com/online/leonardo-dicaprio-boosts-thom-hartmann-apocalyptic-global-warming-film-last-hours/>

In a statement issued by University of Leicester Press Office on 2 October 2017, professor Jan Zalasiewicz from the University of Leicester's School of Geography, Geology, and the Environment said: "Our findings suggest that the Anthropocene should follow on from the Holocene Epoch that has seen 11.7 thousand years of relative environmental stability, since the retreat of the last Ice Age, as we enter a more unstable and rapidly evolving phase of our planet's history,"⁴

"We conclude that human impact has now grown to the point that it has changed the course of Earth history by at least many millennia, in terms of the anticipated long-term climate effects (e.g. postponement of the next glacial maximum: see Ganopolski et al., 2016; Clark et al., 2016), and in terms of the extensive and ongoing transformation of the biota, including a geologically unprecedented phase of human-mediated species invasions, and by species extinctions which are accelerating (Williams et al., 2015, 2016)."

The report stated that defining characteristics of the period include "marked acceleration of rates of erosion and sedimentation; large-scale chemical perturbations to the cycles of carbon, nitrogen, phosphorus and other elements; the inception of significant change in global climate and sea level; and biotic changes including unprecedented levels of species invasions across the Earth. Many of these changes are geologically long-lasting, and some are effectively irreversible."

Loss of biodiversity

Tropical rain forests are the most biologically diverse places in the world. This is because they have not been affected by the periods of glaciation that have periodically destroyed the forests of temperate and boreal regions. The destruction of species-rich tropical rain forests is one of the mechanisms driving the present high rate of species loss.

According to a recent article published in *The Guardian*⁵ "Conservation experts have already signalled that the world is in the grip of the "sixth great extinction" of species, driven by the destruction of natural habitats, hunting, the spread of alien predators and disease, and climate change.

"The IUCN⁶ created shock waves with its major assessment of the world's biodiversity in 2004, which calculated that the rate of extinction had reached 100-1,000 times that suggested by the fossil records before humans.

"No formal calculations have been published since, but conservationists agree the rate of loss has increased since then, and Stuart said it was possible that the dramatic predictions of experts like the renowned Harvard biologist E O Wilson, that the rate of loss could reach 10,000 times the background rate in two decades, could be correct."

A recent article by Profs. Gerardo Ceballos, Paul R. Ehrlich and Rodolfo Dirzo in the *Proceedings of the National Academy of Sciences* was entitled "Biological Annihilation

⁴<http://www2.le.ac.uk/offices/press/press-releases/2017/october/significant-scale-of-human-impact-on-planet-has-changed-course-of-earth2019s-history-scientists-suggest>

⁵<https://www.theguardian.com/environment/2010/mar/07/extinction-species-evolve>

⁶International Union for the Conservation of Nature

via the Ongoing Sixth Mass Extinction Signaled by Vertebrate Population Losses and Declines”.

The Abstract of the paper reads as follows: “The population extinction pulse we describe here shows, from a quantitative viewpoint, that Earth’s sixth mass extinction is more severe than perceived when looking exclusively at species extinctions. Therefore, humanity needs to address anthropogenic population extirpation and decimation immediately. That conclusion is based on analyses of the numbers and degrees of range contraction (indicative of population shrinkage and/or population extinctions according to the International Union for Conservation of Nature) using a sample of 27,600 vertebrate species, and on a more detailed analysis documenting the population extinctions between 1900 and 2015 in 177 mammal species. We find that the rate of population loss in terrestrial vertebrates is extremely high, even in ‘species of low concern.’ In our sample, comprising nearly half of known vertebrate species, 32% (8,851/27,600) are decreasing; that is, they have decreased in population size and range. In the 177 mammals for which we have detailed data, all have lost 30% or more of their geographic ranges and more than 40% of the species have experienced severe population declines (>80% range shrinkage). Our data indicate that beyond global species extinctions Earth is experiencing a huge episode of population declines and extirpations, which will have negative cascading consequences on ecosystem functioning and services vital to sustaining civilization. We describe this as a ‘biological annihilation’ to highlight the current magnitude of Earth’s ongoing sixth major extinction event.”

4.4 Global warming and atmospheric water vapor

A feedback loop is a self-re-enforcing trend. One of the main positive feedback loops in global warming is the tendency of warming to increase the atmospheric saturation pressure for water vapor, and hence amount of water vapor in the atmosphere, which in turn leads to further warming, since water vapor is a greenhouse gas.

Wikipedia’s article on greenhouse gases states that, “Water vapor accounts for the largest percentage of the greenhouse effect, between 36% and 66% for clear sky conditions and between 66% and 85% when including clouds.”

4.5 The albedo effect

Albedo is defined to be the fraction of solar energy (shortwave radiation) reflected from the Earth back into space. It is a measure of the reflectivity of the earth’s surface. Ice, especially with snow on top of it, has a high albedo: most sunlight hitting the surface bounces back towards space.

Loss of sea ice

Especially in the Arctic and Antarctic regions, there exists a dangerous feedback loop involving the albedo of ice and snow. As is shown in Figure 4.1, Arctic sea ice is rapidly

disappearing. It is predicted that during the summers, the ice covering arctic seas may disappear entirely during the summers. As a consequence, incoming sunlight will encounter dark light-absorbing water surfaces rather than light-reflecting ice and snow.

This effect is self-re-enforcing. In other words, it is a feedback loop. The rising temperatures caused by the absorption of more solar radiation cause the melting of more ice, and hence even more absorption of radiation rather than reflection, still higher temperatures, more melting, and so on.

The feedback loop is further strengthened by the fact that water vapor acts like a greenhouse gas. As polar oceans become exposed, more water vapor enters the atmosphere, where it contributes to the greenhouse effect and rising temperatures.

Darkened snow on Greenland's icecap

Greenland's icecap is melting, and as it melts, the surface becomes darker and less reflective because particles of soot previously trapped in the snow and ice become exposed. This darkened surface absorbs an increased amount of solar radiation, and the result is accelerated melting.

4.6 The methane hydrate feedback loop

If we look at the distant future, by far the most dangerous feedback loop involves methane hydrates or methane clathrates. When organic matter is carried into the oceans by rivers, it decays to form methane. The methane then combines with water to form hydrate crystals, which are stable at the temperatures and pressures which currently exist on ocean floors. However, if the temperature rises, the crystals become unstable, and methane gas bubbles up to the surface. Methane is a greenhouse gas which is 70 times as potent as CO₂.

The worrying thing about the methane hydrate deposits on ocean floors is the enormous amount of carbon involved: roughly 10,000 gigatons. To put this huge amount into perspective, we can remember that the total amount of carbon in world CO₂ emissions since 1751 has only been 337 gigatons.

A runaway, exponentially increasing, feedback loop involving methane hydrates could lead to one of the great geological extinction events that have periodically wiped out most of the animals and plants then living. This must be avoided at all costs.

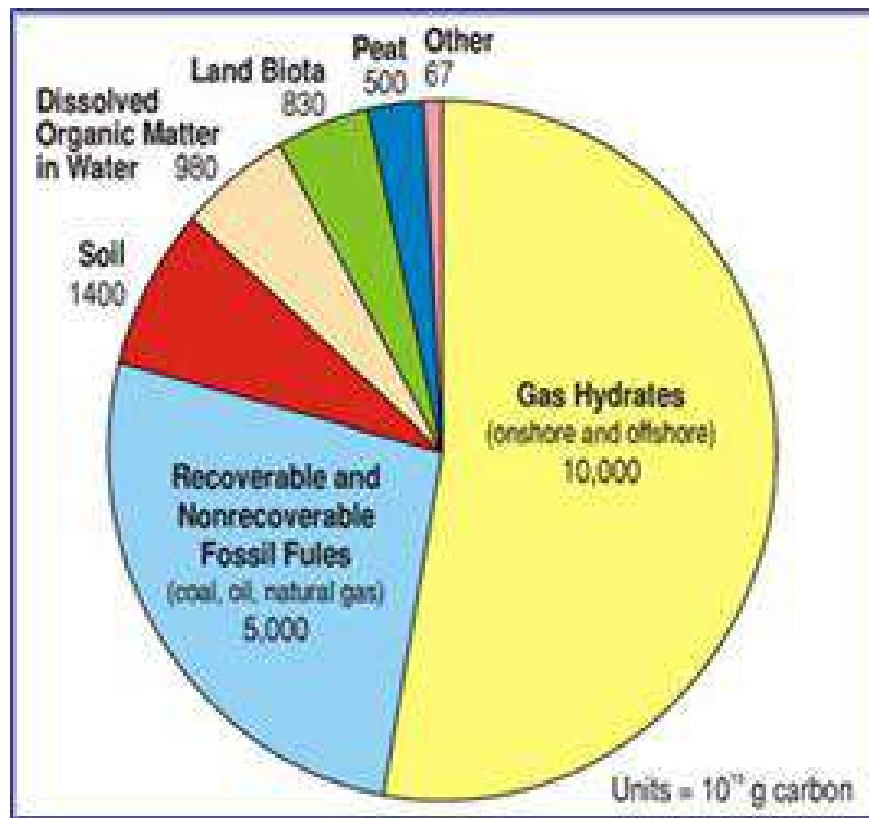


Figure 4.3: The worrying thing about the methane hydrate feedback loop is the enormous amount of carbon in the form of hydrate crystals, 10,000 gigatons most of it on the continental shelves of oceans. This greater than the amount of carbon in all other forms that might potentially enter the earth's atmosphere.



Figure 4.4: When ocean temperatures rise, methane hydrate crystals become unstable, and methane gas bubbles up to ocean surfaces.

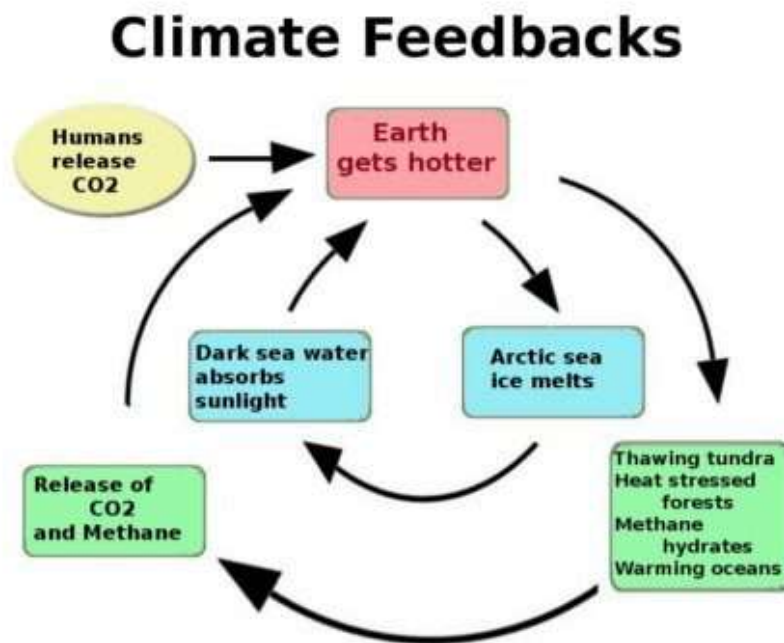


Figure 4.5: This diagram shows two important feedback loops, one involving the albedo effect, and the other involving methane hydrates.

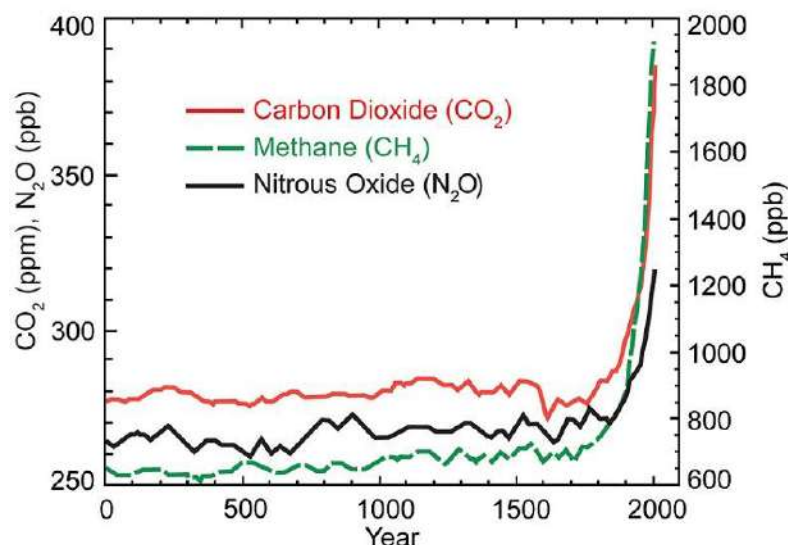


Figure 4.6: A “hockey stick” graph showing atmospheric concentrations of three important greenhouse gases during the last 2,000 years. The most dramatically increasing of these is methane.

4.7 A feedback loop from warming of soils

On October 6, 2017, the journal *Science* published an article entitled *Long-term pattern and magnitude of soil carbon feedback to the climate system in a warming world*⁷. The lead author, Jerry Melillo, is an ecologist working at the Marine Biological Laboratory, Woods Hole Massachusetts. In an interview with *Newsweek*, he said: “This self-reinforcing feedback is potentially a global phenomenon with soils, and once it starts it may be very difficult to turn off. It’s that part of the problem that I think is sobering... We think that one of the things that may be happening is both a reorganization of the microbial community structure and its functional capacity,”

The study reported on three decades of observations of heated sections of a forest owned by Harvard University. The heated sections were 5°C warmer than control sections.

4.8 Drying of forests and forest fires

According to a recent article in *Nature*⁸, “Across the American west, the area burned each year has increased significantly over the past several decades, a trend that scientists attribute both to warming and drying and to a century of wildfire suppression and other human activities. Allen suggests that the intertwined forces of fire and climate change

⁷J.M. Melillo et al., *Long-term pattern and magnitude of soil carbon feedback to the climate system in a warming world*, *Science*, Vol. 358, pp. 101-105, (2017).

⁸<http://www.nature.com/news/forest-fires-burn-out-1.11424>

will take ecosystems into new territory, not only in the American west but also elsewhere around the world. In the Jemez, for example, it could transform much of the ponderosa pine (*Pinus ponderosa*) forest into shrub land. 'We're losing forests as we've known them for a very long time,' says Allen. 'We're on a different trajectory, and we're not yet sure where we're going.'

"All around the American west, scientists are seeing signs that fire and climate change are combining to create a 'new normal'. Ten years after Colorado's largest recorded fire burned 56,000 hectares southwest of Denver, the forest still has not rebounded in a 20,000-hectare patch in the middle, which was devastated by an intense crown fire. Only a few thousand hectares, which the US Forest Service replanted, look anything like the ponderosa-pine stands that previously dominated the landscape."

4.9 Tipping points and feedback loops

A tipping point is usually defined as the threshold for an abrupt and irreversible change⁹. To illustrate this idea, we can think of a book lying on a table. If we gradually push the book towards the edge of the table, we will finally reach a point after which more than half of the weight of the book will not be supported by the table. When this "tipping point" is passed the situation will suddenly become unstable, and the book will fall to the floor. Analogously, as the earth's climate gradually changes, we may reach tipping points. If we pass these points, sudden instabilities and abrupt climatic changes will occur.

Greenland ice cores supply a record of temperatures in the past, and through geological evidence we have evidence of sea levels in past epochs. These historical records show that abrupt climatic changes have occurred in the past.

Timothy Michael Lenton, FRS, Professor of Climate Change and Earth System Science at the University of Exeter, lists the following examples of climatic tipping points:

- Boreal forest dieback
- Amazon rainforest dieback
- Loss of Arctic and Antarctic sea ice (Polar ice packs) and melting of Greenland and Antarctic ice sheets
- Disruption to Indian and West African monsoon
- Formation of Atlantic deep water near the Arctic ocean, which is a component process of the thermohaline circulation.
- Loss of permafrost, leading to potential Arctic methane release and clathrate gun effect

⁹Other definitions of tipping points are possible. A few authors define these as points beyond which change is inevitable, emphasizing that while inevitable, the change may be slow.

It can be seen from this list that climate tipping points are associated with feedback loops. For example, the boreal forest dieback and the Amazon rainforest dieback tipping points are associated with the feedback loop involving the drying of forests and forest fires, while the tipping point involving loss of Arctic and Antarctic sea ice is associated with the Albedo effect feedback loop. The tipping point involving loss of permafrost is associated with the methane hydrate feedback loop.

Once a positive feedback loop starts to operate in earnest, change may be abrupt.

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Chapter 5

WARNINGS FROM THE POLES

5.1 A British-US expedition studies Thwaites Glacier melting

Scientists from the multi-million-dollar expedition bored 2,000 feet through the ice to measure the water temperature at the point where the glacier leaves dry land and starts to float on the ocean. They found water temperatures more than 2 degrees C above the freezing point. “That is really bad”, said David Holland, a New York University glaciologist, “That’s not a sustainable situation for that glacier.”

The scientists already knew that the Thwaites Glacier was losing massive amounts of ice - more than 600 billion tons over the past several decades - but until now the mechanism had not been confirmed directly. “The biggest thing to say at the moment is, indeed, there is very warm water there, and clearly, it could not have been there forever, or the glacier could not be there,” Holland said.

Melting of the Thwaites Glacier could potentially unleash more than ten feet of sea level rise, threatening coastal cities and low-lying countries around the world.

5.2 Thwaites Glacier could shatter like a windscreen

Recently diagonal cracks have been observed in Antarctica’s Thwaites Glacier, and scientists fear that the glacier could shatter into many pieces, like the windscreen of an automobile.

Here are some quotations from a January 1, 2022 article by Ella Gilbert, of the University of Reading:

“The massive Thwaites glacier in West Antarctica contains enough ice to raise global sea levels by 65cm if it were to completely collapse. And, worryingly, recent research suggests that its long-term stability is doubtful as the

glacier hemorrhages more and more ice.

Adding 65cm to global sea levels would be coastline-changing amounts. For context, there's been around 20cm of sea-level rise since 1900, an amount that is already forcing coastal communities out of their homes and exacerbating environmental problems such as flooding, saltwater contamination and habitat loss.

“But the worry is that Thwaites, sometimes called the ‘doomsday glacier’ because of its keystone role in the region, might not be the only glacier to go. Were it to empty into the ocean, it could trigger a regional chain reaction and drag other nearby glaciers in with it, which would mean several meters of sea-level rise. That’s because the glaciers in West Antarctica are thought to be vulnerable to a mechanism called Marine Ice Cliff Instability or MICI, where retreating ice exposes increasingly tall, unstable ice cliffs that collapse into the ocean.

“A sea level rise of several meters would inundate many of the world’s major cities - including Shanghai, New York, Miami, Tokyo, and Mumbai. It would also cover huge swathes of land in coastal regions and largely swallow up low-lying island nations like Kiribati, Tuvalu, and the Maldives.”

5.3 100.4 degrees Fahrenheit north of the Arctic Circle

The Arctic is heating more than twice as fast as the remainder of the world. The World Meteorological Organization has confirmed a new high temperature Arctic record: 100.4 degrees Fahrenheit, recorded in the Siberian town of Verkhoyansk, 70 kilometers north of the Arctic Circle. The reading, taken on June 20, 2020, has now been officially confirmed by the World Meteorological Organization. A spokesman commented that “the temperature is more befitting for the Mediterranean than the Arctic”.

According to data taken from the Russian Forestry Agency, Siberia’s wildfires were the worst since records began, destroying an area of more than 46 million Acres (18.6 million hectares) of Russian forest in 2021 alone. The smoke from the enormous infernos even travelled as far as the North Pole. Black soot from the wildfires settles on Arctic snow, making it reflect less and absorb more heat. Another feedback loop is caused by the CO2 released by Arctic wildfires, which contributes to further warming and more fires.



Figure 5.1: An Arctic wildfire. Layers of peat are burning, and the carbon stored in the peat is being released into the atmosphere.

5.4 166 billion tons lost in 2021

According to a report from Polar Portal,

“2021 is the 25th year in a row in which Greenland’s ice sheet lost more mass during the course of the melting season than it gained during the winter...”

The Polar Portal is a Danish service that monitors the Greenland ice sheet. According to their report, the ice sheet lost about 166 billion tonnes of ice during the 12-month period that ended in August, 2021.

5.5 The threat of catastrophic destabilization

A new report has been issued by the Potsdam Institute for Climate Impact Research, which is located at the Free University of Berlin. According to the lead author, Niklas Boers,

“Our results suggest there will be substantially enhanced melting in the future - which is quite worrying... [The] mechanism is long known, and it is one of the prime suspects for the detected destabilization of the central-western parts of the Greenland ice sheet. But we cannot exclude that other feedbacks, for example related to the albedo of the ice sheet, play an important role too,..We urgently need to better understand the interplay of the different positive and negative feedback mechanisms that determine the current stability and the future evolution of the ice sheet”



Figure 5.2: Unstable cliffs of ice on the coast of Greenland.

5.6 Wikipedia's article on ice cores

The Wikipedia article, *Ice core*, gives the following description of how isotope analysis can be used to deduce the temperature at which the ancient snow fell before turning to ice:

“The isotopic composition of the oxygen in a core can be used to model the temperature history of the ice sheet. Oxygen has three stable isotopes, ^{16}O , ^{17}O and ^{18}O . The ratio between ^{18}O and ^{16}O indicates the temperature when the snow fell...

“Hydrogen ratios can also be used to calculate a temperature history. Deuterium (^2H , or D) is heavier than hydrogen (^1H) and makes water more likely to condense and less likely to evaporate.”

“

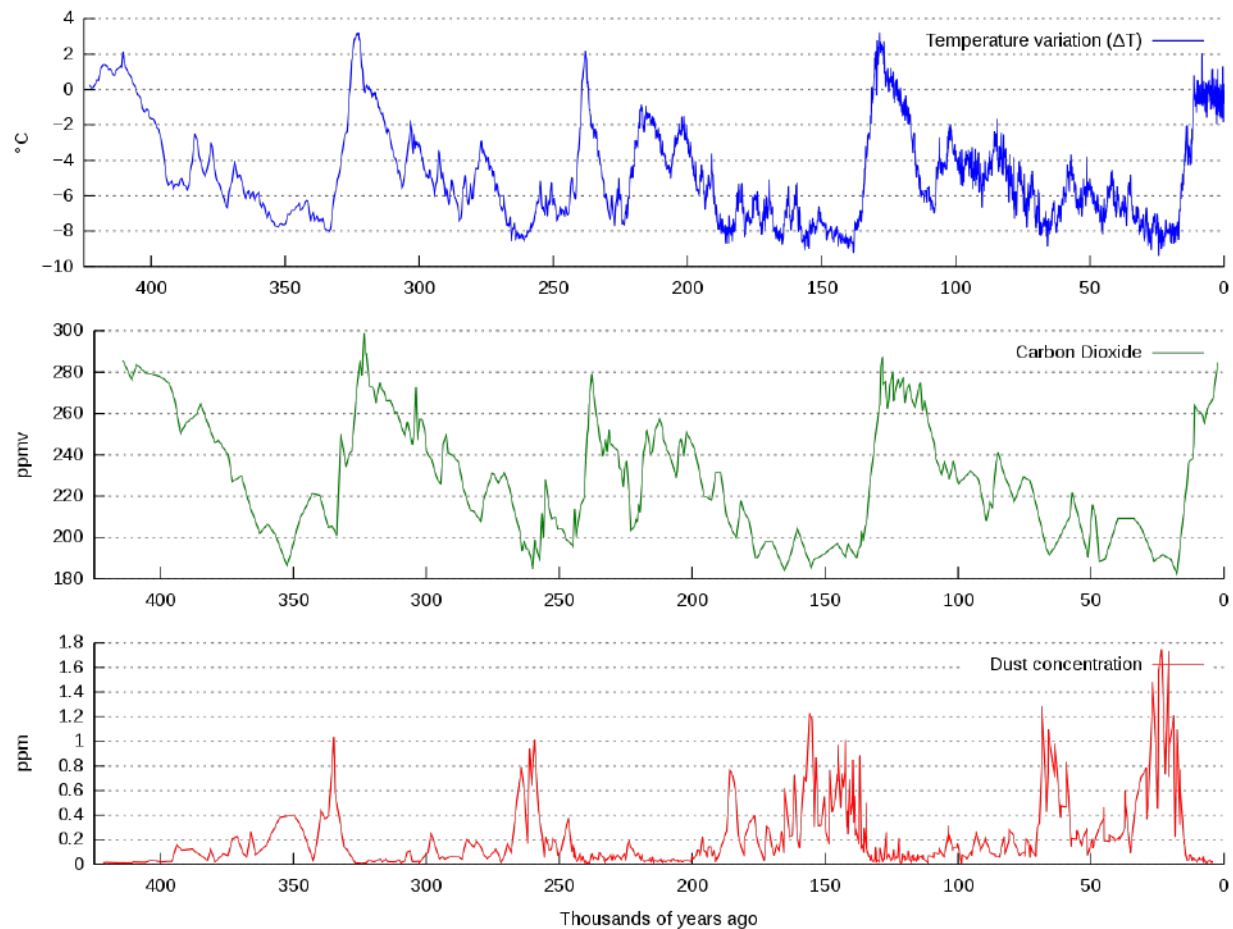


Figure 5.3: Graph of CO₂ (green), reconstructed temperature (blue) and dust (red) from the Vostok ice core for the past 420,000 years. Notice the strong correlation between CO₂ concentration and temperature. The dust content is helpful in determining the age of the core samples. The figure is taken from the Wikipedia article.

5.7 The albedo effect

There is a dangerous feedback loop involving ice on the Arctic Ocean through the *albedo effect*: Ice-free water is dark on color, and it absorbs the sun's warmth strongly. By contrast, snow-covered ice fields reflect much of the sun's warmth. Thus, the lower the ice cover, the more the sun's rays are absorbed, warming the region and causing further sea ice melting - a dangerous feedback loop.

5.8 5-meter-high waves in the Beaufort sea

According to Wikipedia,

“Scientists recently measured sixteen-foot (five-meter) wave heights during a storm in the Beaufort Sea in mid-August until late October 2012. This is a new phenomenon for the region, since a permanent sea ice cover normally prevents wave formation. Wave action breaks up sea ice, and thus could become a feedback mechanism, driving sea ice decline.”

5.9 The death spiral of Arctic sea ice

As is shown in the figure below, the Arctic Ocean will soon be entirely free of sea ice in September. This change will have many impacts on the ecology of the region.

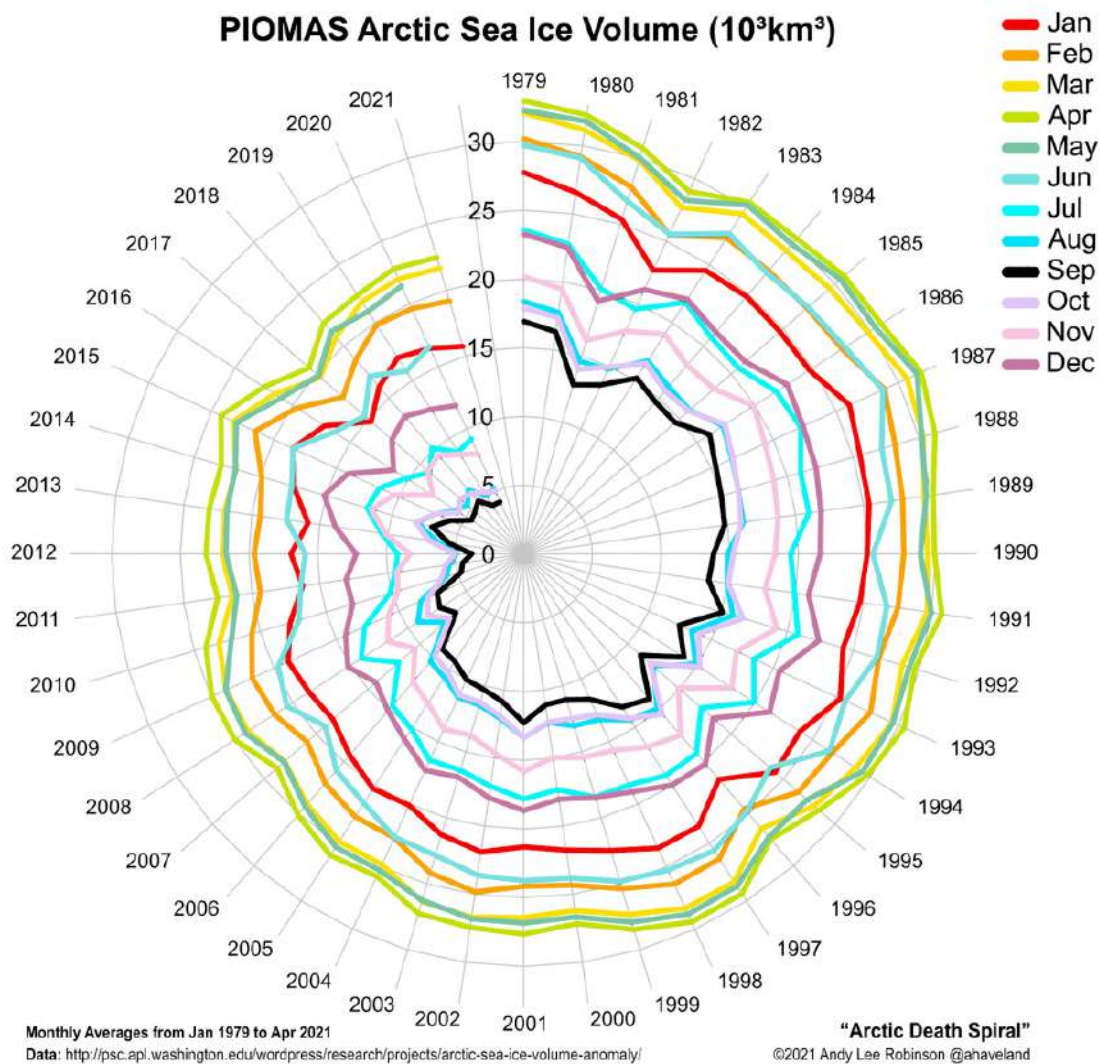


Figure 5.4: Monthly averages 1979-2021. Data source via the Polar Science Center (University of Washington). The September monthly average is spiraling in towards zero, implying that September will soon be a month when the Arctic ocean is completely free of ice.

Chapter 6

THE OCEANS

6.1 Thermal inertia of the oceans

Calories required to warm a gram of water

We all know that saucepan full of water on the kitchen stove does not start to boil immediately when the heat under it is turned on. In fact, for every gram of water in the saucepan, one calorie is needed for every degree C in temperature rise. If the pan contains a kilogram of water, a kilocalorie is needed to make it warm by 1°C.

The same principle, vastly scaled up in size, holds for the earth's oceans. When humans "turn on the heat" by releasing greenhouse gases into the atmosphere, the oceans respond very slowly because of the vast amount of energy needed to warm them. The total volume of the oceans is estimated to be $1.35 \times 10^9 \text{ km}^3$ or $1.35 \times 10^{24} \text{ cm}^3$. Thus to warm the earth's oceans by 1°C requires 1.35×10^{24} calories, and the current imbalance between incoming and outgoing radiation supplies only a small fraction of this amount each year.

This means that even if the CO₂ and other greenhouse gases in our atmosphere were stabilized at their current levels, the oceans would continue to warm for many decades. This does not mean that our efforts to reduce greenhouse gas emissions are futile. We must certainly experience some very unpleasant effects of sea level rise, ocean life destruction and global warming during the next few decades, but how bad these become is up to us.

Cultural and institutional inertia

Physical systems are slow to respond to forcing, as we have just seen in our discussion of the thermal inertia of the oceans. Human social and economic systems are also slow to respond, even when quick action is urgently needed.

Technology develops with lightning-like speed. Population and industrial production grow with astonishing rapidity. But our habits and attitudes, our political, economic and social institutions, our systems of laws, our educational systems - all these are very slow to change, slow to respond to the climate emergency that we face today. This contrast

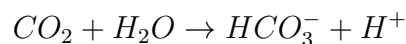


Figure 6.1: **How bad sea level rise becomes is up to us.**

between rapidly changing circumstances and slowly changing institutions is discussed more thoroughly in Chapter 10.

6.2 Carbon dioxide content and acidity

Roughly 30-40% of the CO₂ released into the atmosphere by human activities is absorbed by oceans and lakes. Much of the dissolved CO₂ undergoes a reaction with water which converts it into carbonic acid:



Between 1751 and 1995 the amount of H⁺ ion in ocean surface water is estimated to have increased by 35%. Living organisms are very sensitive to acidity, and today we can observe the alarming death of many forms of marine life, for example the death of coral in the Great Barrier Reef and other coral reef systems. Over a billion people depend on fish from coral reef habitats for protein in their diets.

6.3 Pollution with plastic waste

Our oceans are now massively polluted with carelessly discarded plastic waste. Plastic waste is found in huge quantities on the beaches of the remotest islands and in the blocked digestive systems of dead whales. A recent study ¹ found that in 2010, 8 million tonnes of plastic went into our oceans,

The problem of plastic waste in our oceans is connected with the climate emergency, but in an indirect way. Today, most plastics are synthesized from starting chemicals extracted from fossil fuels. But the use of fossil fuels must stop if catastrophic climate change is to be avoided. However, there are new methods for synthesizing biodegradable plastics starting with chemicals extracted from plants.

According to the polymer chemist Professor Andrew Holmes,² the world may have to move to fully biodegradable plastics, made out of plants. But these have drawbacks. “The challenge is, is there enough arable land to produce the building blocks of plastic when we also need to produce food?”

In the meantime, he said, we must recycle anything we can.

“Ideally all plastics should be recyclable, but at present that is not the case.”

Professor Holmes said plastics that cannot be recycled - such as those used in plastic bags, or expanded polystyrene foam used in coffee cups and packaging around electronic goods - must be responsibly disposed into landfill or by burning.

“The plastic waste in the oceans is disastrous for marine and bird life, and the human race has to avoid disposal of this waste in a way that enables it to enter drains, rivers, and eventually the ocean,” he said.”

¹<http://www.abc.net.au/science/articles/2015/02/13/4178113.htm>

²University of Melbourne

<http://www.abc.net.au/news/science/2017-02-27/plastic-and-plastic-waste-explained/8301316>

6.4 Overfishing

Like the massive pollution of our oceans with plastic waste, overfishing is only indirectly related to climate change. However, all three phenomena are part of the ecological megacatastrophe that may result if humans continue to over-exploit and degrade the earth's ecological systems.

Wikipedia's article on overfishing states that "As much as 85% of the world's fisheries may be over-exploited, depleted, fully exploited or in recovery from exploitation....

"With present and forecast world population levels it is not possible to solve the over fishing issue; however, there are mitigation measures that can save selected fisheries and forestall the collapse of others...

"The United Nations Convention on the Law of the Sea treaty deals with aspects of over fishing in articles 61, 62, and 65:

- Article 61 requires all coastal states to ensure that the maintenance of living resources in their exclusive economic zones is not endangered by over-exploitation. The same article addresses the maintenance or restoration of populations of species above levels at which their reproduction may become seriously threatened.
- Article 62 provides that coastal states: "shall promote the objective of optimum utilization of the living resources in the exclusive economic zone without prejudice to Article 61"
- Article 65 provides generally for the rights of, inter alia, coastal states to prohibit, limit, or regulate the exploitation of marine mammals.

"Several scientists have called for an end to subsidies paid to deep sea fisheries. In international waters beyond the 200 nautical mile exclusive economic zones of coastal countries, many fisheries are unregulated, and fishing fleets plunder the depths with state-of-the-art technology. In a few hours, massive nets weighing up to 15 tons, dragged along the bottom by deep-water trawlers, can destroy deep-sea corals and sponge beds that have taken centuries or millennia to grow. The trawlers can target orange roughy, grenadiers, or sharks. These fish are usually long-lived and late maturing, and their populations take decades, even centuries to recover."

6.5 Rate of melting of Arctic ice

Loss of Arctic sea ice

The melting of Arctic sea ice is taking place far more rapidly than was predicted by IPCC reports. David Wasdell, Director of the Apollo-Gaia Project, points out that the observed melting has been so rapid that within less than five years, the Arctic may be free of sea ice at the end of each summer. It will, of course continue to re-freeze during the winters, but the thickness and extent of the winter ice will diminish.

For January 2016, the satellite based data showed the lowest overall Arctic sea ice extent of any January since records begun in 1979. Bob Henson from *Wundergrund* commented: “Hand in hand with the skimpy ice cover, temperatures across the Arctic have been extraordinarily warm for midwinter. Just before New Year’s, a slug of mild air pushed temperatures above freezing to within 200 miles of the North Pole. That warm pulse quickly dissipated, but it was followed by a series of intense North Atlantic cyclones that sent very mild air poleward, in tandem with a strongly negative Arctic Oscillation during the first three weeks of the month.”

During some periods, Arctic temperatures have been 50°C above normal for the time of year. Equally alarming is the fact that plumes of methane several km² in area have been observed bubbling up from the sea floor in the shallow ice-free seas north of Russia.³

6.6 Temperature and CO₂ in ice cores

Ice cores from the Greenland and Antarctic ice sheets and from glaciers have yielded valuable data on climate changes as far back as 800,000 years in the past. The ice cores show that there is a close correlation between global temperatures and the CO₂ content of the atmosphere. The cores also show that climatic changes can take place with great rapidity.

An article by Richard B. Alley in the Proceedings of the National Academy of Science (US)⁴ Here is an excerpt from the article:

“Ice-core records show that climate changes in the past have been large, rapid, and synchronous over broad areas extending into low latitudes, with less variability over historical times. These ice-core records come from high mountain glaciers and the polar regions, including small ice caps and the large ice sheets of Greenland and Antarctica.

“As the world slid into and out of the last ice age, the general cooling and warming trends were punctuated by abrupt changes. Climate shifts up to half as large as the entire difference between ice age and modern conditions occurred over hemispheric or broader regions in mere years to decades. Such abrupt changes have been absent during the few key millennia when agriculture and industry have arisen. The speed, size, and extent of these abrupt changes required a reappraisal of climate stability. Records of these changes are especially clear in high-resolution ice cores. Ice cores can preserve histories of local climate (snowfall, temperature), regional (wind-blown dust, sea salt, etc.), and broader (trace gases in the air) conditions, on a common time scale, demonstrating synchrony of climate changes over broad regions.”

³N. Shakhova et al., *Methane release on the Arctic East Siberian shelf*, Geophysical Research Abstracts, Vol.9, 01071, 2007

⁴Proc Natl Acad Sci U S A. 2000 Feb 15; 97(4): 1331-1334. PMID: PMC34297

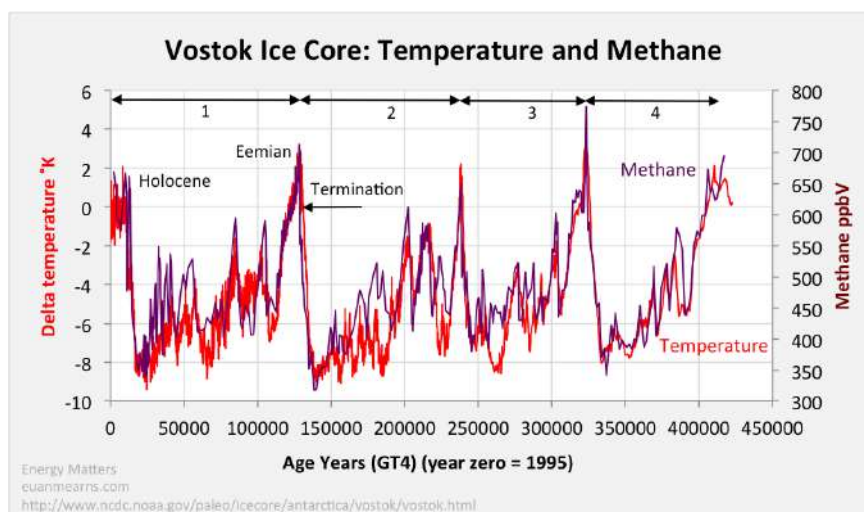


Figure 6.2: In ice core data, we see a close correlation between temperature and atmospheric CO₂. There is also a close correlation between temperature and atmospheric methane.

6.7 Short-term sea level rise

Flooding of coastal cities in the United States

The *National Geographic* recently published an article by Laura Parker entitled “Sea Level Rise Will Flood Hundreds of Cities in the Near Future+.”⁵ Here are a few excerpts from the article:

“Sea level rise caused by global warming is usually cast as a doomsday scenario that will play out so far into the future, it’s easy to ignore. Just ask anyone in South Florida, where new construction proceeds apace. Yet already, more than 90 coastal communities in the United States are battling chronic flooding, meaning the kind of flooding that’s so unmanageable it prompts people to move away.

“That number is expected to roughly double to more than 170 communities in less than 20 years.

“Those new statistics, compiled in the first comprehensive mapping of the entire coastline of the Lower 48 states, paint a troubling picture, especially for the East and Gulf coasts, which are home to some of the nation’s most populated areas.

“By the end of the century, chronic flooding will be occurring from Maine to Texas and along parts of the West Coast. It will affect as many as 670 coastal communities, including Cambridge, Massachusetts; Oakland, California; Miami and St. Petersburg, Florida; and four of the five boroughs of New York City. The magnitude of the coming calamity is so great, the ripple effects will reach far into the interior.”

Just as an iceberg the size of Delaware broke away from an ice shelf in Antarctica

⁵<http://news.nationalgeographic.com/2017/07/sea-level-rise-flood-global-warming-science/>

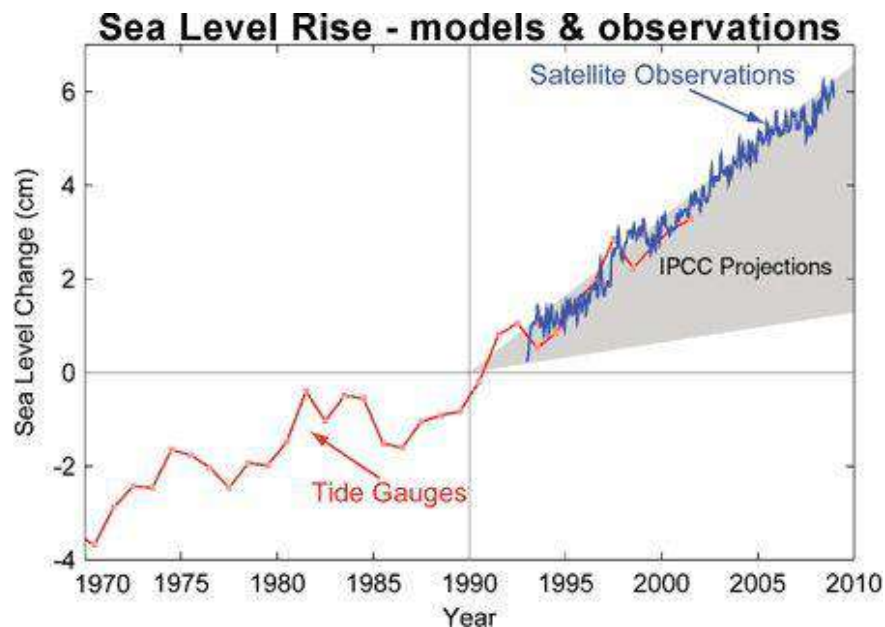


Figure 6.3: **Observed sea-level rise, 1970-2010.**

Wednesday, July 12, 2017, scientists released findings that up to 668 U.S. communities could face chronic flooding from rising sea levels by the end of the century.

The Union of Concerned Scientists recently published a report entitled “When Rising Seas Hit Home: Hard Choices Ahead for Hundreds of US Coastal Communities”⁶ The report states that “Chronic inundation will dramatically alter the landscape and the livability rise of just three feet would submerge the Maldives and make them uninhabitable of many coastal communities.” rise of just three feet would submerge the Maldives and make them uninhabitable

Island nations threatened by rising oceans

The US National Academy of Sciences predictions from 2009 suggest that by 2100, sea level could increase by anywhere from 16 inches to 56 inches, depending how the Earth responds to changing climate.

The Maldives, consisting of over 1,100 islands to the west of India, is the world’s lowest-lying nation. On average the islands are only 1.3 meters above sea level. The 325,000 (plus 100,000 expatriate workers who are not counted in the census) residents of the islands are threatened by rising sea levels. A rise of just three feet would submerge the Maldives and make them uninhabitable. Many island nations in the Pacific are also severely threatened by sea level rise.

⁶<http://www.ucsusa.org/sites/default/files/attach/2017/07/when-rising-seas-hit-home-full-report.pdf>

Displacement of populations in Southeast Asia

A World Bank press release has stated that “Bangladesh will be among the most affected countries in South Asia by an expected 2°C rise in the world’s average temperatures in the next decades, with rising sea levels and more extreme heat and more intense cyclones threatening food production, livelihoods, and infrastructure as well as slowing the reduction on poverty, according to a new scientific report released today by the World Bank Group.

“ ‘Bangladesh faces particularly severe challenges with climate change threatening its impressive progress in overcoming poverty,’ said Johannes Zutt, World Bank Country Director for Bangladesh and Nepal. ‘Bangladesh has demonstrated itself as a leader in moving the climate change agenda forward’-

“In Bangladesh, 40% of productive land is projected to be lost in the southern region of Bangladesh for a 65cm sea level rise by the 2080s. About 20 million people in the coastal areas of Bangladesh are already affected by salinity in drinking water. Rising sea levels and more intense cyclones and storm surges could intensify the contamination of groundwater and surface water causing more diarrhea outbreak.”

Important rice-growing river delta regions of Viet Nam will also be lost during the present century.

Effects on the Netherlands, Danish islands, and Venice

Although the Netherlands, the Danish islands and Venice have had many years of experience in coping with floods due to high sea levels and storm surges, these European areas may have difficulties during the present century.

Greenland’s icecap is melting much faster than was predicted by the IPCC, and sea level rise may exceed 100 cm. before 2100. Hurricanes are also becoming more severe, as has already been shown by Katrina and Sandy. Future hurricanes hitting Europe’s Atlantic coasts will produce dangerous storm surges. In Venice, the danger from hurricanes is less severe, but Venice already experiences severe flooding and the rise of sea levels during the present century may endanger the priceless cultural monuments of the famous ancient city.

6.8 Long-term sea level rise

A 2012 article by Jevrejeva, S., Moore, J. C. and Grinsted, A. in the *Journal of Global and Planetary Change*⁷ deals with sea level rise until 2500. Of course, the long-term future runs over hundreds of millennia, but nevertheless, the article, entitled “Sea level projections to AD2500 with a new generation of climate change scenarios” is of interest.

The article states that “Sea level rise over the coming centuries is perhaps the most damaging side of rising temperature. The economic costs and social consequences of coastal flooding and forced migration will probably be one of the dominant impacts of global

⁷Volumes 80-81, January 2012, Pages 14.20

warming. To date, however, few studies on infrastructure and socio-economic planning include provision for multi-century and multi-meter rises in mean sea level...

“We estimate sea level rise of 0.57 - 1.10 m by 2100 with four new RCP scenarios. Sea level will continue to rise for several centuries reaching 1.84 - 5.49 m by 2500. Due to long response time most rise is expected after stabilization of forcing. 200-400 years will require dropping the rate to the 1.8 mm/yr- 20th century average.”

According to an article published by the Potsdam Institute for Climate Impact Research⁸ “The Greenland ice sheet is likely to be more vulnerable to global warming than previously thought. The temperature threshold for melting the ice sheet completely is in the range of 0.8 to 3.2 degrees Celsius global warming, with a best estimate of 1.6 degrees above pre-industrial levels, shows a new study by scientists from the Potsdam Institute for Climate Impact Research (PIK) and the Universidad Complutense de Madrid. Today, already 0.8 degrees global warming has been observed. Substantial melting of land ice could contribute to long-term sea-level rise of several meters and therefore it potentially affects the lives of many millions of people.

“The time it takes before most of the ice in Greenland is lost strongly depends on the level of warming. ‘The more we exceed the threshold, the faster it melts,’ says Alexander Robinson, lead-author of the study now published in *Nature Climate Change*. In a business-as-usual scenario of greenhouse-gas emissions, in the long run humanity might be aiming at 8 degrees Celsius of global warming. This would result in one fifth of the ice sheet melting within 500 years and a complete loss in 2000 years, according to the study. ‘This is not what one would call a rapid collapse,’ says Robinson. ‘However, compared to what has happened in our planet’s history, it is fast. And we might already be approaching the critical threshold.’

“In contrast, if global warming would be limited to 2 degrees Celsius, complete melting would happen on a timescale of 50.000 years. Still, even within this temperature range often considered a global guardrail, the Greenland ice sheet is not secure. Previous research suggested a threshold in global temperature increase for melting the Greenland ice sheet of a best estimate of 3.1 degrees, with a range of 1.9 to 5.1 degrees. The new study’s best estimate indicates about half as much.

“‘Our study shows that under certain conditions the melting of the Greenland ice sheet becomes irreversible. This supports the notion that the ice sheet is a tipping element in the Earth system,’ says team-leader Andrey Ganopolski of PIK. ‘If the global temperature significantly overshoots the threshold for a long time, the ice will continue melting and not re-grow - even if the climate would, after many thousand years, return to its preindustrial state- This is related to feedbacks between the climate and the ice sheet: The ice sheet is over 3000 meters thick and thus elevated into cooler altitudes. When it melts its surface comes down to lower altitudes with higher temperatures, which accelerates the melting. Also, the ice reflects a large part of solar radiation back into ‘Our study shows that under certain conditions the melting of the Greenland ice sheet becomes irreversible.

⁸<https://www.pik-potsdam.de/news/press-releases/archive/2012/gronlands-eismassen-konnten-komplett-schmelzen-bei-1-6-grad-globaler-erwarmung>

This supports the notion that the ice sheet is a tipping element in the Earth system,' says team-leader Andrey Ganopolski of PIK. 'If the global temperature significantly overshoots the threshold for a long time, the ice will continue melting and not re-grow - even if the climate would, after many thousand years, return to its preindustrial state.' This is related to feedbacks between the climate and the ice sheet: The ice sheet is over 3000 meters thick and thus elevated into cooler altitudes. When it melts its surface comes down to lower altitudes with higher temperatures, which accelerates the melting. Also, the ice reflects a large part of solar radiation back into space. When the area covered by ice decreases, more radiation is absorbed and this adds to regional warming.space. When the area covered by ice decreases, more radiation is absorbed and this adds to regional warming."

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Chapter 7

DESTRUCTION OF FORESTS

7.1 Illegal burning for palm oil plantations

According to a recent article published by the Union of Concerned Scientists, “One huge source of global warming emissions associated with palm oil is the draining and burning of the carbon-rich swamps known as peatlands. Peatlands can hold up to 18 to 28 times as much carbon as the forests above them; when they are drained and burned, both carbon and methane are released into the atmosphere - and unless the water table is restored, peatlands continue to decay and release global warming emissions for decades.

“As if that wasn’t bad enough, the burning of peatlands releases a dangerous haze into the air, resulting in severe health impacts and significant economic losses. Each year, more than 100,000 deaths in Southeast Asia can be attributed to particulate matter exposure from landscape fires, many of which are peat fires.

“Beyond its global warming and human health impacts, palm oil production also takes a toll on biodiversity and human rights. Only about 15 percent of native animal species can survive the transition from primary forest to plantation. Among the species vulnerable to palm oil expansion are orangutans, tigers, rhinoceros, and elephants. Furthermore, palm oil growers have also been accused of using forced labor, seizing land from local populations, and other human rights abuses.”

Licences to burn forests for palm oil plantations are often granted by corrupt government officials. Fortunately, through the efforts of NGO’s the public has become increasingly aware of the problem, and supermarkets are being urged to purchase products containing deforestation-free palm oil.

Another recent article¹ states that “Indonesia is being deforested faster than any other country in the world, and it has everything to do with one product: palm oil.

“According to a new study in the journal *Nature Climate Change*, deforestation in the Southeast Asian archipelago is nearly double the rate in the Amazon. Indonesia is said to have lost 840,000 hectares (3,250 square miles) of forest in 2012 while Brazil - which has four times Indonesia’s rainforest - lost a still-massive 460,000 hectares.

¹<https://news.vice.com/article/indonesia-is-killing-the-planet-for-palm-oil>

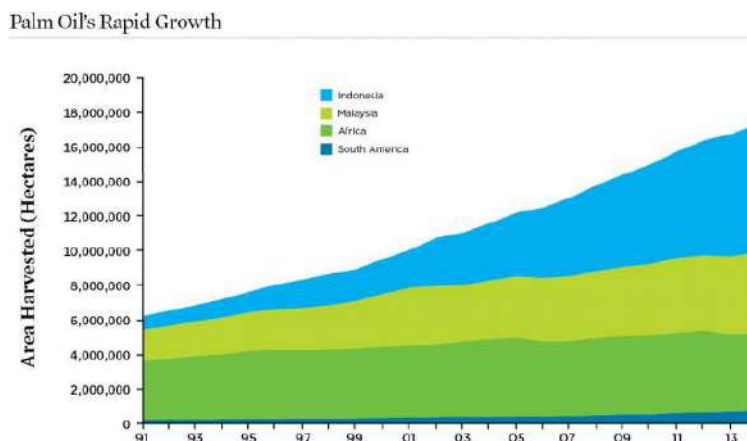


Figure 7.1: The growth of palm oil cultivation between 1993 and 2013. The dark area at the top of the graph indicates the dramatic growth of palm oil production in Southeast Asia, especially Indonesia.

“The report’s authors found that government figures underestimated the true toll of forest clearing by as much as half. In the last 12 years, it’s possible that the destruction of one million hectares of ‘primary forest’ went unreported.

“The tree-killing spree is largely due to slashing and burning vegetation for the expansion of palm oil plantations to feed growing demand in countries like China and India. Americans and Europeans are still far and away the top consumers per capita - it’s estimated that palm oil can be found in roughly half the manufactured goods in any supermarket or drug store. Everything from peanut butter to soap to cosmetics contains the oil in its various forms.

“In Indonesia, where much of the land consists of carbon-rich soil known as peat, the problem is acute. Water-logged peat is commonly found in the jungles of Sumatra and Borneo, and merely exposing it to the air releases carbon dioxide into the atmosphere.”

7.2 The beef industry in South America

Beef is killing the rainforest

Beef Production is Killing the Amazon Rainforest. That is the title of an article published by [onegreenplanet.org](http://www.onegreenplanet.org)². Here are some excerpts from the article

“The Amazon rainforest has been facing severe deforestation problems for several decades - it has lost about a fifth of its forest in the past three. While there are many causes, one of the main causes is cattle ranching, particularly in Brazil. Trees are cut and the land is converted into a pasture for cattle grazing. According to one report, an estimated 70 percent of deforestation in the Amazon basin can be attributed to cattle

²<http://www.onegreenplanet.org/animalsandnature/beef-production-is-killing-the-amazon-rainforest/>

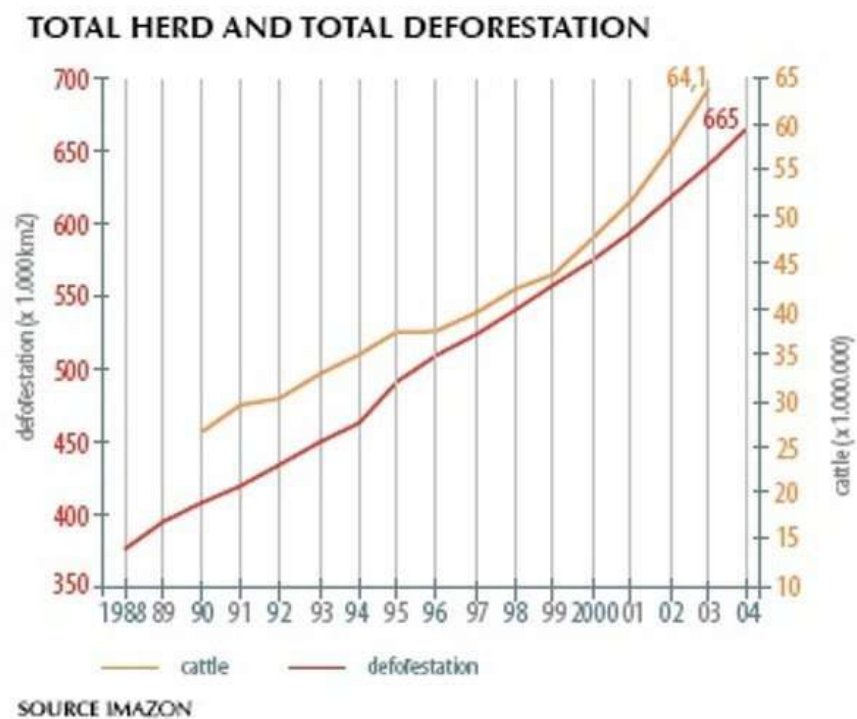


Figure 7.2: Total cattle herds and total deforestation in Amazonia between 1988 and 2004. Deforestation is measured in thousands of square kilometers, while herd size is measured in millions.

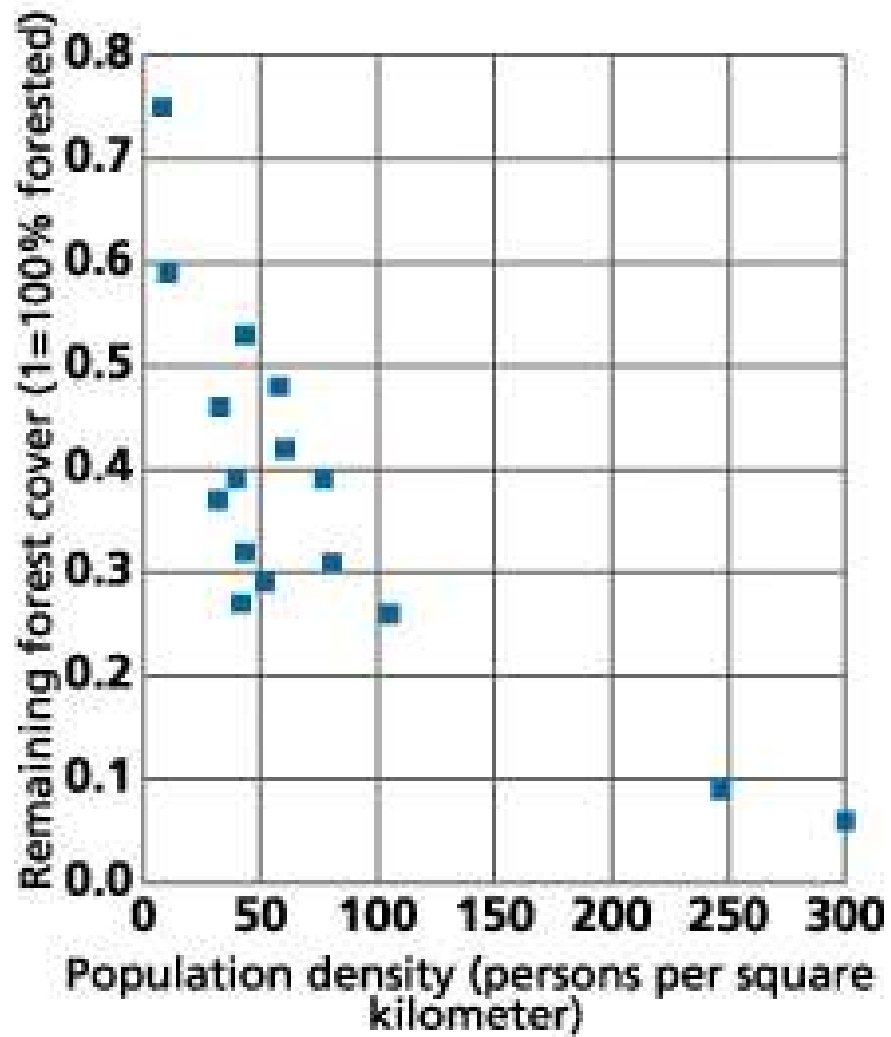


Figure 7.3: Population density and forest size.

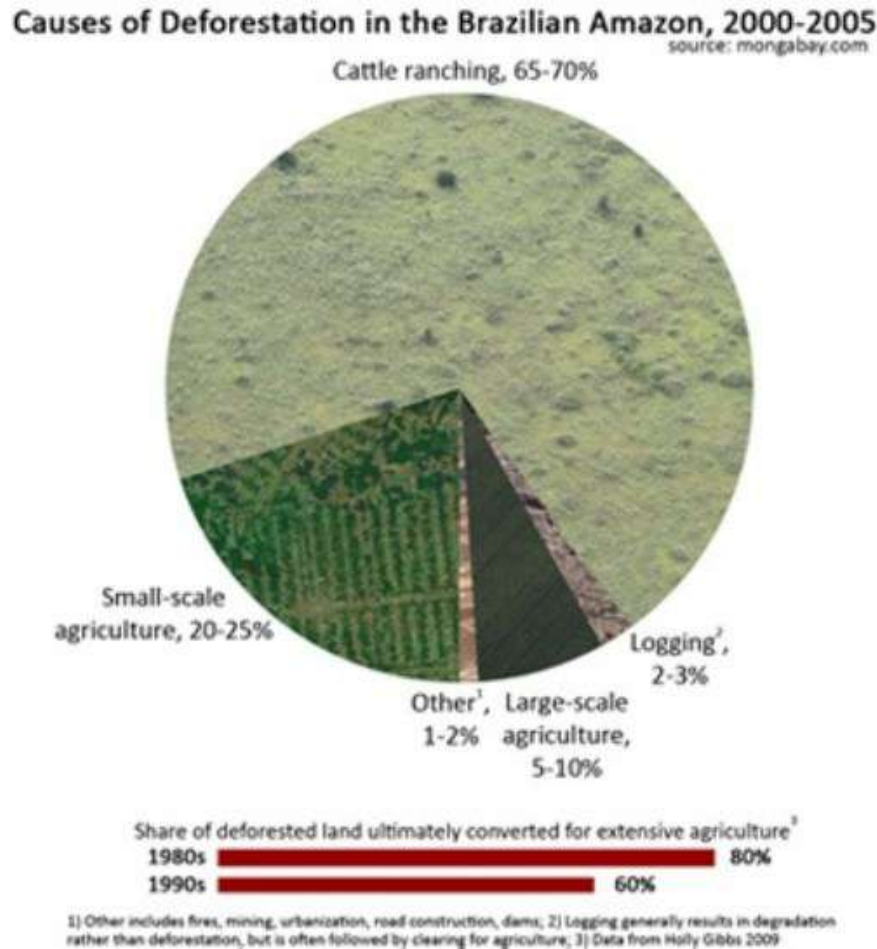


Figure 7.4: This figure shows the causes of Amazonian deforestation. The largest is beef production.

ranching. Using these numbers, cattle ranching in the Amazon has resulted in the loss of an area larger than the state of Washington.

“The government of Brazil offers loans of billions of dollars to support the expansion of its beef industry. Approximately 200 million pounds of beef is imported by the United States from Central America every year. While the chief importers of Brazilian beef were previously Europe and North America, nowadays Asian countries such as China and Russia consume more Brazilian beef than the European market. So, the demand is increasing day by day.

“With increasing population and increased per capita meat consumption, the rate of deforestation is increasing every day as well. It is expected that by 2018, the beef export will increase 93 percent, thereby increasing Brazil’s beef market share of world exports to 61 percent. Beef is the most carbon-intensive form of meat production on the planet. The United Nations Food and Agriculture Organization finds that beef production gives rise to more greenhouse gases than the transportation industry.”

Beef production and methane

A cow (or a bull) releases between 70 and 120 kg of methane per year. Methane is a greenhouse gas like carbon dioxide, but the negative effect on the climate of methane (CH₄) is 23 times higher than the effect of CO₂. Therefore the release of about 100 kg methane per year for each cow is equivalent to about 2,300 kg CO₂ per year.

World-wide, there are about 1.5 billion cows and bulls. All ruminants (animals which regurgitates food and re-chews it) on the world emit about two billion metric tons of CO₂, equivalents per year. In addition, clearing of tropical forests and rain forests to get more grazing land and farm land is responsible for an extra 2.8 billion metric tons of CO₂ emission per year!

According to the Food and Agriculture Organization of the United Nations (FAO) agriculture is responsible for 18% of the total release of greenhouse gases world-wide (this is more than the whole transportation sector). Cattle-breeding is taking a major factor for these greenhouse gas emissions according to FAO. Says Henning Steinfeld, Chief of FAO's Livestock Information and Policy Branch and senior author of the report: "Livestock are one of the most significant contributors to today's most serious environmental problems. Urgent action is required to remedy the situation."

Livestock now use 30 percent of the earth's entire land surface, mostly permanent pasture but also including 33 percent of the global arable land used to producing feed for livestock, the report notes. As forests are cleared to create new pastures, it is a major driver of deforestation, especially in Latin America where, for example, some 70 percent of former forests in the Amazon have been turned over to grazing.

Dietary changes can help

You and I can help to save our common future by changing our diets, especially by cutting out beef. Not only does beef production produce methane and destroy rainforests, it also requires much more land per calorie than other forms of agriculture. By switching from beef to other protein-rich foods, we not only substantially reduce greenhouse gas emissions, but we also shorten the food chain, so that more grain will be available to feed the world's growing population. Furthermore a changed diet with less meat would improve our health, since animal fats have been linked with heart disease, circulatory problems and strokes.

7.3 Growing populations and forest loss

Deforestation is occurring at alarming rates, especially in countries that have high levels of population growth.³ The following table shows the forest loss in some countries where it is particularly high, together with their present and projected populations⁴. In the table, the

³<http://www.prb.org/Publications/Articles/2004>

/PopulationGrowthandDeforestationACriticalandComplexRelationship.aspx

⁴Population Action International, *Why Population Matters to Forests*

annual rate of forest loss in the period 2000-2010. measured both in thousands of hectares and in percent. Populations in millions in 2010 are shown, together with projected populations in 2050.

country	forest loss	percent	pop. 2010	pop. 2050
Brazil	-2642	-0.49	194.9	222.8
Australia	-562	-0.37	22.3	31.4
Indonesia	-498	-0.51	239.9	293.5
Nigeria	-410	-3.67	158.4	389.6
Tanzania	-403	-1.13	44.8	138.3
Zimbabwe	-327	-1.88	12.6	20.6
Dem. Rep. Congo	.311	-0.20	66.0	148.5
Myanmar	-310	-0.93	47.9	55.3
Bolivia	-290	-0.49	9.9	16.8
Venezuela	-288	-0.60	28.0	41.8

The main mechanism through which rapid population growth is linked to forest loss is felling forests for the sake of agriculture.

Notice that Nigeria is losing 3.67% of its forests each year. The population of Nigeria is projected to more than double by 2050, but rising death rates from heat, famine and conflicts may prevent this. In general, rising death rates from these causes may ultimately lead populations in the tropics to decrease rather than increase.

Population Action International points out that “Deforestation threatens the well-being and livelihoods of millions of people who heavily depend on forest resources. It is particularly devastating for women and children in poor rural communities.” The organization recommends that information and materials for family planning be made available to all through universal provision of primary health care.

7.4 Desertification and soil erosion

The Princeton University Dictionary defines *desertification* as “the process of fertile land transforming into desert typically as a result of deforestation, drought or improper/inappropriate agriculture”. It is estimated that approximately a billion people are under threat from further expansions of deserts.

Southward expansion of the Gobi desert

The Gobi desert is the fastest moving desert on earth. The rapid southward expansion of the Gobi is mainly due to human activities, such as overgrazing, deforestation and overuse

of water. Dust storms from the Gobi desert are becoming more and more frequent. Sand dunes are reportedly forming only 70 km north of Beijing.

The Sahel

Another region in which the threat of desertification is extremely acute is the Sahel, which is the boundary between Africa's Sahara desert to the north and a region of savanna to the south. The Sahel stretches between the Atlantic Ocean and the Red Sea. During the last 50 years, the Sahel has lost approximately 650,000 km² of fertile land to the desert, and the boundary of the Sahara has moved 250 km southward.

The southward expansion of the Sahara has been caused partly by climate change, and partly by human activities. Growing human populations have put pressure on the fragile arid environment by overgrazing, tree-cutting for firewood and inappropriate agriculture.

7.5 Forest drying and wildfires: a feedback loop

When climate change produces aridity in a forested region, wildfires produced by lightning, stray sparks from falling stones, or human carelessness become increasingly likely. Forest fires contribute to global warming by releasing CO₂ into the atmosphere and by destroying climate-friendly tree-covered areas. Thus a dangerous feedback loop can be formed, and as was discussed in Chapter 4, with every feedback loop there is an associated tipping point. In the case of forest drying and wildfires, passing the tipping point means that forest cover will be lost irrevocably. We must avoid passing wildfire tipping points through human activities, such as the deliberate burning of rainforests for the sake of oil palm plantations.

7.6 Degraded forests are carbon emitters

According to an article published in the journal *Science* on 28 September, 2017⁵, degraded tropical forest throughout the world have stopped being carbon absorbers, and are now carbon emitters.

Reporting on the study, *The Guardian*,⁶ noted that "Researchers found that forest areas in South America, Africa and Asia - which have until recently played a key role in absorbing greenhouse gases - are now releasing 425 teragrams of carbon annually, which is more than all the traffic in the United States.

"The study went further than any of its predecessors in measuring the impact of disturbance and degradation - the thinning of tree density and the culling of biodiversity below

⁵A. Baccini et al., *Tropical forests are a net carbon source based on aboveground measurements of gain and loss*, DOI: 10.1126/science.aam5962

⁶<https://www.theguardian.com/environment/2017/sep/28/alarm-as-study-reveals-worlds-tropical-forests-are-huge-carbon-emission-source>

an apparently protected canopy - usually as a result of selective logging, fire, drought and hunting.

“Overall, more carbon was lost to degradation and disturbance than deforestation. The researchers stressed this was an opportunity as well as a concern because it was now possible to identify which areas are being affected and to restore forests before they disappeared completely.”

7.7 Replanting forests

Around the world, people interested in replanting forests can take inspiration from the Green Belt Movement, which was founded in 1977 by Wangari Maathai.

The Green Belt Movement organizes women in rural Africa to combat deforestation by planting trees. In this way they restore their main source of fuel for cooking, generate income and stop soil erosion. Since its foundation in 1977, the movement has planted 51 million trees. Over 30,000 women have been trained in forestry, food processing, bee-keeping, and other trades. The movement emphasizes economic justice and empowerment of women. This work is particularly valuable in regions of water scarcity, because besides preventing soil erosion, forests prevent the rapid run-off of water.

In order to combat climate change and to prevent southward expansion of the Sahara, the African Union has initiated a project called the Great Green Wall. The project aims at creating a mosaic of green and productive landscapes stretching across Africa, the Sahel region to the Horn of Africa, a strip of forested land 15 km wide and 7,500 km long, stretching from Dakar to Djibouti.

In China, the Green Great Wall project aims at preventing the expansion of the Gobi desert by planting a 4,500-kilometer-long windbreaking line of forests. The project is expected to be completed by 2050.

Reforestation initiatives also exist in other countries, for example in India, Lebanon, Philippines, Japan, Germany, Canada and the United States.



Figure 7.5: Nobel Laureate Wangari Maathai (1940-2011).

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Chapter 8

CLIMATE CHANGE AND AGRICULTURE

8.1 Lester Brown's lecture in Copenhagen

After a lecture at the University of Copenhagen in the 1980's, Lester R. Brown of the Earth Policy Institute was asked which resource would be the first to become critically scarce. Everyone in the audience expected him to say “oil”, but instead he said “fresh water”. He went on to explain that falling water tables in China would soon make China unable to feed its population. This would not cause famine in China itself because of the strength of the Chinese economy, which would allow the Chinese to purchase grain on the world market. However, shortages of fresh water in China would indeed cause famine, for example in Africa, because Chinese demand for grain would raise prices on the world market beyond the ability of poor countries to pay.



Figure 8.1: Lester R. Brown

8.2 Predictions of drought in the Stern Review

According to a report presented to the Oxford Institute of Economic Policy by Sir Nicholas Stern on 31 January, 2006, areas likely to lose up to 30% of their rainfall by the 2050's because of climate change include much of the United States, Brazil, the Mediterranean region, Eastern Russia and Belarus, the Middle East, Southern Africa and Southern Australia. Meanwhile rainfall is predicted to increase up to 30% in Central Africa, Pakistan, India, Bangladesh, Siberia, and much of China.

Stern and his team point out that "We can... expect to see changes in the Indian monsoon, which could have a huge impact on the lives of hundreds of millions of people in India, Pakistan and Bangladesh. Most climate models suggest that the monsoon will change, although there is still uncertainty about exactly how. Nevertheless, small changes in the monsoon could have a huge impact. Today, a fluctuation of just 10% in either direction from average monsoon rainfall is known to cause either severe flooding or drought. A weak summer monsoon, for example, can lead to poor harvests and food shortages among the rural population - two-thirds of India's almost 1.1 billion people. Heavier-than-usual monsoon downpours can also have devastating consequences..."

In some regions, melting of glaciers can be serious from the standpoint of dry-season water supplies. For example, melts from glaciers in the Hindu Kush and the Himalayas now supply much of Asia, including China and India, with a dry-season water supply. Complete melting of these glacial systems would cause an exaggerated runoff for a few decades, after which there would be a drying out of some of the most densely populated regions of the world.

8.3 Ocean current changes and failure of monsoons

It is expected that climate change will affect ocean currents, and hence also affect monsoon rainfall. We are already experiencing a diversion of the Gulf Stream due to southward currents of cold water from melting ice in the Arctic. This has caused what is known as the *North Atlantic Anomaly*. While most regions of the world are experiencing rising temperatures, the North Atlantic and several northern European countries are exceptions to this rule, and have cooled. Complete failure of the Gulf Stream would lead to much colder temperatures in Europe.

Changes in ocean currents have already lead to the failure of the West African Monsoon, and this has already produced severe food insecurity in West Africa.

In the future, climate-changed ocean currents may lead to failures of monsoons in South-east Asia, and thus damage the food supply of almost two billion people.

8.4 Falling water tables around the world

Under many desert areas of the world are deeply buried water tables formed during glacial periods when the climate of these regions was wetter. These regions include the Middle

East and large parts of Africa. Water can be withdrawn from such ancient reservoirs by deep wells and pumping, but only for a limited amount of time.

In oil-rich Saudi Arabia, petroenergy is used to drill wells for ancient water and to bring it to the surface. Much of this water is used to irrigate wheat fields, and this is done to such an extent that Saudi Arabia exports wheat. The country is, in effect, exporting its ancient heritage of water, a policy that it may, in time, regret. A similarly short-sighted project is Muammar Qaddafi's enormous pipeline, which will bring water from ancient sub-desert reservoirs to coastal cities.

In the United States, the great Ogallala aquifer is being overdrawn. This aquifer is an enormous stratum of water-saturated sand and gravel under-lying parts of northern Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming and South Dakota. The average thickness of the aquifer is about 70 meters. The rate of water withdrawal from the aquifer exceeds the rate of recharge by a factor of eight.

Thus we can see that in many regions, the earth's present population is living on its inheritance of water, rather than its income. This fact, coupled with rapidly increasing populations and climate change, may contribute to a very serious food crisis partway through the 21st century.

8.5 Glacial melting and summer water supplies

The summer water supplies of both China and India are threatened by the melting of glaciers. The Gangotri glacier, which is the principle glacier feeding India's great Ganges River, is reported to be melting at an accelerating rate, and it could disappear within a few decades. If this happens, the Ganges could become seasonal, flowing only during the monsoon season. Chinese agriculture is also threatened by disappearing Himalayan glaciers, in this case those on the Tibet-Quinghai Plateau. The respected Chinese glaciologist Yao Tandong estimates that the glaciers feeding the Yangtze and Yellow Rivers are disappearing at the rate of 7% per year.¹

8.6 Advances in desalinization technology

Scientists at the Massachusetts Institute of Technology have developed a new desalinization process, called shock electrodialysis. In this process, water flows through a porous material - in this case, made of tiny glass particles, called a frit - with membranes or electrodes sandwiching the porous material on each side. When an electric current flows through the system, the salty water divides into regions where the salt concentration is either depleted or enriched. When that current is increased to a certain point, it generates a shockwave

¹<http://www.commondreams.org/news/2015/08/04/global-glaciers-melting-three-times-rate-20th-century>

between these two zones, sharply dividing the streams and allowing the fresh and salty regions to be separated by a simple physical barrier at the center of the flow.

“It generates a very strong gradient,” says Martin Bazant, a researcher involved with the project².

Even though the system can use membranes on each side of the porous material, Bazant explains, the water flows across those membranes, not through them. That means they are not as vulnerable to fouling - a buildup of filtered material - or to degradation due to water pressure, as happens with conventional membrane-based desalination, including conventional electrodialysis. “The salt doesn’t have to push through something,” Bazant says. “The charged salt particles, or ions, just move to one side”.

8.7 The Green Revolution

In 1944 the Norwegian-American plant geneticist Norman Borlaug was sent to Mexico by the Rockefeller Foundation to try to produce new wheat varieties that might increase Mexico’s agricultural output. Borlaug’s dedicated work on this project was spectacularly successful. He remained with the project for 16 years, and his group made 6,000 individual crossings of wheat varieties to produce high-yield disease-resistant strains.

In 1963, Borlaug visited India, bringing with him 100 kg. of seeds from each of his most promising wheat strains. After testing these strains in Asia, he imported 450 tons of the Lerma Rojo and Sonora 64 varieties - 250 tons for Pakistan and 200 for India. By 1968, the success of these varieties was so great that school buildings had to be commandeered to store the output. Borlaug’s work began to be called a “Green Revolution”. In India, the research on high-yield crops was continued and expanded by Prof. M.S. Swaminathan and his coworkers. The work of Green Revolution scientists, such as Norman Borlaug and M.S. Swaminathan, has been credited with saving the lives of as many as a billion people.

Despite these successes, Borlaug believes that the problem of population growth is still a serious one. “Africa and the former Soviet republics”, Borlaug states, “and the Cerrado³, are the last frontiers. After they are in use, the world will have no additional sizable blocks of arable land left to put into production, unless you are willing to level whole forests, which you should not do. So, future food-production increases will have to come from higher yields. And though I have no doubt that yields will keep going up, whether they can go up enough to feed the population monster is another matter. Unless progress with agricultural yields remains very strong, the next century will experience human misery that, on a sheer numerical scale, will exceed the worst of everything that has come before.”

A very serious problem with Green Revolution plant varieties is that they require heavy inputs of pesticides, fertilizers and irrigation. Because of this, the use of high-yield varieties contributes to social inequality, since only rich farmers can afford the necessary inputs. Monocultures, such as the Green Revolution varieties may also prove to be vulnerable to future epidemics of plant diseases, such as the epidemic that caused the Irish Potato

² He was quoted in an article published in *MIT News*, November 12, 2015

³ The Cerrado is a large savanna region of Brazil.



Figure 8.2: **Norman Borlaug's work on developing high-yield disease-resistant plant varieties won him a Nobel Peace Prize in 1970.**

Famine in 1845. Even more importantly, pesticides, fertilizers and irrigation all depend on the use of fossil fuels. One must therefore ask whether high agricultural yields can be maintained in the future, when fossil fuels are expected to become prohibitively scarce and expensive.

8.8 Energy inputs of agriculture

Modern agriculture has become highly dependent on fossil fuels, especially on petroleum and natural gas. This is especially true of production of the high-yield grain varieties introduced in the Green Revolution, since these require especially large inputs of fertilizers, pesticides and irrigation. Today, fertilizers are produced using oil and natural gas, while pesticides are synthesized from petroleum feedstocks, and irrigation is driven by fossil fuel energy. Thus agriculture in the developed countries has become a process where inputs of fossil fuel energy are converted into food calories. If one focuses only on the farming operations, the fossil fuel energy inputs are distributed as follows:

1. Manufacture of inorganic fertilizer, 31%
2. Operation of field machinery, 19%
3. Transportation, 16%
4. Irrigation, 13%

5. Raising livestock (not including livestock feed), 8%
6. Crop drying, 5%
7. Pesticide production, 5%
8. Miscellaneous, 8%

The ratio of the fossil fuel energy inputs to the food calorie outputs depends on how many energy-using elements of food production are included in the accounting. David Pimentel and Mario Giampietro of Cornell University estimated in 1994 that U.S. agriculture required 0.7 kcal of fossil fuel energy inputs to produce 1.0 kcal of food energy. However, this figure was based on U.N. statistics that did not include fertilizer feedstocks, pesticide feedstocks, energy and machinery for drying crops, or electricity, construction and maintenance of farm buildings. A more accurate calculation, including these inputs, gives an input/output ratio of approximately 1.0. Finally, if the energy expended on transportation, packaging and retailing of food is included, Pimentel and Giampietro found that the input/output ratio for the U.S. food system was approximately 10, and this figure did not include energy used for cooking.

8.9 Sustainable future populations

In an important and detailed study entitled *Will Limited Land, Water, and Energy Control Human Population Numbers in the Future?*, David Pimentel et al.⁴ discuss the problem of agriculture and global population in the post fossil fuel era. Here are some quotations from the article:

“Nearly 60% of the world’s human population is malnourished and the numbers are growing. Shortages of basic foods related to decreases in per capita cropland, water, and fossil energy resources contribute to spreading malnutrition and other diseases. The suggestion is that in the future only a smaller number of people will have access to adequate nourishment. In about 100 years, when it is reported that the planet will run out of fossil energy, we suggest that a world population of about two billion might be sustainable if it relies on renewable energy technologies and also reduces per capita use of the earth’s natural resources.

“Developed and developing nations need to provide a good quality life for their people while coping with rapid population growth, but ‘Population is the issue no one wants to touch’ (Meadows 2000). The current world population is about 6.8 billion. Based on the present growth rate of 1.2% per year, the population is projected to double in approximately 58 years (Chiras 2006; PRB 2008). Because population growth cannot continue indefinitely, society can either voluntarily control its numbers or let natural forces such as disease, malnutrition, and other disasters limit human numbers (Bartlett 1997-98; Pimentel et al. 1999). Increasing human numbers especially in urban areas, and increasing

⁴D. Pimentel et al., *Human Ecology* DOI 10.1007/s10745-010-9346-y, (2010)

pollution of food, water, air, and soil by pathogenic disease organisms and chemicals, are causing a rapid increase in the prevalence of disease and human mortality (Murray and Lopez 1996; Pimentel et al. 2007). Currently, more than 3.7 billion humans are malnourished worldwide - the largest number ever (WHO 2005a, b).

“The planet’s numerous environmental problems highlight the urgent need to evaluate available land, water, and energy resources and how they relate to the requirements of a rapidly growing human population (Pimentel and Pimentel 2008). In this article we assess the carrying capacity of the Earth’s natural resources, and suggest that humans should voluntarily limit their population growth, rather than letting natural forces control their numbers (Ferguson 1998; Pimentel et al. 1999). In addition, we suggest appropriate policies and technologies that would improve standards of living and quality of life worldwide...

“In 1960, when the world population numbered about 3 billion, approximately 0.5 ha of cropland was available per capita worldwide. This half a hectare is needed to provide a diverse, healthy, nutritious diet of plant and animal products...”

Pimentel et al. state that worldwide, the average cropland per capita has now fallen to 0.22 hectares. This number will continue to fall because global population is increasing at the rate of almost one billion people per decade, while the global area available for cropland is not increasing. On the contrary, it is decreasing because of desertification, erosion, salination and urban sprawl. Pimentel et al. state that cropland is being degraded and lost at a rate of more than 20 million hectares per year-

The current cropland per capita in the United States is 0.56 hectares, and thus still quite large, but in China, the figure is dangerously low: only 0.1 hectares. China will soon be unable to feed its population and will have to buy grain on the world market. As Lester Brown pointed out in his Copenhagen lecture, China will be able to import grain because of its strong economy, but this will raise food prices and will cause widespread famine in other parts of the world.

Added to the agricultural and environmental problems, are problems of finance and distribution. Famines can occur even when grain is available somewhere in the world, because those who are threatened with starvation may not be able to pay for the grain, or for its transportation. The economic laws of supply and demand are not able to solve this type of problem. One says that there is no “demand” for the food (meaning demand in the economic sense), even though people are in fact starving.

What is the optimum population of the world? It is certainly not the maximum number that can be squeezed onto the globe by eradicating every species of plant and animal that cannot be eaten. The optimum global population is one that can be supported in comfort, equality and dignity - and with respect for the environment.

In 1848 (when there were just over one billion people in the world), John Stuart Mill described the optimal global population in the following words:

“The density of population necessary to enable mankind to obtain, in the greatest degree, all the advantages of cooperation and social intercourse, has, in the most populous countries, been attained. A population may be too crowded, although all be amply supplied with food and raiment.”

“... Nor is there much satisfaction in contemplating the world with nothing left to the

spontaneous activity of nature; with every rood of land brought into cultivation, which is capable of growing food for human beings; every flowery waste or natural pasture plowed up, all quadrupeds or birds which are not domesticated for man's use exterminated as his rivals for food, every hedgerow or superfluous tree rooted out, and scarcely a place left where a wild shrub or flower could grow without being eradicated as a weed in the name of improved agriculture. If the earth must lose that great portion of its pleasantness which it owes to things that the unlimited increase of wealth and population would extirpate from it, for the mere purpose of enabling it to support a larger, but not better or happier population, I sincerely hope, for the sake of posterity, that they will be content to be stationary, long before necessity compels them to it."⁵

Dennis Meadows, one of the authors of *Limits to Growth*, stated recently that the optimum human population in the distant future may be about 2 billion people.

But what about the near future? Will the global population of humans crash catastrophically after having exceeded the carrying capacity of the environment? There is certainly a danger that this will happen - a danger that the 21st century will bring very large scale famines to vulnerable parts of the world, because modern energy-intensive agriculture will be dealt a severe blow by prohibitively high petroleum prices. At present, there are only a few major food-exporting countries, notably the United States, Canada, Australia and Argentina. There is a danger that within a few decades, the United States will no longer be able to export food because of falling production and because of the demands of a growing population. We should be aware of these serious future problems if we are to have a chance of avoiding them.

8.10 The demographic transition

The developed industrial nations of the modern world have gone through a process known as the "demographic transition" - a shift from an equilibrium where population growth is held in check by the grim Malthusian forces of disease, starvation and war, to one where it is held in check by birth control and late marriage.

The transition begins with a fall in the death rate, caused by various factors, among which the most important is the application of scientific knowledge to the prevention of disease. Malthus gives the following list of some of the causes of high death rates: "...unwholesome occupations, severe labour and exposure to the seasons, extreme poverty, bad nursing of children, great towns, excesses of all kinds, the whole train of common diseases and epidemics, wars, plague and famine." The demographic transition begins when some of the causes of high death rates are removed.

Cultural patterns require some time to adjust to the lowered death rate, and so the birth rate continues to be high. Families continue to have six or seven children, just as they did when most of the children died before having children of their own. Therefore, at the start of the demographic transition, the population increases sharply. After a certain

⁵John Stuart Mill, *Principles of Political Economy, With Some of Their Applications to Social Philosophy*, (1848).

amount of time, however, cultural patterns usually adjust to the lowered death rate, and a new equilibrium is established, where both the birth rate and the death rate are low.

In Europe, this period of adjustment required about two hundred years. In 1750, the death rate began to fall sharply: By 1800, it had been cut in half, from 35 deaths per thousand people in 1750 to 18 in 1800; and it continued to fall. Meanwhile, the birth rate did not fall, but even increased to 40 births per thousand per year in 1800. Thus the number of children born every year was more than twice the number needed to compensate for the deaths!

By 1800, the population was increasing by more than two percent every year. In 1750, the population of Europe was 150 million; by 1800, it was roughly 220 million; by 1950 it had exceeded 540 million, and in 1970 it was 646 million.

Meanwhile the achievements of medical science and the reduction of the effects of famine and warfare had been affecting the rest of the world: In 1750, the non-European population of the world was only 585 million. By 1850 it had reached 877 million. During the century between 1850 and 1950, the population of Asia, Africa and Latin America more than doubled, reaching 1.8 billion in 1950. In the twenty years between 1950 and 1970, the population of Asia, Africa and Latin America increased still more sharply, and in 1970, this segment of the world's population reached 2.6 billion, bringing the world total to 3.6 billion. The fastest increase was in Latin America, where population almost doubled during the twenty years between 1950 and 1970.

The latest figures show that population has stabilized or in some cases is even decreasing in Europe, Russia, Canada, Japan, Cuba and New Zealand. In Argentina, the United States, China, Myanmar, Thailand and Australia, the rates of population increase are moderate - 0.6%-1.0%; but even this moderate rate of increase will have a heavy ecological impact, particularly in the United States, with its high rates of consumption.

The population of the remainder of the world is increasing at breakneck speed - 2%-4% per year - and it cannot continue to expand at this rate for very much longer without producing widespread famines, since modern intensive agriculture cannot be sustained beyond the end of the fossil fuel era. The threat of catastrophic future famines makes it vital that all countries that have not completed the demographic transition should do so as rapidly as possible.

The Stages of the Demographic Transition.

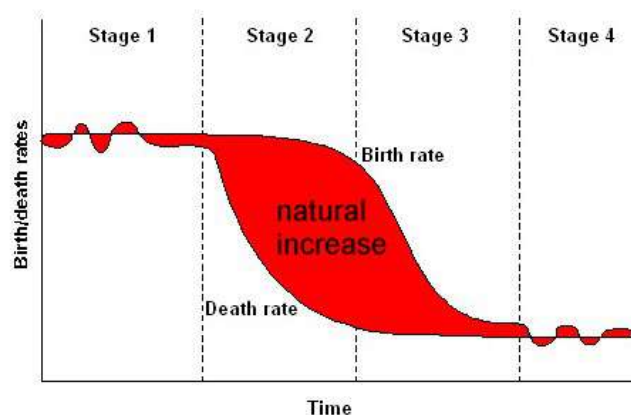


Figure 8.3: The demographic transition.

8.11 Urbanization

The global rate of population growth has slowed from 2.0 percent per year in 1972 to 1.7 percent per year in 1987; and one can hope that it will continue to fall. However, it is still very high in most developing countries. For example, in Kenya, the population growth rate is 4.0 percent per year, which means that the population of Kenya will double in seventeen years.

During the 60 years between 1920 and 1980 the urban population of the developing countries increased by a factor of 10, from 100 million to almost a billion. In 1950, the population of Sao Paulo in Brazil was 2.7 million. By 1980, it had grown to 12.6 million; and it is expected to reach 24.0 million by the year 2000. Mexico City too has grown explosively to an unmanageable size. In 1950, the population of Mexico City was 3.05 million; in 1982 it was 16.0 million; and the population in 2000 was 17.8 million.

A similar explosive growth of cities can be seen in Africa and in Asia. In 1968, Lusaka, the capital of Zambia, and Lagos, the capital of Nigeria, were both growing at the rate of 14 percent per year, doubling in size every 5 years. In 1950, Nairobi, the capital of Kenya, had a population of 0.14 million. In a 1999 census, it was estimated to be between 3 and 4 million, having increased by a factor of 25.

In 1972, the population of Calcutta was 7.5 million. By the turn of the century in 2000, it had almost doubled in size. This rapid growth produced an increase in the poverty and pollution from which Calcutta already suffered in the 1970's. The Hooghly estuary near Calcutta is choked with untreated industrial waste and sewage, and a large percentage of Calcutta's citizens suffer from respiratory diseases related to air pollution.

Governments in the third world, struggling to provide clean water, sanitation, roads, schools, medical help and jobs for all their citizens, are defeated by rapidly growing urban



Figure 8.4: Because of the threat of widespread famine, it is vital that all countries should complete the demographic transition as quickly as possible.



Figure 8.5: Sir Partha Dasgupta of Cambridge University has pointed out that all the changes needed for population stabilization are desirable in themselves. These include education for women, higher status for women, state provision of old-age help for the poor, universal health care, and making safe drinking water available near to dwellings.

populations. Often the makeshift shantytowns inhabited by new arrivals have no piped water; or when water systems exist, the pressures may be so low that sewage seeps into the system.

Many homeless children, left to fend for themselves, sleep and forage in the streets of third world cities. These conditions have tended to become worse with time rather than better. Whatever gains governments can make are immediately canceled by growing populations.

8.12 Achieving economic equality

Today's world is characterized by intolerable economic inequalities, both between nations and within nations. A group of countries including (among others) Japan, Germany, France, the United Kingdom and the United States, has only 13% of the world's population, but receives 45% of the global PPP⁶ income. By contrast, a second group, including 2.1 Billion people (45% of the world's population) receives only 9% of the global PPP income. Another indicator of inequality is the fact that the 50 million richest people in the world receive as much as the 2,700 million poorest.

18 million of our fellow humans die each year from poverty-related causes. Each year, 11 million children die before reaching their fifth birthday. 1.1 billion people live on less than \$1 per day; 2.7 billion live on less than \$2.

At the United Nations Conference on Population and Development, held in Cairo in September, 1994, a theme which emerged very clearly was that one of the most important keys to controlling the global population explosion is giving women better education and equal rights. These goals are desirable for their own sake, and for the sake of the uniquely life-oriented point of view which women can give us; but in addition, education and improved status for women have shown themselves to be closely connected with lowered birth rates. When women lack education and independent careers outside the home, they can be forced into the role of baby-producing machines by men who do not share in the drudgery of cooking, washing and cleaning; but when women have educational, legal, economic, social and political equality with men, experience has shown that they choose to limit their families to a moderate size.

As glaciers melt in the Himalayas, depriving India and China of summer water supplies; as sea levels rise, drowning the fertile rice fields of Viet Nam and Bangladesh; as drought threatens the productivity of grain-producing regions of North America; and as the end of the fossil fuel era impacts modern high-yield agriculture, there is a threat of wide-spread famine. There is a danger that the 1.5 billion people who are undernourished today will not survive an even more food-scarce future.

People threatened with famine will become refugees, desperately seeking entry into countries where food shortages are less acute. Wars, such as those currently waged in the Middle East, will add to the problem.

⁶Purchasing Power Parity



Figure 8.6: Education of women and higher status for women are vitally important measures, not only for their own sake, but also because these social reforms have proved to be the key to lower birth rates.

What can we do to avoid this crisis, or at least to reduce its severity? We must urgently address the problem of climate change; and we must shift money from military expenditure to the support of birth control programs and agricultural research. We must also replace the institution of war by a system of effective global governance and enforceable international laws.

8.13 Achieving a steady-state economic system

Endless economic growth on a finite planet is a logical impossibility. Just as population growth is limited by ecological constraints, so too is the growth of resource-using and pollution-producing industrial production. Culture, of course, can and should continue to grow,

A number of economists have studied this problem, and in particular, outstanding contributions have been made by Frederick Soddy, Nickolas Georgescu-Roegan and Herman Daly. These authors have taken into account the role which entropy plays in economics.

8.14 Harmful effects of industrialized farming

Pharming

A major global public health crisis may soon be produced by the wholesale use of antibiotics in the food of healthy farm animals. The resistance factors produced by shovelling

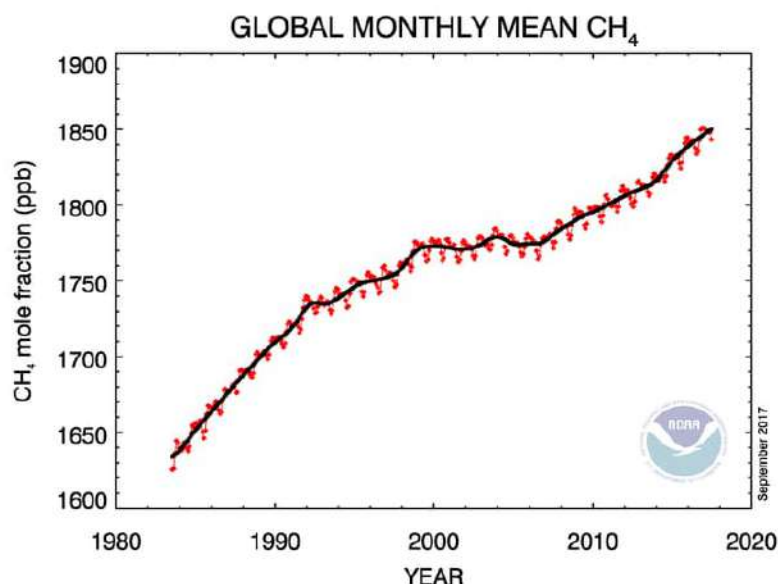


Figure 8.7: Methane emissions are steadily increasing. A new report has shown ruminants are largely responsible for increases in rates of emission.

antibiotics into animal food produces resistance factors (plasmids) which can easily be transferred to human pathogens. A related problem is the excessive use of pesticides and artificial fossil-fuel-derived fertilizers in agriculture. Pharming is not a joke. It is a serious threat.⁷

Meat and methane

Methane is an extremely powerful greenhouse gas. and it is emitted in large quantities by ruminants, such as cattle produced for beef. A new report⁸ finds that cattle are not the biggest contributor to the annual methane budget in the atmosphere, but they may be the biggest contributor to increases in methane emissions over recent years.

⁷<http://ecowatch.com/2014/03/06/misuse-antibiotics-fatal-superbug-crisis/>
<http://ecowatch.com/2013/12/06/8-scary-facts-about-antibiotic-resistance/>
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⁸J. Wolf et al., *Revised methane emissions factors and spatially distributed annual carbon fluxes for global livestock*, Carbon Balance and Management 2017, 12:16

One must also remember that by eating less meat, and in particular less beef, we can shorten the food chain and thus help famine-threatened populations.

Pesticides, artificial fertilizers and topsoil

A closely analogous danger results from the overuse of pesticides and petroleum-derived fertilizers in agriculture. A very serious problem with Green Revolution plant varieties is that they require heavy inputs of pesticides, fertilizers and irrigation. Because of this, the use of high-yield varieties contributes to social inequality, since only rich farmers can afford the necessary inputs. Monocultures, such as the Green Revolution varieties may also prove to be vulnerable to future plant diseases, such as the epidemic that caused the Irish Potato Famine in 1845. Even more importantly, pesticides, fertilizers and irrigation all depend on the use of fossil fuels. One must ask, therefore, whether high-yield agriculture can be maintained in the post-fossil-fuel era.

Topsoil is degraded by excessive use of pesticides and artificial fertilizers. Natural topsoil is rich in organic material, which contains sequestered carbon that would otherwise be present in our atmosphere in the form of greenhouse gases. In addition, natural topsoil contains an extraordinarily rich diversity of bacteria and worms that act to convert agricultural wastes from one year's harvest into nutrients for the growth of next year's crop. Pesticides kill these vital organisms, and make the use of artificial fertilizers necessary.

Finally, many small individual farmers, whose methods are sustainable, are being eliminated by secret land-grabs or put out of business because they cannot compete with unsustainable high-yield agriculture. Traditional agriculture contains a wealth of knowledge and biodiversity, which it would be wise for the world to preserve.

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Chapter 9

REFUGEES FROM CLIMATE CHANGE

9.1 Climate change as genocide

Climate change does not affect all parts of the world equally. The harshest effects of the extreme weather that we are already experiencing are disproportionately felt by the poorest people of the world.

In March, 2017, the Security Council was informed ¹ that 20 million people in four countries, Nigeria, Somalia, South Sudan and Yemen, were in danger of dying unless provided with immediate help. The cost of the necessary aid was estimated to be \$4.4 billion. The developed world's response has been a shrug of indifference. By the midsummer, 2017 only a tenth of the amount needed had been raised.

Conflicts and famine are interlinked. The struggle for food produces conflicts; and famine is often used as an instrument of war. Food aid, when available, is often deliberately blocked or destroyed by warring factions. Boko Haram in Nigeria, al-Shabaab in Somalia, assorted militias and the government in South Sudan, and Saudi-backed forces in Yemen all interfered with the delivery of aid supplies.

In the future, the effects of rising temperatures and reduced rainfall will disproportionately affect poor farmers of Africa, the Middle East, South Asia, and Latin America. If the more affluent parts of the world continue to produce greenhouse gasses in a business-as-usual scenario, and if they continue to ignore calls for help from starving people, these actions will amount to genocide.

¹by Stephen O'Brian, UN Under Secretary General for Humanitarian Affairs



Figure 9.1: A starving child in Somalia.

9.2 The United Nations High Commission on Refugees

In an article on *Climate Change and Disasters* the United Nations High Commission on Refugees makes the following statement:

“The Earth’s climate is changing at a rate that has exceeded most scientific forecasts. Some families and communities have already started to suffer from disasters and the consequences of climate change, forced to leave their homes in search of a new beginning.

“For UNHCR, the consequences of climate change are enormous. Scarce natural resources such as drinking water are likely to become even more limited. Many crops and some livestock are unlikely to survive in certain locations if conditions become too hot and dry, or too cold and wet. Food security, already a concern, will become even more challenging.

“People try to adapt to this situation, but for many this will mean a conscious move to another place to survive. Such moves, or the effects of climate change on natural resources, may spark conflict with other communities, as an increasing number of people compete for a decreasing amount of resources.

“Since 2009, an estimated one person every second has been displaced by a disaster, with an average of 22.5 million people displaced by climate- or weather-related events since 2008 (IDMC 2015). Disasters and slow onsets, such as droughts in Somalia in 2011 and 2012, floods in Pakistan between 2010 and 2012, and the earthquake in Nepal in 2015, can leave huge numbers of people traumatized without shelter, clean water and basic supplies.”

9.3 Populations displaced by sea level rise

In a recent article² discussed the long-term effects of sea level rise and the massive refugee crisis that it might create. By 2060, about 1.4 billion people could be climate change refugees, according to the paper, and that number could reach 2 billion by 2100.

The lead author, Prof. Emeritus Charles Geisler of Cornell University says: “The colliding forces of human fertility, submerging coastal zones, residential retreat, and impediments to inland resettlement is a huge problem. We offer preliminary estimates of the lands unlikely to support new waves of climate refugees due to the residues of war, exhausted natural resources, declining net primary productivity, desertification, urban sprawl, land concentration, ‘paving the planet’ with roads and greenhouse gas storage zones offsetting permafrost melt.”

We should notice that Prof. Geisler’s estimate of 2 billion climate refugees by 2100 includes all causes, not merely sea level rise. However, the number of refugees from sea level rise alone will be very large, since all the world’s coastal cities, and many river deltas will be at risk.

9.4 Populations displaced by drought and famine

Climate change could produce a refugee crisis that is “unprecedented in human history”, Barack Obama has warned as he stressed global warming was the most pressing issue of the age.

Speaking at an international food conference in Milan, the former US President said rising temperatures were already making it more difficult to grow crops and rising food prices were “leading to political instability”.

If world leaders put aside “parochial interests” and took action to reduce greenhouse gas emissions by enough to restrict the rise to one or two degrees Celsius, then humanity would probably be able to cope.

Failing to do this, Mr Obama warned, increased the risk of “catastrophic” effects in the future, “not only real threats to food security, but also increases in conflict as a consequence of scarcity and greater refugee and migration patterns”.

“If you think about monsoon patterns in the Indian subcontinent, maybe half a billion people rely on traditional rain patterns in those areas,”

9.5 Populations displaced by rising temperatures

A new study published in *Nature: Climate Change* has warned that up to 75% of the world’s population could face deadly heat waves by 2100 unless greenhouse gas emissions are rapidly controlled.³ The following is an excerpt from the article:

²Geisler C. et al., *Impediments to inland resettlement under conditions of accelerated sea level rise*, Land Use Policy, Vol 55, July 2017, Pages 322-330

³Mora, C. et al., *Global risk of deadly heat*, *Nature: Climate Change*, 19 June 2017

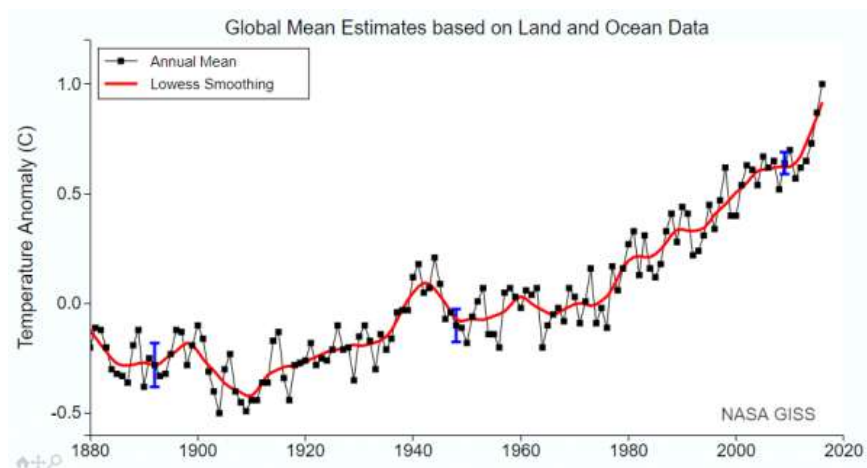


Figure 9.2: **This figure shows an alarming upward turn in the average global temperature**

“Here we conducted a global analysis of documented lethal heat events to identify the climatic conditions associated with human death and then quantified the current and projected occurrence of such deadly climatic conditions worldwide. We reviewed papers published between 1980 and 2014, and found 783 cases of excess human mortality associated with heat from 164 cities in 36 countries.

“Based on the climatic conditions of those lethal heat events, we identified a global threshold beyond which daily mean surface air temperature and relative humidity become deadly. Around 30% of the world’s population is currently exposed to climatic conditions exceeding this deadly threshold for at least 20 days a year.

“By 2100, this percentage is projected to increase to 48% under a scenario with drastic reductions of greenhouse gas emissions and 74% under a scenario of growing emissions. An increasing threat to human life from excess heat now seems almost inevitable, but will be greatly aggravated if greenhouse gases are not considerably reduced.”⁴

9.6 Populations displaced by war

A recent article in *The Guardian*⁵ discusses the relationship between climate change and war, Here are some excerpts from the article:

“Climate change is set to cause a refugee crisis of ‘unimaginable scale’, according to senior military figures, who warn that global warming is the greatest security threat of the 21st century and that mass migration will become the ‘new normal’.

⁴See also <https://phys.org/news/2017-08-deadly-south-asia-century.html> and <https://cleantechnica.com/2017/09/28/extreme-heatwaves-like-recent-lucifer-heatwave-become-normal-europe-2050s/>

⁵Thursday, 1 December, 2016

“The generals said the impacts of climate change were already factors in the conflicts driving a current crisis of migration into Europe, having been linked to the Arab Spring, the war in Syria and the Boko Haram terrorist insurgency.

“Military leaders have long warned that global warming could multiply and accelerate security threats around the world by provoking conflicts and migration. They are now warning that immediate action is required.

“‘Climate change is the greatest security threat of the 21st century,’ said Maj Gen Muniruzzaman.

“Muniruzzaman, chairman of the Global Military Advisory Council on climate change and a former military adviser to the president of Bangladesh. He said one meter of sea level rise will flood 20% of his nation. ‘We’re going to see refugee problems on an unimaginable scale, potentially above 30 million people.’

“Previously, Bangladesh’s finance minister, Abul Maal Abdul Muhith, called on Britain and other wealthy countries to accept millions of displaced people.

“Brig Gen Stephen Cheney, a member of the US Department of State’s foreign affairs policy board and CEO of the American Security Project, said: ‘Climate change could lead to a humanitarian crisis of epic proportions. We’re already seeing migration of large numbers of people around the world because of food scarcity, water insecurity and extreme weather, and this is set to become the new normal’.

9.7 Political reactions to migration

Brexit

Across the developed world, the reaction to threatened migration of refugees from climate change has been less than generous, to say the least. The recent decision of Britain to leave the European Union was motivated largely by the fear of British workers that EU laws would force their country to accept large numbers of refugees.

Swings to the right in Europe

In Germany, Angela Merkel’s generous policies towards refugees have cost her votes, while an openly racist party, the Alternative for Germany (AfD) party, has gained in strength. Frauke Petry, 40, the party’s leader, has said border guards might need to turn guns on anyone crossing a frontier illegally. The party’s policy platform says “Islam does not belong in Germany” and calls for a ban on the construction of mosques.

In September, 2017, eight people from the neo-Nazi Freital Group were put on trial in Dresden for bomb attacks on homes for asylum applicants. Hundreds of similar assaults occur in Germany every year, but they had never before been tried as terrorism in a federal court.

In the German election, which took place on Sunday, October 1, 2017, Angela Merkel won a fourth term as Chancellor, but her party won only 33% of the votes, a percentage

much reduced from the 41% won in the election of 2013. Angela Merkel was paying a high price for her refugee-friendly policies.

Meanwhile the far right anti-immigration AfD party made a historic breakthrough, winning 13.5% of the vote, thus becoming the first overtly nationalist party to sit in the Bundestag in 60 years. The Greens have already complained that “Nazis have returned to parliament”. In fact, members of the AfD party have begun to say that Germans should stop being ashamed of their country’s Nazi past.

In France, the National Front is a nationalist party that uses populist rhetoric to promote its anti-immigration and anti-European Union positions. The party favors protectionist economic policies and would clamp down on government benefits for immigrants.

Similarly, in the Netherlands, the anti-European Union, anti-Islam Party for Freedom has called for closing all Islamic schools and recording the ethnicity of all Dutch citizens. In early November, the party was leading in polls ahead of next year’s parliamentary elections.

Other far-right anti-immigrant parties in Europe include Golden Dawn (Greece), Jobbik (Hungary), Sweden Democrats (Sweden), Freedom Party (Austria), and People’s Party - Our Slovakia (Slovakia). All of these parties have gained in strength because of the widespread fear of immigration.

Populism in the United States

The election of Donald Trump, who ran for President in 2016 on an openly racist and anti-immigrant platform, can also be seen as the result of fear of immigration, especially on the part of industrial workers.

9.8 A more humane response to the refugee crisis

In the long-term future, climate change will make the refugee crisis much more severe. Heat and drought will make large regions of the world uninhabitable, and will threaten many populations with famine. The severity of the refugee crisis will depend on how quickly we reduce greenhouse gas emissions.

While making many parts of the world uninhabitable, long-term climate change will make other regions more suitable for human habitation and agriculture. For example, farming will become more possible in Siberia, Greenland, the Canadian Arctic, Alaska and Patagonia. A humane response to the refugee crisis could include the generous opening of these regions to refugees.

The global population of humans is currently increasing by almost a billion people every decade. Global population must be stabilized, and in the long run, gradually reduced. Money currently wasted (or worse than wasted) on armaments could be used instead to promote universal primary health care, and with it, universal access to the knowledge and materials needed for family planning.

Finally, reduced consumption of meat, particularly beef, would shorten the food chain thus make more food available for famine relief.

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Chapter 10

MONEY DRIVES THE MANIA OF GROWTH

10.1 Madmen and economists

“Anyone who believes in indefinite growth in anything physical, on a physically finite planet, is either mad or an economist”. Kenneth E. Boulding (1910-1993)

Why are economists addicted to growth?

Economists (with a few notable exceptions) have long behaved as though growth were synonymous with economic health. If the gross national product of a country increases steadily by 4 percent per year, most economists express approval and say that the economy is healthy. If the economy could be made to grow still faster (they maintain), it would be still more healthy. If the growth rate should fall, economic illness would be diagnosed. However, it is obvious that on a finite Earth, neither population growth nor economic growth can continue indefinitely.

But why do economists cling almost religiously to the idea of growth? In general, growth brings profits to speculators. For example, purchase of land on the outskirts of a growing city will be rewarded as the land increases in value.; and when the economy grows, stocks rise in value. ’

Today, as economic growth falters, the defects and injustices of our banking system have come sharply into focus, and light has also been thrown onto the much-too-cozy relationship between banking and government. The collapse of banks during the subprime mortgage crisis of 2008 and their subsequent bailout by means of the taxpayer’s money can give us an insight into both phenomena - the faults of our banking system and its infiltration into the halls of government. The same can be said of the present national debt crisis in the Euro zone and elsewhere.



10.2 Fractional reserve banking

One feature of banking that cries out for reform is “fractional reserve banking”, i.e. the practice whereby private banks keep only a tiny fraction of the money entrusted to them by their depositors, and lend out all the remaining amount. By doing so, the banks are in effect coining their own money and putting it into circulation, a prerogative that ought to be reserved for governments. Under the system of fractional reserve banking, profits from any expansion of the money supply go to private banks rather than being used by the government to provide social services. This is basically fraudulent and unjust; the banks are in effect issuing their own counterfeit money.

When the economy contracts instead of expanding, the effect of fractional reserve banking is still worse. In that case the depositors ask the banks for their money, which it is their right to do. But the banks do not have the money - they have lent it out, and thus they fail. However, the bankers have insured themselves against this eventuality by buying the votes of government officials. Thus the banks are bailed out and the taxpayers are left with the bill, as in the recent example in which the US Federal Reserve secretly gave 7.7 trillion of the taxpayers’ dollars to bail out various banks.

Inside Job

The Academy-Award-Winning documentary film **Inside Job**¹ tells the shocking story of the corruption of the financial sector that led to the 2008 subprime mortgage crisis and bank

¹<https://www.theguardian.com/film/2011/feb/17/inside-job-review>
<https://topdocumentaryfilms.com/inside-job/>

bailout. The film can be seen online free of charge, and is well worth viewing. Of particular interest are discussions of the history of bank deregulation, governmental collusion, and the destabilizing effects of the enormous derivative market.

10.3 Information-driven population growth

Today we are able to estimate the population of the world at various periods in history, and we can also make estimates of global population in prehistoric times. Looking at the data, we can see that the global population of humans has not followed an exponential curve as a function of time, but has instead followed a hyperbolic trajectory.

At the time of Christ, the population of the world is believed to have been approximately 220 million. By 1500, the earth contained 450 million people, and by 1750, the global population exceeded 700 million. As the industrial and scientific revolution has accelerated, global population has responded by increasing at a break-neck speed: In 1930, the population of the world reached two billion; in 1958 three billion; in 1974 four billion; in 1988 five billion, and in 1999, six billion. Today, we have reached 7.6 billion, and roughly a billion people are being added to the world's population every twelve years.

As the physicist Murry Gell-Mann has pointed out, a simple mathematical curve which closely approximates the global population of humans over a period of several thousand years is a hyperbola of the form $P = 190,000,000,000/(2025-t)$. Here P represents the global population of humans and t is the year.

How are we to explain the fact that the population curve is not an exponential? We can turn to Malthus for an answer: According to his model, population does not increase exponentially, except under special circumstances, when the food supply is so ample that the increase of population is entirely unchecked.

Malthus gives us a model of culturally-driven population growth. He tells us that population increase tends to press against the limits of the food supply, and since these limits are culturally determined, population density is also culturally-determined. Hunter-gatherer societies need large tracts of land for their support; and in such societies, the population density is necessarily low. Pastoral methods of food production can support populations of a higher density. Finally, extremely high densities of population can be supported by modern agriculture. Thus, Gell-Mann's hyperbolic curve, should be seen as describing the rapidly-accelerating growth of human culture, this being understood to include methods of food production.

If we look at the curve, $P=C/(2025-t)$, it is obvious that human culture has reached a period of crisis. The curve predicts that the world's population will rise to infinity in the year 2025, which of course is impossible. Somehow the actual trajectory of global population as a function of time must deviate from the hyperbolic curve, and in fact, the trajectory has already begun to fall away from the hyperbola.

Because of the great amount of human suffering which may be involved, and the potentially catastrophic damage to the earth's environment, the question of how the actual trajectory of human population will come to deviate from the hyperbola is a matter of

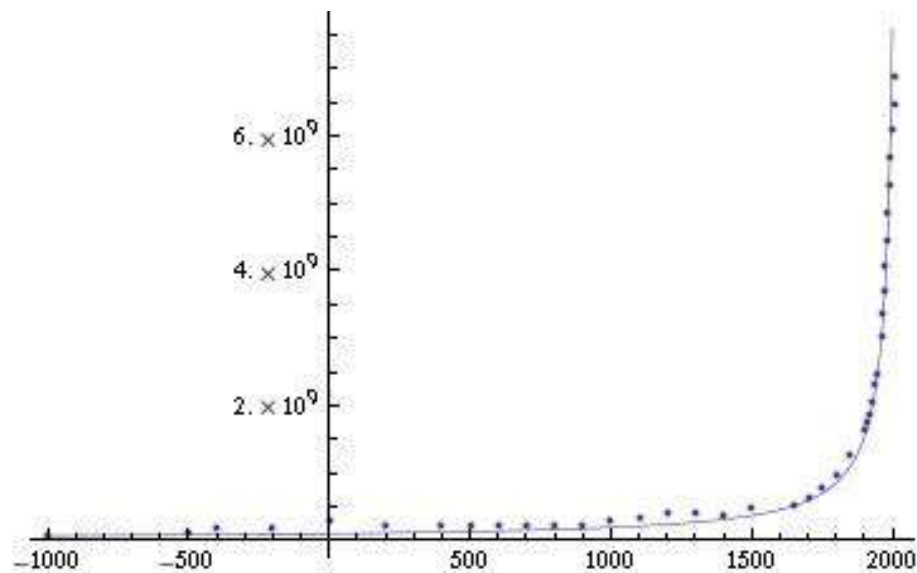


Figure 10.1: The simple mathematical curve that fits best to human population data over the last 3,000 years is not an exponential increase, but rather a hyperbola of the form $P=C/(2025-t)$. Here P represents population, $C=190,000,000,000$ and t is the year. The curve goes to infinity at $t=2025$ (only a few years away), which is of course impossible. Global population has already started to fall away from the hyperbolic trajectory. Will it level off, or will it crash disastrously? Because of the enormous amount of human suffering that would be involved in a population crash, the question has great importance.

enormous importance. Will population overshoot the sustainable limit, and crash? Or will it gradually approach a maximum? In the case of the second alternative, will the checks which slow population growth be later marriage and family planning? Or will the grim Malthusian forces - famine, disease and war - act to hold the number of humans within the carrying capacity of their environment?

We can anticipate that as the earth's human population approaches 10 billion, severe famines will occur in many developing countries. The beginnings of this tragedy can already be seen. It is estimated that roughly 30,000 children now die every day from starvation, or from a combination of disease and malnutrition.

Beyond the fossil fuel era

An analysis of the global ratio of population to cropland shows that we have probably already exceeded the sustainable limit of population through our dependence on petroleum: Between 1950 and 1982, the use of cheap synthetic fertilizers increased by a factor of 8. Much of our present agricultural output depends on their use, but their production is expensive in terms of energy. Furthermore, petroleum-derived synthetic fibers have reduced the amount of cropland needed for growing natural fibers, and petroleum-driven tractors have replaced draft animals which required cropland for pasturage.

Also, petroleum fuels have replaced fuelwood and other fuels derived from biomass. The reverse transition, from fossil fuels back to renewable energy sources, will require a considerable diversion of land from food production to energy production. For example, 1.1 hectares are needed to grow the sugarcane required for each alcohol-driven Brazilian automobile. This figure may be compared with the steadily falling average area of cropland available to each person in the world: .24 hectares in 1950, .16 hectares in 1982.

Thus there is a danger that just as global population reaches the unprecedented level of 10 billion or more, the agricultural base for supporting it may suddenly collapse. Ecological catastrophe, possibly compounded by war and other disorders, could produce famine and death on a scale unprecedented in history - a disaster of unimaginable proportions, involving billions rather than millions of people.

What would Malthus say today?

What would Malthus tell us if he were alive today? Certainly he would say that we have reached a period of human history where it is vital to stabilize the world's population if catastrophic environmental degradation and famine are to be avoided. He would applaud efforts to reduce suffering by eliminating poverty, widespread disease, and war; but he would point out that, since it is necessary to stop the rapid increase of human numbers, it follows that whenever the positive checks to population growth are removed, it is absolutely necessary to replace them by preventive checks. Malthus' point of view became more broad in the successive editions of his Essay; and if he were alive today, he would probably agree that family planning is the most humane of the preventive checks.

Eliminating poverty and war

In most of the societies which Malthus described, a clear causal link can be seen, not only between population pressure and poverty, but also between population pressure and war. As one reads his Essay, it becomes clear why both these terrible sources of human anguish saturate so much of history, and why efforts to eradicate them have so often met with failure: The only possible way to eliminate poverty and war is to reduce the pressure of population by preventive checks, since the increased food supply produced by occasional cultural advances can give only very temporary relief.

Today, the links between population pressure, poverty, and war are even more pronounced than they were in the past, because the growth of human population has brought us to the absolute limits imposed by ecological constraints. Furthermore, the development of nuclear weapons has made war prohibitively dangerous.

How many people can the earth support in comfort?

The resources of the earth and the techniques of modern science can support a global population of moderate size in comfort and security; but the optimum size is undoubtedly smaller than the world's present population. Given a sufficiently small global population, renewable sources of energy can be found to replace disappearing fossil fuels. Technology may also be able to find renewable substitutes for many disappearing mineral resources for a global population of a moderate size. What technology cannot do, however, is to give a global population of 10 billion people the standard of living which the industrialized countries enjoy today.

10.4 Entropy and economics

We urgently need to shift quickly from fossil fuels to renewable energy if we are to avoid a tipping point after which human efforts to avoid catastrophic climate change will be futile because feedback loops will have taken over. The dangerous methane hydrate feedback loop is discussed in an excellent short video made by Thom Hartmann and the Leonardo DiCaprio Foundation.²

Celebrated author and activist Naomi Klein has emphasized the link between need for economic reform and our urgent duty to address climate change.³

Rebel economist Prof. Tim Jackson discusses the ways in which our present economic system has failed us, and the specific reforms that are needed. In one of his publications, he says: "The myth of growth has failed us. It has failed the two billion people who still live on 2 dollars a day. It has failed the fragile ecological systems on which we depend for

²<https://www.youtube.com/watch?v=sRGVTK-AAvw>
<http://lasthours.org/>

³<http://thischangeseverything.org/naomi-klein/>
<http://www.theguardian.com/profile/naomiklein>

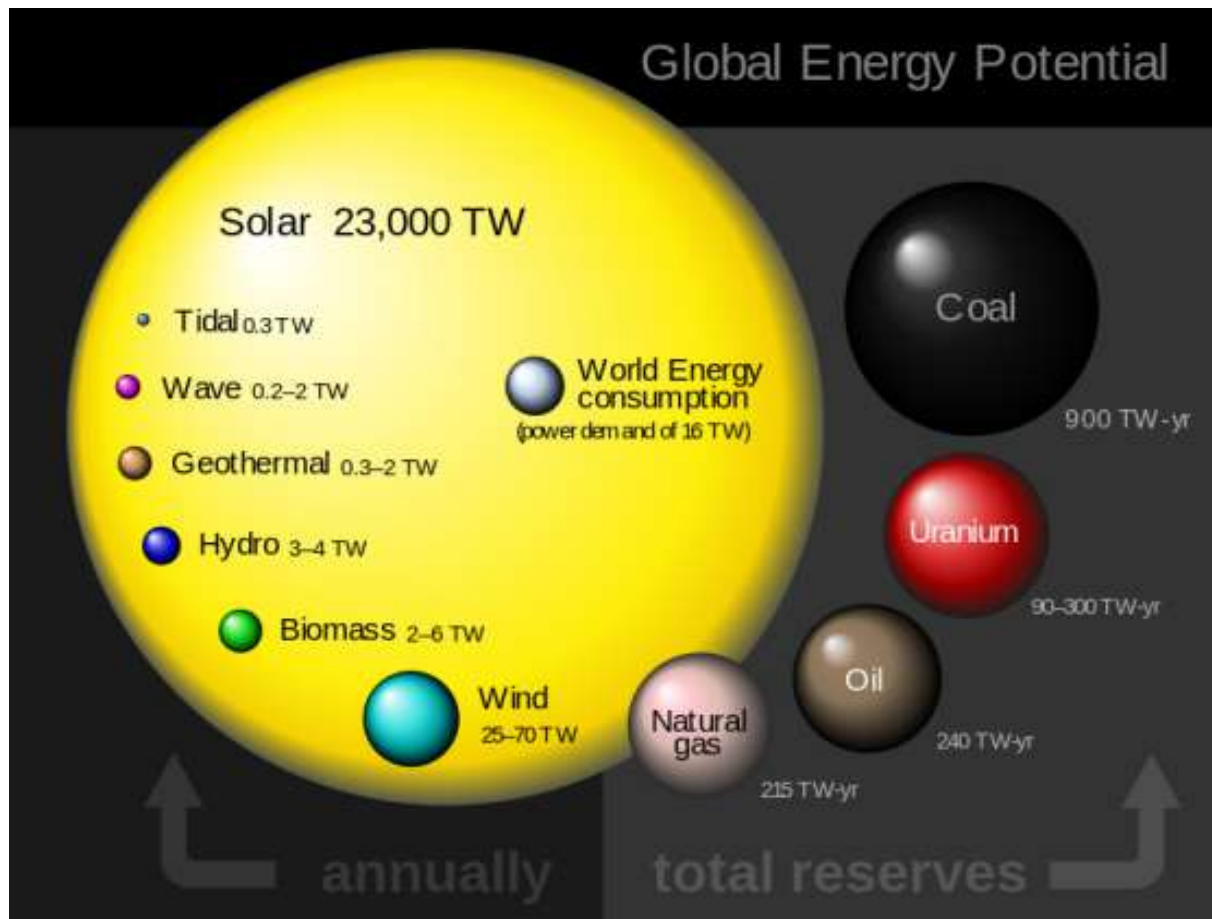


Figure 10.2: Global energy potential. Comparison of renewable and conventional planetary energy reserves and sources. While renewables display their power potential in terawatts (TW) with the corresponding annual amount of energy, conventional sources display their total recoverable energy reserves in terawatt-years (TW-yr). Author: Rfassbind, Wikimedia Commons

survival. It has failed, spectacularly, in its own terms, to provide economic stability and secure people's livelihood." ⁴

What is entropy?

Entropy is a quantity, originally defined in statistical mechanics and thermodynamics. It is a measure of the statistical probability of any state of a system: The greater the entropy, the greater the probability. The second law of thermodynamics asserts that entropy of the universe always increases with time. In other words, the universe as a whole is constantly moving towards states of greater and greater probability.

For any closed system, the same is true. Such systems move in time towards states of greater and greater probability. However, the earth, with its biosphere, is not a closed system. The earth constantly receives an enormous stream of light from the sun. The radiation which we receive from the sun brings us energy that can be used to perform work, and in physics this is called "free energy". Because of this flood of incoming sunlight, plants, animals and humans are able to create structures which from a statistical point of view are highly unlikely.

The disorder and statistical probability of the universe is constantly increasing, but because the earth is not a closed system, we are able to create local order, and complex, statistically improbable structures, like the works of Shakespeare, the Mona Lisa and the Internet. The human economy is driven by the free energy which we receive as income from the sun. Money is, in fact, a symbol for free energy, and free energy might be thought of as "negative entropy". There is also a link between free energy and information.⁵

Human society as a superorganism, with the global economy as its digestive system

A completely isolated human being would find it as difficult to survive for a long period of time as would an isolated ant or bee or termite. Therefore it seems correct to regard human society as a superorganism. In the case of humans, the analog of the social insects' nest is the enormous and complex material structure of civilization. It is, in fact, what we call the human economy. It consists of functioning factories, farms, homes, transportation links, water supplies, electrical networks, computer networks and much more.

Almost all of the activities of modern humans take place through the medium of these external "exosomatic" parts of our social superorganism. The terms "exosomatic" and "endosomatic" were coined by the American scientist Alfred Lotka (1880-1949). A lobster's claw is endosomatic; it is part of the lobster's body. The hammer used by a human is exosomatic, like a detachable claw. Lotka spoke of "exosomatic evolution", including in

⁴<http://www.theguardian.com/sustainable-business/rio-20-tim-jackson-leaders-green-economy?newsfeed=true>

<http://www.theguardian.com/sustainable-business/consumerism-sustainability-short-termism>

⁵<http://www.amazon.com/Information-Theory-And-Evolution-Edition/dp/9814401234>

this term not only cultural evolution but also the building up of the material structures of civilization.

The economy associated with the human superorganism “eats” resources and free energy. It uses these inputs to produce local order, and finally excretes them as heat and waste. The process is closely analogous to food passing through the alimentary canal of an individual organism. The free energy and resources that are the inputs of our economy drive it just as food drives the processes of our body, but in both cases, waste products are finally excreted in a degraded form.

Almost all of the free energy that drives the human economy came originally from the sun’s radiation, the exceptions being geothermal energy which originates in the decay of radioactive substances inside the earth, and tidal energy, which has its origin in the slowing of the motions of the earth-moon system. However, since the start of the Industrial Revolution, our economy has been using the solar energy stored in of fossil fuels. These fossil fuels were formed over a period of several hundred million years. We are using them during a few hundred years, i.e., at a rate approximately a million times the rate at which they were formed.

The present rate of consumption of fossil fuels is more than 14 terawatts and, if used at the present rate, fossil fuels would last less than a century. However, because of the very serious threats posed by climate change, human society would be well advised to stop the consumption of coal, oil and natural gas within the next two decades.

The rate of growth of of new renewable energy sources is increasing rapidly. These sources include small hydro, modern biomass, solar, wind, geothermal, wave and tidal energy. There is an urgent need for governments to set high taxes on fossil fuel consumption and to shift subsidies from the petroleum and nuclear industries to renewables. These changes in economic policy are needed to make the prices of renewables more competitive.

The shock to the global economy that will be caused by the end of the fossil fuel era will be compounded by the scarcity of other non-renewable resources, such as metals. While it is true (as neoclassical economists emphasize) that “matter and energy can neither be created nor destroyed”, free energy can be degraded into heat, and concentrated deposits of minerals can be dispersed. Both the degradation of free energy into heat and the dispersal of minerals involve increases of entropy.

Frederick Soddy

One of the first people to call attention to the relationship between entropy and economics was the English radiochemist Frederick Soddy (1877-1956). Soddy won the Nobel Prize for Chemistry in 1921 for his work with Ernest Rutherford demonstrating the transmutation of elements in radioactive decay processes. His concern for social problems then led him to a critical study of the assumptions of classical economics. Soddy believed that there is a close connection between free energy and wealth, but only a very tenuous connection between wealth and money.

Soddy was extremely critical of the system of “fractional reserve banking” whereby private banks keep only a small fraction of the money that is entrusted to them by their

depositors and lend out the remaining amount. He pointed out that this system means that the money supply is controlled by the private banks rather than by the government, and also that profits made from any expansion of the money supply go to private corporations instead of being used to provide social services. Fractional reserve banking exists today, not only in England but also in many other countries. Soddy's criticisms of this practice cast light on the subprime mortgage crisis of 2008 and the debt crisis of 2011.

As Soddy pointed out, real wealth is subject to the second law of thermodynamics. As entropy increases, real wealth decays. Soddy contrasted this with the behavior of debt at compound interest, which increases exponentially without any limit, and he remarked:

"You cannot permanently pit an absurd human convention, such as the spontaneous increment of debt [compound interest] against the natural law of the spontaneous decrement of wealth [entropy]". Thus, in Soddy's view, it is a fiction to maintain that being owed a large amount of money is a form of real wealth.

Frederick Soddy's book, "Wealth, virtual wealth and debt: The solution of the economic paradox", published in 1926 by Allen and Unwin, was received by the professional economists of the time as the quixotic work of an outsider. Today, however, Soddy's common-sense economic analysis is increasingly valued for the light that it throws on the problems of our fractional reserve banking system, which becomes more and more vulnerable to failure as economic growth falters.⁶

Currency reform, and nationalization of banks

Frederick Soddy was writing at a time when England's currency was leaving the gold standard, and in order to replace this basis for the currency, he proposed an index system. Soddy's index was to be based on a standard shopping basket containing household items, such as bread, milk, potatoes and so on. If the price of the items in the basket rose, more currency would be issued by the nationalized central bank. If the price fell, currency would be withdrawn.

Nationalization of banks was proposed by Soddy as a means of avoiding the evils of the fractional reserve banking system. Today we see a revival of the idea of nationalized banks, or local user-owned cooperative banks. The Grameen Bank, founded by Prof. Muhammad Yunus, pioneered the idea of socially-motivated banks for the benefit poor people who would ordinarily be unable to obtain loans. The bank and its founder won a Nobel Peace Prize in 2006.⁷

⁶www.fadedpage.com/link.php?file=20140873-a5.pdf
<http://human-wrongs-watch.net/2015/07/08/debt-slavery/>

⁷<http://www.grameen-info.org/history/>
<http://www.ibtimes.com/greece-drawing-contingency-plans-nationalize-banks-bring-parallel-currency-report-1868830>
<http://www.quora.com/Why-were-banks-nationalized-in-India>
<http://www.bloomberg.com/news/articles/2015-01-28/greek-bank-investors-hammered-as-3-day-slump-wipes-12-billion>
<http://www.armstrongeconomics.com/archives/30531>
<https://en.wikipedia.org/wiki/Nationalization>

Nicholas Georgescu-Roegen

The incorporation of the idea of entropy into economic thought also owes much to the mathematician and economist Nicholas Georgescu-Roegen (1906-1994), the son of a Romanian army officer. Georgescu-Roegen's talents were soon recognized by the Romanian school system, and he was given an outstanding education in mathematics, which later contributed to his success and originality as an economist.

Between 1927 and 1930 the young Georgescu studied at the Institute de Statistique in Paris, where he completed an award-winning thesis: "On the problem of finding out the cyclical components of phenomena". He then worked in England with Karl Pearson from 1930 to 1932, and during this period his work attracted the attention of a group of economists who were working on a project called the Harvard Economic Barometer. He received a Rockefeller Fellowship to join this group, but when he arrived at Harvard, he found that the project had been disbanded.

In desperation, Georgescu-Roegen asked the economist Joseph Schumpeter for an appointment to his group. Schumpeter's group was in fact a remarkably active and interesting one, which included the future Nobel laureate Wassily Leontief; and there followed a period of intense intellectual activity during which Georgescu-Roegen became an economist.

Despite offers of a permanent position at Harvard, Georgescu-Roegen returned to his native Romania in the late 1930's and early 1940's in order to help his country. He served as a member of the Central Committee of the Romanian National Peasant Party. His experiences at this time led to his insight that economic activity involves entropy. He was also helped to this insight by Borel's monograph on Statistical Mechanics, which he had read during his Paris period.

Georgescu-Roegen later wrote: "The idea that the economic process is not a mechanical analogue, but an entropic, unidirectional transformation began to turn over in my mind long ago, as I witnessed the oil wells of the Ploesti field of both World Wars' fame becoming dry one by one, and as I grew aware of the Romanian peasants' struggle against the deterioration of their farming soil by continuous use and by rains as well. However it was the new representation of a process that enabled me to crystallize my thoughts in describing the economic process as the entropic transformation of valuable natural resources (low entropy) into valueless waste (high entropy)."

After making many technical contributions to economic theory, Georgescu-Roegen returned to this insight in his important 1971 book, "The Entropy Law and the Economic Process" (Harvard University Press), where he outlines his concept of bioeconomics. In a later book, "Energy and Economic Myths" (Pergamon Press, New York, 1976), he offered the following recommendations for moving towards a bioeconomic society:

1. The complete prohibition of weapons production, thereby releasing productive forces for more constructive purposes;

<http://www.theguardian.com/world/2015/jul/23/beppe-grillo-calls-for-nationalisation-of-italian-banks-and-exit-from-euro>

<http://dissidentvoice.org/2015/07/whats-wrong-with-our-monetary-system-and-how-to-fix-it/>

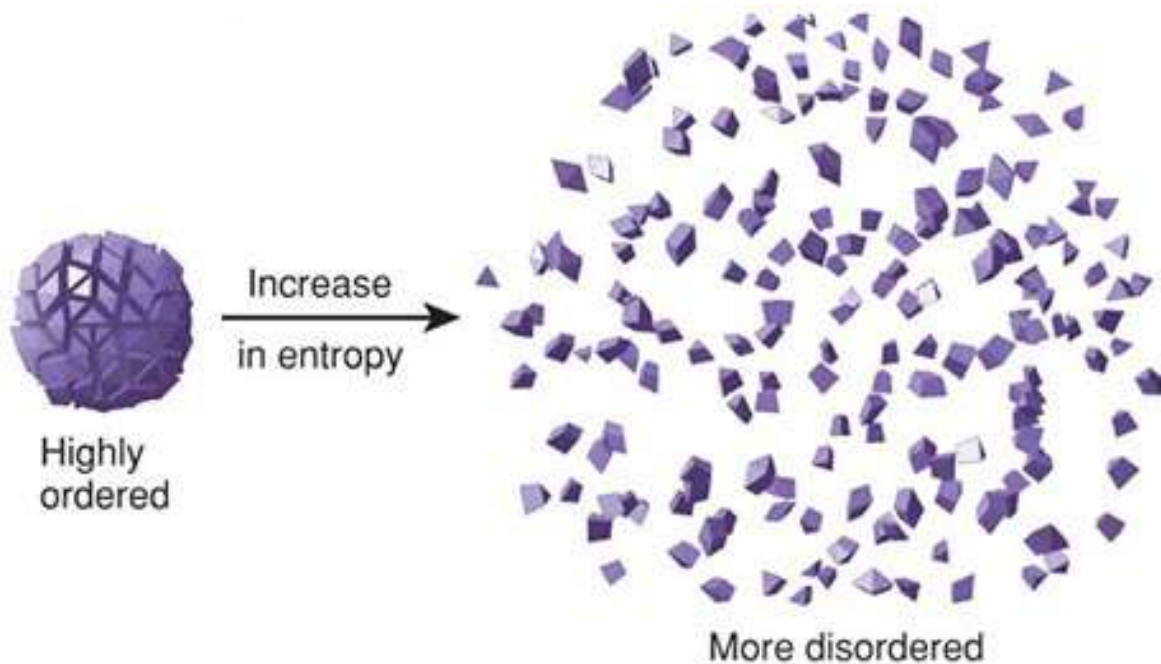


Figure 10.3: According to the second law of thermodynamics, the entropy of the universe constantly increases. Increase of entropy corresponds to increase of disorder, and also to increase of statistical probability. Living organisms on the earth are able to achieve a high degree of order and highly improbable structures because the earth is not a closed system. It constantly receives free energy (i.e. energy capable of doing work) from the sun, and this free energy can be thought of as carrying thermodynamic information, or “negative entropy”. Source: flowchainsensel.wordpress.co,



Figure 10.4: **Wind, solar, and biomass are three emerging renewable sources of energy. Wind turbines in a rapeseed field in Sandesneben, Germany. Author: Jürgen from Sandesneben, Germany, Wikimedia Commons**

2. Immediate aid to underdeveloped countries;
3. Gradual decrease in population to a level that could be maintained only by organic agriculture;
4. Avoidance, and strict regulation if necessary, of wasteful energy use;
5. Abandon our attachment to “extravagant gadgetry”;
6. “Get rid of fashion”;
7. Make goods more durable and repairable; and
8. Cure ourselves of workaholic habits by re-balancing the time spent on work and leisure, a shift that will become incumbent as the effects of the other changes make themselves felt.

Georgescu-Roegen did not believe that his idealistic recommendations would be adopted, and he feared that human society is headed for a crash.

Limits to Growth: A steady-state economy

Nicholas Georgescu-Roegen’s influence continues to be felt today, not only through his own books and papers but also through those of his students, the distinguished economists Herman E. Daly and Kozo Mayumi, who for many years have been advocating a steady-state economy. As they point out in their books and papers, it is becoming increasingly apparent that unlimited economic growth on a finite planet is a logical impossibility. However, it is important to distinguish between knowledge, wisdom and culture, which can and should

continue to grow, and growth in the sense of an increase in the volume of material goods produced. It is growth in the latter sense that is reaching its limits.

Daly describes our current situation as follows: “The most important change in recent times has been the growth of one subsystem of the Earth, namely the economy, relative to the total system, the ecosphere. This huge shift from an ‘empty’ to a ‘full’ world is truly ‘something new under the sun’... The closer the economy approaches the scale of the whole Earth, the more it will have to conform to the physical behavior mode of the Earth... The remaining natural world is no longer able to provide the sources and sinks for the metabolic throughput necessary to sustain the existing oversized economy, much less a growing one. Economists have focused too much on the economy’s circulatory system and have neglected to study its digestive tract.”⁸

In the future, the only way that we can avoid economic collapse is to build a steady-state economy. There exists much literature on how this can be achieved, and these writings ought to become a part of the education of all economists and politicians.

10.5 The global food crisis

Optimum population in the long-term future

What is the optimum population of the world? It is certainly not the maximum number that can be squeezed onto the globe by eradicating every species of plant and animal that cannot be eaten. The optimum global population is one that can be supported in comfort, equality and dignity, and with respect for the environment.

In 1848 (when there were just over one billion people in the world), John Stuart Mill described the optimal global population in the following words: “The density of population necessary to enable mankind to obtain, in the greatest degree, all the advantages of cooperation and social intercourse, has, in the most populous countries, been attained. A population may be too crowded, although all be amply supplied with food and raiment.”

“... Nor is there much satisfaction in contemplating the world with nothing left to the spontaneous activity of nature; with every rood of land brought into cultivation, which is capable of growing food for human beings; every flowery waste or natural pasture plowed up, all quadrupeds or birds which are not domesticated for man’s use exterminated as his rivals for food, every hedgerow or superfluous tree rooted out, and scarcely a place left where a wild shrub or flower could grow without being eradicated as a weed in the name of improved agriculture. If the earth must lose that great portion of its pleasantness which it owes to things that the unlimited increase of wealth and population would extirpate from it, for the mere purpose of enabling it to support a larger, but not better or happier

⁸<http://dalynews.org/learn/blog/>
<http://steadystate.org/category/herman-daly/>
<https://www.youtube.com/watch?v=EN5esbvAt-w>
<https://www.youtube.com/watch?v=wIR-VsXtM4Y>
<http://www.imf.org/external/pubs/ft/survey/so/2015/car031315a.htm>

John Stuart Mill (1806-1873, England)



Mill “had a lifelong goal of reforming the world in the interest of human well-being”

<http://plato.stanford.edu/entries/mill/>

Figure 10.5: Mill wrote: “I sincerely hope, for the sake of posterity, that they will be content to be stationary, long before necessity compels them to it.”
Source: www.slideshare.net

population, I sincerely hope, for the sake of posterity, that they will be content to be stationary, long before necessity compels them to it.” (From John Stuart Mill, “Principles of Political Economy, With Some of Their Applications to Social Philosophy”, 1848.)

Has the number of humans in the world already exceeded the earth’s sustainable limits? Will the global population of humans crash catastrophically after having exceeded the carrying capacity of the environment? There is certainly a danger that this will happen - a danger that the 21st century will bring very large scale famines to vulnerable parts of the world, because modern energy-intensive agriculture will be dealt a severe blow by the end of the fossil fuel era, and because climate change will reduce the world’s agricultural output.

When the major glaciers in the Himalayas have melted, they will no longer be able to give India and China summer water supplies; rising oceans will drown much agricultural land; and aridity will reduce the output of many regions that now produce much of the world’s grain. Falling water tables in overdrawn aquifers, and loss of topsoil will add to the problem. We should be aware of the threat of a serious global food crisis in the 21st century if we are to have a chance of avoiding it.

The term *ecological footprint* was introduced by William Rees and Mathis Wackernagel in the early 1990’s to compare demands on the environment with the earth’s capacity to regenerate. In 2015, humanity used environmental resources at such a rate that it would take 1.6 earths to renew them. In other words, we have already exceeded the earth’s carrying capacity. Since eliminating the poverty that characterizes much of the world today will require more resources per capita, rather than less, it seems likely that in the

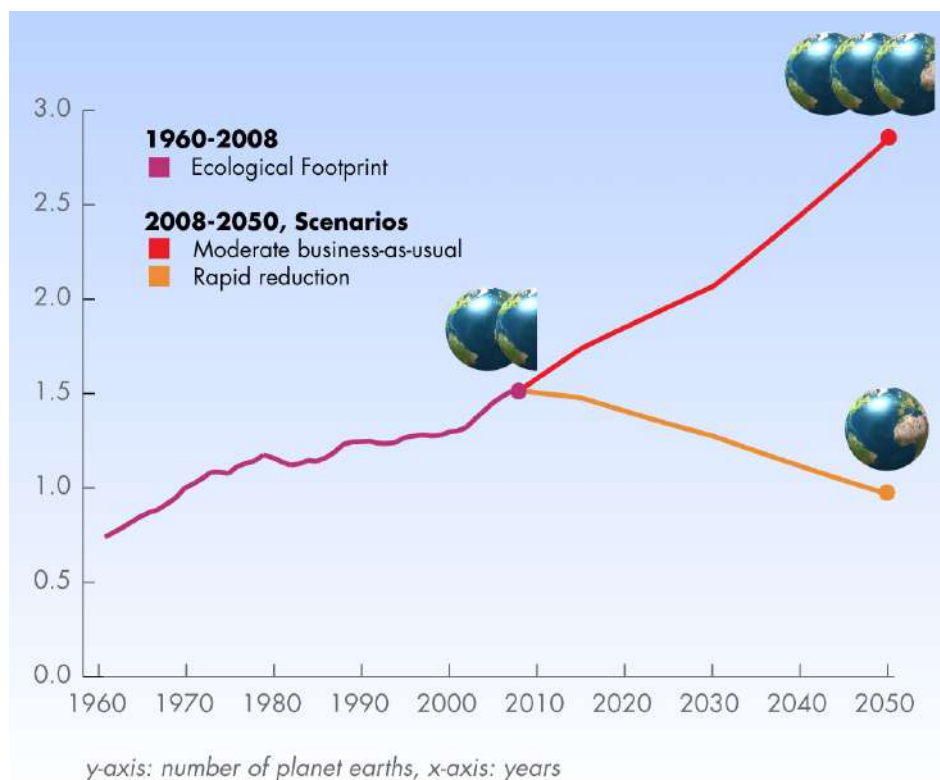


Figure 10.6: **Our present trajectory is completely unsustainable. If we follow it, then by 2050 it would take almost three earths to regenerate our demands on resources.** Source: footprintnetwork.org

era beyond fossil fuels, the optimum global population will be considerably less than the present population of the world.

Limitations on cropland

In 1944 the Norwegian-American plant geneticist Norman Borlaug was sent to Mexico by the Rockefeller Foundation to try to produce new wheat varieties that might increase Mexico's agricultural output. Borlaug's dedicated work on this project was spectacularly successful. He remained with the project for 16 years, and his group made 6,000 individual crossings of wheat varieties to produce high-yield disease-resistant strains.

In 1963, Borlaug visited India, bringing with him 100 kg. of seeds from each of his most promising wheat strains. After testing these strains in Asia, he imported 450 tons of the Lerma Rojo and Sonora 64 varieties: 250 tons for Pakistan and 200 for India. By 1968, the success of these varieties was so great that school buildings had to be commandeered to store the output. Borlaug's work began to be called a "Green Revolution". In India, the research on high-yield crops was continued and expanded by Prof. M.S. Swaminathan and his co-workers. The work of Green Revolution scientists, such as Norman Borlaug and



Figure 10.7: Norman Borlaug and agronomist George Harrer in 1943. Source: beforeitsnews.com

M.S. Swaminathan, has been credited with saving the lives of as many as a billion people.

Despite these successes, Borlaug believes that the problem of population growth is still a serious one. “Africa and the former Soviet republics”, Borlaug states, “and the Cerrado, are the last frontiers. After they are in use, the world will have no additional sizable blocks of arable land left to put into production, unless you are willing to level whole forests, which you should not do. So, future food-production increases will have to come from higher yields. And though I have no doubt that yields will keep going up, whether they can go up enough to feed the population monster is another matter. Unless progress with agricultural yields remains very strong, the next century will experience human misery that, on a sheer numerical scale, will exceed the worst of everything that has come before.”

With regard to the prospect of increasing the area of cropland, a report by the United Nations Food and Agricultural Organization (Provisional Indicative World Plan for Agricultural Development, FAO, Rome, 1970) states that “In Southern Asia,... in some countries of Eastern Asia, in the Near East and North Africa... there is almost no scope for expanding agricultural area... In the drier regions, it will even be necessary to return to permanent pasture the land that is marginal and submarginal for cultivation. In most of Latin America and Africa south of the Sahara, there are still considerable possibilities for expanding cultivated areas; but the costs of development are high, and it will often be more economical to intensify the utilization of areas already settled.” Thus there is a possibility of increasing the area of cropland in Africa south of the Sahara and in Latin America, but only at the cost of heavy investment and at the additional cost of destruction of tropical rain forests.

Rather than an increase in the global area of cropland, we may encounter a future loss of cropland through soil erosion, salination, desertification, loss of topsoil, depletion of minerals in topsoil, urbanization and failure of water supplies. In China and in the Southwestern part of the United States, water tables are falling at an alarming rate. The Ogallala aquifer (which supplies water to many of the plains states in the central and southern parts of the United States) has a yearly overdraft of 160%.

In the 1950's, both the U.S.S.R and Turkey attempted to convert arid grasslands into wheat farms. In both cases, the attempts were defeated by drought and wind erosion, just as the wheat farms of Oklahoma were overcome by drought and dust in the 1930's. If irrigation of arid lands is not performed with care, salt may be deposited, so that the land is ruined for agriculture. This type of desertification can be seen, for example, in some parts of Pakistan. Another type of desertification can be seen in the Sahel region of Africa, south of the Sahara. Rapid population growth in the Sahel has led to overgrazing, destruction of trees, and wind erosion, so that the land has become unable to support even its original population.

Especially worrying is a prediction of the International Panel on Climate Change concerning the effect of global warming on the availability of water: According to Model A1 of the IPCC, global warming may, by the 2050's, have reduced by as much as 30% the water available in large areas of world that now are large producers of grain.

Added to the agricultural and environmental problems, are problems of finance and distribution. Famines can occur even when grain is available somewhere in the world, because those who are threatened with starvation may not be able to pay for the grain, or for its transportation. The economic laws of supply and demand are not able to solve this type of problem. One says that there is no "demand" for the food (meaning demand in the economic sense), even though people are in fact starving.⁹

Energy-dependence of modern agriculture

A very serious problem with Green Revolution plant varieties is that they require heavy inputs of pesticides, fertilizers and irrigation. Because of this, the use of high-yield varieties contributes to social inequality, since only rich farmers can afford the necessary inputs. Monocultures, such as the Green Revolution varieties may also prove to be vulnerable to future epidemics of plant diseases, such as the epidemic that caused the Irish Potato Famine in 1845. Even more importantly, pesticides, fertilizers and irrigation all depend on the use of fossil fuels. One must therefore ask whether high agricultural yields can be maintained in the future, when fossil fuels are expected to become prohibitively scarce and expensive.

⁹<http://www.independent.co.uk/environment/climate-change/society-will-collapse-by-2040-due-to-catastrophic-food-shortages-says-study-10336406.html>
<http://www.truth-out.org/news/item/32131-the-new-climate-normal-abrupt-sea-level-rise-and-predictions-of-civilization-collapse>
<http://www.commondreams.org/views/2015/08/13/dignity-democracy-and-food-interview-frances-moore-lappe>

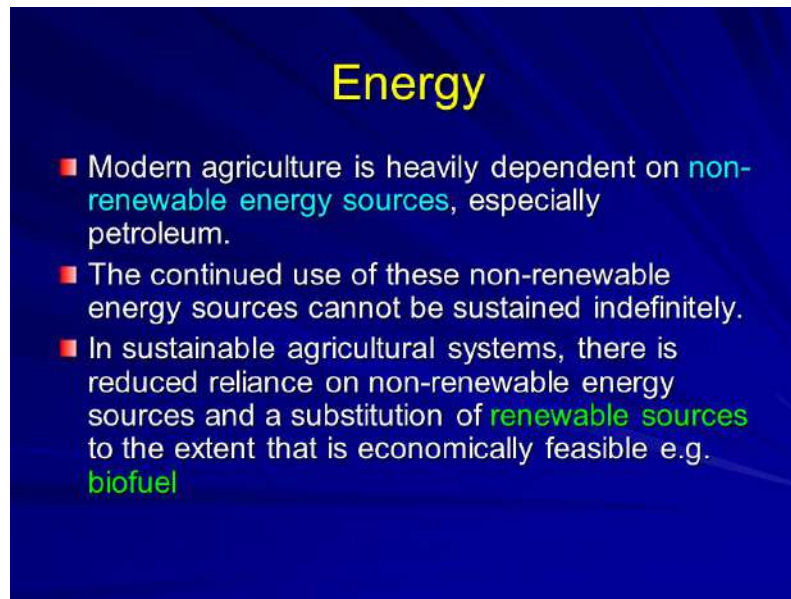


Figure 10.8: Source: slideplayer.com

Modern agriculture has become highly dependent on fossil fuels, especially on petroleum and natural gas. This is especially true of production of the high-yield grain varieties introduced in the Green Revolution, since these require especially large inputs of fertilizers, pesticides and irrigation. Today, fertilizers are produced using oil and natural gas, while pesticides are synthesized from petroleum feedstocks, and irrigation is driven by fossil fuel energy. Thus agriculture in the developed countries has become a process where inputs of fossil fuel energy are converted into food calories.

The ratio of the fossil fuel energy inputs to the food calorie outputs depends on how many energy-using elements of food production are included in the accounting. David Pimental and Mario Giampietro of Cornell University estimated in 1994 that U.S. agriculture required 0.7 kcal of fossil fuel energy inputs to produce 1.0 kcal of food energy. However, this figure was based on U.N. statistics that did not include fertilizer feedstocks, pesticide feedstocks, energy and machinery for drying crops, or electricity, construction and maintenance of farm buildings. A more accurate calculation, including these inputs, gives an input/output ratio of approximately 1.0. Finally, if the energy expended on transportation, packaging and retailing of food is included, Pimental and Giampietro found that the input/output ratio for the U.S. food system was approximately 10, and this figure did not include energy used for cooking.

The Brundtland Report's estimate of the global potential for food production assumes "that the area under food production can be around 1.5 billion hectares (3.7 billion acres - close to the present level), and that the average yields could go up to 5 tons of grain equivalent per hectare (as against the present average of 2 tons of grain equivalent)." In other words, the Brundtland Report assumes an increase in yields by a factor of 2.5. This would perhaps be possible if traditional agriculture could everywhere be replaced

by energy-intensive modern agriculture using Green Revolution plant varieties. However, Pimental and Giampietro's studies show that modern energy-intensive agricultural techniques cannot be maintained after fossil fuels have been exhausted or after their use has been discontinued to avoid catastrophic climate change.

At the time when the Brundtland Report was written (1987), the global average of 2 tons of grain equivalent per hectare included much higher yields from the sector using modern agricultural methods. Since energy-intensive petroleum-based agriculture cannot be continued in the post-fossil-fuel era, future average crop yields will probably be much less than 2 tons of grain equivalent per hectare.

The 1987 global population was approximately 5 billion. This population was supported by 3 billion tons of grain equivalent per year. After fossil fuels have been exhausted, the total world agricultural output is likely to be considerably less than that, and therefore the population that it will be possible to support sustainably will probably be considerably less than 5 billion, assuming that our average daily per capita use of food calories remains the same, and assuming that the amount of cropland and pasturage remains the same (1.5 billion hectares cropland, 3.0 billion hectares pasturage).

The Brundtland Report points out that "The present (1987) global average consumption of plant energy for food, seed and animal feed amounts to 6,000 calories daily, with a range among countries of 3,000-15,000 calories, depending on the level of meat consumption." Thus there is a certain flexibility in the global population that can survive on a given total agricultural output. If the rich countries were willing to eat less meat, more people could be supported.¹⁰

Effects of climate change on agriculture

a) The effect of temperature increase

There is a danger that when climate change causes both temperature increases and increased aridity in regions like the US grain belt, yields will be very much lowered. Of the three main grain types (corn, wheat and rice) corn is the most vulnerable to the direct effect of increases in temperature. One reason for this is the mechanism of pollination of corn: A pollen grain lands on one end of a corn-silk strand, and the germ cell must travel the length of the strand in order to fertilize the kernel. At high temperatures, the corn silk becomes dried out and withered, and is unable to fulfill its biological function. Furthermore, heat can cause the pores on the underside of the corn leaf to close, so that photosynthesis stops.

According to a study made by Mohan Wali and coworkers at Ohio State University, the photosynthetic activity of corn increases until the temperature reaches 20°C. It then remains constant until the temperature reaches 35°C, after which it declines. At 40°C and above, photosynthesis stops altogether.

¹⁰<http://www.truth-out.org/news/item/32354-environmentalists-sue-epa-over-dead-zone-in-gulf-of-mexico>

Scientists in the Phillipines report that the pollination of rice fails entirely at 40°C, leading to crop failures. Wheat yields are also markedly reduced by temperatures in this range.¹¹

b) The effect of decreased rainfall

According to the Stern Report, some of the major grain-producing areas of the world might loose up to 30% of their rainfall by 2050. These regions include much of the United States, Brazil, the Mediterranean region, Eastern Russia and Belarus, the Middle East, Southern Africa and Australia. Of course possibilities for agriculture may simultaneously increase in other regions, but the net effect of climate change on the world's food supply is predicted to be markedly negative.

c) Unsustainable use of groundwater

It may seem surprising that fresh water can be regarded as a non-renewable resource. However, groundwater in deep aquifers is often renewed very slowly. Sometimes renewal requires several thousand years. When the rate of withdrawal of groundwater exceeds the rate of renewal, the carrying capacity of the resource has been exceeded, and withdrawal of water becomes analogous to mining a mineral. However, it is more serious than ordinary mining because water is such a necessary support for life.

In many regions of the world today, groundwater is being withdrawn faster than it can be replenished, and important aquifers are being depleted. In China, for example, groundwater levels are falling at an alarming rate. Considerations of water supply in relation to population form the background for China's stringent population policy. At a recent lecture, Lester Brown of the Worldwatch Institute was asked by a member of the audience to name the resource for which shortages would most quickly become acute. Most of the audience expected him to name oil, but instead he replied "water".

Lester Brown then cited China's falling water table. He predicted that within decades, China would be unable to feed itself. He said that this would not cause hunger in China itself: Because of the strength of China's economy, the country would be able to purchase grain on the world market. However Chinese purchases of grain would raise the price, and put world grain out of reach of poor countries in Africa. Thus water shortages in China will produce famine in parts of Africa, Brown predicted.

Under many desert areas of the world are deeply buried water tables formed during glacial periods when the climate of these regions was wetter. These regions include the Middle East and large parts of Africa. Water can be withdrawn from such ancient reservoirs by deep wells and pumping, but only for a limited amount of time.

In oil-rich Saudi Arabia, petroenergy is used to drill wells for ancient water and to bring it to the surface. Much of this water is used to irrigate wheat fields, and this is done to such an extent that Saudi Arabia exports wheat. The country is, in effect, exporting its ancient

¹¹<http://ecowatch.com/2015/08/03/heat-wave-iran/>



Figure 10.9: **Lester R. Brown** has been a pioneer in the study of the future global food crisis. Source: www.azquotes.com

heritage of water, a policy that it may, in time, regret. A similarly short-sighted project is Muammar Qaddafi's enormous pipeline, which will bring water from ancient sub-desert reservoirs to coastal cities.

In the United States, the great Ogallala aquifer is being overdrawn. This aquifer is an enormous stratum of water-saturated sand and gravel under-lying parts of northern Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming and South Dakota. The average thickness of the aquifer is about 70 meters. The rate of water withdrawal from the aquifer exceeds the rate of recharge by a factor of eight.

Thus we can see that in many regions, the earth's present population is living on its inheritance of water, rather than its income. This fact, coupled with rapidly increasing populations and climate change, may contribute to a very serious food crisis partway through the 21st century.

d) Glacial melting and summer water supplies

The summer water supplies of both China and India are threatened by the melting of glaciers. The Gangotri glacier, which is the principle glacier feeding India's great Ganges River, is reported to be melting at an accelerating rate, and it could disappear within a few decades. If this happens, the Ganges could become seasonal, flowing only during the monsoon season. Chinese agriculture is also threatened by disappearing Himalayan glaciers, in this case those on the Tibet-Quinghai Plateau. The respected Chinese glaciologist Yao Tandong estimates that the glaciers feeding the Yangtze and Yellow Rivers are disappearing at the rate of 7% per year.¹²

¹²<http://www.commondreams.org/news/2015/08/04/global-glaciers-melting-three-times-rate-20th->



Figure 10.10: Whitechuck Glacier in the North Cascades National Park in 1973.
Source: www.nichols.ewdu



Figure 10.11: The same glacier in 2006. Source: www.nichols.edu

The Indus and Mekong Rivers will be similarly affected by the melting of glaciers. Lack of water during the summer season could have a serious impact on the irrigation.

Mature forests contain vast amounts of sequestered carbon, not only in their trees, but also in the carbon-rich soil of the forest floor. When a forest is logged or burned to make way for agriculture, this carbon is released into the atmosphere.

One fifth of the global carbon emissions are at present due to destruction of forests. This amount is greater than the CO₂ emissions for the world's transportation systems. An intact forest pumps water back into the atmosphere, increasing inland rainfall and benefiting agriculture. By contrast, deforestation, for example in the Amazonian rainforest, accelerates the flow of water back into the ocean, thus reducing inland rainfall. There is a danger that the Amazonian rainforest may be destroyed to such an extent that the region will become much more dry. If this happens, the forest may become vulnerable to fires produced by lightning strikes. This is one of the feedback loops against which the Stern Report warns: the drying and burning of the Amazonian rainforest may become irreversible, greatly accelerating climate change, if destruction of the forest proceeds beyond a certain point.

e) Erosion of topsoil.

Besides depending on an adequate supply of water, food production also depends on the condition of the thin layer of topsoil that covers the world's croplands. This topsoil is being degraded and eroded at an alarming rate: According to the World Resources Institute and the United Nations Environment Programme, "It is estimated that since World War II, 1.2 billion hectares... has suffered at least moderate degradation as a result of human activity. This is a vast area, roughly the size of China and India combined." This area is 27% of the total area currently devoted to agriculture. The report goes on to say that the degradation is greatest in Africa. The risk of topsoil erosion is greatest when marginal land is brought into cultivation, since marginal land is usually on steep hillsides which are vulnerable to water erosion when wild vegetation is removed.

David Pimental and his associates at Cornell University pointed out in 1995 that "Because of erosion-associated loss of productivity and population growth, the per capita food supply has been reduced over the past 10 years and continues to fall. The Food and Agricultural Organization reports that the per capita production of grains which make up 80% of the world's food supply, has been declining since 1984...During the past 40 years nearly one-third of the world's cropland (1.5 billion hectares) has been abandoned because of soil erosion and degradation. Most of the replacement has come from marginal land made available by removing forests. Agriculture accounts for 80% of the annual deforestation."

Topsoil can also be degraded by the accumulation of salt when irrigation water evaporates. The worldwide area of irrigated land has increased from 8 million hectares in 1800 to more than 100 million hectares today. This land is especially important to the world food supply because it is carefully tended and yields are large in proportion to the area.

To protect this land from salination, it should be irrigated in such a way that evaporation is minimized.

Finally cropland with valuable topsoil is being lost to urban growth and highway development, a problem that is made more severe by growing populations and by economic growth.

Every year, more than 100,000 square kilometers of rain forest are cleared and burned, an area which corresponds to that of Switzerland and the Netherlands combined. Almost half of the world's tropical forests have already been destroyed. Ironically, the land thus cleared often becomes unsuitable for agriculture within a few years. Tropical soils may seem to be fertile when covered with luxuriant vegetation, but they are usually very poor in nutrients because of leeching by heavy rains. The nutrients which remain are contained in the vegetation itself; and when the forest cover is cut and burned, the nutrients are rapidly lost.

Often the remaining soil is rich in aluminum oxide and iron oxide. When such soils are exposed to oxygen and sun-baking, a rock-like substance called Laterite is formed.

Secret land purchases in Africa

According to a report released by the Oakland Institute, in 2009 alone, hedge funds bought or leased nearly 60 million hectares of land in Africa, an area the size of France.

As populations increase, and as water becomes scarce, China, and other countries, such as Saudi Arabia are also buying enormous tracts of agricultural land, not only in Africa, but also in other countries.

These land purchases are very often kept secret from the local populations by corrupt governments.¹³

Some conclusions

There is a danger that just as global population reaches the unprecedented level of 9 billion or more, the agricultural base for supporting it may suddenly collapse. Ecological catastrophe, possibly compounded by war and other disorders, could produce famine and death on a scale unprecedented in history, a disaster of unimaginable proportions, involving billions rather than millions of people.

The resources of the earth and the techniques of modern science can support a global population of moderate size in comfort and security; but the optimum size is undoubtedly smaller than the world's present population. Given a sufficiently small global population, renewable sources of energy can be found to replace disappearing fossil fuels. Technology may also be able to find renewable substitutes for many disappearing mineral resources for a global population of moderate size. What technology cannot do, however, is to give a global population of 9 billion people the standard of living which the industrialized countries enjoy today.

¹³<http://www.latimes.com/world/asia/la-fg-china-foreign-farmland-20140329-story.html>
<http://www.bbc.com/news/world-africa-13688683>

10.6 Limits to growth

The Club of Rome

In 1968 Aurelio Peccei, Thorkil Kristensen and others founded the Club of Rome, an organization of economists and scientists devoted to studying the predicament of human society. One of the first acts of the organization was to commission an MIT study of future trends using computer models. The result was a book entitled “Limits to Growth”, published in 1972. From the outset the book was controversial, but it became a best-seller. It was translated into many languages and sold 30 million copies. The book made use of an exponential index for resources, i.e. the number of years that a resource would last if used at an exponentially increasing rate.

Today the more accurate Hubbert Peak model is used instead to predict rate of use of a scarce resource as a function of time. Although the specific predictions of resource availability in “Limits to Growth” lacked accuracy, its basic thesis, that unlimited industrial growth on a finite planet is impossible, was indisputably correct. Nevertheless the book was greeted with anger and disbelief by the community of economists, and these emotions still surface when it is mentioned.

Economic activity is usually divided into two categories, 1) production of goods and 2) provision of services. It is the rate of production of goods that will be limited by the carrying capacity of the global environment. Services that have no environmental impact will not be constrained in this way. Thus a smooth transition to a sustainable economy will involve a shift of a large fraction the work force from the production of goods to the provision of services.

In his recent popular book “The Rise of the Creative Class” the economist Richard Florida points out that in a number of prosperous cities, for example Stockholm, a large fraction of the population is already engaged in what might be called creative work, a type of work that uses few resources, and produces few waste products, work which develops knowledge and culture rather than producing material goods. For example, producing computer software requires few resources and results in few waste products. Thus it is an activity with a very small ecological footprint.

Similarly, education, research, music, literature and art are all activities that do not weigh heavily on the carrying capacity of the global environment. Furthermore, cultural activities lead in a natural way to global cooperation and internationalism, since cultural achievements are shared by the people of the entire world. Indeed, the shared human inheritance of culture and knowledge is growing faster than ever before.

Florida sees this as a pattern for the future, and maintains that everyone is capable of creativity. He visualizes the transition to a sustainable future economy as one in which a large fraction of the work force moves from industrial jobs to information-related work. Meanwhile, as Florida acknowledges, industrial workers feel uneasy and threatened by such trends.¹⁴

¹⁴<http://www.clubofrome.org/?p=326>
<http://www.donellameadows.org/wp-content/userfiles/Limits-to-Growth-digital-scan-version.pdf>

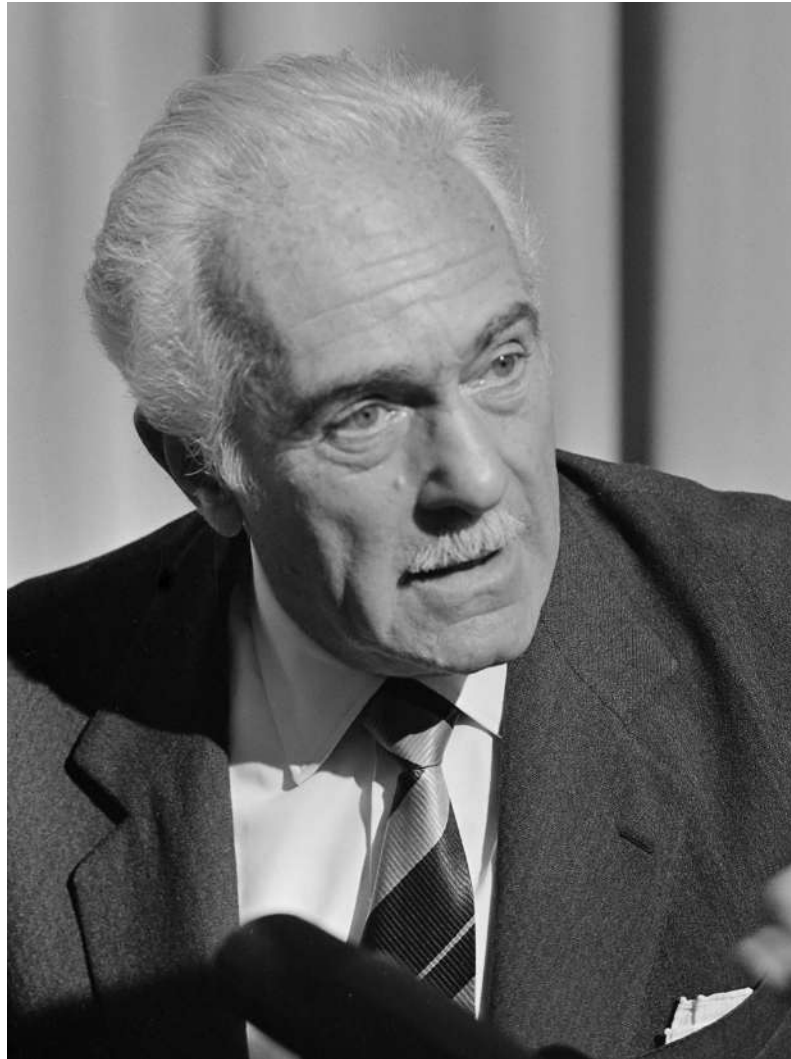


Figure 10.12: Aurelio Peccei (1908-1984), main founder of the Club of Rome. Concerning our present economic system, he wrote: “The only way we have devised to meet the surging waves of our rampant militarism and consumerism is to draw increasingly on the natural environment and to exploit, indiscriminately, the most accessible mineral and fuel deposits and all living resources we can lay our hands on. Such actions irreversibly impoverish our unique, irreplaceable, world, whose bounty and generosity are not infinite. Even if all the other adverse situations we find ourselves in today were to be alleviated, in itself, our high-handed treatment of Nature can bring about our doom.” Photograph by Koen Suyk/Anefo (Nationaal Archief), CC BY-SA 3.0, Wikimedia Commons



Figure 10.13: **When a forest is destroyed, topsoil is often lost to erosion. Source: United Nations.**

Biological Carrying capacity and Economics

Classical economists pictured the world as largely empty of human activities. According to the empty-world picture of economics, the limiting factors in the production of food and goods are shortages of human capital and labor. The land, forests, fossil fuels, minerals, oceans filled with fish, and other natural resources upon which human labor and capital operate, are assumed to be present in such large quantities that they are not limiting factors. In this picture, there is no naturally-determined upper limit to the total size of the human economy. It can continue to grow as long as new capital is accumulated, as long as new labor is provided by population growth, and as long as new technology replaces labor by automation.

Biology, on the other hand, presents us with a very different picture. Biologists remind us that if any species, including our own, makes demands on its environment which exceed the environment's carrying capacity, the result is a catastrophic collapse both of the environment and of the population which it supports. Only demands which are within the carrying capacity are sustainable. For example, there is a limit to regenerative powers of a forest.

It is possible to continue to cut trees in excess of this limit, but only at the cost of a loss of forest size, and ultimately the collapse and degradation of the forest. Similarly, cattle populations may for some time exceed the carrying capacity of grasslands, but the

<http://www.donellameadows.org/archives/a-synopsis-limits-to-growth-the-30-year-update/>

ultimate penalty for overgrazing will be degradation or desertification of the land. Thus, in biology, the concept of the carrying capacity of an environment is extremely important; but in economic theory this concept has not yet been given the weight which it deserves.

Exponential growth of human population and economic activity have brought us, in a surprisingly short time, from the empty-world situation to a full-world situation. In today's world, we are pressing against the absolute limits of the earth's carrying capacity, and further growth carries with it the danger of future collapse.

Full-world economics, the economics of the future, will no longer be able to rely on industrial growth to give profits to stockbrokers or to solve problems of unemployment or to alleviate poverty. In the long run, neither the growth of industry nor that of population is sustainable; and we have now reached or exceeded the sustainable limits.

The limiting factors in economics are no longer the supply of capital or human labor or even technology. The limiting factors are the rapidly vanishing supplies of petroleum and metal ores, the forests damaged by acid rain, the diminishing catches from over-fished oceans, and the cropland degraded by erosion or salination, or lost to agriculture under a cover of asphalt.

Neoclassical economists have maintained that it is generally possible to substitute man-made capital for natural resources; but a closer examination shows that there are only very few cases where this is really practical. (See G.E. Tverberg, "Thoughts on why energy use and CO₂ emissions are rising as fast as GDP", www.ourfiniteworld.com, November 30, 2011.)

The size of the human economy is, of course, the product of two factors the total number of humans, and the consumption per capita. If we are to achieve a sustainable global society in the future, a society whose demands are within the carrying capacity of of the global environment, then both these factors must be reduced.

The responsibility for achieving sustainability is thus evenly divided between the North and the South: Where there is excessively high consumption per capita, it must be reduced; and this is primarily the responsibility of the industrialized countries. High birth rates must also be reduced; and this is primarily the responsibility of the developing countries. Both of these somewhat painful changes are necessary for sustainability; but both will be extremely difficult to achieve because of the inertia of institutions, customs and ways of thought which are deeply embedded in society, in both the North and the South.

Population and food supply

Let us look first at the problem of high birth rates: The recent spread of modern medical techniques throughout the world has caused death rates to drop sharply; but since social customs and attitudes are slow to change, birth rates have remained high. As a result, between 1930 and 2011, the population of the world increased with explosive speed from two billion to seven billion.

During the last few decades, the number of food-deficit countries has lengthened; and it now reads almost like a United Nations roster. The food-importing nations are dependent,



Figure 10.14: Our global food system is broken. Source: Oxfam

almost exclusively, on a single food-exporting region, the grain belt of North America. In the future, this region may be vulnerable to droughts produced by global warming.

An analysis of the global ratio of population to cropland shows that we probably already have exceeded the sustainable limit of population through our dependence on petroleum: Between 1950 and 1982, the use of cheap petroleum-derived fertilizers increased by a factor of 8, and much of our present agricultural output depends their use. Furthermore, petroleum-derived synthetic fibers have reduced the amount of cropland needed for growing natural fibers, and petroleum-driven tractors have replaced draft animals which required cropland for pasturage. Also, petroleum fuels have replaced fuelwood and other fuels derived for biomass. The reverse transition, from fossil fuels back to renewable energy sources, will require a considerable diversion of land from food production to energy production.

As population increases, the cropland per person will continue to fall, and we will be forced to make still heavier use of fertilizers to increase output per hectare. Also marginal land will be used in agriculture, with the probable result that much land will be degraded through erosion or salination.

Reserves of oil are likely to be exhausted by the middle of this century. Thus there is a danger that just as global population reaches the unprecedented level of 9 billion or more, the agricultural base for supporting it may suddenly collapse. The resulting catastrophe, possibly compounded by war and other disorders, could produce famine and death on a scale unprecedented in history, a disaster of unimaginable proportions, involving billions rather than millions of people. The present tragic famine in Africa is to this possible future disaster what Hiroshima is to the threat of thermonuclear war a tragedy of smaller scale, whose horrors should be sufficient, if we are wise, to make us take steps to avoid the larger catastrophe.

At present a child dies from starvation every six seconds. Five million children die from hunger every year. Over a billion people in today's world are chronically undernourished.

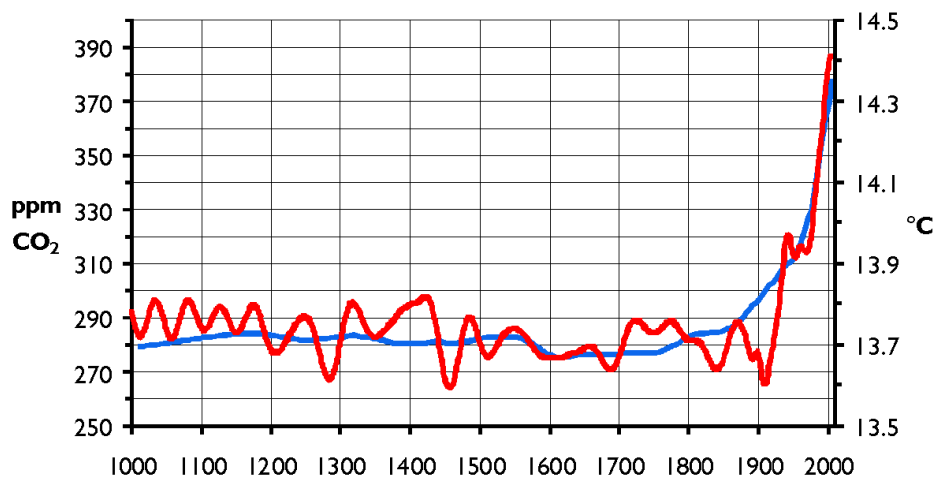


Figure 10.15: The Hango graph used by the United Nations Climate Change Compendium 2009. Source: wattsupwiththat.com

There is a threat that unless prompt and well-informed action is taken by the international community, the tragic loss of life that is already being experienced will increase to unimaginable proportions.

As glaciers melt in the Himalayas, threatening the summer water supplies of India and China; as ocean levels rise, drowning the fertile rice-growing river deltas of Asia; as aridity begins to decrease the harvests of Africa, North America and Europe; as populations grow; as aquifers are overdrawn; as cropland is lost to desertification and urban growth; and as energy prices increase, the billion people who now are undernourished but still survive, might not survive. They might become the victims of a famine whose proportions could exceed anything that the world has previously experienced.

It is vital for the world to stabilize its population, not only because of the threat of a catastrophic future famine, but also because rapid population growth is closely linked with poverty. Today, a large fraction of the world's people live in near-poverty or absolute poverty, lacking safe water, sanitation, elementary education, primary health care and proper nutrition. Governments struggling to solve these problems, and to provide roads, schools, jobs and medical help for all their citizens, find themselves defeated by the rapid doubling times of populations. For example, in Liberia, the rate of population growth is 4% per year, which means that the population of Liberia doubles in size every eighteen years.

Under such circumstances, despite the most ambitious development programs, the infrastructure per capita decreases. Also, since new jobs must be found for the new millions added to the population, the introduction of efficient modern methods in industry and agriculture aggravates the already-serious problem of unemployment.

Education of women and higher status for women are vitally important measures, not only for their own sake, but also because in many countries these social reforms have proved

to be strongly correlated with lower birth rates. Religious leaders who oppose programs for the education of women and for family planning on “ethical” grounds should think carefully about the scope and consequences of the catastrophic global famine which will undoubtedly occur within the next 50 years if population is allowed to increase unchecked.

One of the most important keys to controlling the global population explosion is giving women better education and equal rights. These goals are desirable for the sake of increased human happiness, and for the sake of the uniquely life-oriented point of view which women can give us; but in addition, education and improved status for women have shown themselves to be closely connected with lowered birth rates.

When women lack education and independent careers outside the home, they can be forced into the role of baby-producing machines by men who do not share in the drudgery of cooking, washing and cleaning; but when women have educational, legal, economic, social and political equality with men, experience has shown that they choose to limit their families to a moderate size.

Sir Partha Dasgupta of Cambridge University has pointed out that the changes needed to break the cycle of overpopulation and poverty are all desirable in themselves. Besides education and higher status for women, they include state-provided social security for old people, provision of water supplies near to dwellings, provision of health services to all, abolition of child labor and general economic development.¹⁵

Social Values and Levels of Consumption

Let us next turn to the problem of reducing the per-capita consumption in the industrialized countries. The whole structure of western society seems designed to push its citizens in the opposite direction, towards ever-increasing levels of consumption. The mass media hold before us continually the ideal of a personal utopia filled with material goods. Every young man in a modern industrial society feels that he is a failure unless he fights his way to the “top”; and in recent years, women too have been drawn into this competition.

Of course not everyone can reach the top; there would not be room for everyone; but society urges all us to try, and we feel a sense of failure if we do not reach the goal. Thus, modern life has become a struggle of all against all for power and possessions.

One of the central problems in reducing consumption is that in our present economic and social theory, consumption has no upper bound; there is no definition of what is enough; there is no concept of a state where all of the real needs of a person have been satisfied. In our growth-oriented present-day economics, it is assumed that, no matter how much a person earns, he or she is always driven by a desire for more.

The phrase “conspicuous consumption” was invented by the Norwegian-American economist Thorstein Veblen (1857-1929) in order to describe the way in which our society uses economic waste as a symbol of social status. In “The Theory of the Leisure Class”, first published in 1899, Veblen pointed out that it was wrong to believe that human economic behavior is rational, or that it can be understood in terms of classical economic theory.

¹⁵<http://www.poverties.org/famine-in-africa.html>

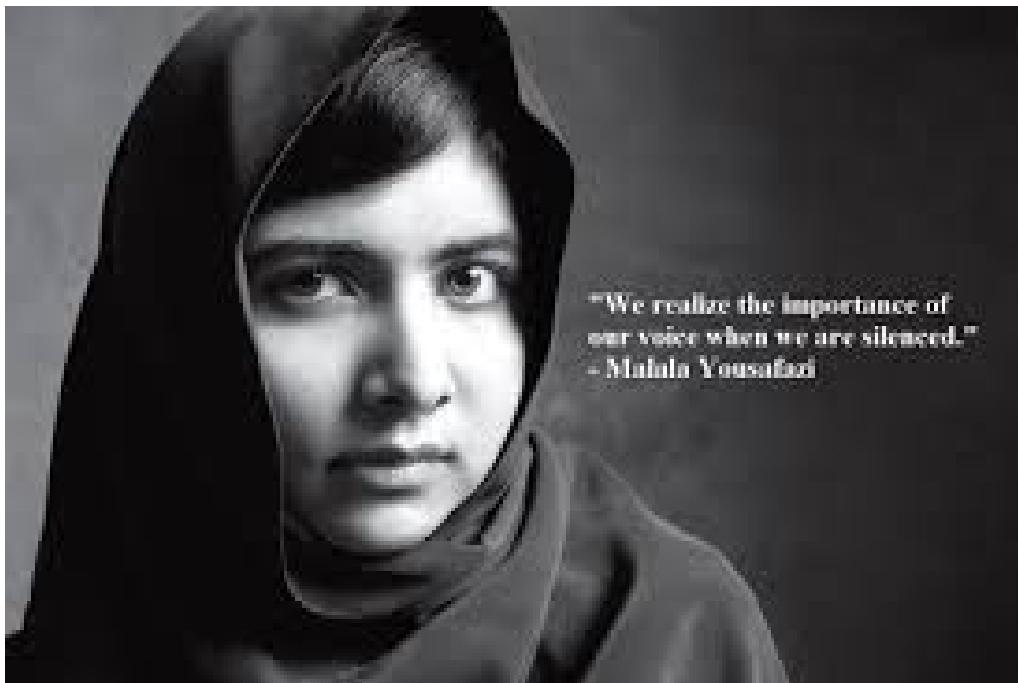


Figure 10.16: The changes needed to break the cycle of overpopulation and poverty are all desirable in themselves. Besides education and higher status for women, they include state-provided social security for old people, provision of water supplies near to dwellings, provision of health services to all, abolition of child labor, and general economic development. Source: unesco.usmission.gov



Figure 10.17: **FAO, IFAD and WFP joint project “Mainstreaming food loss reduction initiatives for smallholders in food deficit areas” aims to improve food security and income generation through reduction of food losses in food grains and pulses value chains. Photo: FAO/Alessandra Benedetti**

To understand it, Veblen maintained, one might better make use of insights gained from anthropology, psychology, sociology, and history.

The sensation caused by the publication of Veblen’s book, and the fact that his phrase, “conspicuous consumption”, has become part of our language, indicate that his theory did not completely miss its mark. In fact, modern advertisers seem to be following Veblen’s advice: Realizing that much of the output of our economy will be used for the purpose of establishing the social status of consumers, advertising agencies hire psychologists to appeal to the consumer’s longing for a higher social position.

When possessions are used for the purpose of social competition, demand has no natural upper limit; it is then limited only by the size of the human ego, which, as we know, is boundless. This would be all to the good if unlimited economic growth were desirable. But today, when further industrial growth implies future collapse, western society urgently needs to find new values to replace our worship of power, our restless chase after excitement, and our admiration of excessive consumption.

The values which we need, both to protect nature from civilization and to protect civilization from itself, are perhaps not new: Perhaps it would be more correct to say that we need to rediscover ethical values which once were part of human culture, but which were lost during the process of industrialization, when technology allowed us to break traditional environmental constraints.

Our ancestors were hunter-gatherers, living in close contact with nature, and respecting the laws and limitations of nature. There are many hunter-gatherer cultures existing today, from whose values and outlook we could learn much. Unfortunately, instead of learning from them, we often move in with our bulldozers and make it impossible for their way of life to continue. During the past several decades, for example, approximately one tribe of South American forest Indians has died out every year. Of the 6000 human languages now

spoken, it is estimated that half will vanish during the next 50 years.

In some parts of Africa, before cutting down a tree, a man will offer a prayer of apology to the spirit of the tree, explaining why necessity has driven him to such an act. The attitude involved in this ritual is something which industrialized society needs to learn, or relearn. Older cultures have much to teach industrial society because they already have experience with full-world situation which we are fast approaching.

In a traditional culture, where change is extremely slow, population has an opportunity to expand to the limits which the traditional way of life allows, so that it reaches an equilibrium with the environment. For example, in a hunter-gatherer culture, population has expanded to the limits which can be supported without the introduction of agriculture. The density of population is, of course, extremely low, but nevertheless it is pressing against the limits of sustainability. Overhunting or overfishing would endanger the future. Respect for the environment is thus necessary for the survival of such a culture.

Similarly, in a stable, traditional agricultural society which has reached an equilibrium with its environment, population is pressing against the limits of sustainability. In such a culture, one can usually find expressed as a strong ethical principle the rule that the land must not be degraded, but must be left fertile for the use of future generations.

Today, the whole world seems to be adopting values, fashions, and standards of behavior presented in the mass media of western society. The unsustainable, power-worshipping, consumption-oriented values of western society are so strongly propagandized by television, films and advertising, that they overpower and sweep aside the wisdom of older societies. This is unfortunate, since besides showing us unsustainable levels of affluence and economic waste, the western mass media depict values and behavior patterns which are hardly worthy of imitation. We need to reverse this trend. The industrialized countries must learn from the values of older traditional cultures. The wisdom of our ancestors, their respect for nature and their hospitable traditions of sharing, can help us to create a new economic system founded on social and environmental ethics.¹⁶

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Chapter 11

MONEY BEHIND THE FOSSIL FUEL GIANTS

11.1 Banks give fossil fuel giants \$1.9 trillion since Paris

Banking on Climate Change 2019 - Fossil Fuel Report Card / : Alison Kirsch et al Rainforest Action Network (RAN) et al.. For the first time, this report adds up lending and underwriting from 33 global banks to the fossil fuel industry as a whole. The findings are stark: these Canadian, Chinese, European, Japanese, and U.S. banks have financed fossil fuels with \$1.9 trillion since the Paris Agreement was adopted (2016-2018), with financing on the rise each year. This report finds that fossil fuel financing is dominated by the big U.S. banks, with JPMorgan Chase as the world's top funder of fossil fuels by a wide margin. In other regions, the top bankers of fossil fuels are Royal Bank of Canada in Canada, Barclays in Europe, MUFG in Japan, and Bank of China in China. Here are some quotations from the report:

In October 2018, the Intergovernmental Panel on Climate Change (IPCC) released a sobering report on the devastating impacts our world will face with 1.5° Celsius of warming - let alone 2°C - while setting out the emissions trajectory the nations of the world need to take if we are to have any shot at keeping to that 1.5°C limit. This 10th edition of the annual fossil fuel finance report card, greatly expanded in scope, reveals the paths banks have taken in the past three years since the Paris Agreement was adopted, and finds that overall bank financing continues to be aligned with climate disaster.

For the first time, this report adds up lending and underwriting from 33 global banks to the fossil fuel industry as a whole. The findings are stark: these Canadian, Chinese, European, Japanese, and U.S. banks have financed fossil fuels with \$1.9 trillion since the Paris Agreement was adopted (2016-2018), with financing on the rise each year. This report finds that fossil fuel

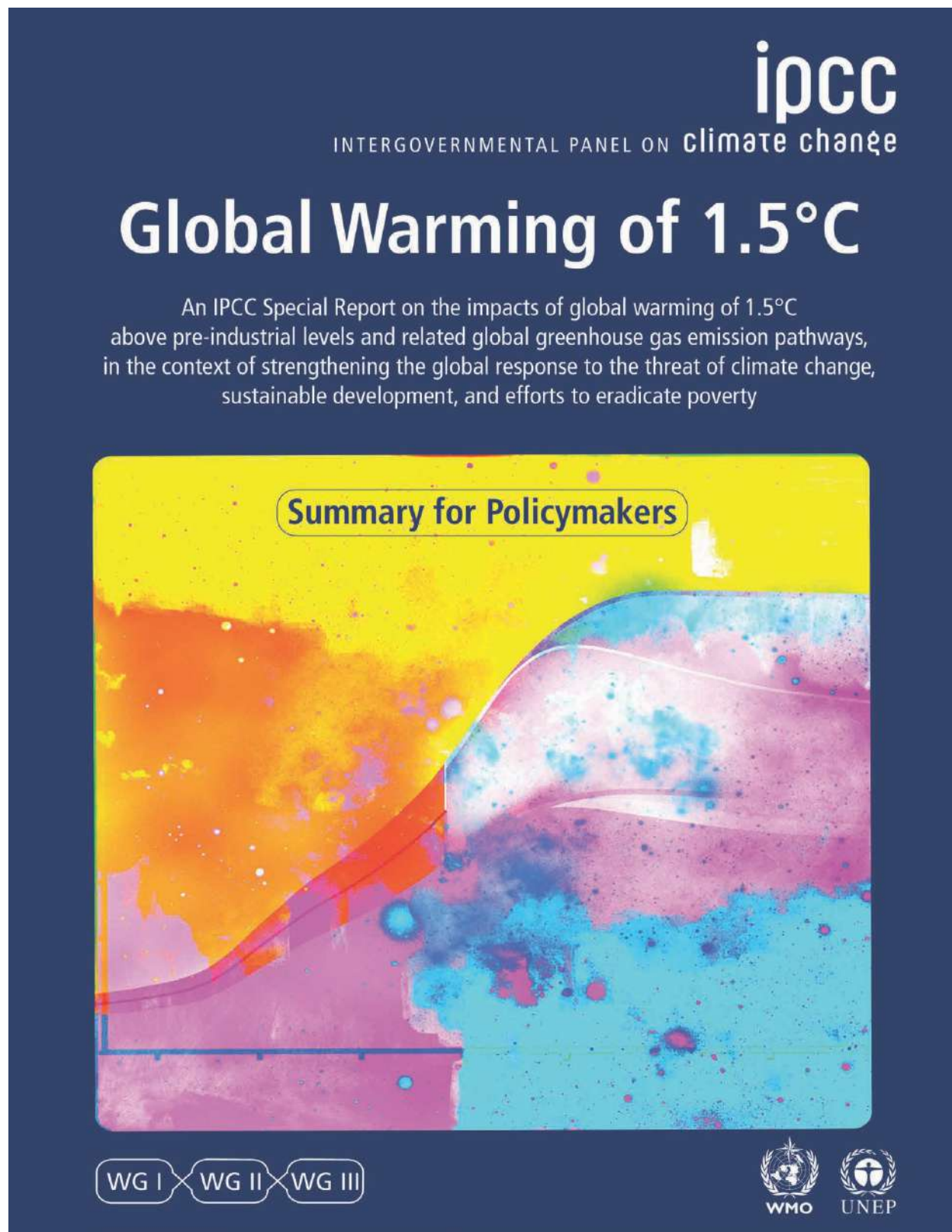
financing is dominated by the big U.S. banks, with JPMorgan Chase as the world's top funder of fossil fuels by a wide margin. In other regions, the top bankers of fossil fuels are Royal Bank of Canada in Canada, Barclays in Europe, MUFG in Japan, and Bank of China in China.

This report also puts increased scrutiny on the banks' support for 100 top companies that are expanding fossil fuels, given that there is no room for new fossil fuels in the world's carbon budget. And yet banks supported these companies with \$600 billion in the last three years. JPMorgan Chase is again on top, by an even wider margin, and North American banks emerge as the biggest bankers of expansion as well.

This report also grades banks' overall future-facing policies regarding fossil fuels, assessing them on restrictions on financing for fossil fuel expansion and commitments to phase out fossil fuel financing on a 1.5°C-aligned trajectory. While some banks have taken important steps, overall major global banks have simply failed to set trajectories adequate for dealing with the climate crisis.

As in past editions, this fossil fuel finance report card also assesses bank policy and practice around financing in certain key fossil fuel subsectors, with league tables and policy grades on:

- **Tar sands oil:** RBC, TD, and JPMorgan Chase are the biggest bankers of 30 top tar sands producers, plus four key tar sands pipeline companies. In particular, these banks and their peers support companies working to expand tar sands infrastructure, such as Enbridge and Teck Resources.
- **Arctic oil and gas:** JPMorgan Chase is the world's biggest banker of Arctic oil and gas by far, followed by Deutsche Bank and SMBC Group. Worryingly, financing for this subsector increased from 2017 to 2018.
- **Ultra-deepwater oil and gas:** JPMorgan Chase, Citi, and Bank of America are the top bankers here. Meanwhile, none of the 33 banks have policies to proactively restrict financing for ultra-deepwater extraction.
- **Fracked oil and gas:** For the first time, the report card looks at bank support for top fracked oil and gas producers and transporters - and finds financing is on the rise over the past three years. Wells Fargo and JPMorgan Chase are the biggest bankers of fracking overall - and, in particular, they support key companies active in the Permian Basin, the epicenter of the climate-threatening global surge of oil and gas production.
- **Liquefied natural gas (LNG):** Banks have financed top companies building LNG import and export terminals around the world with \$46 billion since the Paris Agreement, led by JPMorgan Chase, Société Générale, and SMBC Group. Banks have an opportunity to avoid further damage by not financing Anadarko's Mozambique LNG project, in particular.



- **Coal mining:** Coal mining finance is dominated by the four major Chinese banks, led by China Construction Bank and Bank of China. Though many European and U.S. banks have policies in place restricting financing for coal mining, total financing has only fallen by three to five percentage points each year.
- **Coal power:** Coal power financing is also led by the Chinese banks - Bank of China and ICBC in particular - with Citi and MUFG as the top non-Chinese bankers of coal power. Policy grades for this subsector show some positive examples of European banks restricting financing for coal power companies.

The human rights chapter of this report shows that as fossil fuel companies are increasingly held accountable for their contributions to climate change, finance for these companies also poses a growing liability risk for banks. The fossil fuel industry has been repeatedly linked to human rights abuses, including violations of the rights of Indigenous peoples and at-risk communities, and continues to face an ever-growing onslaught of lawsuits, resistance, delays, and political uncertainty.

The IPCC's 2018 report on the impacts of a 1.5°C increase in global temperature showed clearly the direction the nations of the world need to take, and the emissions trajectory we need to get there. Banks must align with that trajectory by ending financing for expansion, as well as for these particular spotlight fossil fuels - while committing overall to phase out all financing for fossil fuels on a Paris Agreement-compliant timeline.



Figure 11.1: Tar sands in Alberta, Canada.

11.2 Fossil fuel industry's disinformation campaign

The Wikipedia article on climate change denial describes it with the following words: “Although scientific opinion on climate change is that human activity is extremely likely to be the primary driver of climate change, the politics of global warming have been affected by climate change denial, hindering efforts to prevent climate change and adapt to the warming climate. Those promoting denial commonly use rhetorical tactics to give the appearance of a scientific controversy where there is none.”

It is not surprising that the fossil fuel industry supports, on a vast scale, politicians and mass media that deny the reality of climate change. The amounts of money at stake are vast. If catastrophic climate change is to be avoided, coal, oil and natural gas “assets” worth trillions of dollars must be left in the ground. Giant fossil fuel corporations are desperately attempting to turn these “assets” into cash.

According to a recent article published in “The Daily Kos”¹, companies like Shell and Exxon, knew, as early as the 1970s, how their combustible products were contributing to irreversible warming of the planet, became public knowledge over the last few years.

A series of painstakingly researched articles² published in 2015 by the Pulitzer-prize winning Inside Climate News revealed an industry totally aware and informed for decades about the inevitable warming certain to occur as more and more carbon dioxide from the burning of fossil fuels was released into the atmosphere.

The article states that “In fact, the oil industry, and Exxon in particular, had the best climate models available, superior to those relied on by scientific community.”³ And armed with the foreknowledge developed through those models, Exxon and the other oil companies planned and executed an elaborate, cynical long term strategy: to invest hundreds of millions of dollars in a comprehensive propaganda effort designed to raise doubts about the existence and cause of climate change, a phenomenon they well knew was irrefutable, based on their own research. By 2016 the industry’s lobbying to discredit the science of climate change had surpassed two billion dollars.

“Meanwhile, as newly discovered documents reported in The Guardian⁴ attest, the same companies were preparing projections of what type of world they would be leaving for the rest of humanity. In the 1980s, oil companies like Exxon and Shell carried out internal assessments of the carbon dioxide released by fossil fuels, and forecast the planetary consequences of these emissions. In 1982, for example, Exxon predicted that by about 2060, CO₂ levels would reach around 560 parts per million - double the preindustrial level - and that this would push the planet’s average temperatures up by about 2°C over then-current

¹www.dailykos.com/stories/2018/9/23/1797888/-The-Oil-Companies-not-only-knew-fossil-fuels-caused-climate-change-they-knew-how-bad-it-would-get?detail=emaildkre

²<https://insideclimatenews.org/news/15092015/Exxons-own-research-confirmed-fossil-fuels-role-in-global-warming>

³<https://insideclimatenews.org/news/18092015/exxon-confirmed-global-warming-consensus-in-1982-with-in-house-climate-models>

⁴<https://www.theguardian.com/environment/climate-consensus-97-per-cent/2018/sep/19/shell-and-exxons-secret-1980s-climate-change-warnings>

levels (and even more compared to pre-industrial levels).”⁵

The Fossil Free MIT report, 2014

Here are some excerpts from a report entitled “The Fossil Fuel Industry’s Role in Hindering Climate Change Action: Lobbying and Disinformation Against Science and Scientists”⁶:

In response to the unprecedented urgency of global climate change, Fossil Free MIT’s petition, signed by more than 2,400 MIT members, is calling on MIT to divest its \$11 billion endowment from the 200 fossil fuel companies with the world’s largest publicly traded carbon reserves.

Fossil Free MIT believes that divestment from the fossil fuel industry presents MIT with a unique opportunity to lead the global effort to combat climate change. We wholeheartedly support our Institute’s cutting-edge climate science and renewable energy technology research, as well as MIT’s campus sustainability initiatives, and we propose divestment as a highly complementary strategy that will bring MIT’s investments in line with the goals of its research and sustainability activities. There are three central reasons why we urge MIT to divest from the fossil fuel industry:

- The fossil fuel industry’s business practice is fundamentally inconsistent with the science of climate change mitigation. A 66% chance of limiting global warming to less than 2°C above pre-industrial temperatures demands that no more than 35% of proven fossil fuel reserves can be burned prior to 2100. Yet in 2012, the fossil fuel industry spent \$674 billion developing new reserves.
- The fossil fuel industry spends hundreds of millions of dollars lobbying and donating in Washington, D.C. against legislation for climate change action.
- Many fossil fuel companies are responsible for funding or orchestrating targeted anti-science disinformation campaigns that confuse the public,

⁵See also <https://truthout.org/articles/self-immolation-as-the-world-burns-an-earth-day-report/>
<https://countercurrents.org/2018/04/29/the-methane-time-bomb-and-the-future-of-the-biosphere/>
<https://countercurrents.org/2018/08/07/hothouse-earth-evidence-for-ademise-of-the-planetary-life-support-system/>
<https://www.independent.co.uk/environment/global-warming-temperature-rise-climate-change-end-century-science-a8095591.html>
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<https://www.independent.co.uk/news/business/news/bp-shell-oil-global-warming-5-degree-paris-climate-agreement-fossil-fuels-temperature-rise-a8022511.html>

⁶<https://www.fossilfreemit.org/wp-content/uploads/2014/08/FossilFreeMIT-Lobbying-Disinformation.pdf>

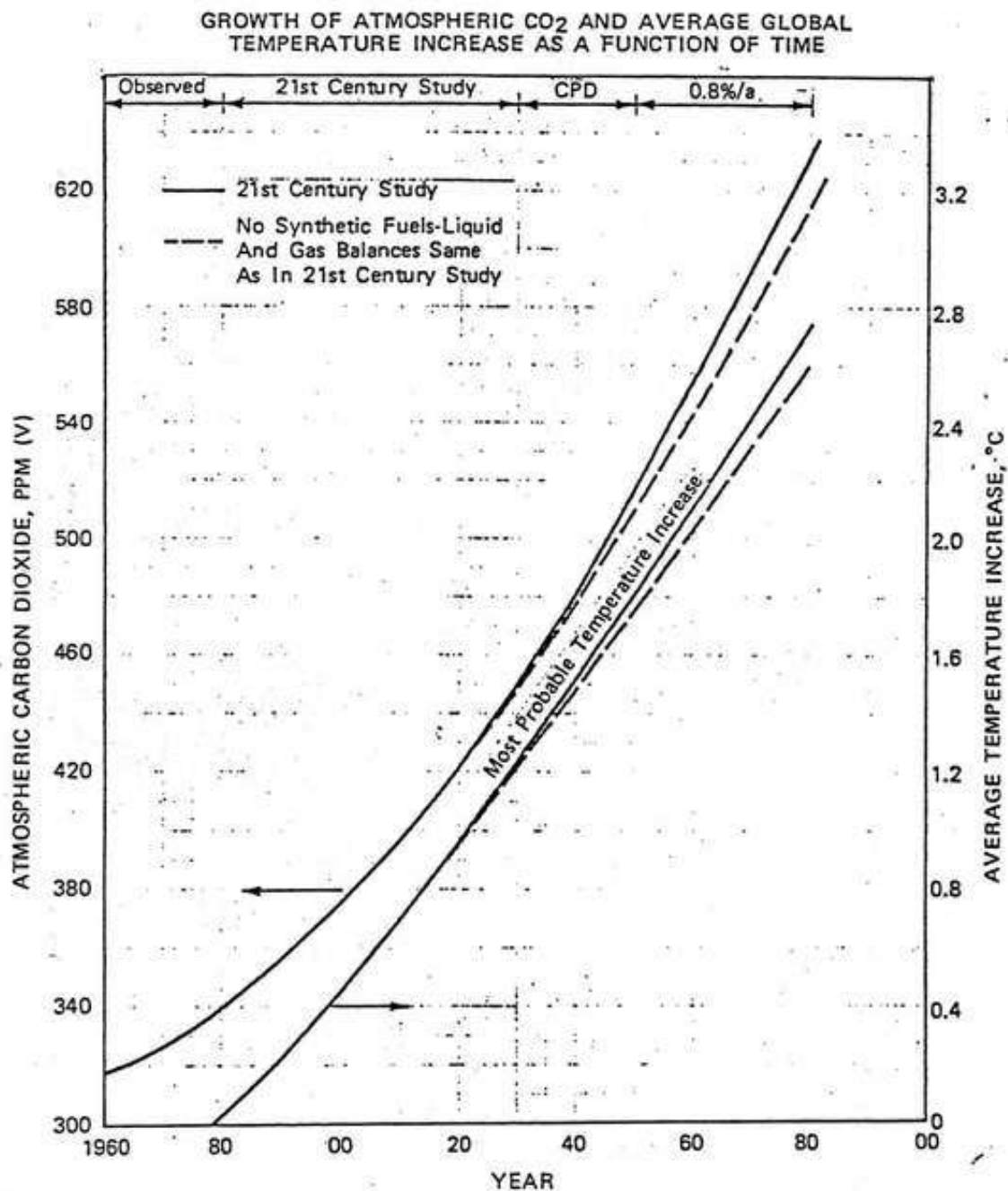


Figure 11.2: Exxon's 1982 internal projections of the future increase in carbon dioxide levels shows CO₂ percentages increasing to 600 ppm and temperature increases of up to 3°C.

sabotage science, and slander scientists.

Disinformation from fossil fuel and tobacco industries

Here are some excerpts from a February 19 2019 article by Mat Hope entitled “**Revealed: How the Tobacco and Fossil Fuel Industries Fund Disinformation Campaigns Around the World**”⁷:

Fossil fuel companies have a long history of adopting public relations strategies straight from the tobacco industry’s playbook. But a new analysis shows the two industries’ relationship goes much deeper - right down to funding the same organizations to do their dirty work.

MIT Associate Professor David Hsu analyzed organizations in DeSmog’s disinformation database and the Guardian’s tobacco database and found 35 thinktanks based in the US, UK, Australia, and New Zealand that promote both the tobacco and fossil fuel industries’ interests.

Of these organizations, DeSmog can reveal that 32 have taken direct donations from the tobacco industry, 29 have taken donations from the fossil fuel industry, and 28 have received money from both. Two key networks, based around the Koch brothers and Atlas Network, are involved in coordinating or funding many of the thinktanks.

⁷<https://www.desmogblog.com/2019/02/19/how-tobacco-and-fossil-fuel-companies-fund-disinformation-campaigns-around-world>



Figure 11.3: Smoke destroys human health, regardless of whether it is from cigarettes or coal-fired power plants. Fossil fuel corporations and tobacco companies have exhibited an astonishing degree of cynicism and lack of social responsibility.

11.3 The divestment movement begins to hurt

In a December 16, 2018 article in *The Guardian*⁸, Bill McKibben wrote:

I remember well the first institution to announce it was divesting from fossil fuel. It was 2012 and I was on the second week of a gruelling tour across the US trying to spark a movement. Our roadshow had been playing to packed houses down the west coast, and we'd crossed the continent to Portland, Maine. As a raucous crowd jammed the biggest theatre in town, a physicist named Stephen Mulkey took the mic. He was at the time president of the tiny Unity College in the state's rural interior, and he announced that over the weekend its trustees had voted to sell their shares in coal, oil and gas companies. "The time is long overdue for all investors to take a hard look at the consequences of supporting an industry that persists in destructive practices," he said.

Six years later, we have marked the 1,000th divestment in what has become by far the largest anti-corporate campaign of its kind. The latest to sell their shares - major French and Australian pension funds, and Brandeis University in Massachusetts - bring the total size of portfolios and endowments in the campaign to just under \$8 trillion.

⁸<https://www.theguardian.com/commentisfree/2018/dec/16/divestment-fossil-fuel-industry-trillions-dollars-investments-carbon>

The list of institutions that have cut their ties with this most destructive of industries encompasses religious institutions large and small (the World Council of Churches, the Unitarians, the Lutherans, the Islamic Society of North America, Japanese Buddhist temples, the diocese of Assisi); philanthropic foundations (even the Rockefeller family, heir to the first great oil fortune, divested its family charities); and colleges and universities from Edinburgh to Sydney to Honolulu are on board, with more joining each week. Forty big Catholic institutions have already divested; now a campaign is urging the Vatican bank itself to follow suit. Ditto with the Nobel Foundation, the world's great art museums, and every other iconic institution that works for a better world.

Thanks to the efforts of groups such as People & Planet (and to the Guardian, which ran an inspiring campaign), half the UK's higher education institutions are on the list. And so are harder-nosed players, from the Norwegian sovereign wealth fund (at a trillion dollars, the largest pool of investment capital on Earth) to European insurance giants such as Axa and Allianz. It has been endorsed by everyone from Leonardo DiCaprio to Barack Obama to Ban Ki-moon (and, crucially, by Desmond Tutu, who helped run the first such campaign a generation ago, when the target was apartheid).

And the momentum just keeps growing: 2018 began with New York City deciding to divest its \$189bn pension funds. Soon the London mayor Sadiq Khan was on board, joining the New York mayor Bill de Blasio to persuade the other financial capitals of the planet to sell. By midsummer Ireland became the first nation to divest its public funds. And this month, a cross-party group of 200 MPs and former MPs called on the their pension fund to phase out its substantial investment in fossil fuel giants.

Heavy hitters like that make it clear that the first line of objection to fossil fuel divestment has long since been laid to rest: this is one big action you can take against climate change without big cost. Indeed, early divesters have made out like green-tinged bandits: since the fossil fuel sector has badly underperformed on the market over recent years, moving money into other investments has dramatically increased returns. Pity, for instance, the New York state comptroller Thomas DeNapoli - unlike his New York City counterpart, he refused to divest, and the cost has been about \$17,000 per pensioner.

The deeper question, though, is whether divestment is making a dent in the fossil fuel industry. And there the answer is even clearer: this has become the deepest challenge yet to the companies that have kept us on the path to climate destruction.

At first we thought our biggest effect would be to rob fossil fuel companies of their social licence. Since their political lobbying power is above all what prevents governments taking serious action on global warming, that would have been worth the fight. And indeed academic research makes it clear that's happened - one study concluded that "liberal policy ideas (such as a carbon tax), which had previously been marginalised in the US debate, gained increased

attention and legitimacy”. That makes sense: most people don’t have a coal mine or gas pipeline in their backyard, but everyone has - through their alma mater, their church, their local government - some connection to a large pot of money.

As time went on, though, it became clear that divestment was also squeezing the industry. Peabody, the world’s biggest coal company, announced plans for bankruptcy in 2016; on the list of reasons for its problems, it counted the divestment movement, which was making it hard to raise capital. Indeed, just a few weeks ago analysts at that radical collective Goldman Sachs said the “divestment movement has been a key driver of the coal sector’s 60% de-rating over the past five years”...

11.4 Some hopeful signs of change

According to a 5 April 2019 article in *The Guardian*⁹, “Norway’s \$1tn oil fund, the world’s largest sovereign wealth fund, is to plunge billions of dollars into wind and solar power projects. The decision follows Saudi Arabia’s oil fund selling off its last oil and gas assets.

“Other national funds built up from oil profits are also thought to be ramping up their investments in renewables. The moves show that countries that got rich on fossil fuels are diversifying their investments and seeking future profits in the clean energy needed to combat climate change. Analysts say the investments are likely to power faster growth of green energy.

According to IRENA, “Renewable energy now accounts for a third of global power capacity”. Here are some excerpts from the Danish government’s State of Green newsletter of April 3, 2019:

The decade-long trend of strong growth in renewable energy capacity continued in 2018 with global additions of 171 gigawatts (GW), according to new data released by the International Renewable Energy Agency (IRENA). The annual increase of 7.9 per cent was bolstered by new additions from solar and wind energy, which accounted for 84 per cent of the growth. A third of global power capacity is now based on renewable energy.

IRENA’s annual Renewable Capacity Statistics 2019,¹⁰ the most comprehensive, up-to-date and accessible figures on renewable energy capacity indicates growth in all regions of the world, although at varying speeds. While Asia accounted for 61 per cent of total new renewable energy installations and grew installed renewables capacity by 11.4 per cent, growth was fastest in Oceania that witnessed a 17.7 per cent rise in 2018. Africa’s 8.4 per cent growth put it

⁹<https://www.theguardian.com/environment/2019/apr/05/historic-breakthrough-norways-giant-oil-fund-dives-into-renewables>

¹⁰<https://www.irena.org/publications/2019/Mar/Capacity-Statistics-2019>

in third place just behind Asia. Nearly two-thirds of all new power generation capacity added in 2018 was from renewables, led by emerging and developing economies.

“Through its compelling business case, renewable energy has established itself as the technology of choice for new power generation capacity,” said IRENA Director-General Adnan Z. Amin.

Suggestions for further reading

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Chapter 12

MONEY CONTROLS MEDIA AND GOVERNMENTS

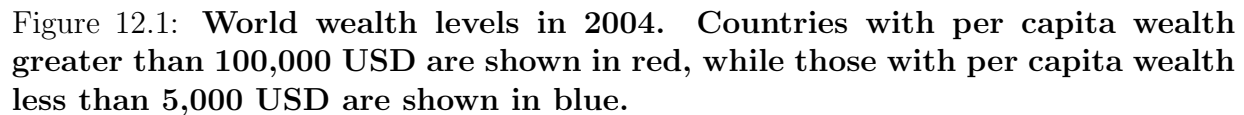
12.1 Benefits of equality

The Industrial Revolution opened up an enormous gap in military strength between the industrialized nations and the rest of the world. Taking advantage of their superior weaponry, Europe, the United States and Japan rapidly carved up the remainder of the world into colonies, which acted as sources of raw materials and food, and as markets for manufactured goods. Between 1800 and 1914, the percentage of the earth under the domination of colonial powers increased to 85 percent, if former colonies are included.

The English economist and Fabian, John Atkinson Hobson (1858-1940), offered a famous explanation of the colonial era in his book “Imperialism: A Study” (1902). According to Hobson, the basic problem that led to colonial expansion was an excessively unequal distribution of incomes in the industrialized countries. The result of this unequal distribution was that neither the rich nor the poor could buy back the total output of their society. The incomes of the poor were insufficient, and rich were too few in number. The rich had finite needs, and tended to reinvest their money. As Hobson pointed out, reinvestment in new factories only made the situation worse by increasing output.

Hobson had been sent as a reporter by the Manchester Guardian to cover the Second Boer War. His experiences had convinced him that colonial wars have an economic motive. Such wars are fought, he believed, to facilitate investment of the excess money of the rich in African or Asian plantations and mines, and to make possible the overseas sale of excess manufactured goods. Hobson believed imperialism to be immoral, since it entails suffering both among colonial peoples and among the poor of the industrial nations. The cure that he recommended was a more equal distribution of incomes in the manufacturing countries.

Interestingly, TED Talks (ideas worth spreading) was recently under fire from many progressive groups for censoring a short talk by the adventure capitalist, Nick Hanauer, entitled “Income Inequality”. In this talk, Hanauer said exactly the same thing as John Hobson, but he applies the ideas, not to colonialism, but to current unemployment in the



TED has now posted Hanauer's talk, and the interested reader can find another wonderful TED talk dealing with the same issues from the standpoint of health and social problems. In a splendid lecture entitled "How economic inequality harms societies", Richard Wilkinson demonstrates that there is almost no correlation between gross national product and a number of indicators of the quality of life, such as physical health, mental health, drug abuse, education, imprisonment, obesity, social mobility, trust, violence, teenage pregnancies and child well-being. On the other hand he offers comprehensive statistical evidence that these indicators are strongly correlated with the degree of inequality within countries, the outcomes being uniformly much better in nations where income is more equally distributed.

Warren Buffet famously remarked, “There’s class warfare, all right. But it’s my class, the rich class, that’s making war, and we’re winning.” However, the evidence presented by Hobson, Hanauer and Wilkinson shows conclusively that no one wins in a society where inequality is too great, and everyone wins when incomes are more evenly distributed.



Figure 12.2: In many countries, children live by scavaging from garbage dumps.



Figure 12.3: Even in rich countries, many millions of people live in poverty,

12.2 Extreme inequality today

Here are some quotations from a report by the Global Inequality organization: ¹

Inequality has been on the rise across the globe for several decades. Some countries have reduced the numbers of people living in extreme poverty. But economic gaps have continued to grow as the very richest amass unprecedented levels of wealth. Among industrial nations, the United States is by far the most top-heavy, with much greater shares of national wealth and income going to the richest 1 percent than any other country.

The world's richest 1 percent, those with more than \$1 million, own 45 percent of the world's wealth. Adults with less than \$10,000 in wealth make up 64 percent of the world's population but hold less than 2 percent of global wealth. The world's wealthiest individuals, those owning over \$100,000 in assets, total less than 10 percent of the global population but own 84 percent of global wealth. Credit Suisse defines "wealth" as the value of a household's financial assets plus real assets (principally housing), minus their debts.

"Ultra high net worth individuals" - the wealth management industry's term for people worth more than \$30 million - hold an astoundingly disproportionate share of global wealth. These wealth owners hold 11.3 percent of total global wealth, yet represent only a tiny fraction (0.003%) of the world population.

The world's 10 richest billionaires, according to Forbes, own \$745 billion in combined wealth, a sum greater than the total goods and services most nations produce on an annual basis. The globe is home to 2,208 billionaires, according to the 2018 Forbes ranking.

Those with extreme wealth have often accumulated their fortunes on the backs of people around the world who work for poor wages and under dangerous conditions. According to Oxfam, the wealth divide between the global billionaires and the bottom half of humanity is steadily growing. Between 2009 and 2017, the number of billionaires it took to equal the wealth of the world's poorest 50 percent fell from 380 to 42...

The United States has more wealth than any other nation. But America's top-heavy distribution of wealth leaves typical American adults with far less wealth than their counterparts in other industrial nations.

12.3 Oligarchy replaces democracy in many countries

The jaws of power

"Every government degenerates when trusted to the rulers of the people alone. The people themselves, therefore, are its only safe depositories." Thomas Jeffer-

¹<https://inequality.org/facts/global-inequality/>

son, (1743-1826)

“The jaws of power are always open to devour, and her arm is always stretched out, if possible, to destroy the freedom of thinking, speaking, and writing.”
John Adams, (1735-1826)

According to the Nuremberg Principles, the citizens of a country have a responsibility for the crimes that their governments commit. But to prevent these crimes, the people need to have some knowledge of what is going on. Indeed, democracy cannot function at all without this knowledge.

What are we to think when governments make every effort to keep their actions secret from their own citizens? We can only conclude that although they may call themselves democracies, such governments are in fact oligarchies or dictatorships.

At the end of World War I, it was realized that secret treaties had been responsible for its outbreak, and an effort was made to ensure that diplomacy would be more open in the future. Needless to say, these efforts did not succeed, and diplomacy has remained a realm of secrecy.

Many governments have agencies for performing undercover operations (usually very dirty ones). We can think, for example of the KGB, the CIA, M5, or Mossad. How can countries that have such agencies claim to be democracies, when the voters have no knowledge of or influence over the acts that are committed by the secret agencies of their governments?

Nuclear weapons were developed in secret. It is doubtful whether the people of the United States would have approved of the development of such antihuman weapons, or their use against an already-defeated Japan, if they had known that these things were going to happen. The true motive for the nuclear bombings was also kept secret. In the words of General Groves, speaking confidentially to colleagues at Los Alamos, the real motive was “to control the Soviet Union”.

The true circumstances surrounding the start of the Vietnam war would never have been known if Daniel Ellsberg had not leaked the Pentagon Papers. Ellsberg thought that once the American public realized that their country’s entry into the war was based on a lie, the war would end. It did not end immediately, but undoubtedly Ellsberg’s action contributed to the end of the war.

We do not know what will happen to Julian Assange. If his captors send him to the US, and if he dies there for the crime of publishing leaked documents (a crime that he shares with the New York Times), he will not be the first martyr to the truth. The ageing Galileo was threatened with torture and forced to recant his heresy - that the earth moves around the sun. Galileo spent the remainder of his days in house arrest. Giordano Bruno was less lucky. He was burned at the stake for maintaining that the universe is larger than it was then believed to be. If Julian Assange becomes a martyr to the truth like Galileo or Bruno, his name will be honored by generations in the future, and the shame of his captors will be remembered too.

The deep state

Can a government, many of whose operations are secret, be a democracy? Obviously this is impossible. The recent attempts of the United States to arrest whistleblower Edward Snowden call attention to the glaring contradiction between secrecy and democracy.

In a democracy, the power of judging and controlling governmental policy is supposed to be in the hands of the people. It is completely clear that if the people do not know what their government is doing, then they cannot judge or control governmental policy, and democracy has been abolished. There has always been a glaring contradiction between democracy and secret branches of the government, such as the CIA, which conducts its assassinations and its dirty wars in South America without any public knowledge or control.

The gross, wholesale electronic spying on citizens revealed by Snowden seems to be specifically aimed at eliminating democracy. It is aimed at instilling universal fear and conformity, fear of blackmail and fear of being out of step, so that the public will not dare to oppose whatever the government does, no matter how criminal or unconstitutional.

Henry Kissinger famously remarked: "The illegal we do at once. The unconstitutional takes a little longer". Well, Henry, that may have been true in your time, but today the unconstitutional does not take long at all.

The Magna Carta is trashed. No one dares to speak up. Habeas Corpus is trashed. No one dares to speak up. The United Nations Charter is trashed. No one dares to speak up. The Universal Declaration of Human Rights is trashed. No one dares to speak up. The Fourth Amendment to the US Constitution is trashed. No one dares to speak up. The President claims the right to kill both US and foreign citizens, at his own whim. No one dares to speak up.

But perhaps this is unjust. Perhaps some people would dare to protest, except that they cannot get their protests published in the mainstream media. We must remember that the media are owned by the same corporate oligarchs who own the government.

George Orwell, you should be living today! We need your voice today! After Snowden's revelations, the sale of Orwell's "1984" soared. It is now on the bestseller list. Sadly, Orwell's dystopian prophesy has proved to be accurate in every detail.

What is the excuse for the massive spying reported by Snowden, spying not only on US citizens but also on the citizens of other countries throughout the world? "We want to protect you from terrorism.", the government answers. But terrorism is not a real threat, it is an invented one. It was invented by the military-industrial complex because, at the end of the Cold War, this enormous money-making conglomerate lacked enemies.

Globally, the number of people killed by terrorism is vanishingly small compared to the number of children who die from starvation every year. It is even vanishingly small compared with the number of people who are killed in automobile accidents. It is certainly small compared with the number of people killed in wars aimed at gaining western hegemony over oil-rich regions of the world.

But in Shelley's words, "We are many; they are few!" The people who want democracy greatly outnumber those who profit from maintaining a government based on secrecy and fear. Let us "rise like lions after slumbers, in unvanquishable numbers". Let us abolish

governmental secrecy and reclaim our democracy.

12.4 Media in the service of powerholders

Throughout history, art was commissioned by rulers to communicate, and exaggerate, their power, glory, absolute rightness etc, to the populace. The pyramids gave visual support to the power of the Pharaoh; portraits of rulers are a traditional form of propaganda supporting monarchies; and palaces were built as symbols of power.

Modern powerholders are also aware of the importance of propaganda. Thus the media are a battleground where reformers struggle for attention, but are defeated with great regularity by the wealth and power of the establishment. This is a tragedy because today there is an urgent need to make public opinion aware of the serious problems facing civilization, and the steps that are needed to solve these problems. The mass media could potentially be a great force for public education, but often their role is not only unhelpful - it is negative.

It is certainly possible to find a few television programs and newspaper articles that present the facts about climate change in a realistic way. For example *The Guardian* gives outstanding climate change coverage. However, the mass media could do very much more. One has to conclude that the media are neglecting their great responsibilities at a time of acute crisis for human civilization and the biosphere. The same can be said of our educational systems at both the primary and advanced levels. We urgently need much more public education about the severe dangers that we face today.

12.5 Television as a part of our educational system

In the mid-1950's, television became cheap enough so that ordinary people in the industrialized countries could afford to own sets. During the infancy of television, its power was underestimated. The great power of television is due to the fact that it grips two senses simultaneously, both vision and hearing. The viewer becomes an almost-hypnotized captive of the broadcast.

In the 1950's, this enormous power, which can be used both for good and for ill, was not yet fully apparent. Thus insufficient attention was given to the role of television in education, in setting norms, and in establishing values. Television was not seen as an integral part of the total educational system. It is interesting to compare the educational systems of traditional cultures with those of modern industrial societies.

In traditional societies, multigenerational families often live together in the same dwelling. In general, there is a great deal of contact between grandparents and grandchildren, with much transmission of values and norms between generations. Old people are regarded with great respect, since they are considered to be repositories of wisdom, knowledge, and culture.

By contrast, modern societies usually favor nuclear families, consisting of only parents

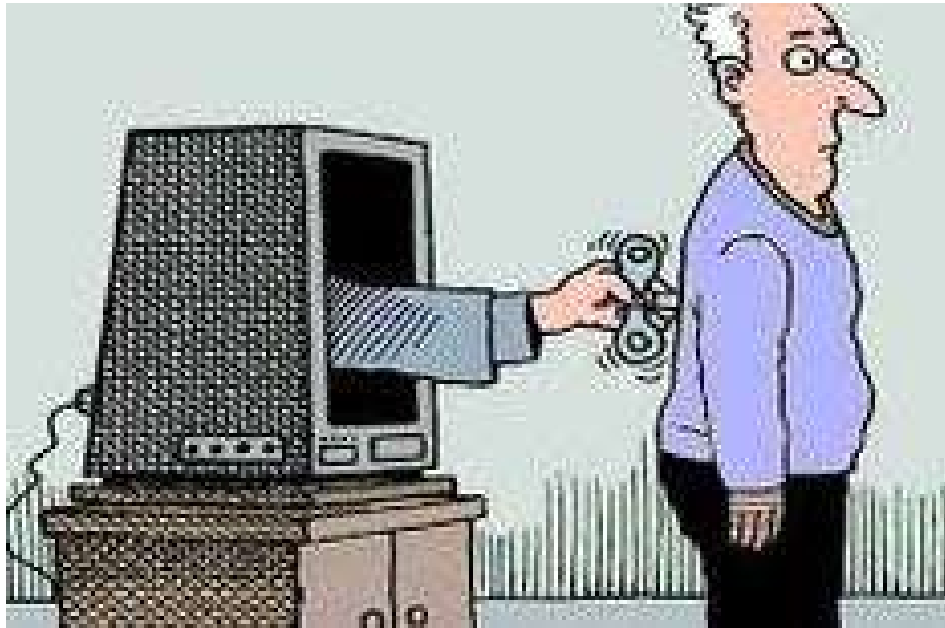


Figure 12.4: **The role of the media.**



Figure 12.5: **Liberty?**

and children. Old people are marginalized. They live by themselves in communities or homes especially for the old. Their cultural education knowledge and norms are not valued because they are “out of date”. In fact, during the life of a young person in one of the rapidly-changing industrial societies of the modern world, there is often a period when they rebel against the authority of their parents and are acutely embarrassed by their parents, who are “so old-fashioned that they don’t understand anything”.

Although the intergenerational transmission of values, norms, and culture is much less important in industrial societies than it is in traditional ones, modern young people of the West and North are by no means at a loss over where to find their values, fashions and role models. With every breath, they inhale the values and norms of the mass media. Totally surrounded by a world of television and film images, they accept this world as their own.

12.6 Neglect of climate change in the mass media

The predicament of humanity today has been called “a race between education and catastrophe”: How do the media fulfil this life-or-death responsibility? Do they give us insight? No, they give us pop music. Do they give us an understanding of the sweep of evolution and history? No, they give us sport. Do they give us an understanding of the ecological catastrophes that threaten our planet because of unrestricted growth of population and industries? No, they give us sit-coms and soap operas. Do they give us unbiased news? No, they give us news that has been edited to conform with the interests of powerful lobbies. Do they present us with the urgent need to leave fossil fuels in the ground? No, they do not, because this would offend the powerholders. Do they tell of the danger of passing tipping points after which human efforts to prevent catastrophic climate change will be useless? No, they give us programs about gardening and making food.

A consumer who subscribes to the “package” of broadcasts sold by a cable company can often search through all 95 channels without finding a single program that offers insight into the various problems that are facing the world today. What the viewer finds instead is a mixture of pro-establishment propaganda and entertainment. Meanwhile the neglected global problems are becoming progressively more severe.

In general, the mass media behave as though their role is to prevent the peoples of the world from joining hands and working to change the world and to save it from thermonuclear war, environmental catastrophes and threatened global famine. The television viewer sits slumped in a chair, passive, isolated, disempowered and stupefied. The future of the world hangs in the balance, the fate of children and grandchildren hangs in the balance, but the television viewer feels no impulse to work actively to change the world or to save it. The Roman emperors gave their people bread and circuses to numb them into political inactivity. The modern mass media seem to be playing a similar role.



Figure 12.6: Network administrators have noticed that programs about climate change often have low viewer ratings. Since they see delivering high viewer ratings to their advertisers as their primary duty, these executives seldom allow programs dealing with the danger of catastrophic climate change. The duty to save the earth from environmental catastrophe is neglected for the sake of money. As Al Gore said, “Instead of having a well-informed electorate, we have a well-amused audience”.

12.7 Climate change denial in mass media

The Wikipedia article on climate change denial describes it with the following words: “Although scientific opinion on climate change is that human activity is extremely likely to be the primary driver of climate change, the politics of global warming have been affected by climate change denial, hindering efforts to prevent climate change and adapt to the warming climate. Those promoting denial commonly use rhetorical tactics to give the appearance of a scientific controversy where there is none.”

It is not surprising that the fossil fuel industry supports, on a vast scale, politicians and mass media that deny the reality of climate change. The amounts of money at stake are vast. If catastrophic climate change is to be avoided, coal, oil and natural gas “assets” worth trillions of dollars must be left in the ground. Giant fossil fuel corporations are desperately attempting to turn these “assets” into cash.



Preventing an ecological apocalypse

Here are some excerpts from an article entitled “**Only Rebellion will prevent an ecological apocalypse**” by George Monbiot, which was published on April 15 2019 in The Guardian²:

No one is coming to save us. Mass civil disobedience is essential to force a political response.

Had we put as much effort into preventing environmental catastrophe as we’ve spent on making excuses for inaction, we would have solved it by now. Everywhere I look, I see people engaged in furious attempts to fend off the moral challenge it presents...

As the environmental crisis accelerates, and as protest movements like YouthStrike4Climate and Extinction Rebellion make it harder not to see what we face, people discover more inventive means of shutting their eyes and shedding responsibility. Underlying these excuses is a deep-rooted belief that if we really are in trouble, someone somewhere will come to our rescue: “they” won’t let it happen. But there is no they, just us.

The political class, as anyone who has followed its progress over the past three years can surely now see, is chaotic, unwilling and, in isolation, strategically incapable of addressing even short-term crises, let alone a vast existential predicament. Yet a widespread and wilful naivety prevails: the belief that voting is the only political action required to change a system. Unless it is accompanied by the concentrated power of protest - articulating precise de-

²<https://www.theguardian.com/commentisfree/2019/apr/15/rebellion-prevent-ecological-apocalypse-civil-disobedience>

mands and creating space in which new political factions can grow - voting, while essential, remains a blunt and feeble instrument.

The media, with a few exceptions, is actively hostile. Even when broadcasters cover these issues, they carefully avoid any mention of power, talking about environmental collapse as if it is driven by mysterious, passive forces, and proposing microscopic fixes for vast structural problems. The BBC's Blue Planet Live series exemplified this tendency.

Those who govern the nation and shape public discourse cannot be trusted with the preservation of life on Earth. There is no benign authority preserving us from harm. No one is coming to save us. None of us can justifiably avoid the call to come together to save ourselves...

Predatory delay

Here are some excerpts from a May 3 2019 article by Bill Henderson entitled "Neoliberalism, Solution Aversion, Implicatory Denial and Predatory Delay"³:

Looking back at the history, that it's not really a failure of human beings and human nature that's the problem here. It's a hijacking of our political and economic system by the fossil fuel industry and a small number of like-minded people. It was our bad luck that this idea that markets solve all problems and that government should be left to wither away crested just at the moment when it could do the most damage.

Despite the urgent need to reduce greenhouse gas emissions globally if we are to lower the risks of catastrophic climate change, wealthy industrialized nations persist with a widespread public silence on the issue and fail to address climate change. This is despite there being ever more conclusive evidence of its severity. Why is there an undercurrent of inaction, despite the challenge of climate change being ever more daunting? One element is denial.

George Marshall discovered that there has not been a single proposal, debate or even position paper on limiting fossil fuel production put forward during international climate negotiations. From the very outset fossil fuel production lay outside the frame of the discussions and, as with other forms of socially constructed silence, the social norms among the negotiators and policy specialists kept it that way.

Global climate leadership is being redefined. There is a growing recognition that you cannot be a climate leader if you continue to enable new fossil fuel production, which is inconsistent with climate limits. If no major producers step up to stop the expansion of extraction and begin phasing out existing fields and mines, the Paris goals will become increasingly difficult to achieve.

³<https://countercurrents.org/2019/05/03/neoliberalism-solution-aversion-implicatory-denial-and-predatory-delay-bill-henderson/>

Wealthy fossil fuel producers have a responsibility to lead, and this must include planning for a just and equitable managed decline of existing production.

The (emissions reduction) curve we've been forced onto bends so steeply, that the pace of victory is part of victory itself. Winning slowly is basically the same thing as losing outright. We cannot afford to pursue past strategies, aimed at limited gains towards distant goals. In the face of both triumphant denialism and predatory delay, trying to achieve climate action by doing the same things, the same old ways, means defeat. It guarantees defeat.

A fast, emergency-scale transition to a post-fossil fuel world is absolutely necessary to address climate change. But this is excluded from consideration by policymakers because it is considered to be too disruptive. The orthodoxy is that there is time for an orderly economic transition within the current short-termist political paradigm. Discussion of what would be safe - less warming than we presently experience - is non-existent. And so we have a policy failure of epic proportions. Policymakers, in their magical thinking, imagine a mitigation path of gradual change, to be constructed over many decades in a growing, prosperous world...

12.8 Showing unsustainable lifestyles in mass media

Television and other mass media contribute indirectly to climate change denial by showing unsustainable lifestyles. Television dramas show the ubiquitous use of gasoline-powered automobiles and highways crowded with them. just as though there did not exist an urgent need to transform our transportation systems. Motor racing is shown. A program called "Top Gear" tells viewers about the desirability of various automobiles. In general, cyclists are not shown. In television dramas, the protagonists fly to various parts of the world for their holidays. The need for small local self-sustaining communities is not shown.

Advertisements in the mass media urge us to consume more, to fly, to purchase large houses, and to buy gasoline-driven automobiles, just as though such behavior ought to be the norm. Such norms are leading us towards environmental disaster.

12.9 Alternative media

Luckily, the mass media do not have a complete monopoly on public information. With a little effort, citizens who are concerned about the future can find alternative media. These include a large number of independent on-line news services that are supported by subscriber donations rather than by corporate sponsors. *YouTube* videos also represent an extremely important source of public information.



12.10 Outstanding voices calling for climate action

The Guardian

There are exceptions to the general rule that the mass media downplay or completely ignore the climate emergency. The Guardian is a newspaper with absolutely outstanding coverage of all issues related to climate change. No praise can be strong enough for the courageous environmental editorial policy of this famous old British newspaper.

Al Gore

Albert Arnold Gore Jr. served as the 45th Vice President of the United States from January 1985 to January 1993. He then ran for the office of President, but was defeated by George W. Bush in a controversial election whose outcome was finally decided by the US Supreme Court⁴.

Al Gore is the founder and current Chairman of the Alliance for Climate Protection. He was one of the first important political figures to call attention to the problem of steadily increasing CO₂ levels in the atmosphere and the threat of catastrophic climate change. He produced the highly influential documentary film *An Inconvenient Truth*⁵. Because of his important efforts to save the global environment, Al Gore shared the 2007 Nobel Peace Prize with the Intergovernmental Panel on Climate Change.

⁴Many people believe that Al Gore won the election.

⁵<https://www.youtube.com/watch?v=I-SV13UQXdk>

Al Gore's TED talk: The Case for Optimism on Climate Change

In 2016, Al Gore gave an important talk to a TED audience⁶. in which he pointed out the an economic tipping point has just been passed. Solar energy and wind energy are now cheaper than energy form fossil fuels. This means that economic forces alone can drive a rapid transition to 100% renewable energy. Investors will realize that renewables represent an unparalleled investment opportunity.

Sir David Attenborough

In a 2011 interview in The Guardian, Sir David Attenborough was asked: “What will it take to wake people up about climate change?”. He replied “Disaster. It’s a terrible thing to say, isn’t it? And even disaster doesn’t always do it. I mean, goodness me, there have been disasters in North America, with hurricanes, and one thing and another, and floods; and still a lot of people would deny it, and say it’s nothing to do with climate change. Well it visibly has to do with climate change!”

Sir David Attenborough’s almost unbelievably enormous and impressive opus of television programs about the natural world have helped to raise public awareness of the importance of the natural environment. He also has made a number of television programs specifically related to questions such as saving threatened species, the dangers of exploding global human populations, and the destruction of forests for the sake of palm oil plantations.

Let us return to The Guardian’s 2011 interview with Sir David. Had it been made in the autumn of 2017, the interview would certainly have included a discussion of recent hurricanes of unprecedented power and destructiveness, such as Harvey, Irma and Maria, as well as 2017’s wildfires and Asian floods. It is possible that such events, which will certainly become more frequent and severe during the next few years, will provide the political will needed to silence climate change denial, to stop fossil fuel extraction, and to promote governmental policies favoring renewable energy.

Although the mass media almost have entirely neglected the link between climate change and recent disastrous hurricanes, floods droughts and wildfires, many individuals and organizations emphasized the cause and effect relationship. For example, UK airline billionaire Sir Richard Branson, whose Caribbean summer residence was destroyed by Hurricane Irma said:

“Look, you can never be 100 percent sure about links, But scientists have said the storms are going to get more and more and more intense and more and more often. We’ve had four storms within a month, all far greater than that have ever, ever, ever happened in history, Sadly, I think this is the start of things to come. Climate change is real. Ninety-nine percent of scientists know it’s real. The whole world knows it’s real except for maybe one person in the White House.”

May Boeve, executive director of the NGO 350.org, said “With a few exceptions, the major TV networks completely failed to cover the scientifically proven ways that climate

⁶<https://www.youtube.com/watch?v=I-SV13UQXdk>

change is intensifying extreme weather events like hurricanes Harvey and Irma. That's not just disappointing, it's dangerous. We won't be able to turn this crisis around if our media is asleep at the wheel."

Commenting on the destruction of Puerto Rico by Hurricane Maria, historian Juan Cole wrote: "When you vote for denialist politicians, you are selecting people who make policy. The policy they make will be clueless and will actively endanger the public. Climate change is real. We are causing it by our emissions. If you don't believe that, you are not a responsible steward of our infrastructure and of our lives."

When interviewed by Amy Goodman of *Democracy Now*, musician Stevie Wonder said: "... we should begin to love and value our planet, and anyone who believes that there is no such thing as global warming must be blind or unintelligent."

Another well-known musician, Beyoncé, added: "The effects of climate change are playing out around the world every day. Just this past week, we've seen devastation from the monsoon in India...and multiple catastrophic hurricanes. Irma alone has left a trail of death and destruction from the Caribbean to Florida to Southern United States. We have to be prepared for what comes next..."

In her September 2017 publication *Season of Smoke*⁷, prizewinning author Naomi Klein wrote:

"We hear about the record-setting amounts of water that Hurricane Harvey dumped on Houston and other Gulf cities and towns, mixing with petrochemicals to pollute and poison on an unfathomable scale. We hear too about the epic floods that have displaced hundreds of thousands of people from Bangladesh to Nigeria (though we don't hear enough). And we are witnessing, yet again, the fearsome force of water and wind as Hurricane Irma, one of the most powerful storms ever recorded, leaves devastation behind in the Caribbean, with Florida now in its sights.

"Yet for large parts of North America, Europe, and Africa, this summer has not been about water at all. In fact it has been about its absence; it's been about land so dry and heat so oppressive that forested mountains exploded into smoke like volcanoes. It's been about fires fierce enough to jump the Columbia River; fast enough to light up the outskirts of Los Angeles like an invading army; and pervasive enough to threaten natural treasures, like the tallest and most ancient sequoia trees and Glacier National Park.

"For millions of people from California to Greenland, Oregon to Portugal, British Columbia to Montana, Siberia to South Africa, the summer of 2017 has been the summer of fire. And more than anything else, it's been the summer of ubiquitous, inescapable smoke.

"For years, climate scientists have warned us that a warming world is an extreme world, in which humanity is buffeted by both brutalizing excesses and stifling absences of the core elements that have kept fragile life in equilibrium for millennia. At the end of the summer of 2017, with major cities submerged in water and others licked by flames, we are currently living through Exhibit A of this extreme world, one in which natural extremes

⁷<https://theintercept.com/2017/09/09/in-a-summer-of-wildfires-and-hurricanes-my-son-asks-why-is-everything-going-wrong/>



Figure 12.7: Sir David Attenborough: “Disaster. It’s a terrible thing to say, isn’t it?”

come head-to-head with social, racial, and economic ones.”

It seems likely that the climate-linked disasters of 2019 and 2020 will be even more severe than those that we have witnessed during 2017 and 2018. But will such disasters be enough to wake us up?

The BBC has recently announced that Sir David Attenborough is currently producing a new series, *Blue Planet II*, which will focus on environmental issues.⁸

“My hope is that the world is coming to its senses ... I’m so old I remember a time when ... we didn’t talk about climate change, we talked about animals and species extermination,” Sir David told Greenpeace in an interview, “For the first time I’m beginning to think there is actually a groundswell, there is a change in the public view. I feel many more people are concerned and more aware of what the problems are. Young people - people who’ve got 50 years of their life ahead of them - they are thinking they ought to be doing something about this. That’s a huge change.”

Climate Change, The Facts

Now Sir David Attenborough has completed a new one-hour BBC program on the danger of catastrophic climate change. Here are some excerpts from an April 18 2019 review of the program by Rebecca Nicholson in *The Guardian*:

The Facts is a rousing call to arms. It is an alarm clock set at a horrifying volume. The first 40 minutes are given over to what Attenborough calls, without hyperbole, “our greatest threat in thousands of years”. Expert af-

⁸<http://www.bbcearth.com/blueplanet2/>



Figure 12.8: Speaking at the opening ceremony of COP24, the universally loved and respected naturalist Sir David Attenborough said: “If we don’t take action, the collapse of our civilizations and the extinction of much of the natural world is on the horizon.”

ter expert explains the consequences of rising CO₂ levels, on the ice caps, on coastal regions, on weather and wildlife and society itself. The most powerful moments are in footage shot not by expert crews who have spent years on location, but on shaky cameras, capturing the very moment at which the reality of our warming planet struck the person holding the phone. In Cairns, Australia, flying foxes are unable to survive the extreme temperatures; rescuers survey the terrible massacre, and we learn that while 350 were saved, 11,000 died. A man and his son talk through their escape from raging wildfires, over the film they took while attempting to drive through a cavern of blazing red trees. These are horror movies playing out in miniature. It is difficult to watch even five minutes of this and remain somehow neutral, or unconvinced.

Yet as I kept on, scribbling down an increasingly grim list of statistics, most of which I knew, vaguely, though compiled like this they finally sound as dreadful as they truly are - 20 of the warmest years on record happened in the last 22 years; Greenland’s ice sheet is melting five times faster than it was 25 years ago - I started to wonder about responsibility, and if and where it would be placed. This would be a toothless film, in the end, if it were hamstrung by political neutrality, and if its inevitable “it’s not too late” message rested solely on individuals and what relatively little tweaks we might make as consumers. What about corporations? What about governments?

Then, at that exact moment, having played the despair through to its crescendo, the experts served up unvarnished honesty. They lined up to lay out the facts, plain and simple. Fossil fuel companies are the most profitable businesses man has ever known, and they engage in PR offensives, using the same consultants as tobacco companies, and the resulting uncertainty and denial, designed to safeguard profits, has narrowed our window for action. It is unforgivable. I find it hard to believe that anyone, regardless of political affiliation, can watch footage of Trump calling climate change “a hoax ... a money-making industry” and not be left winded by such staggering ignorance or astonishing deceit, though it is, more likely, more bleakly, a catastrophic combination of the two. At least Nigel Lawson only appears here in archive footage, and his argument sounds limp, to put it kindly.

Climate Change: The Facts should not have to change minds, but perhaps it will change them anyway, or at least make this seem as pressing as it needs to be. With the Extinction Rebellion protests across London this week, disrupting day-to-day business, and this, on primetime BBC One, maybe the message will filter through. At the very least, it should incite indignation that more was not done, sooner, and then urgency and a decision to both change and push for change at a much higher level. Because there is, for a brief moment, just possibly, still time.

Greta Thunberg meets Pope Francis

On 19 April 2019, Greta Thunberg met briefly with Pope Francis at the end of his general audience. “Continue, continue!” the Pope told her, “Go on, go ahead!” Greta answered Pope Francis with the words: “Thank you for standing up for the climate, for speaking the truth. It means a lot.” Greta’s father, Svante Thunberg, expressed his gratitude to the pope: “Thank you so much for what you are doing. It means everything. Everything.”

The Pope has made fighting climate change and caring for God’s creation a pillar of his papacy. He wrote an entire encyclical about it, blaming a thirst for money for turning the Earth into a wasteland and demanding immediate action to curb global warming.

While in Rome, Greta Thunberg will also address the Italian Parliament and participate in a school strike for action to avoid catastrophic climate change.

In June, 2015, His Holiness Pope Francis I addressed the climate crisis in an encyclical entitled “*Laudato Si’*”⁹. Here are a few excerpts from this enormously important encyclical, which is addressed not only to the world’s 1.2 billion Catholics, but also to concerned people of all faiths. After reviewing the contributions of his predecessors. Pope Francis makes the following points:

23. The climate is a common good, belonging to all and meant for all. At the global level, it is a complex system linked to many of the essential conditions

⁹<https://unfccc.int/news/pope-francis-releases-encyclical-on-climate-and-environment>

for human life. A very solid scientific consensus indicates that we are presently witnessing a disturbing warming of the climatic system. In recent decades this warming has been accompanied by a constant rise in the sea level and, it would appear, by an increase of extreme weather events, even if a scientifically determinable cause cannot be assigned to each particular phenomenon. Humanity is called to recognize the need for changes of lifestyle, production and consumption, in order to combat this warming or at least the human causes which produce or aggravate it. It is true that there are other factors (such as volcanic activity, variations in the earth's orbit and axis, the solar cycle), yet a number of scientific studies indicate that most global warming in recent decades is due to the great concentration of greenhouse gases (carbon dioxide, methane, nitrogen oxides and others) released mainly as a result of human activity. As these gases build up in the atmosphere, they hamper the escape of heat produced by sunlight at the earth's surface. The problem is aggravated by a model of development based on the intensive use of fossil fuels, which is at the heart of the worldwide energy system. Another determining factor has been an increase in changed uses of the soil, principally deforestation for agricultural purposes.

24. Warming has effects on the carbon cycle. It creates a vicious circle which aggravates the situation even more, affecting the availability of essential resources like drinking water, energy and agricultural production in warmer regions, and leading to the extinction of part of the planet's biodiversity. The melting in the polar ice caps and in high altitude plains can lead to the dangerous release of methane gas, while the decomposition of frozen organic material can further increase the emission of carbon dioxide. Things are made worse by the loss of tropical forests which would otherwise help to mitigate climate change. Carbon dioxide pollution increases the acidification of the oceans and compromises the marine food chain. If present trends continue, this century may well witness extraordinary climate change and an unprecedented destruction of ecosystems, with serious consequences for all of us. A rise in the sea level, for example, can create extremely serious situations, if we consider that a quarter of the world's population lives on the coast or nearby, and that the majority of our megacities are situated in coastal areas.

25. Climate change is a global problem with grave implications: environmental, social, economic, political and for the distribution of goods. It represents one of the principal challenges facing humanity in our day. Its worst impact will probably be felt by developing countries in coming decades. Many of the poor live in areas particularly affected by phenomena related to warming, and their means of subsistence are largely dependent on natural reserves and ecosystemic services such as agriculture, fishing and forestry. They have no other financial activities or resources which can enable them to adapt to climate change or to



Figure 12.9: Greta Thunberg had the privilege of meeting Pope Francis. Both are outstanding voices for climate action.

face natural disasters, and their access to social services and protection is very limited. For example, changes in climate, to which animals and plants cannot adapt, lead them to migrate; this in turn affects the livelihood of the poor, who are then forced to leave their homes, with great uncertainty for their future and that of their children. There has been a tragic rise in the number of migrants seeking to flee from the growing poverty caused by environmental degradation. They are not recognized by international conventions as refugees; they bear the loss of the lives they have left behind, without enjoying any legal protection whatsoever. Sadly, there is widespread indifference to such suffering, which is even now taking place throughout our world. Our lack of response to these tragedies involving our brothers and sisters points to the loss of that sense of responsibility for our fellow men and women upon which all civil society is founded.

At a London event arranged by The Guardian, Greta Thunberg was asked whether she believed that a general strike could alert politicians to the urgency of the climate emergency. She replied “yes”. Here are some of her other comments:



Figure 12.10: Of the fossil fuels, all are bad, but coal is the worst.



Figure 12.11: Speaking to a crowd of many thousands at Marble Arch, London, on April 21, 2019, Greta Thunberg said: “For way too long the politicians and the people in power have gotten away with not doing anything ... But we will make sure that they will not get away with it any longer, We will never stop fighting, we will never stop fighting for this planet, for ourselves, our futures and for the futures of our children and grandchildren.”

This is not just young people being sick of politicians. It's an existential crisis. It is something that will affect the future of our civilization. It's not just a movement. It's a crisis and we must take action accordingly.

At a later meeting with members of the U.K. Parliament, Greta Thunberg said:

The U.K.'s active current support of new exploitation of fossil fuels, like for example the U.K. shale gas fracking industry, the expansion of its North Sea oil and gas fields, the expansion of airports, as well as the planning permission for a brand new coalmine, is beyond absurd.

This ongoing irresponsible behavior will no doubt be remembered in history as one of the greatest failures of humankind. .

Leonardo DiCaprio

Leonardo DiCaprio has won many awards for his work as an actor, writer and producer in both television and films. These include 50 awards from 167 nominations. DiCaprio has been nominated for six Academy Awards, four British Academy Film Awards and nine Screen Actors Guild Awards, winning one award each from them and three Golden Globe Awards from eleven nominations.

In accepting his Best Actor award at the 2016 Oscars ceremony, DiCaprio said: "Climate change is real, it is happening right now. It is the most urgent threat facing our entire species, and we need to work collectively together and stop procrastinating. We need to support leaders around the world who do not speak for the big polluters, but who speak for all of humanity, for the indigenous people of the world, for the billions and billions of underprivileged people out there who would be most affected by this. For our children's children, and for those people out there whose voices have been drowned out by the politics of greed."

Leonardo DiCaprio has used his great success as an actor in the service of environmental causes. In 1997, following the box office success of *Titanic*, he set up the Leonardo DiCaprio Foundation, which is devoted to environmental causes. He chaired the national Earth Day celebrations in 2000 during which he interviewed US President Bill Clinton, with whom he discussed the actions needed to avoid catastrophic climate change. In 2007 he had a major role in *The 11th Hour*, a documentary about people's relationship to nature and global warming. He also co-produced and co-wrote the film.

DiCaprio's most influential film on climate change is *Before the Flood*¹⁰. This film, released in 2016, is a 1 hour and 36 minute documentary in which Leonardo DiCaprio travels to many countries to let viewers observe the already visible effects of global warming. He also talks with many of the world's leaders, including Pope Francis I, US Presidents Bill Clinton and Barack Obama, and UN Secretary General Ban Ki-moon.

¹⁰<http://www.get.filmovie.us/play.php?movie=tt5929776t>



Figure 12.12: Leonardo DiCaprio at a press conference in 2000 (Wikipedia).



Figure 12.13: **Thom Hartmann** speaks to the 2010 Chicago Green Festival (Wikipedia).

Thom Hartmann

Thom Hartmann was born in 1951 in Lansing Michigan. He worked as a disk jockey during his teens, and, after a highly successful business career, he sold his businesses and devoted his energies to writing, humanitarian projects and public education. His influential book, *Last Hours of Ancient Sunlight* was published by Three Rivers Press in 1997 and republished in a revised edition in 2004. In 2013, Hartmann published another extremely important book on the same theme: *The Last Hours of Humanity: Warming the World To Extinction*¹¹.

Hartmann has hosted a nationally syndicated radio show, The Thom Hartmann Program, since 2003 and a nightly television show, The Big Picture, since 2008.

Concerning Hartmann's radio show, Wikipedia states that "As of March 2016, the show was carried on 80 terrestrial radio stations in 37 states as well as on Sirius and XM satellite radio. A community radio station in Africa, Radio Builsa in Ghana, also broadcasts the show. Various local cable TV networks simulcast the program. In addition to Westwood One, the show is now also offered via Pacifica Audiopoint to non-profit stations in a non-profit compliant format and is simulcast on Dish Network channel 9415 and DirecTV channel 348 via Free Speech TV. The program is carried on Radio Sputnik in London, England."

"Sen. Bernie Sanders (I-VT) appears every Friday during the first hour of the show titled 'Brunch with Bernie'. Ellen Ratner of the Talk Radio News Service provides Washington commentary daily. Victoria Jones who is the White House correspondent for Talk

¹¹<https://www.amazon.com/Last-Hours-Humanity-Warming-Extinction/dp/1629213640>

Radio News Service appears occasionally as does Dr. Ravi Batra an economics professor at SMU.”

Together with Leonardo DiCaprio, Thom Hartman recently produced and narrated an extremely important short film entitled *Last Hours*¹². This film, draws a parallel between the Permian-Triassic mass extinction, and the danger of a human-induced 6th mass extinction. Various experts who appear in the film confirm that our release of CO₂ into the atmosphere is similar to the greenhouse gasses produced by volcanic eruptions prior to the Permian event. The methane hydrate feedback loop is also discussed. The film should be seen by everyone concerned with the future of human civilization and the biosphere. Concerned citizens should also urgently see Hartman and DiCaprio’s short films *Carbon*, *Green World Rising* and *Reforestation*, also available on YouTube .

James Hansen

James Hansen was born in 1941 in Denison, Iowa. He was educated in physics, mathematics and astronomy at the University of Iowa in the space sciences program initiated James Van Allen. He graduated with great distinction. The studies of the atmosphere and temperature of Venus which Hansen made under Van Allen’s supervision lead him to become extremely concerned about similar effects in the earth’s atmosphere.

From 1962 to 1966, James Hansen participated in the National Aeronautical and Space Administration graduate traineeship and, at the same time, between 1965 and 1966, he was a visiting student at the Institute of Astrophysics at the University of Kyoto and in the Department of Astronomy at the University of Tokyo. Hansen then began work at the Goddard Institute for Space Studies in 1967. He began to work for the Goddard Institute for Space Studies in 1967. Between 1981 and 2013, he was head of the Goddard Institute of Space Studies in New York, and since 2014, he has been the director of the Program on Climate Science, Awareness and Solutions at Columbia University’s Earth Institute.

Hansen continued his work with radiative transfer models, attempting to understand the Venusian atmosphere. Later he applied and refined these models to understand the Earth’s atmosphere, in particular, the effects that aerosols and trace gases have on Earth’s climate. Hansen’s development and use of global climate models has contributed to the further understanding of the Earth’s climate. In 2009 his first book, *Storms of My Grandchildren*, was published.

James Hansen has refined climate change models, focusing on the balance between aerosols and greenhouse gases. He believes that there is a danger that climate change will become much more rapid if the balance shifts towards the greenhouse gases.

Hansen’s Congressional testimony leads to broad public awareness of the dangers

In 1988, Prof. Hansen was asked to testify before the US Congress on the danger of uncontrolled climate change. The testimony marked the start of broad public awareness

¹²<https://www.youtube.com/watch?v=2bRrg96UtMc>



Figure 12.14: **Prof. James Hansen**

of the seriousness of the danger, and it was reported in a front page article by the New York Times. However, Hansen believes that governmental energy policies still favor fossil fuels. Therefore he has participated in public demonstrations and he was even arrested in 2011 together with more than a thousand other activists for protesting outside the White House.

James Hansen's TED talk and book

In 2012 he presented a TED Talk: *Why I Must Speak Out About Climate Change*. This talk is easily available on the Internet, and it should be required viewing for everyone who is concerned with the earth's future.

Hansen's book, *Storms of My Grandchildren: The Truth About The Coming Climate Catastrophe, and Our Last Chance To Save Humanity* was published in New York by Bloomsbury Publishing in 2009.

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Chapter 13

POPULATION STABILIZATION TO AVOID FAMINE

13.1 Population stabilization today

The phrase “developing countries” is more than a euphemism; it expresses the hope that with the help of a transfer of technology from the industrialized nations, all parts of the world can achieve prosperity. One of the factors factor that prevents the achievement of worldwide prosperity is population growth.

In the words of Dr. Halfdan Mahler, former Director General of the World Health Organization, “Country after country has seen painfully achieved increases in total output, food production, health and educational facilities and employment opportunities reduced or nullified by excessive population growth.”

The growth of population is linked to excessive urbanization, infrastructure failures and unemployment. In rural districts in the developing countries, family farms are often divided among a growing number of heirs until they can no longer be subdivided. Those family members who are no longer needed on the land have no alternative except migration to overcrowded cities, where the infrastructure is unable to cope so many new arrivals. Often the new migrants are forced to live in excrement-filled makeshift slums, where dysentery, hepatitis and typhoid are endemic, and where the conditions for human life sink to the lowest imaginable level. In Brazil, such shanty towns are called “favelas”.

If modern farming methods are introduced in rural areas while population growth continues, the exodus to cities is aggravated, since modern techniques are less labor-intensive and favor large farms. In cities, the development of adequate infrastructure requires time, and it becomes a hopeless task if populations are growing rapidly. Thus, population stabilization is a necessary first step for development.

It can be observed that birth rates fall as countries develop. However, development is sometimes blocked by the same high birth rates that economic progress might have prevented. In this situation (known as the “demographic trap”), economic gains disappear immediately because of the demands of an exploding population.

For countries caught in the demographic trap, government birth control programs are especially important, because one cannot rely on improved social conditions to slow birth rates. Since health and lowered birth rates should be linked, it is appropriate that family-planning should be an important part of programs for public health and economic development.

A recent study conducted by Robert F. Lapham of Demographic Health Surveys and W. Parker Maudlin of the Rockefeller Foundation has shown that the use of birth control is correlated both with socio-economic setting and with the existence of strong family-planning programs. The implication of this study is that even in the absence of increased living standards, family-planning programs can be successful, provided they have strong government support.

China, the world's most populous nation, has adopted the somewhat draconian policy of allowing only one child for families in living in towns and cities (35.9% of the population). Chinese leaders obtained popular support for their one-child policy by means of an educational program which emphasized future projections of diminishing water resources and diminishing cropland per person if population increased unchecked. Like other developing countries, China has a very young population, which will continue to grow even when fertility has fallen below the replacement level because so many of its members are contributing to the birth rate rather than to the death rate. China's present population is 1.4 billion. Its projected population for the year 2025 is 1.6 billion. China's one-child policy is supported by 75% of the country's people, but the methods of enforcement are sometimes criticized, and it has led to a M/F sex ratio of 1.17/1.00. The natural baseline for the sex ratio ranges between 1.03/1.00 and 1.07/1.00.

Education of women and higher status for women are vitally important measures, not only for their own sake, but also because in many countries these social reforms have proved to be the key to lower birth rates. Religious leaders who oppose programs for the education of women and for family planning on "ethical" grounds should think carefully about the scope and consequences of the catastrophic global famine which will undoubtedly occur within the next 50 years if population is allowed to increase unchecked. Do these leaders really wish to be responsible for the suffering and death from starvation of hundreds of millions of people?

At the United Nations Conference on Population and Development, held in Cairo in September, 1994, a theme which emerged very clearly was that one of the most important keys to controlling the global population explosion is giving women better education and equal rights. These goals are desirable for the sake of increased human happiness, and for the sake of the uniquely life-oriented point of view which women can give us; but in addition, education and improved status for women have shown themselves to be closely connected with lowered birth rates. When women lack education and independent careers outside the home, they can be forced into the role of baby-producing machines by men who do not share in the drudgery of cooking, washing and cleaning; but when women have educational, legal, economic, social and political equality with men, experience has shown that they choose to limit their families to a moderate size.

Sir Partha Dasgupta of Cambridge University has pointed out that the changes needed

to break the cycle of overpopulation and poverty are all desirable in themselves. Besides education and higher status for women, they include state-provided social security for old people, provision of water supplies near to dwellings, provision of health services to all, abolition of child labor and general economic development.

13.2 Information-driven population growth

Today we are able to estimate the population of the world at various periods in history, and we can also make estimates of global population in prehistoric times. Looking at the data, we can see that the global population of humans has not followed an exponential curve as a function of time, but has instead followed a hyperbolic trajectory. At the time of Christ, the population of the world is believed to have been approximately 220 million. By 1500, the earth contained 450 million people, and by 1750, the global population exceeded 700 million. As the industrial and scientific revolution has accelerated, global population has responded by increasing at a break-neck speed: In 1930, the population of the world reached two billion; in 1958 three billion; in 1974 four billion; in 1988 five billion, and in 1999, six billion. Today, roughly a billion people are being added to the world's population every fifteen years.

As the physicist Murry Gell-Mann has pointed out, a simple mathematical curve which closely approximates the global population of humans over a period of several thousand years is a hyperbola of the form

$$P = \frac{190,000,000,000}{2025 - t}$$

Here P is the population and t is the year. How are we to explain the fact that the population curve is not an exponential? We can turn to Malthus for an answer: According to his model, population does not increase exponentially, except under special circumstances, when the food supply is so ample that the increase of population is entirely unchecked. Malthus gives us a model of culturally-driven population growth. He tells us that population increase tends to press against the limits of the food supply, and since these limits are culturally determined, population density is also culturally-determined. Hunter-gatherer societies need large tracts of land for their support; and in such societies, the population density is necessarily low. Pastoral methods of food production can support populations of a higher density. Finally, extremely high densities of population can be supported by modern agriculture. Thus, the hyperbolic curve, $P=C/(2025-t)$, where C is a constant, should be seen as describing the rapidly-accelerating growth of human culture, this being understood to include methods of food production.

If we look at the curve, $P=C/(2025-t)$, it is obvious that human culture has reached a period of crisis. The curve predicts that the world's population will rise to infinity in the year 2025, which of course is impossible. Somehow the actual trajectory of global population as a function of time must deviate from the hyperbolic curve, and in fact, the trajectory has already begun to fall away from the hyperbola. Because of the great amount

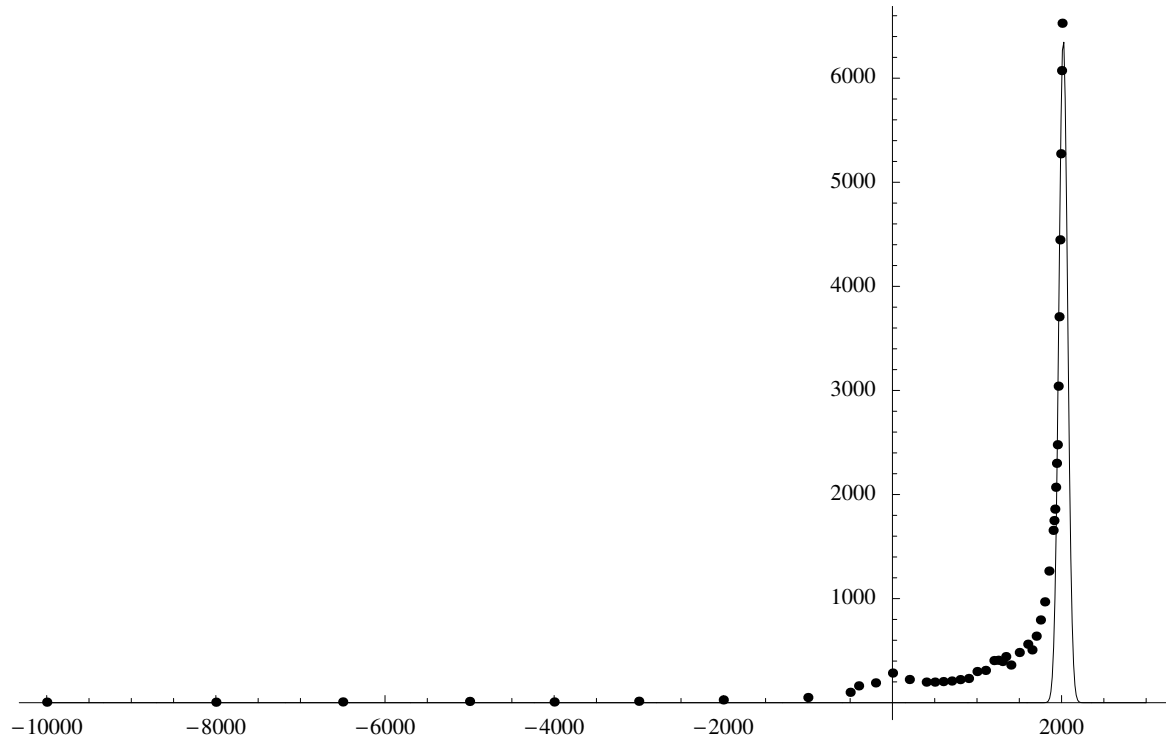


Figure 13.1: Population growth and fossil fuel use, seen on a time-scale of several thousand years. The dots are population estimates in millions from the US Census Bureau. Fossil fuel use appears as a spike-like curve, rising from almost nothing to a high value, and then falling again to almost nothing in the space of a few centuries. When the two curves are plotted together, the explosive rise of global population is seen to be simultaneous with, and perhaps partially driven by, the rise of fossil fuel use. This raises the question of whether the world's population is headed for a crash when the fossil fuel era has ended. (Author's own graph)

of human suffering which may be involved, and the potentially catastrophic damage to the earth's environment, the question of how the actual trajectory of human population will come to deviate from the hyperbola is a matter of enormous importance. Will population overshoot the sustainable limit, and crash? Or will it gradually approach a maximum? In the case of the second alternative, will the checks which slow population growth be later marriage and family planning? Or will the grim Malthusian forces - famine, disease and war - act to hold the number of humans within the carrying capacity of their environment?

We can anticipate that as the earth's human population approaches 10 billion, severe famines will occur in many developing countries. The beginnings of this tragedy can already be seen. It is estimated that roughly 30,000 children now die every day from starvation, or from a combination of disease and malnutrition.

An analysis of the global ratio of population to cropland shows that we have probably already exceeded the sustainable limit of population through our dependence on petroleum: Between 1950 and 1982, the use of cheap synthetic fertilizers increased by a factor of 8. Much of our present agricultural output depends on their use, but their production is expensive in terms of energy. Furthermore, petroleum-derived synthetic fibers have reduced the amount of cropland needed for growing natural fibers, and petroleum-driven tractors have replaced draft animals which required cropland for pasturage.

Also, petroleum fuels have replaced fuelwood and other fuels derived for biomass. The reverse transition, from fossil fuels back to renewable energy sources, will require a considerable diversion of land from food production to energy production. For example, 1.1 hectares are needed to grow the sugarcane required for each alcohol-driven Brazilian automobile. This figure may be compared with the steadily falling average area of cropland available to each person in the world: .24 hectares in 1950, .16 hectares in 1982.

As population increases, the cropland per person will continue to fall, and we will be forced to make still heavier use of fertilizers to increase output per hectare. Also marginal land will be used in agriculture, with the probable result that much land will be degraded through erosion and salination. Climate change will reduce agricultural output. The Hubbert peaks for oil and natural gas will occur within one or two decades, and the fossil fuel era will be over by the end of 21st century. Thus there is a danger that just as global population reaches the unprecedented level of 10 billion or more, the agricultural base for supporting it may suddenly collapse. Ecological catastrophe, possibly compounded by war and other disorders, could produce famine and death on a scale unprecedented in history - a disaster of unimaginable proportions, involving billions rather than millions of people.

The resources of the earth and the techniques of modern science can support a global population of moderate size in comfort and security; but the optimum size is undoubtedly smaller than the world's present population (see Chapter 4). Given a sufficiently small global population, renewable sources of energy can be found to replace disappearing fossil fuels. Technology may also be able to find renewable substitutes for many disappearing mineral resources for a global population of a moderate size. What technology cannot do, however, is to give a global population of 10 billion people the standard of living which the industrialized countries enjoy today.

What would Malthus tell us if he were alive today? Certainly he would say that we have



Figure 13.2: **The number of hectares of cropland available per person as a function of time.**

reached a period of human history where it is vital to stabilize the world's population if catastrophic environmental degradation and famine are to be avoided. He would applaud efforts to reduce suffering by eliminating poverty, widespread disease, and war; but he would point out that, since it is necessary to stop the rapid increase of human numbers, it follows that whenever the positive checks to population growth are removed, it is absolutely necessary to replace them by preventive checks. Malthus' point of view became more broad in the successive editions of his *Essay*, and if he were alive today, he would probably agree that family planning is the most humane of the preventive checks.

In Malthus' *Essay on the Principle of Population*, population pressure appears as one of the main causes of war; and Malthus also discusses many societies in which war is one of the the principle means by which population is reduced to the level of the food supply. Thus, his *Essay* contains another important message for our own times: If he were alive today, Malthus would also say that there is a close link between the two most urgent tasks which history has given to the 21st century - stabilization of the global population, and abolition of the institution of war.

In most of the societies which Malthus described, a clear causal link can be seen, not only between population pressure and poverty, but also between population pressure and war. As one reads his *Essay*, it becomes clear why both these terrible sources of human anguish saturate so much of history, and why efforts to eradicate them have so often met with failure: The only possible way to eliminate poverty and war is to reduce the pressure of population by preventive checks, since the increased food supply produced by occasional cultural advances can give only very temporary relief. Today, the links between population pressure, poverty, and war are even more pronounced than they were in the past, because the growth of human population has brought us to the absolute limits imposed by ecological constraints.

13.3 Biology and economics

Classical economists like Smith and Ricardo pictured the world as largely empty of human activities. According to the “empty-world” picture of economics, the limiting factors in the production of food and goods are shortages of capital and labor. The land, forests, fossil fuels, minerals, oceans filled with fish, and other natural resources upon which human labor and capital operate, are assumed to be present in such large quantities that they are not limiting factors. In this picture, there is no naturally-determined upper limit to the total size of the human economy. It can continue to grow as long as new capital is accumulated, as long as new labor is provided by population growth, and as long as new technology replaces labor by automation.

Biology, on the other hand, presents us with a very different picture. Biologists remind us that if any species, including our own, makes demands on its environment which exceed the environment’s carrying capacity, the result is a catastrophic collapse both of the environment and of the population which it supports. Only demands which are within the carrying capacity are sustainable. For example, there is a limit to regenerative powers of a forest. It is possible to continue to cut trees in excess of this limit, but only at the cost of a loss of forest size, and ultimately the collapse and degradation of the forest. Similarly, cattle populations may for some time exceed the carrying capacity of grasslands, but the ultimate penalty for overgrazing will be degradation or desertification of the land. Thus, in biology, the concept of the carrying capacity of an environment is extremely important; but in economic theory this concept has not yet been given the weight that it deserves.

The terminology of economics can be applied to natural resources: For example, a forest can be thought of as natural capital, and the sustainable yield from the forest as interest. Exceeding the biological carrying capacity then corresponds, in economic terms, to spending one’s capital.

If it is to be prevented from producing unacceptable contrasts of affluence and misery within a society, the free market advocated by Adam Smith needs the additional restraints of ethical principles, as well as a certain amount of governmental regulation. Furthermore, in the absence of these restraints, it will destroy the natural environment of our planet.

There is much evidence to indicate that the total size of the human economy is rapidly approaching the absolute limits imposed by the carrying capacity of the global environment. For example, a recent study by Vitousek et. al. showed that 40 percent of the net primary product of landbased photosynthesis is appropriated, directly or indirectly, for human use. (The net primary product of photosynthesis is defined as the total quantity of solar energy converted into chemical energy by plants, minus the energy used by the plants themselves). Thus we are only a single doubling time away from 80 percent appropriation, which would imply a disastrous environmental degradation.

Another indication of our rapid approach to the absolute limits of environmental carrying capacity can be found in the present rate of loss of biodiversity. Biologists estimate that between 10,000 and 50,000 species are being driven into extinction each year as the earth’s rainforests are destroyed.

The burning of fossil fuels and the burning of tropical rain forests have released so much

carbon dioxide that the atmospheric concentration of this greenhouse gas has increased from a preindustrial value of 260 ppm to its present value: 380 ppm. Most scientists agree that unless steps are taken to halt the burning of rain forests and to reduce the use of fossil fuels, the earth's temperature will steadily rise during the coming centuries. This gradual long-term climate change will threaten future agricultural output by changing patterns of rainfall. Furthermore, the total melting of the Arctic and Antarctic icecaps, combined with the thermal expansion of the oceans, threatens to produce a sea level rise of up to 12 meters. Although these are slow, long-term effects, we owe it to future generations to take steps now to halt global warming.

The switch from fossil fuels to renewable energy sources is vital not only because of the need to reduce global warming, but also because the earth's supply of fossil fuels is limited. A peak in the production and consumption of conventional petroleum is predicted within one or two decades. Such a peak in the use of any non-renewable natural resource is called a "Hubbert peak" after the oil expert Dr. M. King Hubbert. It occurs when reserves of the resource are approximately half exhausted. After that point, the resource does not disappear entirely, but its price increases steadily because supply fails to meet demand, and because of rising extraction costs. It is predicted that the Hubbert peak for both oil and natural gas will also occur within a few decades. The peak for oil may occur within the present decade. Thus, halfway through the 21st Century, oil and natural gas will become very expensive - perhaps so expensive that they will not be burned but will instead be reserved as starting points for chemical synthesis.

The reserves of coal are much larger, and at the present rate of use they would last for slightly more than two centuries. However, it seems likely that as petroleum is exhausted, coal will be converted into liquid fuels, as was done in Germany during World War II, and in South Africa during the oil embargo. Thus, in predicting a date for the end of the fossil fuel era, we ought to lump oil, natural gas and coal together. If we do so, we find the total supply has an energy content of 1260 terawatt-years. (1 terawatt is equal to 1,000,000,000,000 Watts). One finds in this way that if they are used at the present rate of 13 terawatts, fossil fuels will last about 100 years.

Resolute government intervention is needed to promote energy conservation measures and to bring about the switch from fossil fuels to renewable energy sources, such as biomass, photovoltaics, solar thermal power, wind and wave power, and hydropower. Both subsidies for renewable energy technologies, to help them get started, and taxes on fossil fuels will be needed. Changes in tax structure could also encourage smaller families, encourage resource conservation, or diminish pollution. In general, taxation should be used, not merely to raise money, but, more importantly, to guide the evolution of society towards humane and sustainable goals.

13.4 Loss of biodiversity

Agricultural monocultures

In modern agriculture it has become common to plant large regions with a single crop variety. For example, it is common to plant large regions with a single high-yield wheat variety. Monocultures of this kind offer farmers advantages of efficiency in the timing of planting and harvesting. With regard to pest and disease control, there may be short-term advantages, but these have to be weighed against the threat of long-term disasters. In the great Irish Potato Famine of 1845-1849, the potato monoculture which had sustained Ireland's growing population was suddenly devastated by *Phytophthora infestans*, commonly called "potato blight". The result was a catastrophic famine that resulted in the death or emigration of much of Ireland's population.

In general, monocultures are vulnerable to plant disease. Thus the replacement of traditional varieties with the high-yield crops developed by the "Green Revolution" carries serious risks. Adjustment to climate change also requires genetic diversity. In general, a genetically diverse population is far better to adjust to environmental changes than a genetically homogeneous population. This being so, it is vital to preserve civilization's heritage of genetically diverse crops.

Deforestation and loss of biodiversity

The earth's tropical rain forests are rapidly being destroyed for the sake of new agricultural land. Tropical rain forests are thought to be the habitat of more than half of the world's species of plants, animals and insects; and their destruction is accompanied by an alarming rate of extinction of species. The Harvard biologist, E.O. Wilson, estimates that the rate of extinction resulting from deforestation in the tropics may now exceed 4,000 species per year - 10,000 times the natural background rate (*Scientific American*, September, 1989).

The enormous biological diversity of tropical rain forests has resulted from their stability. Unlike northern forests, which have been affected by glacial epochs, tropical forests have existed undisturbed for millions of years. As a result, complex and fragile ecological systems have had a chance to develop. Professor Wilson expresses this in the following words:

"Fragile superstructures of species build up when the environment remains stable enough to support their evolution during long periods of time. Biologists now know that biotas, like houses of cards, can be brought tumbling down by relatively small perturbations in the physical environment. They are not robust at all."

The number of species which we have until now domesticated or used in medicine is very small compared with the number of potentially useful species still waiting in the world's tropical rain forests. When we destroy them, we damage our future. But we ought to regard the annual loss of thousands of species as a tragedy, not only because biological diversity is potential wealth for human society, but also because every form of life deserves our respect and protection.

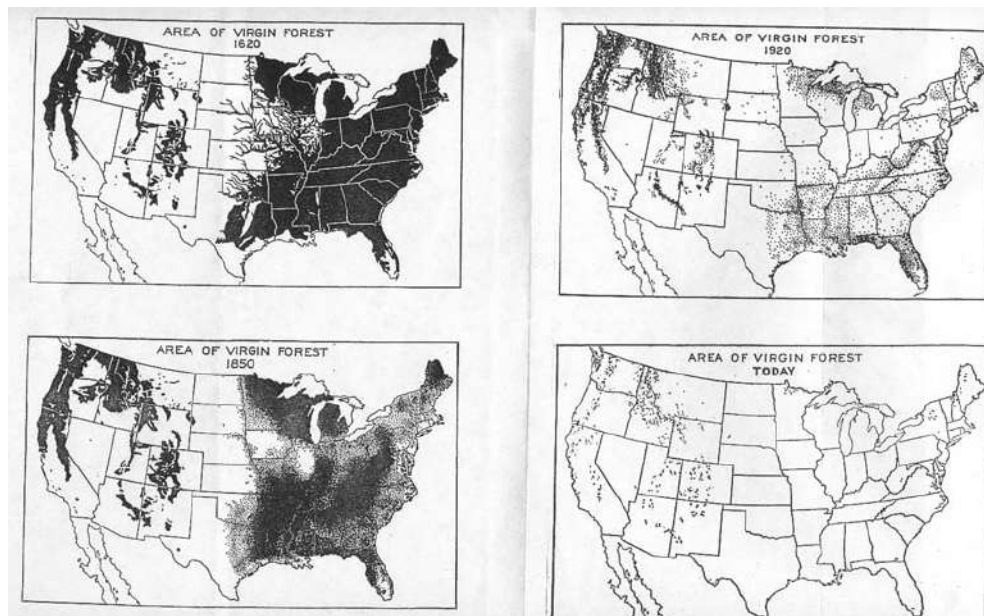


Figure 13.3: Deforestation in the United States between 1620 and the present.



Figure 13.4: Jungle burned for agriculture in southern Mexico.

13.5 Economics without growth

According to Adam Smith, the free market is the dynamo of economic growth. The true entrepreneur does not indulge in luxuries for himself and his family, but reinvests his profits, with the result that his business or factory grows larger, producing still more profits, which he again reinvests, and so on. This is indeed the formula for exponential economic growth.

Economists (with a few notable exceptions such as Aurelio Pecci and Herman Daly) have long behaved as though growth were synonymous with economic health. If the gross national product of a country increases steadily by 4% per year, most economists express approval and say that the economy is healthy. If the economy could be made to grow still faster (they maintain), it would be still more healthy. If the growth rate should fall, economic illness would be diagnosed. However, the basic idea of Malthus is applicable to exponential increase of any kind. It is obvious that on a finite Earth, neither population growth nor resource-using and pollution-generating economic growth can continue indefinitely.

A “healthy” economic growth rate of 4% per year corresponds to an increase by a factor of 50 in a century. (The reader is invited to calculate the factor of increase in five centuries. The answer is $50^5 = 312,500,000$.) No one can maintain that this type of growth is sustainable except by refusing to look more than a short distance into the future. Sooner or later (perhaps surprisingly soon) an entirely new form of economics will be needed - not the empty-world economics of Adam Smith, but what might be called “full-world economics”, or “steady-state economics”.

Economic activity is usually divided into two categories, 1) production of goods and 2) provision of services. It is the rate of production of goods that will be limited by the carrying capacity of the global environment. Services that have no environmental impact will not be constrained in this way. Thus a smooth transition to a sustainable economy will involve a shift of a large fraction the work force from the production of goods to the provision of services.

In his recent popular book *The Rise of the Creative Class*, the economist Richard Florida points out that in a number of prosperous cities - for example Stockholm - a large fraction of the population is already engaged in what might be called creative work - a type of work that uses few resources, and produces few waste products - work which develops knowledge and culture rather than producing material goods. For example, producing computer software requires few resources and results in few waste products. Thus it is an activity with a very small ecological footprint. Similarly, education, research, music, literature and art are all activities that do not weigh heavily on the carrying capacity of the global environment. Furthermore, cultural activities lead in a natural way to global cooperation and internationalism. Florida sees this as a pattern for the future, and maintains that everyone is capable of creativity. He visualizes the transition to a sustainable future economy as one in which a large fraction of the work force moves from industrial jobs to information-related work. Meanwhile, as Florida acknowledges, industrial workers feel uneasy and threatened by such trends.

The present use of resources by the industrialized countries is extremely wasteful. A

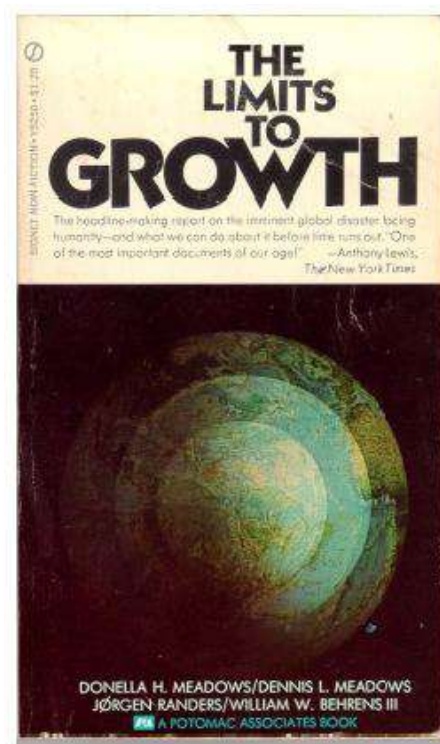


Figure 13.5: In 1968 Aurelio Pecci, Thorkil Kristensen and others founded the Club of Rome, an organization of economists and scientists devoted to studying the predicament of human society. One of the first acts of the organization was to commission an MIT study of future trends using computer models. The result was a book entitled “Limits to Growth”, published in 1972. From the outset the book was controversial, but it became a best-seller. It was translated into many languages and sold 30 million copies. The book made use of an exponential index for resources, i.e. the number of years that a resource would last if used at an exponentially increasing rate. Today the more accurate Hubbert Peak model is used instead to predict rate of use of a scarce resource as a function of time. Although the specific predictions of resource availability in “Limits to Growth” lacked accuracy, its basic thesis - that unlimited economic growth on a finite planet is impossible - was indisputably correct. Nevertheless the book was greeted with anger and disbelief by the community of economists, and these emotions still surface when it is mentioned. Perhaps part of this collective blindness was and is due to the polarization of opinion produced by the Cold War. In any case, the myth of unlimited growth has remained the central dogma of western economics.

growing national economy must, at some point, exceed the real needs of the citizens. It has been the habit of the developed countries to create artificial needs by means of advertising, in order to allow economies to grow beyond the point where all real needs have been met; but this extra growth is wasteful, and in the future it will be important not to waste the earth's diminishing supply of non-renewable resources.

Thus, the times in which we live present a challenge: We need a revolution in economic thought. We must develop a new form of economics, taking into account the realities of the world's present situation - an economics based on real needs and on a sustainable equilibrium with the environment, not on the thoughtless assumption that growth can continue forever.

Adam Smith was perfectly correct in saying that the free market is the dynamo of economic growth; but rapid growth of human population and economic activity have brought us, in a surprisingly short time, from the empty-world situation in which he lived to a full-world situation. In today's world, we are pressing against the absolute limits of the earth's carrying capacity, and further growth carries with it the danger of future collapse. Full-world economics, the economics of the future, will no longer be able to rely on growth to give profits to stockbrokers or to solve problems of unemployment or to alleviate poverty. In the long run, growth of any kind is not sustainable (except perhaps growth of culture and knowledge); and we are now nearing the environmentally-imposed limits.

Transition to a sustainable economy

Like a speeding bus headed for a brick wall, the earth's rapidly-growing population of humans and its rapidly-growing resource-using and pollution-generating economic activity are headed for a collision with a very solid barrier - the carrying capacity of the global environment. As in the case of the bus and the wall, the correct response to the situation is to apply the brakes in time - but fear prevents us from doing this. What will happen if we slow down very suddenly? Will not many of the passengers be injured? Undoubtedly. But what will happen if we hit the wall at full speed? Perhaps it would be wise, after all, to apply the brakes!

The memory of the great depression of 1929 makes us fear the consequences of an economic slowdown, especially since unemployment is already a serious problem in many parts of the world. Although the history of the 1929 depression is frightening, it may nevertheless be useful to look at the measures which were used then to bring the global economy back to its feet. A similar level of governmental responsibility may help us to avoid some of the more painful consequences of the necessary transition from the economics of growth to steady-state economics.

In the United States, President Franklin D. Roosevelt was faced with the difficult problems of the depression during his first few years in office. Roosevelt introduced a number of special governmental programs, such as the WPA, the Civilian Construction Corps and the Tennessee Valley Authority, which were designed to create new jobs on projects directed towards socially useful goals - building highways, airfields, auditoriums, harbors, housing projects, schools and dams. The English economist John Maynard Keynes, (1883-1946),

provided an analysis of the factors that had caused the 1929 depression, and a theoretical justification of Roosevelt's policies.

The transition to a sustainable global society will require a similar level of governmental responsibility, although the measures needed are not the same as those which Roosevelt used to end the great depression. Despite the burst of faith in the free market which has followed the end of the Cold War, it seems unlikely that market mechanisms alone will be sufficient to solve problems of unemployment in the long-range future, or to achieve conservation of land, natural resources and environment.

The Worldwatch Institute, Washington D.C., lists the following steps as necessary for the transition to sustainability¹:

1. Stabilizing population
2. Shifting to renewable energy
3. Increasing energy efficiency
4. Recycling resources
5. Reforestation
6. Soil Conservation

All of these steps are labor-intensive; and thus, wholehearted governmental commitment to the transition to sustainability can help to solve the problem of unemployment.

In much the same spirit that Roosevelt (with Keynes' approval) used governmental powers to end the great depression, we must now urge our governments to use their powers to promote sustainability and to reduce the trauma of the transition to a steady-state economy. For example, an increase in the taxes on fossil fuels could make a number of renewable energy technologies economically competitive; and higher taxes on motor fuels would be especially useful in promoting the necessary transition from private automobiles to bicycles and public transportation. Tax changes could also be helpful in motivating smaller families.

The present economic recession offers us an opportunity to take steps towards the creation of a sustainable steady-state economic system. Government measures to avoid unemployment could at the same time shift the work force to jobs that promote sustainability, i.e., jobs in the areas listed by the Worldwatch Institute.

Governments already recognize their responsibility for education. In the future, they must also recognize their responsibility for helping young people to make a smooth transition from education to secure jobs. If jobs are scarce, work must be shared, in a spirit of solidarity, among those seeking employment; hours of work (and if necessary, living standards) must be reduced to insure a fair distribution of jobs. Market forces alone cannot achieve this. The powers of government are needed.

Population and goods per capita

In the distant future, the finite carrying capacity of the global environment will impose limits on the amount of resource-using and waste-generating economic activity that it will

¹L.R. Brown and P. Shaw, 1982.



Figure 13.6: Lester R. Brown, founder of the Worldwatch Institute, and for many years its President. He is now the leader of the Earth Policy Institute. His recent book, “Plan B”, gives important information about the ecological crisis now facing the world. It may be downloaded free of charge from the website of the Earth Policy Institute.

be possible for the world to sustain. The consumption of goods per capita will be equal to this limited total economic activity divided by the number of people alive at that time. Thus, our descendants will have to choose whether they want to be very numerous and very poor, or less numerous and more comfortable, or very few and very rich. Perhaps the middle way will prove to be the best.

Given the fact that environmental carrying capacity will limit the sustainable level of resource-using economic activity to a fixed amount, average wealth in the distant future will be approximately inversely proportional to population over a certain range of population values. Obviously, if the number of people is reduced to such an extent that it approaches zero, the average wealth will not approach infinity, since a certain level of population is needed to maintain a modern economy. However, if the global population becomes extremely large, the average wealth will indeed approach zero.

In the 1970's the equation $I = P \times A \times T$ was introduced in the course of a debate between Barry Commoner, Paul R. Ehrlich and John P. Holdren. Here I represents environmental impact, P is population, while A represents goods per capita, and T is an adjustable factor that depends on the technology used to produce the goods. The assertion of the previous paragraph can be expressed by solving for A and setting I equal to a constant: $A = I/(P \times T)$. In the distant future, the environmental impact I will not be allowed to increase, and therefore for a given value of T , A will be inversely proportional to P .

If the environmental impact I is broken up into several components, a few of them have historically fallen with increasing values of $A \times P$ because of diminishing T (thus exhibiting the *environmental Kuznets curve*). However, most components of I , such as energy, land and resource use, have historically increased with increasing $A \times P$.

13.6 China and India

Table 2.1 shows the population of China at the start of various dynasties. In 125 AD, at the start of the Eastern Han Dynasty, the population was 48,690,789. The precision of this figure is surprising, and it is perhaps the result of the strength of the central government of China even at that early date. As seen in Table 2.1 the population seems to have fallen again, probably to famine and war. Fear of these terrible Malthusian forces explains the Chinese preference for a strong central government. At the start of the Qing dynasty in the 17th century, the population of China began to increase rapidly, probably because of improved flood control and irrigation methods. By 1901, the population of China had reached 426,447,325.

Figure 2.19 shows the growth of Chinese population between 1960 and the present. China's population continues to increase, dispute the government's one-child policy, and today the country has approximately 1.4 billion people. China's rate of population growth is currently only 0.59%.

The post-1949 Chinese government leaders at first viewed population growth as an asset. However, worries about falling water tables and the future availability of fresh



Figure 13.7: The one-child policy: A Chinese mother and her only child at a market in Jiayuguan.

water for agriculture, as well as the realization that rapid population growth would block economic development soon produced a policy switch; and the Chinese government began to strongly support both birth control and late marriage.

Since 1979, the Chinese government has advocated a one-child policy for both rural and urban areas. However, this policy admits many exceptions and has been most effective in cities, where the government is able to exert its power by giving apartments only to families with a single child. In 2016, the one-child policy began to be phased out.

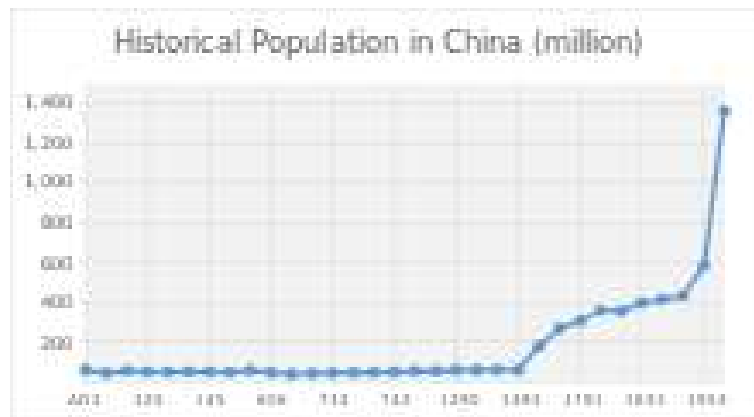


Figure 13.8: Historical estimates of China's population, in millions, from AD 2 until the present. After Ming and earlier period of Qing dynasty founded population moved around 100 million to 150 million until 1700s. In the period between 1749 and 1851, the population doubled in a century. During 1960-2015, the population doubled to nearly 1.4 billion .

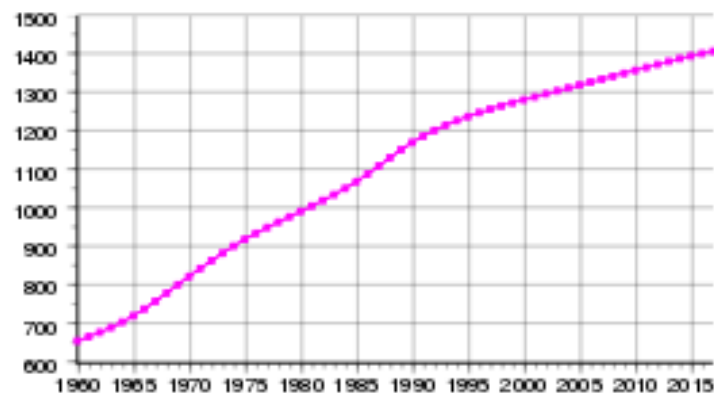


Figure 13.9: This graph shows the population growth of China, in billions, since 1900. Despite China's one-child policy, the country's population continues to grow because of exceptions to the policy and because so many young people are now reaching reproductive age.

Table 13.1: China's Dynastic Census Data

Dynasty	Date (AD)	Households	Population
Eastern Han	125	9,647,838	48,690,789
Western Jin	280	2,458,480	16,163,863
Tang	639	3,120,151	13,252,894
Song	1003	6,864,160	14,278,040
Ming	1398	10,699,399	58,323,933
Qing	1661	not recorded	58,323,933
Qing	1722	not recorded	103,053,992
Qing	1812	not recorded	333,700,560
Qing	1901	not recorded	426,447,325

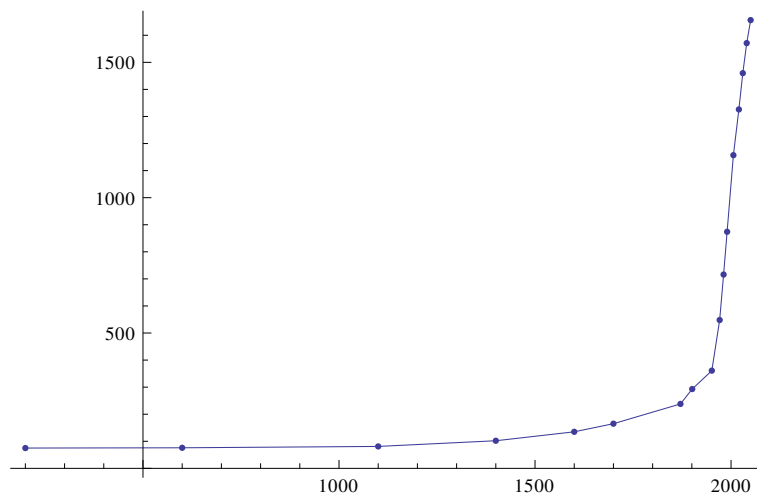


Figure 13.10: The historical and projected population of India as a function of time, from 200 AD to 2050, based on data from the Wikipedia article on *Demographics of India*. If the projections hold, there will be 1.4 billion people in India by 2050, making it the most populous country in the world. However, there is a danger that death rates may rise sharply because of famine and because of deaths due to rising temperatures.



Figure 13.11: This figure shows China's economic growth rate in recent years. The doubling time for a quantity growing at the rate of 6.8% per year is only 11 years. This high rate of economic growth, compounded by China's still-growing population, cannot continue without producing an ecological catastrophe, the beginnings of which can already be seen in China.

Table 13.2: **World Population in 2050 (in billions).** Global population reached 8 billion in 2022. Projections for 2050 may be unrealistically high because of rising death rates.

Region	2000	2050	growth
Asia	3.73	5.26	41%
Africa	0.82	2.53	209%
Europe	0.73	0.72	-2%
Latin America	0.53	0.78	48%
North America	0.31	0.43	39%
Oceania	0.03	0.06	84%
World	6.14	9.77	60%

13.7 Population projections in Africa

Wikipedia's article on *Projections of Population Growth* states that "By 2070, the bulk of the world's population growth will take place in Africa: of the additional 2.4 billion people projected between 2015 and 2050, 1.3 billion will be added in Africa, 0.9 billion in Asia and only 0.2 billion in the rest of the world. Africa's share of global population is projected to grow from 16% in 2015 to 25% in 2050 and 39% by 2100, while the share of Asia will fall from 60% in 2015 to 54% in 2050 and 44% in 2100. The strong growth of the African population will happen regardless of the rate of decrease of fertility, because of the exceptional proportion of young people already living today. For example, the UN projects that the population of Nigeria will surpass that of the United States by 2050."

"During 2005-2050, twelve countries are expected to account for half of the world's projected population increase: India, China, United States, Indonesia, Nigeria, Pakistan, Brazil, Democratic Republic of the Congo, Ethiopia, Philippines, Mexico and Egypt, listed according to the size of their contribution to population growth."

The predictions shown in Table 2.2, especially the prediction that the population of Africa will be 2.53 billion people, raise some worrying questions. It seems likely that because of climate change, failure of the West African monsoon, desertification, and sale of African agricultural land to rich countries such China and Saudi Arabia, the food available to the people of Africa will diminish rather than increasing. Can the population of Africa really increase by 209% by 2050? Or will this be prevented by the terrible Malthusian forces of famine, disease and war? In some parts of Africa famine is already present.

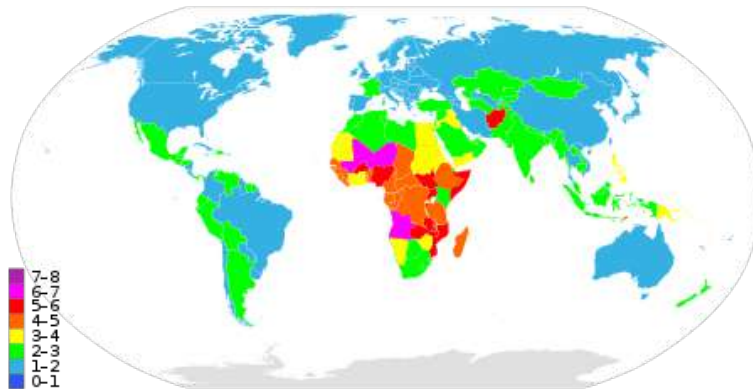


Figure 13.12: A map from the Wikipedia article showing global fertility rates in 2015. The highest fertility rates (purple, 7-8 children per woman-life) occur in Africa.

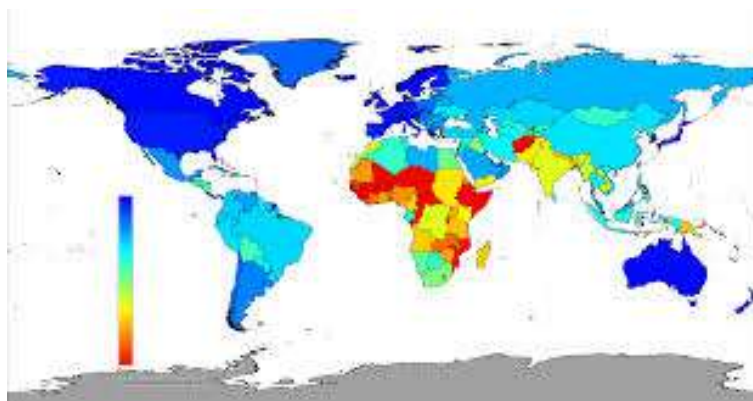


Figure 13.13: A map showing the human development index (HDI) in various parts of the world. The index is based on educational levels, life expectancy, and GDP per capita. It can be seen that regions of high fertility generally have low HDI values.

13.8 What is the future of megacities?

A transformation in cities is going on. Over 80% of the people on the planet today are living in cities. Over 100 new cities will be created within 25 years in China alone. Over 20 new Megacities will redefine the consumer marketplace and society. Most of these cities of over 8 million people each will be in the developing world. With the huge migration to cities of the global population, what challenges will these cities face? What are the opportunities and risks? How should global organizations prepare for the future of cities?

Transition Towns

The Transition Town Movement of today is a response to the end of the fossil fuel era and the threat of economic collapse. It can be thought of as a modern branch of the Cooperative Movement. In 2006, the Transition Town of Totnes in Devon, England was the first to use this name, which implied a transition from globalism, consumerism and growth to a sustainable, local and self-sufficient economy. The ideal was to produce locally all the necessary food for the town, and as much of other necessities as possible. In this way, the energy expenditures involved in transportation could be avoided.

Today there are more than a thousand Transition Towns and they are located in 43 countries. Many of them have local currencies which are legal tender within the town. If the pioneers of this movement are right in saying that this is the only sustainable model for the future, we may wonder whether mega-cities will be able to survive in the long-term future.²

²<https://en.wikipedia.org/wiki/Degrowth>
<http://commondreams.org/views/2015/07/31/we-are-all-greece>
<http://www.localfutures.org/>
<http://www.powells.com/biblio/7-9780871566430-2>

Table 13.3: The World's Largest Cities in 2016

Rank	Name	Country	Population
1	Tokyo	Japan	38,140,000
2	Shanghai	China	34,000,000
3	Jakarta	Indonesia	31,500,000
4	Delhi	India	27,200,000
5	Seoul	Korea	25,600,000
6	Guangzhou	China	25,000,000
7	Beijing	China	24,900,000
8	Manila	Philippines	24,100,000
9	Mumbai	India	23,900,000
10	New York City	United States	23,876,155
11	Shenzhen	China	23,300,000
12	Sao Paulo	Brazil	21,242,939



Figure 13.14: Totnes, Devon, England: a transition town.

13.9 The threat of a large-scale global famine

Unless efforts are made to stabilize and ultimately reduce global population, there is a serious threat that climate change, population growth, and the end of the fossil fuel era could combine to produce a large-scale famine by the middle of the 21st century.

As glaciers melt in the Himalayas and the Andes, depriving India, China and South America of summer water supplies; as sea levels rise, drowning fertile rice-growing regions of Southeast Asia; as droughts reduce the food production of North America and Southern Europe; as groundwater levels fall in China, India, the Middle East and the United States; and as high-yield modern agriculture becomes less possible because fossil fuel inputs are lacking, the 800 million people who are currently undernourished may not survive at all.

Energy inputs of agriculture

Modern agriculture has become highly dependent on fossil fuels, especially on petroleum and natural gas. This is especially true of production of the high-yield grain varieties introduced in the Green Revolution, since these require especially large inputs of fertilizers, pesticides and irrigation. Today, fertilizers are produced using oil and natural gas, while pesticides are synthesized from petroleum feedstocks, and irrigation is driven by fossil fuel energy. Thus agriculture in the developed countries has become a process where inputs of fossil fuel energy are converted into food calories.

Predictions of drought in the Stern Review

According to a report presented to the Oxford Institute of Economic Policy by Sir Nicholas Stern on 31 January, 2006, areas likely to lose up to 30% of their rainfall by the 2050's because of climate change include much of the United States, Brazil, the Mediterranean

region, Eastern Russia and Belarus, the Middle East, Southern Africa and Southern Australia. Meanwhile rainfall is predicted to increase up to 30% in Central Africa, Pakistan, India, Bangladesh, Siberia, and much of China.

Stern and his team point out that “We can... expect to see changes in the Indian monsoon, which could have a huge impact on the lives of hundreds of millions of people in India, Pakistan and Bangladesh. Most climate models suggest that the monsoon will change, although there is still uncertainty about exactly how. Nevertheless, small changes in the monsoon could have a huge impact. Today, a fluctuation of just 10% in either direction from average monsoon rainfall is known to cause either severe flooding or drought. A weak summer monsoon, for example, can lead to poor harvests and food shortages among the rural population - two-thirds of India’s almost 1.1 billion people. Heavier-than-usual monsoon downpours can also have devastating consequences...”

In some regions, melting of glaciers can be serious from the standpoint of dry-season water supplies. For example, melts from glaciers in the Hindu Kush and the Himalayas now supply much of Asia, including China and India, with a dry-season water supply. Complete melting of these glacial systems would cause an exaggerated runoff for a few decades, after which there would be a drying out of some of the most densely populated regions of the world.

Ocean current changes and failure of monsoons

It is expected that climate change will affect ocean currents, and hence also affect monsoon rainfall. We are already experiencing a diversion of the Gulf Stream due to southward currents of cold water from melting ice in the Arctic. This has caused what is known as the *North Atlantic Anomaly*. While most regions of the world are experiencing rising temperatures, the North Atlantic and several northern European countries are exceptions to this rule, and have cooled. Complete failure of the Gulf Stream would lead to much colder temperatures in Europe.

Changes in ocean currents have already lead to the failure of the West African Monsoon, and this has already produced severe food insecurity in West Africa.

In the future, climate-changed ocean currents may lead to failures of monsoons in South-east Asia, and thus damage the food supply of almost two billion people.

Falling water tables around the world

Under many desert areas of the world are deeply buried water tables formed during glacial periods when the climate of these regions was wetter. These regions include the Middle East and large parts of Africa. Water can be withdrawn from such ancient reservoirs by deep wells and pumping, but only for a limited amount of time.

In oil-rich Saudi Arabia, petroenergy is used to drill wells for ancient water and to bring it to the surface. Much of this water is used to irrigate wheat fields, and this is done to such an extent that Saudi Arabia exports wheat. The country is, in effect, exporting its ancient heritage of water, a policy that it may, in time, regret. A similarly short-sighted project

is Muammar Qaddafi's enormous pipeline, which will bring water from ancient sub-desert reservoirs to coastal cities.

In the United States, the great Ogallala aquifer is being overdrawn. This aquifer is an enormous stratum of water-saturated sand and gravel under-lying parts of northern Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming and South Dakota. The average thickness of the aquifer is about 70 meters. The rate of water withdrawal from the aquifer exceeds the rate of recharge by a factor of eight.

Thus we can see that in many regions, the earth's present population is living on its inheritance of water, rather than its income. This fact, coupled with rapidly increasing populations and climate change, may contribute to a very serious food crisis partway through the 21st century.

13.10 Reforming our food and agricultural systems

The medical journal *The Lancet* recently published a report which aimed at changing the diets of people throughout the world. The commission which produced the report brought together 37 experts in agriculture, environmental sustainability, human health, and political science from 16 countries. Over three years, they developed the "planetary health diet," which aims to address the global food system's devastating environmental impact as well as mass malnutrition.

"The food we eat and how we produce it determines the health of people and the planet, and we are currently getting this seriously wrong," declared Tim Lang, a co-author of the EAT-Lancet Commission and professor at City, University of London. "We need a significant overhaul, changing the global food system on a scale not seen before in ways appropriate to each country's circumstances."

"To be healthy," he explained, "diets must have an appropriate calorie intake and consist of a variety of plant-based foods, low amounts of animal-based foods, unsaturated rather than saturated fats, and few refined grains, highly processed foods, and added sugars."

"Humanity now poses a threat to the stability of the planet," co-lead commissioner Johan Rockström of the Stockholm Resilience Center told the *Guardian*. "[This requires] nothing less than a new global agricultural revolution."

Here are some of the commission's recommendations:

1. Seek international and national commitment to shift toward healthy diets that feature more plant-based foods - including fruits, vegetables, nuts, seeds, and whole grains - and less animal products.
2. Reorient agricultural priorities from producing high quantities of food to producing healthy food that nurtures human health and supports environmental sustainability.



Figure 13.15: **We should eat more vegetables, fruits, whole grains and nuts, while consuming much less meat and dairy products. Beef is especially damaging to the global environment.**

3. Sustainably intensify food production to increase high-quality output with a series of reforms that include becoming a net carbon sink from 2040 forward to align with the goals of the Paris climate agreement.
4. Strong and coordinated governance of land and oceans, including by implementing a "Half Earth" strategy for biodiversity conservation.
5. At least halve food losses and waste, in line with the U.N. Sustainable Development Goals (SDGs), on both the production side and the consumption side.

Here are some excerpts from a 16 January 2019 article in *The Guardian* by Damian Cammeron:

Globally, the diet requires red meat and sugar consumption to be cut by half, while vegetables, fruit, pulses and nuts must double. But in specific places the changes are stark. North Americans need to eat 84% less red meat but six times more beans and lentils. For Europeans, eating 77% less red meat and 15 times more nuts and seeds meets the guidelines.

The diet is a "win-win", according to the scientists, as it would save at least 11 million people a year from deaths caused by unhealthy food, while preventing the collapse of the natural world that humanity depends upon. With 10 billion people expected to live on Earth by 2050, a continuation of today's unsustainable diets would inevitably mean even greater health problems and severe global warming.



Figure 13.16: Forests are the lungs of our planet. They convert CO_2 into organic material and thus remove it from the atmosphere. It is therefore vitally important to protect existing forests and to plant new ones.

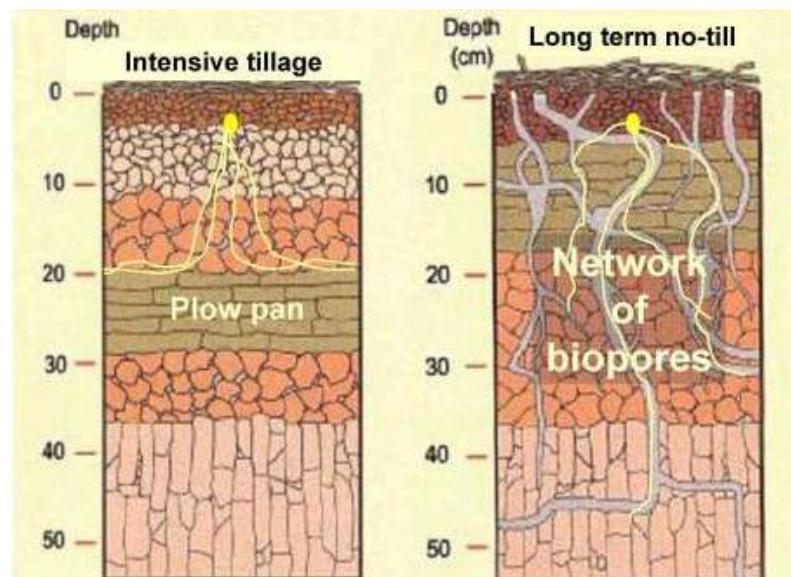


Figure 13.17: Recent research on No-Till Agriculture points to many benefits that could result from this practice, especially higher CO_2 content in the top-soil.

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Chapter 14

A BETTER WORLD IS POSSIBLE

Today, the world is facing several threats, and to avoid them we need to act. The greatest threats are catastrophic climate change and thermonuclear war, but a large-scale global famine also has to be considered.^S

We give our children loving care, but it makes no sense do so and at the same time to neglect to do all that is within our power to ensure that they and their descendants will inherit an earth in which they can survive. We also have a responsibility to all the other living organisms with which we share the gift of life.

Inaction is not an option. We have to act with courage and dedication because the stakes are so high. The mass media could mobilize us to action, but they have failed in their duty. Our educational system could also wake us up and make us act, but it too has failed us. The battle to save the earth from human greed and folly has to be fought in the alternative media.

We need a new economic system, a new society, a new social contract, a new way of life. Here are the great tasks that history has given to our generation:

14.1 We need a steady-state economic system

A steady-state economic system is necessary because neither population growth nor economic growth can continue indefinitely on a finite earth. No one can maintain that exponential industrial growth is sustainable in the long run except by refusing to look more than a short distance into the future.

Of course, it is necessary to distinguish between industrial growth, and growth of culture and knowledge, which can and should continue to grow. Qualitative improvements in human society are possible and desirable, but resource-using and pollution-producing industrial growth is reaching its limits, both because of ecological constraints and because of the exhaustion of petroleum, natural gas and other non-renewable resources, such as metals. The threat of catastrophic climate change makes it imperative for us to stop using fossil fuels within very few decades.

14.2 We must restore democracy

It is obvious, almost by definition, that excessive governmental secrecy and true democracy are incompatible. If the people of a country have no idea what their government is doing, they cannot possibly have the influence on decisions that the word “democracy” implies.

Governmental secrecy is not something new. Secret diplomacy contributed to the outbreak of World War I, and the secret Sykes-Picot Agreement later contributed to the bitterness of conflicts in the Middle East. However, in recent years, governmental secrecy has grown enormously.

The revelations of Edward Snowden have shown that the number of people involved in secret operations of the United States government is now as large as the entire population of Norway: roughly 5 million. The influence of this dark side of government has become so great that no president is able to resist it.

We must restore democracy wherever it has been replaced by oligarchy. When we do so, we will free ourselves from many evils, including excessive economic inequality, violation of civil rights, and the suffering produced by perpetual wars.

14.3 We must decrease economic inequality

In a recent speech, Senator Bernie Sanders quoted Pope Francis extensively and added: “We have a situation today, Mr. President, incredible as it may sound, where the wealthiest 85 people in the world own more wealth than the bottom half of the world’s population.”¹

The social epidemiologist Prof. Richard Wilkinson, has documented the ways in which societies with less economic inequality do better than more unequal societies in a number of areas, including increased rates of life expectancy, mathematical performance, literacy, trust, social mobility, together with decreased rates of infant mortality, homicides, imprisonment, teenage births, obesity and mental illness, including drug and alcohol addiction.² We must also remember that according to the economist John A. Hobson, the basic problem that led to imperialism was an excessively unequal distribution of incomes in the industrialized countries. The result of this unequal distribution was that neither the rich nor the poor could buy back the total output of their society. The incomes of the poor were insufficient, and rich were too few in number.

¹https://www.youtube.com/watch?v=9_LJpN893Vg
<https://www.oxfam.org/en/tags/inequality>
https://www.oxfam.org/sites/www.oxfam.org/files/file_attachments/cr-even-it-up-extreme-inequality-291014-en.pdf

²<https://www.youtube.com/watch?v=cZ7LzE3u7Bw>
https://en.wikipedia.org/wiki/Richard_G._Wilkinson

14.4 We must break the power of corporate greed

Why is war continually threatened? Why is Russia threatened? Why is war with Iran threatened? Why fan the flames of conflict with China? Is it to “protect” civilians? Absolutely not! In a thermonuclear war, hundreds of millions of civilians would die horribly everywhere in the world, also in neutral countries. What is really being protected are the profits of arms manufacturers. As long as there are tensions; as long as there is a threat of war, military budgets are safe; and the profits of arms makers are safe. The people in several “democracies”, for example the United States, do not rule at the moment. Greed rules.

As Institute Professor Noam Chomsky of MIT has pointed out, greed and lack of ethics are built into the structure of corporations. By law, the Chief Executive Officer of a corporation must be entirely motivated by the collective greed of the stockholders. He must maximize profits. If the CEO abandons this single-minded chase after corporate profits for ethical reasons, or for the sake of humanity or the biosphere or the future, he (or she) must, by law, be fired and replaced.

14.5 We must leave fossil fuels in the ground

The threat of catastrophic climate change requires prompt and dedicated action by the global community. Unless we very quickly make the transition from fossil fuels to 100% renewable energy, we will reach a tipping point after which uncontrollable feedback loops could take over, leading to a human-caused 6th geological extinction event. This might even be comparable to the Permian-Triassic event, during which 96% of all marine species and 70% of terrestrial vertebrates became extinct.

14.6 We must stabilize and ultimately reduce the global population

Education of women and higher status for women are vitally important measures, not only for their own sake, but also because in many countries these social reforms have proved to be the key to lower birth rates. As Sir Partha Dasgupta of Cambridge University has pointed out, the changes needed to break the cycle of overpopulation and poverty are all desirable in themselves. Besides education and higher status for women, they include state-provided social security for old people, provision of water supplies near to dwellings, provision of health services to all, abolition of child labor and general economic development. The money required to make these desirable changes is a tiny fraction of the amount that is currently wasted on war.

In order to avoid a catastrophic future famine, it is vitally important that all of the countries of the world should quickly pass through a demographic transition from a situation characterized by high birth rates and high death rates to a new equilibrium, where

low death rates are balanced by low birth rates.

14.7 We must eliminate the institution of war

Today we look with horror at drawings of slave ships, where human beings were packed together like cord-wood, and we are amazed that such cruelty could have been possible. Can we not hope for a time when our descendants, reading descriptions of the wars of our own time, will be equally amazed that such cruelty and stupidity could have been possible? If we use them constructively, the vast resources now wasted on war can initiate a new era of happiness and prosperity for the family of man. It is within our power to let this happen. The example of the men and women who worked to rid the world of slavery can give us courage as we strive for a time when war will exist only as a dark memory fading into the past.

14.8 We need a World Federation

Today's United Nations is a confederation. It tries to control the actions of its member states by imposing economic sanctions. However, these sanctions often affect the poor people of a country, rather than the guilty leaders. Thus, they are both unjust and ineffective.

By contrast, the government of a federation has the power to make laws that act on individuals. Historically, federations have proved to be very successful. Today, the governments of several large countries (for example Russia, the United States, Germany and Australia) are federations.

14.9 New ethics to match new technology

We need a new global ethic, where loyalty to one's family and nation is supplemented by a higher loyalty to humanity as a whole. The Nobel laureate biochemist Albert Szent-Györgyi once wrote:

"The story of man consists of two parts, divided by the appearance of modern science.... In the first period, man lived in the world in which his species was born and to which his senses were adapted. In the second, man stepped into a new, cosmic world to which he was a complete stranger.... The forces at man's disposal were no longer terrestrial forces, of human dimension, but were cosmic forces, the forces which shaped the universe. The few hundred Fahrenheit degrees of our flimsy terrestrial fires were exchanged for the ten million degrees of the atomic reactions which heat the sun."

"This is but a beginning, with endless possibilities in both directions; a building of a human life of undreamt of wealth and dignity, or a sudden end in utmost misery. Man lives in a new cosmic world for which he was not made. His survival depends on how well and how fast he can adapt himself to it, rebuilding all his ideas, all his social and political institutions."

“...Modern science has abolished time and distance as factors separating nations. On our shrunken globe today, there is room for one group only: the family of man.”

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