such as natural gas (methane), oil or coal. Organic materials contain at least carbon and hydrogen and may include oxygen. If other elements are present they also ultimately combine with oxygen to form a variety of pollutant molecules such as sulphur oxides and nitrogen oxides.

Biomass combustion

This is the burning of living and dead vegetation. It includes human-induced burning as well as naturally occurring fires. It happens most in:

- the boreal (northern) forests in Alaska, Canada, Russia, China and Scandinavia
- savannah grasslands in Africa
- tropical forests in Brazil, Indonesia, Colombia, Ivory Coast, Thailand, Laos, Nigeria, Philippines, Burma and Peru
- temperate forests in the US and western Europe
- agricultural waste after harvests in the US and western Europe.

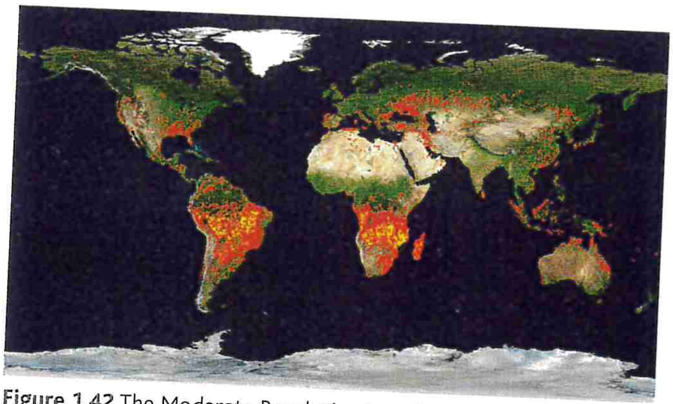


Figure 1.42 The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite shows fires around the world in 2010

Source: NASA

The relationship between forests and carbon dioxide emissions is complex. Forests have a life cycle: trees die after severe fire, setting the stage for new growth to begin. If a forest fully replaces itself, there will be no net carbon change over that life cycle. The fire consumes only about 10 to 20 per cent of the carbon and immediately emits it into the atmosphere. It kills trees but doesn't consume them. So, new trees grow (storing carbon), old trees decompose (emitting carbon) and the organic layer of the soil accumulates (storing carbon). This balance between simultaneous production and decomposition determines whether the forest is a net source or sink. Left alone, terrestrial and atmospheric carbon stays more or less in balance. However, increasingly large and/or more frequent fires, possibly made worse by warming temperatures and changing precipitation levels, can change that carbon balance.

Every year, fires burn 3 to 4 million km^2 of the Earth's land surface area, and release more than a billion tonnes of carbon into the atmosphere in the form of carbon dioxide. However, massive old-growth northern latitude forests are also considered a carbon 'sink' because older trees are repositories of decades or centuries of carbon; their heavy canopy blocks sunlight from reaching the forest floor, slowing decomposition of the forest litter.

Volcanic activity

According to the United States Geological Survey (USGS) *'the carbon dioxide released in recent volcanic eruptions has never caused detectable global warming of the atmosphere.'* This is probably because:

- The warming effect of emitted CO_2 is counterbalanced by the large amount of sulphur dioxide that is given out. **Conversion of this sulphur dioxide to sulphuric acid, which forms fine droplets,** increases the reflection of radiation from the Sun back into space, cooling the Earth's lower atmosphere.
- The amounts of carbon dioxide released have not been enough to produce detectable global warming. For example, all studies to date of global volcanic CO_2 emissions indicate that present-day sub-aerial and submarine volcanoes have released less than 1 per cent of the CO_2 released currently by human activities. It has been proposed that intense volcanic release of carbon dioxide in the deep geologic past did cause a large enough increase in atmospheric CO_2 to cause a rise in atmospheric temperatures and possibly some mass extinctions, though this is a topic of scientific debate.

Hydrocarbon extraction and burning – cement manufacture

Dead plants or animals turn into fossil fuels following burial. The pressure from multiple layers of sediment leads to an anoxic (oxygen free) environment that allows for decomposition to take place without oxygen. When this is combined with heat from the Earth, the carbon in sugar molecules is rearranged to form other compounds. The type of material that is buried helps to determine what the final product will be. Animal remains tend to form petroleum (crude oil) while plant matter is more likely to form coal and natural gas. When these fossil fuels are extracted from the ground and then burnt, carbon dioxide and water are released into the atmosphere.

Cement manufacture contributes CO_2 to the atmosphere when calcium carbonate is heated, producing lime and carbon dioxide. CO_2 is also produced by burning the fossil fuels that provide the heat for the cement manufacture process.

It is estimated that the cement industry produces around 5 per cent of global anthropogenic CO_2 emissions, of which 50 per cent is produced from the chemical process itself, and 40 per cent from burning fuel to power that process. The amount of CO_2 emitted by the cement industry is more than 900 kg of CO_2 for every 1,000 kg of cement produced.

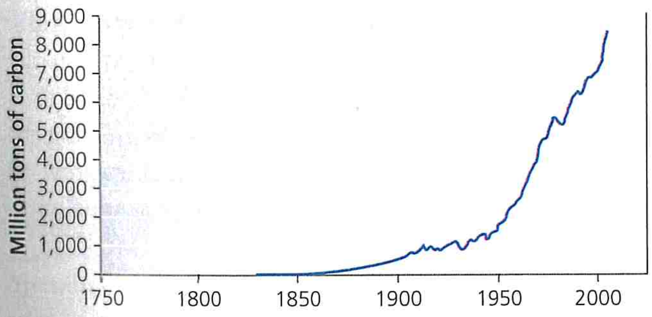


Figure 1.43 Global CO_2 emissions from fossil fuel burning, 1751 to 2006

Source: British Geological Survey

In 2013, global CO_2 emissions due to fossil fuel use and cement production were 36 GtC. This is 61 per cent higher than 1990 (the Kyoto Protocol reference year) and 2.3 per cent higher than 2012. CO_2 emissions were dominated by China (28 per cent), the USA (14 per cent) and India (7 per cent) with growth in all of these countries. The European Union (EU) also contributed 10 per cent but their 28 states were in an overall 1.8 per cent decline.

The 2013 CO_2 emissions (fossil fuel and cement production only) breakdown is: coal (43 per cent), oil (33 per cent), gas (18 per cent), cement (5.5 per cent) and gas flaring from oil wells (0.6 per cent).

Farming practices

When soil is ploughed, the soil layers invert, air mixes in, and soil microbial activity dramatically increases. It results in soil organic matter being broken down much more rapidly, and carbon is lost from the soil into the atmosphere. In addition to the effect on soil from ploughing, emissions from the farm tractors increases carbon dioxide levels in the atmosphere.

The largest source of carbon emissions within agriculture is enteric fermentation – when methane (CH_4) is produced by livestock during digestion and released via belches. This accounted in 2011 for 39 per cent of the sector's total greenhouse gas outputs. Emissions from animals increased by 11 per cent between 2001 and 2011.

Greenhouse gases resulting from biological processes in rice paddies that generate methane make up 10 per cent of total agricultural emissions, while the burning of tropical grasslands accounts for 5 per cent.

According to the United Nations Food and Agriculture Organization (FAO), in 2011, 44 per cent of agriculture-related greenhouse gas outputs occurred in Asia, followed by the Americas (25 per cent), Africa (15 per cent), Europe (12 per cent) and Oceania (4 per cent). This regional distribution has been constant over the last decade.

Land use change

CO_2 emissions that result from land use change (mainly **deforestation**) account for up to 30 per cent of anthropogenic CO_2 emissions.

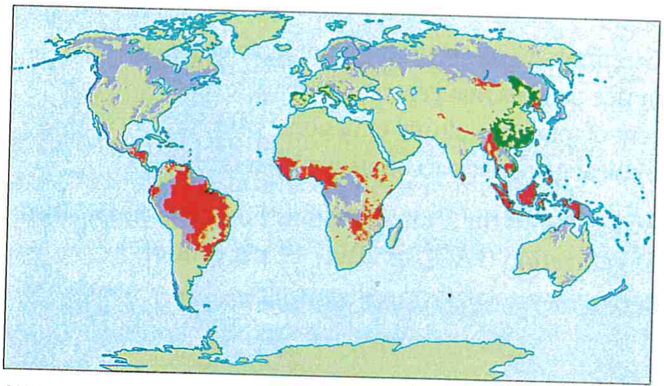
Deforestation

Most deforestation is driven by the need for extra agricultural land. Often subsistence farmers will clear a few hectares to feed their families by cutting down trees and burning them in a process known as 'slash and burn' agriculture.

Logging operations also remove forest. Loggers, some of them acting illegally, also build roads to access more and more remote forests, which in turn leads to further deforestation. Forests are also cut as a result of growing urban sprawl. Not all deforestation is intentional. Some is caused by a combination of human and natural factors like wildfires and subsequent overgrazing, which may prevent the re-establishment of young trees.

The FAO estimates that about 13 million ha, an area roughly equivalent to the size of Greece, of the world's forests are cut down and converted to other land uses every year.

At the same time, planting of trees has resulted in forests being established or expanded on to abandoned agricultural land. This has reduced the net loss of total forest area. In the period 1990 to 2000 the world is estimated to have suffered a net loss of 8.9 million ha of forest each year, but in the period 2000 to 2005 this was reduced to an estimated 7.3 million ha/year. This means that the world lost about three per cent of its forests in the period 1990 to 2005; at present we are losing about 200 km^2 of forest each day. The world's rainforests could completely vanish in a hundred years at the current rate of deforestation.



Key
- >0.50% decrease per year
- >0.50% increase per year
- Change rate between –0.50 and 0.50% per year

Figure 1.44 Countries with large net changes in forest area, 2000–2005

Source: FAO

Skills focus

You should be able to read and interpret atlas maps. Think about how you might describe the distribution of those areas that have a greater than 0.5 per cent decrease in forest area per year.

When forests are cleared for conversion to agriculture or pasture, a large proportion of the above-ground biomass may be burned, rapidly releasing most of its carbon into the atmosphere. Some of the wood may be used as wood products and so preserved for a longer time. Forest clearing also accelerates the decay of dead wood, litter and below-ground organic carbon.

Figure 1.45 shows how deforestation changes the carbon cycle but it is not the only way it affects climate. Forest soils are moist, but without the shade from tree cover they quickly dry out. Trees also help maintain the water cycle by returning water vapour back into the atmosphere through transpiration. Without trees to fill these roles, many former forestlands can quickly become barren deserts.

Urban growth

For the first time in human history, over half the world's population now lives in urban areas. As a proportion of global population, the urban population is expected to reach 60 per cent by 2030, with urban areas growing at a rate of 1.3 million people every week. As cities grow, the land use changes from either natural vegetation or

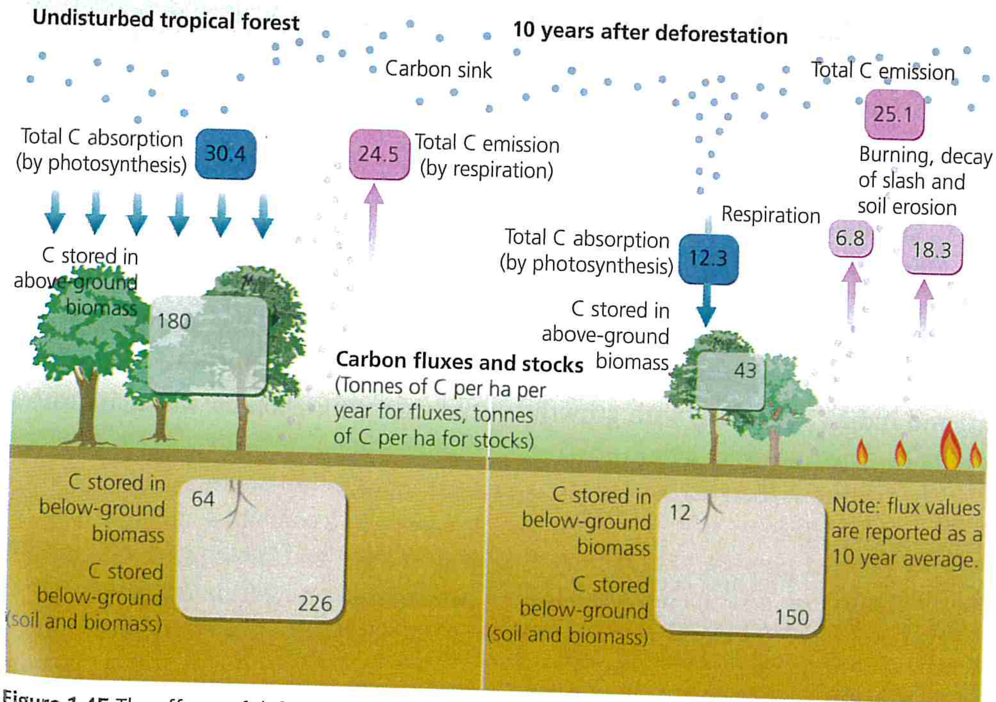


Figure 1.45 The effects of deforestation on the carbon cycle.

agriculture to one which is built up. The CO_2 emissions resulting from energy consumption for transport, industry and domestic use, added to the CO_2 emitted in the cement manufacture required for all the buildings and infrastructure, have increased. In 2012, cities (metropolitan areas above 0.5 million) were responsible for around 47 per cent of global carbon emissions. Under a business-as-usual scenario, this share of emissions is predicted to increase slightly to 49 per cent by 2030. Similar to population and economic output, the distribution of emissions is highly concentrated, with the 21 highest emitting cities contributing 10 per cent of global energy-related carbon emissions, 64 cities contributing 20 per cent and 139 cities contributing 30 per cent.

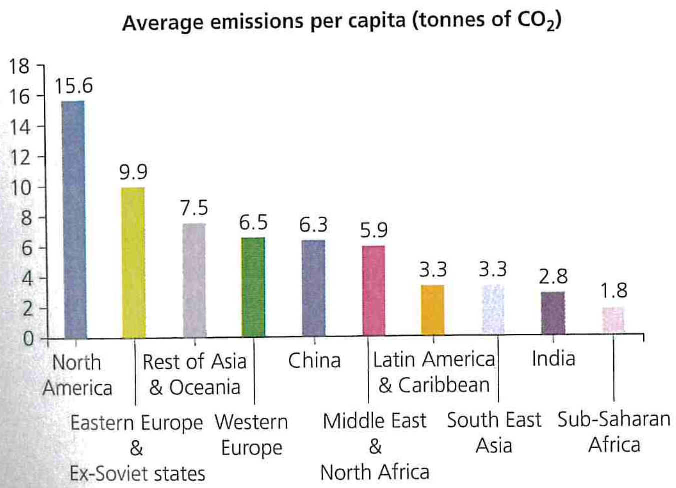


Figure 1.46 Average carbon emissions per capita of cities above 0.5 million by region in 2012

An even greater concentration can be observed for carbon emissions growth from 2012 to 2030. In total, cities are projected to be responsible for 56 per cent of the global increase in carbon emissions during that period, with 10 cities contributing 10 per cent of global emissions growth, 28 cities contributing 20 per cent and 193 cities contributing 50 per cent.

Carbon sequestration

The process of **carbon sequestration** involves capturing CO_2 from the atmosphere and putting it into long-term storage. There are two primary types of carbon sequestration:

- **Geologic sequestration:** CO_2 is captured at its source (for example, power plants or industrial processes) and then injected in liquid form into stores underground. These could be depleted oil and gas reservoirs, thin, uneconomic coal seams, deep salt formations and the deep ocean. This is still at the experimental stage.

  The ocean is very capable of absorbing much more additional carbon than terrestrial systems simply because of its sheer size. An advantage of ocean carbon sequestration is that the carbon sequestered is quite literally 'sunk' within weeks or months of being captured from the air/water. Once in the deep ocean it is in a circulation system commonly measured in thousands of years. By the time this carbon reaches the seabed it has entered the Earth's geological cycle.
- **Terrestrial or biologic sequestration:** this involves the use of plants to capture CO_2 from the atmosphere and then to store it as carbon in the stems and roots of the plants as well as in the soil. The aim is to develop a set of land management practices that maximises the amount of carbon that

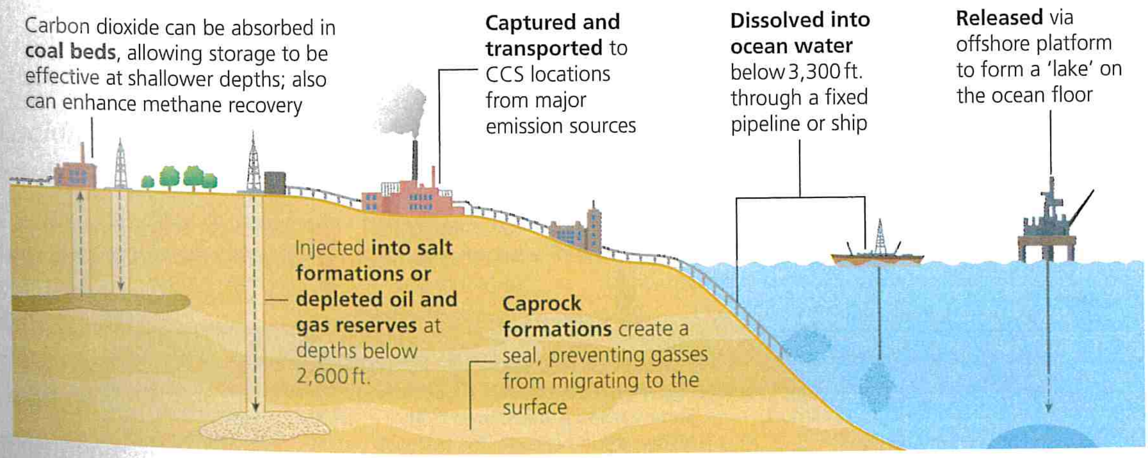


Figure 1.47 Geologic carbon sequestration
Source: IPCC