ENVIRONMENTAL SCIENCE
The sun keeps us all alive, but becomes harmful as impact by people on the atmosphere increases. The Earth gets hotter as greenhouse gases accumulate, and more dangerous as UV radiation increases when the ozone layer is reduced. (Photo: Inga-May Lehman Nådin.)
Modern society is propelled by energy. The energy sector is a major user of natural resources. This use increased greatly in the latter half of the 20th century. From the mid-1950s to mid-1970s (when use stalled due to the sudden oil price increase), energy consumption in Western Europe, and probably very similarly in Eastern and Central Europe, increased nearly fourfold. Today, oil, gas, coal and other fossil fuels are the base of a dramatically enlarged international energy market. We have all become “oil addicts.”

The large-scale turnover of energy has become one of the major sources of local, regional, and global environmental impacts on the atmosphere. Energy conversion has caused large scale changes of the physics of the planet. Firstly, the burning of fossil fuels charges the atmosphere by addition of carbon dioxide, which is believed to be the major reason why Earth is presently going through a period of rapidly increasing temperature, predicted to continue far into the 21st century. Secondly, the chlorine-containing pollutants, in particular freons, have been shown to escape into the upper layer of the atmosphere, the stratosphere, where they contribute to ozone destruction. The consequence of decreasing stratospheric ozone is increased UV radiation, a further change in the physics of the planet.

This chapter contains an overview of energy production in the Baltic Sea basin, and describes the environmental consequences of this production. The impacts of energy use are mainly due to the material flows connected with it. The movement of large amounts of coal from fossil sources to the biosphere is not sustainable. Other means of energy production also have damaging environmental consequences. Large-scale hydropower requires the construction of large dams which dramatically reshape the rivers that power them and the whole landscape, and nuclear power have problems throughout the nuclear fuel chain.

Special attention is given to climate change, and ozone depletion. It is also here that the present international efforts to agree on measures to reduce the impacts on our common atmosphere is most intense. Impacts on air quality are treated in the next chapter.

Energy is used mainly in three areas of society. The traffic sector, corresponding to about 25% of energy used, might be the largest problem, as it is almost entirely dependent on fossil fuel and is rapidly increasing. In the household and industry sectors, which are the other two main users, improvements are being made. Improving energy conservation and efficiency is feasible, especially in the former socialist states where energy use was extremely inefficient. It has been estimated that it is possible to save up to one-third of today’s energy by applying existing technology. With the introduction of better technology, such as low energy houses and improved cars, we should be able to reduce present energy flows by about 50%. However, most important is to make a transition towards solar based energy systems and leave the fossil fuel dependent society behind.

Authors of this chapter
Magnus Andersson, energy systems; Richard S.J. Tol, effects of global warming; L. Phil Graham and Sten Bergström, climate modelling and hydrology; Lars Rydén, energy systems and stratospheric ozone; Christian Azar, carbon dioxide reduction.
# Impacts on the Global Atmosphere

## Climate Change and Ozone Depletion

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Environmental impacts on the global atmosphere

When combusting fuels, such as oil and coal, a number of substances are emitted to the atmosphere: carbon dioxide, nitrogen oxides, sulphur oxides, hydrocarbons and particles. These dramatically influence the properties of the air and the atmosphere, its physics and chemistry, and have severe consequences for biological life. In particular the increased content of carbon in the atmosphere has consequences for its ability to reflect or absorb radiation in several wavelength ranges (see further Chapter 2). These changes are believed to be the main reason for climate change.

The effects are global and therefore particularly serious. The scale of the economic effects are far-reaching for everyone on Earth. Therefore, protection of the atmosphere is today the most important aspect of global negotiations in the environmental field. In this chapter we will examine these impacts on the atmosphere and its consequences. The main cause of the impacts are the energy systems used in societies. Therefore, energy provision and consumption systems are focused on here. The connected question of consequences of combustion of fuels on air quality, is discussed in the next chapter.

Processes similar to those of the energy systems occur when land use patterns are changed. When soil is exposed to air, as in increased agriculture and deforestation, combustion of organic material increases and as a result the same gases, in particular carbon dioxide, are emitted, as in energy production based on combustion of fuels. Therefore, land use changes also have to be considered in connection with the impacts on the global atmosphere.

The current energy systems are not sustainable. The reason is not only that they cause environmental damage but also that the main energy sources are non-renewable, that is, they are not renewed at a rate comparable with their extraction rate. The assimilation of carbon in biomass – in particular as wood in forests and organic components in soil and wetlands – does not keep up with the extraction and combustion of fossil fuel. Nor does the dissolution of carbon dioxide in the oceans keep up with the increased turnover. As a result the flows of carbon, emitted in the combustion are linear rather than cyclic, and this leads to an accumulation in the atmosphere.

Improvement of the situation will require major rethinking and modification of our societies. The energy systems constitute vital parts of the infrastructure in society, particularly in industrialized countries. Energy services like space heating, lighting, cooling, and transportation of goods and people are indispensable parts of everyday life. Industrial production of goods includes a number of energy services. Most energy services are provided by utilizing non-renewable fossil fuels. This is the major reason for the changed properties of the atmosphere.

Globally more energy is believed to be used for cooling than for heating. The coolants used in cooling systems are dominated by chlorine containing substances, freons or its substitutes, which escape and have the same effect on the atmosphere as carbon dioxide. But in addition the freons release atomic chlorine in the upper layer of the atmosphere, which leads to the destruction of ozone in this layer. As a consequence global UV radiation increases. This impact on the global atmosphere is also discussed below.

The atmosphere is changed by:
- greenhouse gases, especially CO₂, which leads to global warming, and
- ozone destructive compounds, e.g. freons, which lead to increased UVB radiation.
Energy systems

Energy systems consist of the extraction of energy sources, transportation of energy carriers, conversion (e.g. in a power plant), distribution, and the final conversion that provides the desired energy service. Also, the organisational framework needed to operate these structures – such as oil companies and governmental authorities – can be seen as part of the energy systems.

For example, in the chain of energy conversions from a coal mine, coal is mined and transported to a power station where it is burned to produce steam. The heat energy in steam is converted to mechanical work in a turbine which drives a generator converting the mechanical work to electricity. The electricity is transported to provide various energy services such as lighting or heating. Energy losses occur in each conversion. Only a small percentage of the energy content of the source is utilised to provide the energy service. Most of the rest is dissipated as heat that cannot be utilised.

Different conversion technologies and practices can show very different results in terms of energy losses. A good example is the conversion of fuels to electricity. The fuel is usually combusted in a boiler which provides steam used to drive a turbo generator which in turn provides the electricity. The steam delivers part of its energy to the turbine. It is then cooled so it condenses to water which is fed back to the boiler. Most of the original energy is lost in this condensing process. This type of plant is called a condensing plant and its energy efficiency is typically 35-40% from fuel to electricity output. If, however, the energy remaining in the steam and the turbine is used to heat buildings or in industrial processes, the energy efficiency is greatly improved. Similarly, the burning of fuel to generate heat, e.g. in a district heating plant using household waste, is much more resourceful if part of the heat is used to run a generator producing electricity.

A major source of pollutants is the combustion of fossil fuels. However, there can be environmental impacts throughout the entire energy system. The more efficient the energy system as a whole, the less the environmental impact. In some cases, it is clear that all stages in an energy system are by themselves actual or potential sources of environmental impact.

Scale of energy use

Energy sources, especially oil and gas, are extracted and utilized on a scale that has increased dramatically over the last few generations both regionally and globally. The use of new energy sources, such as nuclear power and wind power, has also increased. In the last 100 years, global fuel consumption has grown on average by 3% per year. In 1990, total global primary energy use was 10.2 TW of which coal, oil, and gas contributed, respectively, 30%, 36% and 22%. In the late 1990s, nuclear power accounted for 2.3% of global primary energy supply and 17% of global electricity production. Corresponding figures for hydropower were 2.4% and 18%, respectively. Fuels derived from biomass also make important contributions to world energy needs.

Global energy use is forecasted to continue to increase by at least 1% per year. The growth rate is likely to be lower in industrialised countries and higher...
In many developing countries. The richest 25% of world population use approximately 75% of total global energy resources. The other 75% of the population use only one-fourth of global energy resources.

In the Baltic Sea region, a period of dramatic increase in energy use occurred from about 1955 to 1973. During this 20 year period, energy use increased by a factor of almost four in many countries, which was accounted for almost entirely by increased oil consumption. Conversion from a moderately sustainable “traditional” system to an affluent and unsustainable society took place during this period.

The 1973 oil crisis, caused by a dramatic three-fold price increase of Middle East oil, caused an abrupt change in the western part of the region. Since then the growth of energy use has levelled off. During a period in the 1980s it was even declining, while in the 1990s there was a moderate increase. The kinds of energy used have also changed. From 1980 to 1995 the share of oil in the systems fell from 52% to 44%, and coal from 24% to 22%. At the same time the amount of nuclear energy increased three-fold.

Development has been different in the countries in transition. They were not significantly influenced by the oil crisis in 1973 since oil was provided from the Soviet operated Caspian Sea oil fields. The socialist system did not encourage energy efficiency and oil use was growing. After the system’s change in 1989-91 energy prices have been introduced and dramatically increased, resulting in more efficient energy use in all sectors. In addition, outdated, energy-intensive industry has either been improved considerably, or in many cases even closed entirely. As a result, energy use in the entire eastern Baltic Sea region has decreased considerably the last ten year, with e.g. a nearly 30% reduction of energy use by industry. Energy use is now expected to increase as the economy allows.

What is energy used for?
Energy consumption is shared roughly equally between households, industry, and the transport sector. Households use energy for heating, cooling, lighting, and small equipment. This sector is increasingly using renewable energy sources, such as biomass, household waste incineration, and electricity from hydropower or wind power. There is a considerable potential in this sector for both improved energy conservation and efficiency.

Energy use is increasing faster in the transport sector than in the other two sectors. The transport sector is almost completely dependent on fossil fuels.

In the industry sector, many branches have been able to reduce energy consumption while other branches, such as the metallurgic industry, are more difficult to change, even if efficiency has been in focus during the entire 1990s in industries in western Europe.

The first large increase in oil prices in 1973-74 brought into focus the importance of increasing energy efficiency. Energy conservation has focused on adjusting and optimising energy use. That is, to reduce energy requirements per unit of output without negatively affecting socio-economic development.

<table>
<thead>
<tr>
<th>Country</th>
<th>Coal</th>
<th>Oil</th>
<th>Gas</th>
<th>Nuclear</th>
<th>Hydro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway</td>
<td>0.7</td>
<td>9.4</td>
<td>3.5</td>
<td>0</td>
<td>12.2</td>
</tr>
<tr>
<td>Sweden</td>
<td>2</td>
<td>15.2</td>
<td>0.8</td>
<td>14.8</td>
<td>6.8</td>
</tr>
<tr>
<td>Finland</td>
<td>3.5</td>
<td>10.5</td>
<td>3.4</td>
<td>6.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Russia</td>
<td>110.4</td>
<td>123.5</td>
<td>339.5</td>
<td>33.7</td>
<td>14.2</td>
</tr>
<tr>
<td>Belarus</td>
<td>0.1</td>
<td>5.4</td>
<td>14.6</td>
<td>0</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Estonia</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Latvia</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Lithuania</td>
<td>0.1</td>
<td>2.9</td>
<td>2.4</td>
<td>2.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Denmark</td>
<td>4</td>
<td>10.4</td>
<td>4.4</td>
<td>0</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Germany</td>
<td>82.7</td>
<td>129.5</td>
<td>71.3</td>
<td>43.8</td>
<td>2.1</td>
</tr>
<tr>
<td>Poland</td>
<td>57.1</td>
<td>20.6</td>
<td>10</td>
<td>0</td>
<td>0.4</td>
</tr>
</tbody>
</table>


Figure 10.4. Long-term trends in energy consumption. The figures are expressed in million tonnes of oil equivalent. Western Europe is characterised by a dramatic increase up to 1970 after which the level is rather constant. Eastern European energy use increased up to 1990, where we see a decline. Fossil fuels dominate the picture entirely. Coal use is decreasing, and natural gas use is increasing. (Source: http://www.eia.doe.gov/pub/international/iealf/table13.xls and http://www.eia.doe.gov/pub/international/iealf/table61.xls.)
or life-styles. Energy conservation has both environmental and economic benefits.

The relationship between energy demand and economic growth is measured by energy intensity. It can be defined as energy consumption divided by gross domestic product (GDP). In developed market economies, the energy intensity declined by 29% between 1970 and 1990. This was achieved by the switch to less energy-intensive capital goods and consumer durables, and from the application of energy-efficient machinery in industry, heating, and air conditioning.

**Fossil fuels**

Traditional energy sources are the sun, wood (i.e. biomass or biofuel), running water, and the wind. All of these are renewable energy sources, in the end powered by the sun. Modern technology has made the utilisation of these sources of energy very efficient. But the main energy sources today are the fossil fuels.

Fossil fuels include oil, gas, and coal. Each of these have been formed from compressed plant tissues through many millions or hundreds of millions of years at great depths in the Earth. They consist of carbon with a higher (gas) or lower (coal) content of hydrogen. In addition varying amounts – up to some 10% – of sulphur is present together with smaller amounts of many other elements. Fossil fuels are today extracted and combusted at a speed of more than a million times larger than the renewal rate. The waste products – carbon dioxide and sulphur dioxide in particular, water is not relevant here – accumulate in the atmosphere.

Proven reserves of coal, oil, and gas will last about 220, 40 and 60 years, respectively, at current rates of production. Proven reserves are generally taken to be what can be recovered with reasonable certainty from known reservoirs under existing economic conditions. The estimated additional undiscovered coal resources are about 10 times greater than the proven reserves. The estimated additional resources of oil are only half of the proven reserves and those of gas are about equal to the proven reserves. The price of fossil fuels will, however, start to rise long before the resource is emptied. The rather well-established relationship between the percentage of already recovered resource and the price curve predicts that “the end of cheap oil” will happen a few years into the new century. Extraction will stop when it costs more to extract the resource than what one gains from it, either price-wise or energy-wise.

Fossil fuels could be part of a transition to an energy system based on renewables, for example, by using coal and natural gas to produce methanol and hydrogen, energy carriers which could later be produced from a variety of renewable sources.

The countries in the Baltic Sea region are well endowed with fossil energy resources. There are large coal deposits in Germany (hard coal and lignite), Poland (hard coal and lignite), and Russia (hard coal). Poland is the most coal-dependent country in the Baltic Sea basin. Oil-shale, a fossil fuel with low heating value, is mined in north-eastern Estonia and across the Estonian border in Russia.

Oil and gas are exploited both on land and off-shore in the Baltic Sea region. Small volumes are extracted in northern Germany, southern Poland, and northern Lithuania. Oil exploration is taking place along the coasts of Poland, Latvia and Lithuania. In the North Sea, very extensive oil and gas resources are extracted, mostly by Norway.

But there are also excellent possibilities to use renewable energy sources, such as hydro and wind power and biomass. The challenge is to go from fossil fuel dependency to renewable resources, or, as it is often phrased, to “de-carbonize” the energy flows. We will return to this in the end of the chapter.
**Agriculture and soil changes**

Tilling of soil exposes its organic content to air and changes the microbiological and ecological system. This is particularly important when wet soils are drained. As a result, organic material in the soil is used for energy purposes by the microorganisms and carbon dioxide is emitted. This can be physically seen after draining, as the soil shrinks, which might make renewed draining necessary. In the Baltic Sea region it seems that the most significant activity is the draining of soil and exploitation of former wetlands. On a global level the most relevant activity is deforestation and opening up of the new areas to agriculture.

Agriculture also has a considerable impact on the global atmosphere through emissions of methane, another important greenhouse gas. All fermentation processes produce methane. Thus, the fermentation going on in soil, manure, and in composts contribute to methane emissions. As long as access to oxygen is limited, fermentation will result. Aeration is needed to avoid fermentation. A special case is the methane produced by grazers, in particular cows, as a by-product in fermentation in the rumens of the animals, where the grass is digested. This is a considerable amount and of significance to the global atmosphere.

Other important effects are due to the extensive use of fossil energy in agriculture.

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**GREENHOUSE GASES AND GLOBAL CLIMATE**

**A period of climate change**

The Earth is presently going through a period of climate change with increased average global temperature. This is called **global warming**. Over the last 100 years the average global temperature has increased by about 0.7°C. About one-third of this increase has occurred after 1980. Since then the average global temperature has increased steadily. Today we have the warmest climate since the 14th century. Climate change is, however, not a new phenomenon and the reason for the change we are experiencing right now is therefore a topic for discussion. Is it natural or caused by environmental impact by man? Key components in the discussion are the so-called **greenhouse gases**, which make the global atmosphere work like the glass in a greenhouse: they let light in but not heat radiation out. As a result, the greenhouse, that is the Earth, becomes warmer than it would otherwise be (Chapter 2).

But there are many other factors that influence the global climate. The natural variations have caused, as we know, both glaciations and warmer periods. During glaciations the average global temperature is only some 4 or 5 degrees lower than at present. This tells us that the temperature on Earth is a fine-tuned system and only small changes might have dramatic consequences. It is not well understood what causes the natural climate fluctuations. Some factors have been identified. Changed solar influx caused by varied solar activity and astronomical long-term variations is one category of factors. Changes on Earth is another. In 1991, the eruption of the Volcanoe Pinatobo on the Philippines ejected enough ash and sulphate particles to cause an increase in aerosols in the atmosphere and a temperature drop of about 1°C for one year. Another factor is the amount of clouds which influence the albedo of the planet which in turns influences the climate (see Relative contribution of greenhouse gases to the enhanced greenhouse effect (%):

<table>
<thead>
<tr>
<th>Gas</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>65</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>20</td>
</tr>
<tr>
<td>Nitrogen oxides (NOₓ)</td>
<td>5</td>
</tr>
<tr>
<td>Halogenated compounds (e.g. freons)</td>
<td>10</td>
</tr>
</tbody>
</table>
further Chapter 2). Ocean currents play an important role for regional climates. In the Baltic Sea region the Gulf Stream steadily warms, more in the western than the eastern part. The Pacific stream between the South American continent and Indonesia, called El Nino, has a large influence on the climate of the southern Hemisphere.

Greenhouse gases are natural components of the atmosphere and contribute to the heat balance of the Earth (Chapter 2). The most important of the greenhouse gases is water vapour, and the second is carbon dioxide. The concentration of this gas has steadily increased, which might explain part or all of the temperature increase. Enormous amounts of carbon dioxide have been transferred to the atmosphere since the large-scale combustion of coal, oil, and other fossil fuels started with industrialization some 200 years ago. This is still going on and in an accelerated (!) tempo. The natural mechanisms for withdrawing carbon from the atmosphere, such as dissolution in the world oceans, and incorporation of organic matter in soils, are far too slow to keep up. Rather, increasing the area of cultivated land has been an important contributor to atmospheric carbon dioxide. A net increase is the result.

The effect of greenhouse gases have been known since the end of the 19th century, when the Swedish chemist Svante Arrhenius first suggested that they would lead to global warming. Today, sophisticated computer models, climate models, are used to assess the importance of each of the many factors that influence the climate on Earth. There is now near consensus not only that there is an increase in global average temperature, but also that the elevated concentrations of greenhouse gases, most importantly carbon dioxide, is the major reason for this, due to an enhanced greenhouse effect. Energy production is therefore indirectly the major cause of global warming. The predictions, see below, from the simulation models are that the global average temperature will increase by several degrees over the next century.

Climate change is generally regarded as the most important environmental problem of our time. Its effects might be second only to the effects of a nuclear war. The enhanced greenhouse effect will profoundly affect natural and, to a lesser extent, social systems in the whole world for centuries to come; while measures to abate climate change will profoundly affect social and, to a lesser extent, natural systems in the whole world for centuries to come. We have just started to experience what these effects might be. During 1998, ocean coral reefs were reported dying all around the globe. The coral reefs, among the most rich ecosystems of the world, with a spectacular fauna of colourful fish, turned into white lifeless skeletons. The coral death was connected to a water temperature increase of about one degree. Two of the worst flooding events in Europe for centuries took place in Romania, Slovakia, Poland, and Germany during the last few years, especially 1997. Although these may not be easily

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**Figure 10.6. Trends in past average global temperatures.** The four diagrams show the time frames of 1 million, 20,000, 1,000, and 150 years. More recent data seem to indicate that the higher temperatures in the Middle Ages have been overestimated. (Data from US Department of Energy, 1994.)

**Figure 10.7. Average global temperature anomalies 1880-2000.** The temperature increase over the last 100 years is 0.6 °C. The increase is however different for different regions. The increase was most dramatic during the 1990s. (Source: National Climatic Data Center. http://lwf.ncdc.noaa.gov/img/climate/research/anomalies/triad_pg.gif.)
ascribed to a single factor, such as global warming, it gives a sample of what has been predicted to be its effects.

Extensive research activities are ongoing to better understand climate change, its impact, and measures to remedy it. Scientific progress is regularly assessed by the United Nation's Intergovernmental Panel on Climate Change (IPCC), e.g. their 1995 second report (Houghton et al., 1996), and the 2001 third report (Houghton et al., 2001). In parallel, the first steps are taken to set up an international programme to reduce greenhouse gas emissions. In 1997, the global climate negotiations formulated the so-called Kyoto protocol, which presently forms the basis for efforts to reduce greenhouse gas emissions. The implementation mechanisms for the protocol were agreed on in Marrakech, Morocco in October 2001 (see further Chapter 23).

The enhanced greenhouse effect

The greenhouse effect is an uncontested element of atmospheric physics. In summary, atmospheric greenhouse gases absorb the outgoing infrared radiation. Studies indicate that the average global temperature would have been some 30°C lower without the “blanket” of the greenhouse effect (Dickenson et al., 1996).

Greenhouse gases in the atmosphere are part of the biogeochemical cycles of the Earth. Carbon dioxide (CO₂), is part of the carbon cycle. Only a small part of total carbon dioxide is stored in the atmosphere, while much larger amounts are contained in soils, plants, and oceans. These reservoirs exchange carbon dioxide on a massive scale. Each year, some 700 GT (giga tonnes) of carbon are emitted to the atmosphere, and absorbed again – mainly through photosynthesis in plants (Melillo et al., 1996). Human activities interfere with these cycles, disrupting their balance. Fossil fuels are extracted from the ground and burnt, releasing carbon dioxide. Forests are cut, releasing carbon dioxide, and replaced by pasture and arable land, constraining the capacity to absorb carbon dioxide from the atmosphere. At present, human activities add some six GT of carbon to the atmosphere, of which only three GT is immediately absorbed by ocean and land surfaces (Melillo et al., 1996). The result is a slow but steady increase in the amount of carbon dioxide in the atmosphere. Since the start of the industrial transformation, atmospheric carbon dioxide has risen by 30%, from 280 ppm (equals 0.028%) in 1790 to 370 ppm in 1999 (ppm = parts per million).

Other natural trace gases, with “greenhouse properties” show similar trends. Methane (CH₄) and nitrous oxide (N₂O) are the two most important of these, rising from 700 ppb (parts per billion) to 1,700 ppb, and from 290 ppb to 340 ppb, respectively in 1996. Methane sources include rice paddies, cows, termites, natural gas leakage, biomass burning, landfills, and wetlands. Nitrous oxide sources include oceans, fossil fuel and biomass combustion, agricultural fertilisers, and land disturbances. In addition, a number of artificial gases with similar effect are released...
to the atmosphere, particularly chlorofluorocarbons (CFCs) and halocarbons (HFCs) (Schimel et al., 1996). All these other gases are present in lower amounts than CO₂ but are more efficient greenhouse gases. Thus, if these amounts are translated into carbon dioxide equivalents we will end up with a concentration of greenhouse gases corresponding to 400 ppm CO₂ (370 ppm CO₂ + 30 ppm other natural trace gases). This leads to the enhanced greenhouse effect.

Table 10.2 shows some characteristics of greenhouse gas emissions of the Nordic and Baltic Sea countries in 1991. Western Europe and the world are shown for comparison. These countries, with the exception of the former Soviet Union, contribute very little to the total emissions of carbon dioxide and methane. The Nordic countries emit somewhat more carbon dioxide per capita than does the average Western European, and substantially more than the average person on Earth. Emissions per dollar of income are lower than the Western European and world average. Poland and the former Soviet Union emit substantially more, both per capita and per dollar of income. However, these values are decreasing, due to modernisation and closure of inefficient industry in the transition countries. The pattern for methane is very similar.

**Regional climate modelling in the Baltic Sea basin**

The influence of future changes in the atmosphere, most importantly the enhanced greenhouse effect, is studied with the help of computer models. Many groups worldwide are engaged in modelling global climate change. In the Baltic Sea basin, the Swedish Regional Climate Modelling Programme (SWECLIM) produces regional climate scenarios for the Nordic and Baltic Sea region on a time scale of 50 to 100 years in the future. With its research staff of meteorologists, oceanographers, and hydrologists, the Rossby Centre at the Swedish Meteorological and Hydrological Institute is the modelling centre for SWECLIM.

Global atmospheric climate models are typically applied at coarse horizontal scales (~250-400 km). Dynamic downscaling with regional climate models is one way to produce climate scenarios on more local scales. This is done by using output from global climate models to drive finer resolution (~5-100 km) regional climate models over a limited area of the globe. Future climate scenarios are created from differences between control simulations representing the present climate, and simulations with various assumptions about future greenhouse gas emissions.

Regional models are able to provide more detail than global ones. For example, due to finer representation of topography, predicted precipitation may more correctly fall on the Norwegian mountains rather than on eastern Sweden (Rummukainen et al., 2001). Of particular importance for the Baltic Sea basin is that the regional water bodies, the Baltic Sea and Nordic lakes, can be included in regional models (Ljungemyr et al., 1996). However, large-scale circulation and transport of atmospheric moisture still comes from the global models through the “forcing” inputs at the regional model boundaries. Therefore, simulations from different global climate models are used to drive regional models to produce a range of regional climate scenarios.

The regional modelling approach within SWECLIM provides climate scenario results for the Nordic countries and the Baltic Sea basin. The region is characterised by complex coastlines, a regional ocean, prominent inland lake systems, and the Scandinavian mountains. These are at scales too small to be properly represented in typical global models, but they nevertheless exert control in the regional climate, especially on precipitation, snow and runoff. Compared to global models, the regional downscaling allows more local control on surface climate, more detailed hydrology, and better feedback in the scenario simulations.

Results of temperature and precipitation changes in the Baltic Sea basin from regional climate scenario simulations performed in 2000 (SWECLIM, 2001) are shown in Figures 10.12 and 10.13. Summarised in the figures are the annual average
The climate models

SWECLIM simulations are made with the Rossby Centre Regional Atmospheric Climate Model (RCA), based on the international HIRLAM (High Resolution Limited Area Modelling) forecast model (Källén, 1996). Although many of the parameterisation schemes of HIRLAM are retained in RCA, changes in surface treatment were made to enable climate integrations (Rummukainen et al., 2001). The regional model integrations performed to date have ranged in horizontal resolution from 0.2° (~22 km) to 0.8° (~88 km), with 19 vertical levels. The model domain is shown in Figure 10.13. Two global models have been used thus far to provide lateral boundary driving conditions along the perimeter of this domain. These are the HadCM2 model of the Hadley Centre at the United Kingdom Meteorological Office in Reading (Johns et al., 1997) and the ECHAM4/OPYC3 model of the Max-Planck-Institute for Meteorology in Hamburg (Roeckner et al., 1998). Both include full three-dimensional atmosphere and ocean components.

Assumptions about CO₂ emissions

Ten-year paired time slices were used to analyse climate change in regional climate simulations. The “scenario” time slice represents some future climate affected by changes in greenhouse gases. The “control” time slice represents a reference to which the scenario is compared. For HadCM2, the control is the global simulation without changes in greenhouse gases, atmospheric CO₂ from the 1950s (323 ppmv) and flux adjustments based on present-day sea surface climatologies. The scenario is a transient greenhouse gas simulation. The control and scenario time slices differ by an increase in the atmospheric equivalent CO₂ concentration of 150%, increased first as observed for 1860-1990 and thereafter with 1% per year (compounded). For ECHAM4/OPYC3, both of the time slices are from a transient greenhouse gas simulation (Roeckner et al., 1998). The control time slice corresponds to present day conditions (around 1990) in the sense that it is preceded by the radiative forcing changes due to increases in greenhouse gases since 1860. The scenario time slice is taken from the time of doubling of atmospheric equivalent CO₂ concentration compared to the control. The forcing from these two sets of simulations are not directly comparable. However, due to different climate sensitivities in the two global models, the mean global warming between control and scenario time slices is virtually the same in both cases, i.e. 2.6°C.

Uncertainties

There is a wide range of uncertainties for such studies. One source of uncertainty is that between different global scenarios, which are affected by the emission assumptions, how these result in atmospheric concentrations, the ensuing radiative forcing changes and the climate sensitivity to these. Global scenarios also differ even more in their description for particular regions than for global mean results. The different parameterisations used in both global and regional models, and how well they represent the present climate, add another link to the uncertainty chain. There is further uncertainty associated with the interface between the climate model results and the hydrological impact assessment model. A lot of smoothing occurs in the transfer of information between models. For instance, if wintertime temperature increases are more prominent at extreme low temperatures and less prominent for temperatures around zero, use of an average change would result in an overestimation of snowmelt.

Another source of uncertainty lies with the hydrological models. They are calibrated to present conditions and the same parameters are assumed to represent future conditions, although changes in both climate and landscape will occur. Modelling evapotranspiration is a particularly vulnerable process (Bergström et al., 2001).

Figure 10.11. Regional climate modelling is based on studying a smaller region using the world climate models to establish driving conditions.
The calculations are done assuming that the present trends of greenhouse gas emissions will continue. This will then lead to a doubling of carbon dioxide in the atmosphere in the coming 100 years. The enhanced greenhouse effect will result in a gradual warming of the global atmosphere by 2.6 °C, with a confidence interval of 1.5-4.5 °C. For the Baltic Sea region the changes are larger than the world average. In both Baltic Sea basin climate scenarios, the average annual temperature increase is about 4 °C. The regional model with HadCM2 forcing gives slightly lower values and with ECHAM4 forcing slightly higher, but both are considerably higher than the 2.6 °C average annual global increase from these two scenarios. Regional differences between the two cases are most pronounced in the eastern and southern parts of the basin.

Seasonal temperature differences (not shown here) indicate larger increases in temperature during winter months than during summer months for both

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cases. As seen in Figure 10.13, changes in precipitation vary regionally from an average annual change of greater than 30% to lower than -10%. These changes are also highly seasonal, with the largest differences between the two scenarios occurring in summer. Summer temperatures on the Baltic Sea coast in the north, at Umeå e.g., would be like summer temperatures on the present German coast. Summer temperatures in Stockholm, Helsinki, and St. Petersburg would be more like it is today on the European continent. Changes in winter temperatures would be even larger.

**CONSEQUENCES OF CLIMATE CHANGE**

**Impacts on water resources in the Baltic Sea basin**

The analysed hydrological response to climate change in the Baltic Sea basin shows that the combination of changed precipitation and higher temperatures can have a significant impact on water resources in the region. The calculations show quite a dramatic increase in precipitation in the north by as much as 30%, while it will be drier in the south with a decrease in precipitation of as much as -10%. Among other things, this can influence hydropower production, dam safety, water supply, as well as the environment in the Baltic Sea region.

Water resource studies by SWECLIM consist of hydrological model simulations using scenarios of temperature and precipitation changes from climate models. Analyses of both large-scale hydrological impacts for the entire Baltic Sea drainage basin and more local basin-scale hydrological impacts (e.g. in Sweden) are carried out within SWECLIM. A large-scale application of the HBV water balance model (Lindström et al., 1997), referred to as HBV-Baltic, is used to calculate the total runoff to the Baltic Sea (Graham, 1999). Using a method often referred to as the “delta change approach,” scenario changes in both daily temperature and precipitation are added to a present climate database to create a changed climate database for simulations in HBV-Baltic.

Figure 10.15 presents the modelled hydrological response to climate change scenarios for the Baltic Sea drainage basin as average daily modelled river discharge.

*Figure 10.14. Flooding of River Wisła in 1997. The old Wisła, shown here, is used as an overflow-arm. Increasing numbers of flooding events is predicted to be one consequence of climate change. The 1997 flooding was dramatic in both the Polish major rivers, Wisła and Odra, and caused considerable economic damage. (Photo: Pawel Migula.)*
for the five main Baltic Sea drainage basins. Summarised in the figure are results from seven different climate simulations from the RCA model. Aside from the two different global climate scenarios, differences between these seven simulations lie in modifications to the RCA model and in different ways to apply the climate changes to the present climate database. It should be noted that changes in the timing and frequency of extreme weather events from the climate models are not represented here. Rather, the extreme events in the baseline climate are adjusted upward or downward according to the scenario changes applied.

The results show a trend of reduction of the springtime runoff peak from snowmelt as seen in Figure 10.14. This is most pronounced in the northern basins of Bothnian Bay and Bothnian Sea where snow plays a dominant role in the hydrological cycle. River discharge is thus generally more uniform over the year for all basins, with higher flows in winter and lower flows in summer. For parts of the basin (e.g. the north), this further implies changes in flooding potential from a decrease in spring flooding risk to an increase in autumn flooding risk.

Table 10.4 shows how the modelled climate changes affect annual river inflows to the Baltic Sea. According to these results, the total inflow to the Baltic Sea could either increase or decrease, depending on which global model is used for forcing the regional climate model. Large differences between the

The Intergovernmental Panel on Climate Change estimates that sea levels in this century could increase by 15-95 cm above the present level.
estimated effects of these two scenarios are evident in Table 10.4, particularly in the south. However, they both indicate changes in the distribution of freshwater inflow to the Baltic Sea. Annual river discharge from the south decreases significantly under the RCA44-E (ECHAM4) scenario, up to – 43% in the Baltic Sea proper, while river discharge from the Bothnian Bay in the far north increases. The RCA44-H (HadCM2) scenario shows an increase in the contribution of freshwater to all sea basins except for the far south. Such large changes in the distribution of river inflows could affect nutrient transport (e.g. nitrogen) to the sea. Furthermore, an overall increase in freshwater on the magnitude of the RCA44-H scenario will also impact salinity in the Baltic Sea (Omstedt and Axell, 1998).

Aside from simply adding more freshwater volume, changes in river runoff could negatively affect the major inflows of salt rich waters from the Atlantic through the Danish Straits. Matthäus and Schinke (1999) suggest that increased river runoff during winter has a particularly strong effect on salt water inflows. All of these changes could have substantial impact on the ecological conditions in the sea.

**Impacts on seas and oceans**

The oceans are influenced by increased global temperature in several ways. The higher temperature makes the water expand which increases the water level. It is also foreseen that the land ice in the Arctic area and, even more so in Antarctica, will melt and add to the sea level rise. Glaciers all over the world have already started to decrease, which is a sign that such a process has started. The global average sea level is projected to rise about half a metre over the next century, and substantially beyond that in the period thereafter.

The increased sea level would dramatically influence the situation in numerous low lying coastal areas all over the world, where millions of people are living today. Many major cities of the world are situated on the coasts and will be threatened by increased sea levels. The low-lying areas would substantially be affected through loss of wetlands, loss of dryland, saltwater intrusion, and increased risk of floods. However, the land in northern Fennoscandia is still rising, in response to the removal of the ice-caps of the last ice age. Sea level rise is thus unlikely to lead to land loss, it only reduces the expected land gains (Warrick et al., 1996).

The situation at the southern half of the Baltic Sea region is different, however. These coasts do not rise, and are vulnerable to climate change. Studies have been performed for some of these coasts, the results of which are reproduced in Table 10.5. Social and economic impacts of sea level rise in Poland and Estonia.

### Table 10.4. Modelled changes in runoff to the Baltic Sea

Results are given in percentage change according to the two models used. These results indicate that large changes in the runoff pattern are possible with increases in the north and decreases in the south, although uncertainties are relatively large.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Bothnian Sea</th>
<th>Gulf of Finland</th>
<th>Gulf of Riga</th>
<th>Baltic Proper</th>
<th>Total Baltic</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCA44-H:</td>
<td>Maximum</td>
<td>28%</td>
<td>18%</td>
<td>31%</td>
<td>-1%</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>10%</td>
<td>1%</td>
<td>0%</td>
<td>-17%</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>19%</td>
<td>10%</td>
<td>14%</td>
<td>-10%</td>
</tr>
<tr>
<td>RCA44-E:</td>
<td>Maximum</td>
<td>22%</td>
<td>14%</td>
<td>-10%</td>
<td>-26%</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>4%</td>
<td>-4%</td>
<td>-42%</td>
<td>-53%</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>14%</td>
<td>3%</td>
<td>-26%</td>
<td>-43%</td>
</tr>
</tbody>
</table>

### Table 10.5. Social and economic impacts of sea level rise in Poland and Estonia.

<table>
<thead>
<tr>
<th>Country</th>
<th>Sea level rise (m)</th>
<th>People affected (1,000s)</th>
<th>People affected (%)</th>
<th>Capital loss (% GNP)</th>
<th>Dryland loss (km²)</th>
<th>Wet-land loss (km²)</th>
<th>Adaptation (10^9 $)</th>
<th>Adaptation (% GNP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germanya</td>
<td>1.0</td>
<td>3,200</td>
<td>4</td>
<td>0.05</td>
<td>13,900</td>
<td>3.9</td>
<td>2,000</td>
<td>23.5</td>
</tr>
<tr>
<td>Polandb</td>
<td>1.0</td>
<td>240</td>
<td>1</td>
<td>0.24</td>
<td>1,700</td>
<td>0.5</td>
<td>36</td>
<td>1.4</td>
</tr>
<tr>
<td>Polandc</td>
<td>0.1</td>
<td>40</td>
<td>0.2</td>
<td>0.11</td>
<td>845</td>
<td>0.2</td>
<td>n.a.</td>
<td>2.5</td>
</tr>
<tr>
<td>Polande</td>
<td>2.5</td>
<td>235</td>
<td>1</td>
<td>0.82</td>
<td>2,203</td>
<td>0.6</td>
<td>n.a.</td>
<td>10.3</td>
</tr>
<tr>
<td>Estoniaf</td>
<td>1.0</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>60</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
</tbody>
</table>
in Table 10.5. The picture is far from complete, yet the numbers in Table 10.5 suggest that sea level rise is a problem. Table 10.5 also shows what it would cost to protect the coast against sea level rise, by building dikes, nourishing beaches, and so on. It turns out that it is possible to avoid a substantial share of the negative impacts of sea level rise at a modest cost. This would require considerable foresight and planning, however (Beniston et al., 1998).

**Society and climate change**

Climate change would affect all sectors and systems that are exposed and sensitive to the vagaries of the weather, and all sectors and systems that are affected by changes in such sectors and systems (Watson et al., 1996). It is hard to think of a sector or system that is not somehow influenced by weather and climate, but in most cases the effect is small. In other cases, the effect may be large. Climate change may have significant impacts on:

- unmanaged ecosystems and biodiversity,
- agriculture and forestry,
- water resources,
- coastal zones,
- human health, and
- energy consumption.

The sensitivity of these sectors and systems to climate change, and their options to adapt to changing circumstances are treated below.

**Human health.** Vector-borne infectious diseases are perhaps the most sensitive to climate change of all human health aspects. Distributions and activities of mosquitoes, snails, and other little animals carrying parasites depend to a large extent on weather and climate. Such diseases, however, are largely confined to warm countries and populations with limited access to basic health care. Although the potential for diseases such as malaria would undoubtedly increase if the Baltic Sea area were to warm up, it is unlikely that the health care system would allow these diseases to emerge in the area.

More important for the Baltic Sea basin countries are cardiovascular and respiratory diseases. At times of both extraordinary cold and hot weather, the number of people suffering or even dying from such disorders increases significantly, particularly amongst the elderly. Unfortunately, no study has been done to quantify these effects for any of the Baltic Sea countries. Studies for the UK, the Netherlands, the USA, and Canada suggest that, for a mild climate change, the number of heat-related deaths would increase and the number of cold-related deaths would decrease, and that the latter number would be greater than the former (Beniston et al., 1998).

**Energy consumption.** Much energy is used for climate control in buildings, be it for cooling in summer or for heating in winter. In temperate and boreal climates, such as in the Nordic and Baltic countries, the demand for heating in winter far exceeds the demand for cooling in summer. In a warming climate, total energy demand would thus first decrease. This would reduce the energy bill for companies and households, money which can be spent on other things. Kuoppmaeki (1996) reports estimates of the reduced energy demand in Finland of 1.5% in 2025 rising to 4.6% in 2100, and an annual saving of FIM 700 million.

**Other sectors and systems.** Recreation and tourism are obviously affected by weather and climate. People head south to enjoy the sun and to the mountains to go skiing. Climate change would affect the comparative advantages of tourist resorts, and would alter the inclination of people to spend a holiday far away from home. However, no studies have been conducted to estimate these effects.

Figure 10.16. CO₂ emissions in the Baltic Sea region. The national emission data from 1990 and later. The Kyoto protocol uses 1990 as reference year for most countries. (EEA-ETC/AE, 1997.)
The construction sector may benefit from the shorter period of extreme winter cold. The permafrost, however, is likely to shrink, which could damage the structures built on it.

The insurance sector may get hurt by unexpectedly heavy storms or floods. The financial sector may have to cope with the consequences of negative climate impacts (or deficient adaptation) in other sectors (Dlugolecki et al., 1996).

**Impacts on biology and ecosystems**

*Unmanaged ecosystems and biodiversity.* Warmer and wetter ecosystems are more productive and more diverse than colder and dryer ones. Carbon dioxide fertilization would also increase productivity. Warmer and wetter conditions are foreseen for the Baltic Sea region countries by the current generation of climate models. In the long run, therefore, bioproduction would increase due to climate change.

There are three downsides to this. Firstly, the long run is indeed long for ecosystems, in the order of centuries. In the meantime, current species and ecosystems could suffer while new species and ecosystems would just begin to settle. A rather impoverished landscape, occupied by pioneer species could be the result.

Secondly, northward migrations of species and ecosystems are limited, because of the declining amount of available space. The most northerly species could become extinct, a loss of landscape and biodiversity.

Thirdly, similar effects could be observed in lakes, on mountains, and in other ecosystems that are somehow fragmented. As conditions change, current species suffer and, having nowhere to go to, may become extinct (Beniston et al., 1998). A northward movement of distribution patterns of a number of insects have been seen in Europe during the last 20 years. These include some insects that are damaging to agriculture and forestry.

Fish are likely to seek new areas to live and new migration routes. Spawning grounds may be affected by sea level rise, coastal protection, and climate change (Everett et al., 1996).

*Agriculture.* At present, agriculture and forestry are obviously limited by the cold climate of Northern Europe, although soil quality and solar radiation are also important. In a warmer climate, the area suitable for agriculture would extend northwards, perhaps at a speed of 50 km per decade (Saarikko and Carter, 1996). Current agricultural practices and crops planted, however, are adjusted to the current climate, so that in order to reap the potential benefits farmers would have to adapt. It is to be noted that, although warming is beneficial for agricultural crops, it is also beneficial for weeds, pests, and diseases. A higher concentration of ambient carbon dioxide has a similar effect: it stimulates plant growth, of crops as well as of weeds. The balance between the two effects is not really known, but undoubtedly depends on crop management practices. The likely increase in precipitation may also have positive effects, provided that it falls at the proper time, or can be somehow stored, and that not too much falls at time when it hurts, e.g., at harvest (Reilly et al., 1996).

*Forestry.* The situation is similar for forestry. In general, increased carbon dioxide concentrations, higher temperatures, and possibly more precipitation would benefit tree growth, especially as the growth season would become longer. At the southern edge, however, current tree species may suffer from the heat or be out competed by more southern species (Solomon et al., 1996). Even if productivity would unambiguously increase with the enhanced greenhouse effect – as most models suggest – it is not necessarily to the benefit of the Nordic economies. Perez-Garcia et al. (1996) found that forest production would increase so much that world prices would fall substantially, and revenues of producers and exporters of forest products would decrease.

*Figure 10.17.* The biological consequences of climate change can already be noticed in the mountains in northern Scandinavia. The altitude limits for trees and several plants have increased in the last 20 years. Further south, the limits of distribution for several insects have moved north the last 20 years. (Photo: Lars Rydén.)

**Good or bad?**

Will climate change be good or bad? Not only negative but also positive effects are foreseen. People will have to act to reap the potential benefits. Regardless, the transition to a warmer climate may be painful, as “northern” habits and species suffer and “southern” ones are slow to move in. In a global context the effects seem to be very negative. Warmer countries, and particularly less developed countries, may get hurt badly. What is your opinion?
Ozone ($O_3$) is produced when $O_2$ molecules are split by ultraviolet solar radiation to form oxygen atoms which then react with $O_2$ to form $O_3$.

The ozone layer is found at 15-40 km height in the stratosphere where $O_3$ has a concentration of about 1-10 ppm.

Most ozone is produced above the tropical regions where solar radiation is the most intensive.

Stratospheric ozone and UV radiation

The stratospheric ozone layer

Ozone is formed in the atmosphere through reaction of oxygen molecules and oxygen atoms: $O_2 + O$ forms $O_3$, under the influence of ultraviolet light from the sun. Oxygen atoms are in turn formed as oxygen molecules dissociate under the influence of UV light. About 90% of the ozone in the atmosphere is found at a height of about 15-40 km above sea level, in the lower stratosphere.

Ozone is present also at lower atmospheric levels. For example, during lightning ozone is formed which can easily be noticed as it has a very distinct rather stinky smell. Ozone is quite reactive as an oxidant and thus closer to ground level it is an environmental problem, as it reduces plant growth. Economically, this is of importance to forestry where it causes large economic losses (see below).

The concentration of ozone in the stratosphere is determined by the balance between formation and destruction. There is a continuous flow from oxygen to ozone and back to oxygen, both under the influence of UV light. This is the so-called Chapman cycle. At equilibrium it results in 0.001% by volume concentration of ozone in this part of the stratosphere. Compressed to one single pure layer it would be only some 3-4 mm thick at ground level (atmospheric) pressure.

This amount of ozone absorbs very efficiently the ultraviolet (UV) radiation of the sun in the wavelength interval of 240-300 nm, so-called UV B. In this way it protects the Earth against this dangerous radiation. In addition it absorbs the heat radiation from the Earth and is thus a greenhouse gas.

In 1985, British scientists discovered that the concentration of ozone over the South Pole had reduced dramatically, about 50%, during the Antarctic spring in October – November. The data that was then compiled showed that the decline had begun in the late 1970s. The distribution of stratospheric ozone over the planet showed that the Arctic region was unique in this loss of ozone, and it was therefore called the “ozone hole.” The hole has since the 1980s increased in size and is today the size of the North American continent. It also persists longer into the Antarctic spring, into late November.

Since 1979 the annual decrease amounts to 5% globally. The accumulated loss in winter and spring in northern and mid-latitudes is about 11%. The Antarctic ozone hole, which is the largest, appear seasonally in winter-spring and has in the late 1990s tended to start earlier and last longer.

Since 1979 the annual decrease amounts to 5% globally. The accumulated loss in winter and spring in northern and mid-latitudes is about 11%. The Antarctic ozone hole, which is the largest, appear seasonally in winter-spring and has in the late 1990s tended to start earlier and last longer.

Since the late 1990s a reduction of ozone concentrations has also been recorded over the Arctic region. Here it appears in the late (Nordic) winter and early spring. The lowest value so far was recorded in 1997, with some 25% reduction. Reduced ozone levels then persisted into April, that is well into the period with more sunlight.

The consequences of increased UV radiation over the areas closer to the poles are presently subjects for research. It is clear that UV dependent damages on biological life will increase. Thus, there is already an observed increased incidence of skin cancer in Australia. It is also clear that photosynthesis is decreasing in the northern-most areas of Sweden and presumably also in the entire Arctic region.

Loss of stratospheric ozone is one of the major global environmental problems. After the discovery of the ozone hole considerable research has been done to find out the reason for it, and measures have been taken to remedy the situation.
Threats against stratospheric ozone – the freons

In 1974 two American researchers, F.S. Rowland and M.J. Molina, published their result that a major mechanism for ozone destruction was catalysed by atomic chlorine. They recognized that there is a natural low concentration of chlorine in the atmosphere, originating from the oceans. But they also suspected that chlorine-containing pollutants, if diffusing into the stratosphere, would be split by UV light into their component atoms and thus add massively to the destruction of ozone. A group of substances of special interest in this context was the freons, because of their extreme stability, low solubility in water, and low molecular weight. They would easily diffuse into the atmosphere unchanged and be transported to the stratosphere. There freons would be split by the ultraviolet light of the sun into constituent atoms, among them chlorine. Eventually the chlorine atoms diffuse back into the troposphere where they are dissolved in water and precipitate to Earth. But before that the average chlorine atom destroys some 10,000 ozone molecules.

After the discovery of the ozone hole an American research team in 1986 succeeded to prove, by using moonlight as the light for spectroscopy (!), that a dramatically increased concentration of chlorine atoms in the stratosphere explained the destruction of ozone.

Freons were thus proved to be the main culprit for stratospheric ozone destruction. Other chlorine-containing substances, such as the halogenated solvents carbon tetrachloride and three-chloro-ethane, also split to form free chlorine atoms by UV radiation. In addition nitrous oxides may also form free radicals that catalyze the destruction of ozone.

Freons are inert, non-toxic, odourless and with boiling points close to room temperature. They have been used in a range of technical applications over the years. In particular they have been used extensively as propellants in aerosol spray cans, for foam blowing, as coolants in refrigerators and for air conditioning. But they are also used as solvents, in production of plastics, and as insulation material.

Freons are derived from small hydrocarbons such as methane or ethane where all hydrogen atoms are exchanged for chlorine or fluorine. They are called CFCs, chlorofluorocarbons. CCl₃F, also called CFC11, a liquid with boiling point 24°C, is one of the most commonly used freons.

The global production of CFCs reached a peak in 1986 with about 1,300,000 tonnes yearly. In the European Union countries alone the production was then about 700,000 tonnes. Efforts to diminish the use of CFCs started in the 1970s with voluntary actions, and in 1979 they were outlawed as propellants in spray cans. But production increased as they found new uses in the 1980s. After the 1985 discovery of the Antarctic ozone hole the pressure to reduce freon use increased. In 1987 an agreement in Montreal (the Montreal protocol) to totally...
elaborate the use of ozone-depleting substances has led to significant decreases in production. In 1995 the global production was some 10-20% of its peak values. Emissions of CFCs to the atmosphere reached a peak in the period 1975-85 and has since decreased. However, the amount of stratospheric ozone is still increasing. It was calculated in the late 1990s that the amount of freons in the stratosphere would increase up to about the year 2000.

Other halogenated compounds with effects on the ozone layer include methyl bromide originating mainly from agriculture and burning of biomass. Methyl bromide concentrations in the atmosphere have not changed for several decades. A more important concern are nitrous oxides from e.g. burning of biomass, not least from forests fires in tropical areas in South America, Africa, and south-eastern Asia.

Energy for cooling
There is a circumstantial connection between ozone and energy systems. On a global scale it is assumed that more energy is used for cooling than for heating. This assumption might be difficult to substantiate, but it is clear that cooling is a very large and energy intensive sector in modern society. Air conditioning, especially in warmer countries, is continuously installed in buildings, apartments, and cars. Refrigerators and freezers are installed in homes as well as in the business sector, restaurants, shops, and so on. The largest users of cooling techniques may however be the chemical industry, process industry, and sports arenas.

The most prevalent technique for cooling is using the compressor-cooling principle. A cooling medium, or coolant, is circulated in a system where it is in alternatively gas and liquid form. The medium is brought to gas form in the evaporator, when a compressor is reducing the pressure as it continuously is sucking the vapour away through a valve into a condenser, where the medium, back to normal pressure, condenses to a liquid, and finally is recirculated to the evaporator. During the process the evaporator is cooled while the condenser is heated. The energy needed for the heat transfer is the one required to run the compressor. The same principle is used in heat pumps where the heat of the condenser is used to warm a space.

In the early technical developments ammonia was used as cooling medium. However ammonia is toxic, corrosive, and bad smelling. The introduction during the 1930s of a new group of cooling media, the halogenated hydrocarbons among them the freons, was a major technical breakthrough. Since the 1980s, substitutes for freons as coolants have been developed. These are mostly based on fluorine and chlorine containing hydrocarbons, but of a kind that is much less destructive to the ozone layer.

Figure 10.22. The ozone hole over Antarctica. The figure shows the extent of ozone depletion in September 1981, 1987, 1993 and 1999. (Source: NASA; http://earthobservatory.nasa.gov/)

A more generally interesting possibility is distant (district) cooling. Such systems are used e.g. in Stockholm and Uppsala. Main customers are industry and restaurants. The providers are the same as the district heating companies. Central cooling systems have more control over the coolants and can install safety devices to ensure minimum leakage. This is the same principle as when many individual heating furnaces are replaced by a central system to improve dramatically the air quality in a city.

One may of course ask if there are alternatives to conventional cooling technologies. Before the wide spread use of present cooling technologies, a year-round customary technique was to use ice stored in insulated piles for cooling, e.g. of food. This may sometimes be an alternative also today. In Sundsvall, in central Sweden, the snow removed from the streets in winter is kept by the hospital to cool water for the entire hospital. The melted water is in addition cleaned before being returned to the Baltic Sea. The economic gain is considerable as well as the environmental gain.

Alternative cooling techniques
A more generally interesting possibility is distant (district) cooling. Such systems are used e.g. in Stockholm and Uppsala. Main customers are industry and restaurants. The providers are the same as the district heating companies. Central cooling systems have more control over the coolants and can install safety devices to ensure minimum leakage. This is the same principle as when many individual heating furnaces are replaced by a central system to improve dramatically the air quality in a city.

Case

Case

Case

Case

Case

Figure 10.22. The ozone hole over Antarctica. The figure shows the extent of ozone depletion in September 1981, 1987, 1993 and 1999. (Source: NASA; http://earthobservatory.nasa.gov/)
A new energy regime
Taking us out of the damaging impacts on the atmosphere requires a new way to manage energy systems. It is clear that today's systems, highly dependent on fossil fuels, violates both the physical (Chapter 2) and biological (Chapter 3) rules for sustainability. The physical rule requires that substances not be accumulated in the biosphere. However, both carbon and sulphur are accumulating in the present systems. The biological rule points out that all existing ecosystems rely on solar energy to support themselves with energy. We will look at the alternatives here in terms of first how to get out of the carbon dependency of present carbon-linked systems, and secondly how to set up systems that eventually rely on the sun.

The ways in which society implements energy source solutions involves policy making, including international negotiations, economic tools, and legal restraints, as well as some technical means. Even though several of these have been mentioned briefly here, they are mostly dealt with in Part C of this book.

It is important to mention that the energy from the sun that reaches the Earth's surface is large, of the order of 100,000 TW (Tera watts). People use a very minor part, about 1 out of 10,000 units, of this energy. The problem is thus not that there is a lack of energy. The problem are the material flows linked to our energy flows.

Political changes and decisions will be very important for developing alternatives in the future. The European energy sector is in a period of major transition. From a situation characterised by state monopolies and strong regulations, the markets for electricity and gas production are subject to liberalisation at both the member state and EU levels. Liberalisation is changing the context for environmental policies. The liberalisation has resulted in lower prices, and the energy demand is higher than it would otherwise have been. Increased exposure to competition and commercial risk is forcing electricity producers to seek out less capital-intensive forms of production. This has stimulated investment in gas-fired power. However, in the longer term, it could inhibit the adoption of carbon-free renewable energy forms. Another possible impact of liberalisation is a decline in research and

<table>
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<td>* Nuclear</td>
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Figure 10.23. Carbon dioxide reduction options.
technological development activity conducted by utilities in the public interest. Still it is possible that economic policies, such as increased taxation on fossil fuels, will have an opposite effect.

It is important that today’s energy policies facilitate the development of environmentally friendly technologies of energy use. Otherwise, the capital stock of the sector could become locked into a structure which entails high emissions of greenhouse gases and other pollutants. The most difficult aspect of energy policy by far is transport. Transport accounts for 30% of all energy consumption in the EU. Road transport consumes over 80% of transport-related energy. Transport is a sector in which any action to change the course of existing paths is difficult because of the long development times involved. In the household and industry sectors, many actions of transformation of energy technologies and management have already been initiated.

**Taking carbon out of our energy systems**

At present human activity results in emission of about 6 Gton C/year carbon from fossil fuels, and 1-2 Gton C/year from deforestation. In order to stabilise atmospheric concentrations at roughly the present level, emissions must be reduced by about 50%. But, if nothing is done, emissions are expected to increase several-fold over the next century, which will lead to dramatic warming on a global scale. Some options to combat global warming follow.

Future energy related carbon emissions can be discussed using the formula below:

\[
CO_2 = P \cdot \frac{GDP}{P} \cdot \frac{E}{GDP} \cdot \frac{CO_2}{E}
\]

Here \(P\) is population, \(GDP\) is the gross domestic product, but could also be taken to mean the world GDP if a global perspective is taken, and \(E\) is energy use. It can be seen that there are fundamentally four different measures that can be taken to reduce future \(CO_2\) emissions:

- limit global growth rates in population,
- limit average income per capita,
- limit energy use per any given level of income, and
- reduce the carbon content of the supplied energy.

Reduction of global population growth is often overlooked but it is a very important measure that could have a substantial impact in the long run. It could also bring about many other positive benefits. Limiting economic growth may not be desirable nor necessary. Rather, focus should, where possible, be on both reducing the level of \(CO_2\) emissions in on-going activities (increasing efficiency), and reducing the economic activities that cause \(CO_2\) emissions. Therefore, we will concentrate on the latter two measures. Figure 10.24 summarises the various measures discussed in the text below. A separate option is to use less energy by improving efficiency of energy use.

Reducing the carbon content of the supplied energy is an option that focuses on the supply side. At present, 85% of the global commercial energy supply is based on fossil fuels. Reduced carbon emissions can be obtained by the four measures: (1) intra-fossil fuel substitution, (2) fossil fuel decarbonisation, (3) using nuclear energy, and (4) using renewable energy sources. These options are examined below.

Though \(CO_2\) is not emitted at a nuclear power station from the production of electricity. A significant amount of \(CO_2\) however is emitted in the production of nuclear fuel (Sui-San, 1997). Uranium mining, for example, is in general one of the most \(CO_2\) intensive industries. The \(CO_2\) release per uranium combusted energy corresponds to about 10% of coal-based energy.
During the 1960s and the 1970s the nuclear industry grew rapidly, but concerns about accidents, nuclear waste and proliferation of nuclear bombs led to a sharp decline in construction rates (see further Chapter 11). Costs were also, of course, a limiting factor. Fusion technologies would make an improvement in terms of radioactive waste in that no heavy nuclides, e.g., plutonium, would be produced, but it is too distant in time, if it is ever to be realised, to play any role for present energy supply choices.

Below we will consider reduced carbon emissions. However there is also the other end of the carbon flow to consider, carbon sequestration, or flow of carbon from the atmosphere to sinks. Net binding of carbon in biomass is important in the northern Baltic Sea region particularly as peat formation. In the south, especially in Africa, changed agricultural practices might be decisive. It is pointed out (Arrhenius, 1998) that if agriculture and forestry are mixed, as in many traditional systems, the organic content in the soil would increase rather than as now decrease. The microbial activity in the soil is the key component. In full scale this carbon sink would be in the same order of magnitude as the fossil fuel caused carbon net flow. It would lead to both reduced global warming and improved land management.

The role of natural gas

Intra-fossil fuel substitution mainly concerns substituting natural gas for coal in power-plants, but also natural gas for diesel and gasoline in the transportation sector. This contributes to lower carbon emissions, because the carbon content per GJ for natural gas is substantially lower than the corresponding carbon content for oil and coal. In several European countries, e.g., Poland and Germany, an expansion of natural gas in their electricity sector would reduce CO₂ emissions, of course only if this expansion would be substituting coal, or occur at the expense of increased investments in coal fired power plants. However, introduction of natural gas in the Swedish electricity sector does not lead to a reduction of CO₂ emissions in Sweden, since the Swedish electricity sector does not use coal or oil.

At present natural gas is introduced or expanded on a large scale in the entire Baltic Sea region. Both the Russian Federation and Norway are major producers of natural gas. New pipelines are planned from Russia to Poland through Ukraine, and further to western Europe. Another route goes from Arctic Russia through Finland further south along, or on the bottom of, the Baltic Sea to central Europe. A third pipeline runs from the Norwegian oil platforms in the North Sea to Germany.

In parallel with the introduction of natural gas, coal mines have been or are being closed in many countries in Europe, from west to east. With a start a generation ago in Wales coal mines were closed in England, Belgium and Germany, and now also in Poland. Considering the existing economic and social problems one might expect closing coals mines also in Ukraine and Russia in the future. Together these changes constitute a massive scale decarbonisation of energy flows, but does not take us out of fossil fuel dependency. It may be seen as a step towards sustainable energy systems, which however depends on the national policies. Use of natural gas also constitutes a major dematerialisation of energy flows, since transport using pipelines is much less material intensive than transport of coal, and in addition the ecological rucksack of gas is very small compared to that of coal mining.

Another option is fossil fuel decarbonisation or carbon sequestration of the stack gases, and subsequent carbon deposition. Fuel decarbonisation means that carbon is removed from the fuel before it is used. This is done by using the fossil fuel to produce hydrogen. In this process, pure CO₂ is obtained and could be captured and deposited in natural gas wells, aquifers or in the deep ocean. Carbon sequestration is only possible when fossil fuels are used in stationary applications, e.g., electricity generation.

Note that these technologies could also be used for bioenergy, e.g., when converting biomass into hydrogen, CO₂ is obtained and could be stored. If so,
bioenergy would actually be a carbon sink which would remove CO₂ from the atmosphere. The critical issue is to assess the potential for carbon deposition and potential environmental impacts, in particular if it is stored in oceans.

**Renewable energy sources**

Renewable energy sources include biomass, hydropower, wind, solar, tidal, wave, hydrogen, and geothermal technologies. The so-called flowing energies are wind, water, and waves. The use of all three often require installations that make large intrusions in the landscape. Due to physical conditions, wave and tidal power have only a small potential in the Baltic Sea region. However, they can be used in other parts of the world.

Hydropower provided about 18% of the world’s electrical energy in 1990. It has been estimated that only about 15% of the world’s technically exploitable potential is now used. However, the applications are limited by scarcity of capital, environmental effects, and the cost of long-distance transmission. Huge reservoirs constructed upstream of power stations affect flora and fauna and may force population resettlement. They can also change water quality, and affect sedimentation and aquatic ecosystems.

Hydropower is the most important renewable energy source in the Baltic Sea basin. It has been used for almost 100 years. The large hydropower stations in northern Sweden and Norway were built in the early and mid-20th century. In 1993, hydropower accounted for 70% of Latvia’s electricity production. In Sweden and Finland this share was 51% and 20%, respectively. Large-scale hydropower is not expanding in the Baltic Sea region. However the technology for small scale hydropower, which causes much less environmental impact, is developing in a very interesting way. Even very small and sometimes old dams
and waterfalls may be used for electricity production with very little impact on the existing water levels and flows. The installations are often completely automatic and can be managed over computer networks far away from the actual site. The electricity produced may be used for a village or a small number of households. Thousands of such small hydropower installations exist in Sweden, and they are being introduced in e.g. Latvia and Poland.

At present, windpower is the most rapidly growing energy technology (in relative terms) and costs for wind power is already competitive in bulk markets. Denmark, where the natural conditions for windpower are excellent, has expanded its production (year 2000) to account for about 20% of the national electric power. Large scale installations, wind parks, in the open sea are planned along the west coast of Sweden, and on the Baltic Sea side along the German and Swedish coasts, and in the Kaliningrad district. Wind power stations have a considerably larger efficiency over open water than over land.

Environmental problems associated with wind turbines include noise, bird strikes, and aesthetic considerations. The building of wind parks regularly meets resistance due to its impact of the natural landscape.

Hydropower and windpower use turbines to produce electricity. A drawback is that electricity cannot be stored to any significant degree. A way to get around this is to store water in reservoirs, or even use electricity to pump water to such reservoirs, which can be done with great efficiency. The large hydropower dams in the northern Baltic Sea region in other words may serve as “batteries” for the region if other installations are connected to them over the electricity grid.

Using natural photosynthesis – biomass

Biomass is the most traditional form of energy. In the Baltic Sea region the large land areas and forests always provided wood for households as well as industrial activities. Biomass is still a widely used renewable energy source in the Baltic Sea region. In Finland and Sweden, wood waste-products are used for heat production in industry and in district heating stations. In Denmark and Sweden, vegetal waste products from agriculture are increasingly used for heat production. In the Nordic countries, wood waste and other biofuels, such as industrial waste, e.g. from the chemical pulping process in paper production, are increasingly utilized by district heating plants and in industry. In addition peat is an important fuel in e.g. Finland and Estonia as well as other countries in the region.

Dedicated energy plantations, mostly using fast growing Salix, are also important. The negative environmental impacts that may arise from energy plantations are related to the land-use requirements, use of fertilizers, recycling of ashes to maintain soil fertility, and use of pesticides and herbicides.

Technologies for converting biomass into more modern energy carriers, e.g., liquid biofuels, hydrogen, or electricity, are improving at a steady rate. On a global scale, the potential for biomass energy is limited, in particular given that land must also be used for food production.

Incineration of solid waste is one way to use biomass. This technology has been heavily criticised for its possible emission of air pollutants, such as dioxins. However, modern incineration technologies seem to have solved that problem. Even if e.g. sludge from waste water treatment plants are included, the waste incineration will not account for more than about 5-10% of present energy demands.

In the long run the only option to meet energy needs for our society is the direct conversion of solar energy. Direct solar energy can be used for heating, electricity production, and transportation fuel. This seems today to be the only way to dramatically reduce the emission of pollutants and change the negative influence on the atmosphere. These steps toward a sustainable society are further discussed in Chapter 25.
**Review Questions**

1. Summarize the different impacts that energy production has on the atmosphere. List the consequences of each of these impacts.
2. Make a small drawing of the components in an energy system.
3. Describe the fossil fuels and estimated reserves of each.
4. Summarize what the enhanced greenhouse effect is and the emissions that cause it.
5. What climate changes will occur in the Baltic Sea region if there is no change in greenhouse gas emissions?
6. Describe some of the biological, economic, and social consequences of climate change.
7. Describe the role of the ozone in the stratosphere and how it is formed and degraded (the Chappell cycle).
8. What are the present impacts on the ozone layer? Explain the Antarctic and Arctic ozone holes.
9. List the most important pollutants in the destruction of stratospheric ozone and how the destruction occurs.
10. Describe the different strategies of decarbonization of energy flows.
11. Describe the advantages and disadvantages of using wind power and hydropower, and the extent in which these sources of energy are used today.
12. Discuss the possible role of natural gas in making energy systems less damaging to the atmosphere.
13. What changes would you like to see in the energy system in your country to reduce environmental impacts on the atmosphere?

**Literature and References**


**Further reading**


**INTERNET RESOURCES**

BioAlcohol Fuel Foundation  
www.baff.nu

BP Statistical Review of World Energy  
http://www.bp.com/centres/energy/index.asp

CIESIN Ozone depletion and global environmental change  
http://www.ciesin.org/TG/OZ/OZ-home.html

Climate Action Network Europe  
http://www.climnet.org

EEA - European Environment Agency  
http://www.eea.eu.int

EMEP - European Monitoring and Evaluation Programme  
http://www.emep.int

Environment Directorate of the Commission of the European Communities  
http://www.europa.eu.int/comm/environment/air/index.htm

European Environment Agency  
http://www.eea.eu.int

Global Change  
http://www.globalchange.org/default.htm

GRID Arendal, United Nations Environment Programme  
http://www.grida.no/

Hydrogen cars  
www.h2cars.de

IAE - International Energy Agency  
http://www.iea.org

Intergovernmental Panel on Climate Change  
http://www.ipcc.ch/

International Energy Agency  
www.iea.org

International Energy Data  
www.eia.doc.gov/emeu/international/energy.html

IPCC - Intergovernmental Panel on Climate Change  
http://www.ipcc.ch/

ISES - International Solar Energy Society  
http://www.ises.org/

NASA  
http://earthobservatory.nasa.gov/

Potsdam Institute for Climate Impact Research  
http://www.pik-potsdam.de/

Rocky Mountain Institute  
http://www.rmi.org

SEI - Stockholm Environment Institute  
http://www.sei.se/

Svensk vindkraftförening, (Swedish windpower association)  
http://www.svensk-vindkraft.org

SWECLIM  

SWECLIM - Swedish Regional Climate Modelling Program  
http://www.smhi.se/sgn0106/rossby/start.htm

Swedish Environmental Protection Agency  
http://www.environ.se

United Nations Framework Convention on Climate Change  
http://www.unfccc.de

United States Environmental Protection Agency: Ozone Depletion  
http://www.epa.gov/ozone/

US Global Climate Change Research Programme  
http://www.usgcrp.gov

WISE - World Information Service on Energy  
http://www.antenna.nl/wise/

World Coal Institute  
http://www.wci-coal.com

World Energy Council  
http://www.worldenergy.org/wec-geis/

WMO - World Meteorological Organization  
http://www.wmo.ch

WRI - World Resource Institute  
http://www.wri.org/
greenhouse gases

the effect that leads to global warming, caused by anthropogenic release of enhanced greenhouse effect

companies and authorities, can also be included energy service; the organizations needed to operate these structures, consist of energy sources, energy carriers, power plants, distribution, and the energy systems

the service and the rest is dissipated as heat

lighting, heating, etc.; in most energy services a small percentage provides energy services

strategies and measures to reduce energy use or make it more efficient
energy saving

misnomer since energy is not produced just converted or extracted and converted energy consumption

or energy use, since energy is not consumed just converted; energy use is shared roughly equally between households, industry, and the transport sectors

energy conversion

for example when coal is burned in a power station to produce steam which drives a turbine which turns a generator producing electricity
energy for cooling

a major use of energy on a global scale, e.g. in the chemical industry, process industry, sports arenas, and for air conditioning
energy intensity

the relationship between energy demand and economic growth defined as energy consumption divided by gross domestic product
energy production

misnomer since energy is not produced just converted or extracted and converted
energy saving

strategies and measures to reduce energy use or make it more efficient
energy services

lighting, heating, etc.; in most energy services a small percentage provides the service and the rest is dissipated as heat
energy systems

consist of energy sources, energy carriers, power plants, distribution, and the energy service; the organizations needed to operate these structures, companies and authorities, can also be included
enhanced greenhouse effect

the effect that leads to global warming, caused by anthropogenic release of greenhouse gases

fossil fuel

includes oil, gas, and coal, as well as forms thereof such as oil shale
freons

also called CFCs, chlorofluorocarbons, are inert, non-toxic, odourless gases and with boiling points close to room temperature, used especially as propellants in aerosol spray cans, for foam blowing, as coolants in refrigerators and air conditioning; freons are a main cause of the destruction of stratospheric ozone

global climate negotiations

negotiations between the nations of the world, which agreed in 1997 on the Kyoto protocol, which is a basis for efforts to reduce greenhouse gas emissions
global warming, climate change

the present period of climate change with increased average global temperature, which over the last 100 years increased by about 0.7°C., one-third occurring after 1980
greenhouse gases

components of the atmosphere which contributes to the heat balance of the Earth, most importantly water vapour and carbon dioxide, but also methane, freons, ozone and others

coolant

the cooling medium circulated in a system where it is in alternatively a gas and liquid form; heat is transferred from the evaporator to the condenser decarbonisation

reducing the carbon content of the supplied energy through intra-fossil fuel substitution or use of renewable energy sources
district cooling

central cooling systems that provide cold mainly to industry and restaurants
energy consumption

energy conversion

for example when coal is burned in a power station to produce steam which drives a turbine which turns a generator producing electricity
energy for cooling

energy production

misnomer since energy is not produced just converted or extracted and converted energy saving

strategies and measures to reduce energy use or make it more efficient
energy services

lighting, heating, etc.; in most energy services a small percentage provides the service and the rest is dissipated as heat
energy systems

consist of energy sources, energy carriers, power plants, distribution, and the energy service; the organizations needed to operate these structures, companies and authorities, can also be included
enhanced greenhouse effect

the effect that leads to global warming, caused by anthropogenic release of greenhouse gases

IMPACTS ON THE GLOBAL ATMOSPHERE