

Environmental Effects of Thermal Power Generation

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In Sri Lanka, energy requirements are met by burning of biomass, combustion of fossil fuels and hydro-generated electricity. The fossil fuels are also used to supplement hydro-electricity through the operation of thermal power plants, particularly during the drought periods when the hydro power plants are operated below their installed capacity. The existing thermal power plants are :

<u>Plant</u>	<u>Installed Capacity</u>
Kelanitissa Steam Plant	45 MW
Kelanitissa Gas-Turbine Plant	120 MW
Sapugaskanda Diesel Plant	80 MW
Chunnakan Diesel Plant	10 MW
KKS Gas-Turbine Plant	17 MW

The installed capacity of all the five thermal plants is 272 MW and this is only 21% of the total installed capacity of 1290 MW, the balance coming from hydro-electricity[1]. The total electricity generated is about 10% of the gross energy produced in the country. However, in terms of the gross generation of electricity, the contribution from the thermal plants has been only 5 Gwh compared to 3145 Gwh from the hydro-power plants for the year 1990. In the previous year however, these two quantities have been 56 Gwh and 2800 Gwh, respectively. The relative contributions from thermal power and hydro power depend largely on the rain-fall pattern.

The Masterplan for the Electricity Supply of Sri Lanka prepared by a team of German Consultants to the CEB has proposed setting up a mix of thermal power stations within the next two decades[2]. These include oil and coal fired steam power plants, combined cycle plant, diesel plants and gas turbines. The optimization studies carried out by the Con-

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sultants have shown that 240 MW of diesel plants and 110 MW of gas turbines would be feasible by the year 2000. Beyond this period, they have recommended adding on a total of 600 MW coal-fired plants, 400 MW diesel plants and 330 MW gas turbines, subject to fluctuations in the oil and coal prices in the world market. Sites close to load centres in Colombo and Galle have been identified for oil-fired diesel and gas-turbine plants while Trincomalee or Mawella near Matara has been identified for locating coal power plants.

The expected share of energy contribution by various plant types operated by CEB during the two decades upto 2010 is shown in figure 1. According to this diagram, the hydro-energy component will decline steadily beyond the year 2000 with diesel and coal filling the gap. It is envisaged that the coal plant will be operative beyond year 2006. The actual operating schedules cannot be forecast accurately now as it would depend on so many factors such as growth of country's industry, financing available and government policies. It should be remembered that some of the forecasts made a decade ago at the Energy Seminar organized by the Sri Lanka Association for the Advancement of Science and the National Academy of Science have not been realised today. Both the maximum demand and the total energy generation achieved in 1990 have been about two-third the forecasts made in 1980[3]. Whatever the actual values, the trends for future expansion of the country's electricity generation capacity is clear; that is thermal power stations have to be added on to the system to meet the energy requirements of the country at the turn of the century and beyond. The choice of the actual type and capacity of plants have to be carefully done taking into consideration various engineering and operative factors and also economics of their long-term operation. The recommendation made by the consultants for the expansion of the electrical power generating system are obviously based on such factors. However, it is not clear from their report to what degree the environmental impact of the different options have been studied in detail. The report however has worked out the total gaseous emissions expected from the mix of thermal plants recommended by the team (figure 2).

These comprise of SO₂, NO_x and ash. Though CO₂ is not included, it is also emitted from all thermal power plants which burn fossil fuels. It is probably left out from the Masterplan studies because it is not considered a pollutant locally. But at global level, the addition of CO₂ into the atmosphere from various anthropogenic sources is considered a serious threat to the Earth's environment.

The thermal power plants, other than nuclear, derive the necessary energy to generate electricity from burning fossil fuels such as petroleum products and coal. During their combustion, the chemical energy contained in these substances is released. The energy content in fuels is expressed in terms of calorific values, either gross or net. The calorific values corresponding to popular types of fuels are given in Table 1. These are only typical values as the exact values would depend on each batch and the source. An important factor to note here is that oil has almost double the heat value of coal.

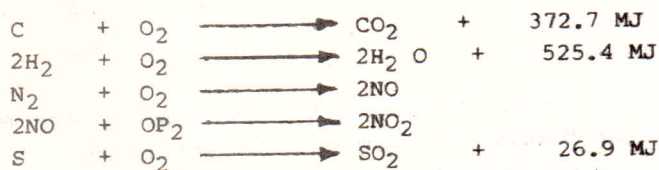
Coal

Coal is found more extensively on the Earth than oil with major deposits in the USSR, USA, China, Australia, Canada, India and some European countries. The total world coal reserves are estimated to be about 10,000 billion TCE* of which only about 640 billion TCE are economically recoverable[4]. At the current production rate these could last another 200 years, much longer than that for oil. Coal has different geological formations and these fall into two broad categories, hard coal and brown coal depending on their heat value; hard coal having heat value more than 5700 kcal/kg(23.76 MJ/kg) and brown coal less[4]. Hard coal is found more extensively than brown coal, at least greater by a factor of 3, and on an average, heat capacity of hard coal is about twice that of brown coal. When burnt, hard coal burns with a blue flame whereas brown coal produces a more

* 1 Ton Coal Equivalent (1 TCE) is the weight of coal having the same calorific value as that of 1 metric ton of hard coal with calorific value 7000 kcal/kg or 23.76 MJ/kg

sooty one, indicating the presence of more non-carbonic matter in the latter.

The combustion of coal gives rise to the following basic reactions.



Complete combustion of carbon produces CO₂ which is added on to the atmosphere. In practice this may not be realized fully and some CO could also be produced as a result. Nitric Oxide and nitrous oxide are also produced when atmospheric nitrogen reacts with oxygen at very high temperatures found inside the combustion chamber.

Modern plants have adopted various techniques to overcome the emission of SO₂ as well as NO_x (NO and NO₂). The first option is to use coal with low sulphur content. Next is to remove Sulphur from coal by cleaning the coal prior to combustion, and improving the combustion process. Any residue SO₂ could be removed from the stacks. Much development work has been done to improve the combustion of coal resulting in less SO₂ formation. Most modern plants use fluidised bed combustion technique where the coal particles are held in suspension on an upward flowing stream of air. The rapid mixing of particles causes more efficient combustion. It also allows introduction of crushed lime or dolomite along with the air stream which is capable of reaching the Sulphur in coal and remove its oxide from the emissions. Because the combustion in a fluidised bed takes place at a lower temperature than in the conventional forms of combustion, the extent of NO_x formation is also reduced, though not completely eliminated. Several modifications to the basic fluidised bed technique are available, some still in the experimented stage. With these improved combustion systems it has now been possible to retain upto 80-90% sulphur in the ash without being emitted into the atmosphere. However, such plants need more careful control of the operating parameters and are generally more complex and costly.

The remaining 10% of the Sulphur will find its way into the stack along with flue-gas. With modern stack designs involving wet scrubbers and desulphurisation techniques, it is possible to cut down the Sulphur content in the flue gas considerably. The SO₂ emitted after mixing with the ambient air would have concentrations below the upper limits imposed by regulations which are in the range 100-500 ug/m³ depending on the country⁵.

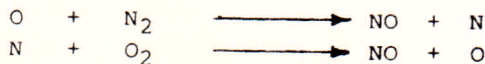
The operation of a coal power plant poses many environmental problems. First is the pollution of the immediate neighbourhood of the plant due to the spread of coal dust. Depending on the quality of coal and the plant efficiency, a 600 MW coal-fired plant complex as planned will require a daily feed in the range 4800-6000 Tons for 100% load factor. Assuming a storage capacity to last at least 3 months, a stock of over half a million Ton is necessary. The transport, handling and storage of such a vast amount of coal would certainly be an environmental problem for the immediate neighbourhood.

Diesel and Gas-turbine Plants

The existing thermal plants are all driven with petroleum fuels; residual fuel oil (RFO) for the diesel generators and distillate oil (DO) for the gas-turbine plants. Among the various options, one proposal includes adding a set of 640 MW of diesel generators and 440 MW of gas-turbine plants over the next two decades. The average efficiencies of these plants are about 32% for the diesel plants and 10% for gas-turbine plants¹. Hence the corresponding heat inputs are 2000 MW and 4400 MW, respectively. Assuming the calorific values are 41 MJ/kg for RFO and 43.5 MJ/kg for DO, the fuel consumed per day amount to 4210 Tons of RFO and 8740 Tons of DO.

In internal combustion engines, the fuel is not burnt completely. Hence the hydrocarbons are not completely converted to CO₂ and H₂O, and a certain amount of CO is also produced. Heavy residual oils as well as distillates also contain sulphur upto concentrations of 1-5%. These generate SO₂ and traces of SO₃ which are emitted in the exhaust. Hence, SO₂ pollution also takes place with oil driven plants as well.

Petroleum oils, unlike coal, do not contain nitrogen. In the combustion chamber where the temperature is over 1600 °C, nitrogen in the air is converted into nitric oxide through the reaction.



NO would subsequently yield nitrous oxide through the reaction



Any attempts to reduce NO_x emissions were found to affect the engine performance, as the NO_x emissions are directly related to the combustion temperature. Catalytic conversion of NO_x to nitrogen has also been investigated without success. Some control techniques tend to increase other emissions or fuel consumption. Hence the emission of nitric oxides from diesel engines is one of the more difficult ones to control.

Spread of Pollutants

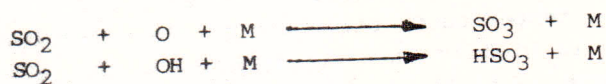
At thermal power plants, the flue gas is released to the atmosphere after traversing through a tall stack tower. With the high concentration of trace gases formed near the stacks, diffusion would take place to make the concentration more evenly distributed. In the atmosphere, diffusion of particles would take place through two independent mechanisms, one is molecular diffusion and the other eddy diffusion. In the upper atmosphere, the eddy diffusion is far more effective than the molecular process. Eddy diffusion is really a lumped parameter representation of various short-term dynamical phenomena including turbulent-mixing and convections which give rise to vertical movements of particles. The rate of diffusion, expressed in terms of a diffusion coefficient, is closely related to the temperature structure of the atmosphere. It is high in the troposphere and the metosphere where the temperature gradient is negative and it is low in the stratosphere where the gradient is positive. This is because a positive temperature gradient inhibits vertical movement of air parcels. Figure 3 shows a plot of diffusion coefficients against height. The diffusion coefficient also determine the residence time of particles at a

given height range. For the values shown, any inert substance will reside for about 2 years in the troposphere. When local temperature inversions occur, it could result in 'tapping' of pollutants into a layer at the conversion. Such temperature inversions however, do not last long.

In addition to the vertical movements, flue gas coming out of a stack is subject to horizontal transport as well. These can be even observed visually when plumes get carried away to long distances by winds. The speed and direction of winds will therefore determine the location where the pollutants are deposited. However, in the course of horizontal transport, the pollutants in the flue gas will get dispersed and mix up with the ambient air, raising the level of pollutant at that location. Raising the stack height will eliminate depositing of pollutants within a close range, but will contribute to polluting air far away. There are reports that emissions of SO₂ from industries in UK are responsible for acid rain in Scandinavian countries. In Sri Lanka where the coal power plants are to be located near sea coast, deposition of pollutants in the land could be avoided at least during the time when the winds are towards the sea.

SO₂ and Acid Rain

Sulphur dioxide released to the atmosphere from thermal power plants, and also from other industries burning sulphur containing fossil fuels, could find its way back on to the Earth surface either as 'dry' deposition or 'wet' deposition. Dry deposition could take place through the conversion of SO₂ to SO₃ by means of three-body reactions involving atomic oxygen O or the free radical OH :



Where M is a third body.

When SO₃ interacts with moist air or clouds, H₂SO₄ is formed :



Wet deposition of SO₂ could take place during rain when SO₂ gets washed out down to the Earth. It also takes place when SO₂ comes into contact with mist hail or snow and precipitate down to the land. The wet deposition or the Acid rain occurs only when there is precipitation or rain and hence is intermittent. On the other hand, dry deposition is a continuous process and makes a significant contribution towards increasing the acidity of lake or stream water (figure 4).

According to the Masterplan 'reference' scenario, the SO₂ emissions from the proposed thermal plants to be established by year 2010 are estimated to be 64 kTon annually. On the other hand, the global SO₂ emissions from all coal and petroleum burning is about 130 x 10³ kTon/year [6]. Though globally Sri Lanka contribution is insignificant, it could have adverse effects on the immediate environment. It has to be remembered that the above SO₂ estimates are based on the fact that all sulphur content in coal and diesel is converted to SO₂ during combustion. If we assume that coal which comprises 88% of the fossil fuel to be consumed in year 2010, and that coal when burnt in a fluidised bed allows only 10% of Sulphur go into the flue gas, the SO₂ released will be around 8 kTon/yr. This could be further reduced if flue gas desulphurisation system is used.

Natural Acidity

Acidity in rain water can also be caused due to the presence of carbonic acid ion HNO₃ and nitric acid ion NO₃⁻. Both these are formed due to natural causes, the carbonic acid through atmospheric CO₂ dissolving in cloud-water which gives rise to a pH value of 5.6 NO_x gases which are present in the atmosphere due to natural sources such as microbial processes in soils (...Tg N per year) and lightning (8 Tg N per year) also contribute to natural acidity of the atmosphere. These values are of the same order of magnitude as the total emissions of NO_x from combustion of fossil fuels (21 Tg N per year). The NO_x gases could yield HNO₃ in the presence of O₃ and H₂O. However, the total acidity due to these natural effects may not be worse than pH = 5. However, measurements indicate that near industrial cities the pH value may even fall below pH of 4 [7].

When environmental pollution due to fossil fuel burning in power generation is discussed, the emission of CO₂ is not considered a pollutant. To generate power, one has to essentially burn a certain minimum quantity of fuel and in the process, CO₂ is emitted. The total CO₂ emission globally arising out of burning fossil fuels is estimated to be 5.7 GtC (Giga-ton-Carbon), with an average annual growth of about 4% since the middle of the last century[8]. It has been estimated that 95% of CO₂ are emitted in industrial countries who on an average release each year 5 tC per capita. On the other hand, CO₂ emissions in most developing countries lie between 0.2 and 0.6 tC per capita per year. However, developing countries do contribute significantly to CO₂ build up in the atmosphere due to deforestation.

The total fossil fuel requirements estimated in the CEB Masterplan for 'reference' scenario is 3140 kt per year in 2010. Assuming 80% of the fuel contains Carbon, the proposed thermal plants will release 2000 ktC of CO₂ per year. Though this is insignificant in the global scene, one has to be conscious of this fact, as any increase in the CO₂ concentration in the atmosphere will contribute to enhancing the Green House Effect, resulting in a significant temperature rise in the atmosphere.

It has been observed that during the last 250 years, the CO₂ concentration has increased from about 275 ppm to 350 ppm[9]. This period coincides with the industrialization era and hence it is believed that the CO₂ build up is due to human activities (See figure 5). Along with this it has been observed that there is an overall increase in the earth's average temperature amounting to 0.5°C since beginning of this century[10]. The working group of the Intergovernmental Panel on Climate Change of the WMO has estimated that if the Green House gases including CO₂ are released at the present rate, the Earth average temperature would rise by about 4°C within the next 60 years. However, if the CO₂ emissions are brought under control to within 50% of 1985 levels, the global temperature would rise only by 0.5°C within the same period. It has been suggested that the industrial countries should shift from thermal power stations to renewable and nuclear in the first half of the next century in order to achieve such a target.

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- [9] Neftel, A., Moor, E., Oeschger H. and Stanffer, B., Evidence from polar ice cores for the increase in atmospheric CO₂ in the past two centuries, Nature 315, pp 45 - 47, 1985.
- [10] Wigley, T.M.L. and Barnet, T.P., 'Detection of the Greenhouse Effect in the Observations' in Scientific Assessment of Climatic Change, Report Prepared for Intergovernmental Panel on Climatic Change, pp 246 - 258, WMO/UNEP, 1990.

Energy	Calorific Value kcal/kg
L.P.G./Fuel Gas	10,950 Net
Gasolene/Naptha	10,630 Net
Kerosene/Avtur	10,390 Net
Diesolene	10,180 Net
Fuel Oil	9,830 Net
Residual	9,750 Net
Coal, hard	5,700 - 8,500 Net
Coal, brown	4,500 - 5,700 Net
Firewood	4,720 Gross
Charcoal	7,830 Gross

Table 1- Calorific values

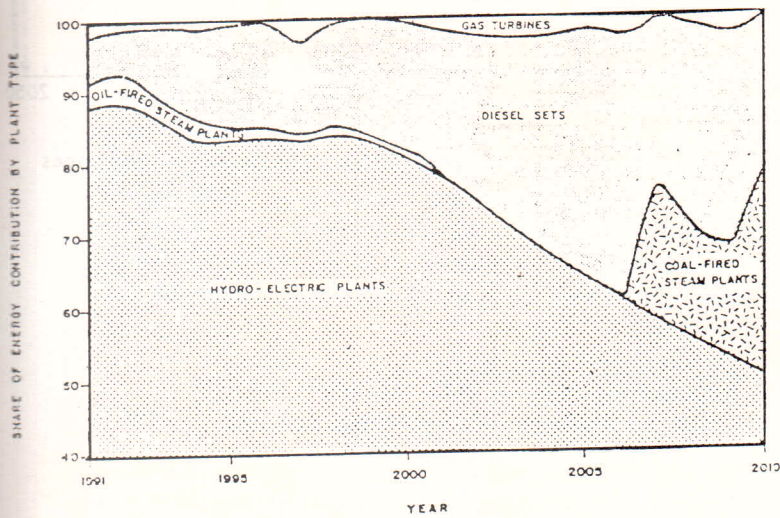


Fig 1. EXPECTED ENERGY CONTRIBUTION BY PLANT TYPE

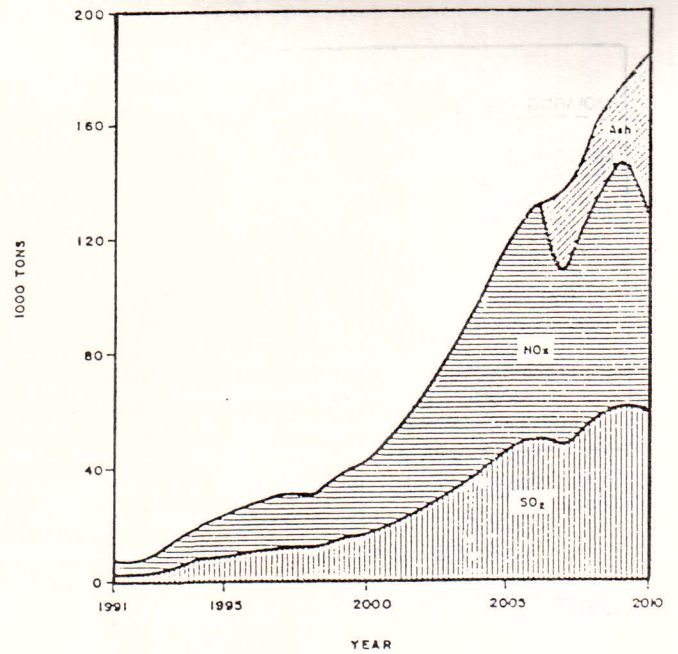


Fig 2. EMISSION FROM THERMAL PLANTS

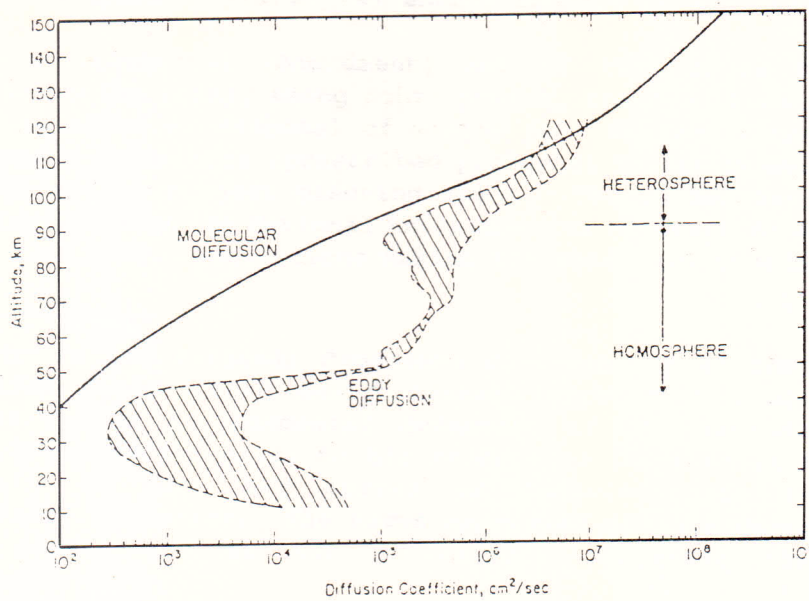


Fig 3 Semi-log plots of diffusion coefficients versus altitude.

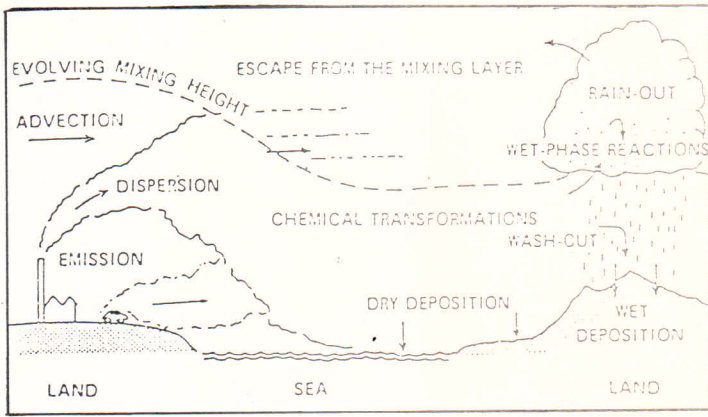


Fig. 4 Processes involved in the wet and dry deposition of atmospheric pollution.

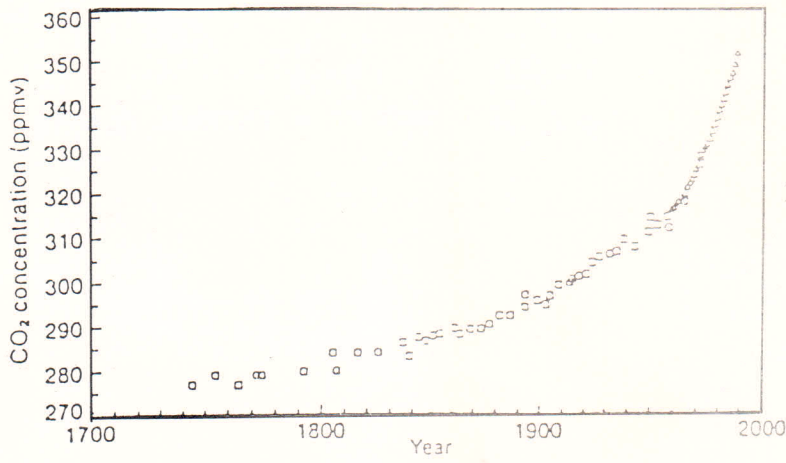


Fig 5 Atmospheric CO₂ increase in the past 250 years

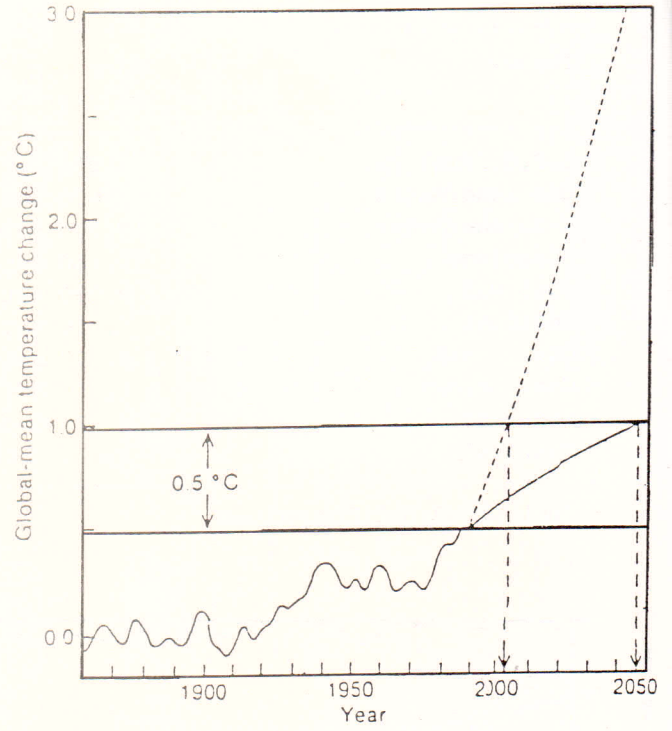


Fig 6 Observed global-mean temperature changes