Patrik Jonsson
Joakim Byström
Uppsala University
November 15, 1995

Is it possible to save the world?

- an analysis of global energy production in a progressively warmer world

Abstract
Today scientists have shown that our effluents of greenhouse gases already have affected the climate of the earth and that great efforts are required to avoid a disaster in a hundred years. The carbon dioxide content of the atmosphere has since the industrialisation increased from 284 to 358 parts per million (volume), ppmv.

Our opinion is that human effects on the climate systems resulting in large changes in the ecosystems and risks of catastrophic climate changes are unacceptable. It is also unacceptable that we throw the costs onto coming generations or that we start irreversible changes resulting in unpredictable, serious results.

Emissions of greenhouse gases corresponding to a doubling of the carbon dioxide content in the atmosphere will result in these unacceptable environmental effects. It is therefore imperative to stabilise the content of greenhouse gases below this level. Our estimate is that this implies stabilisation of the carbon dioxide content at a level of 475 ppmv.

From this estimate and scenarios from the Intergovernmental Panel of Climate Change (IPCC), we have translated the level of 475 ppmv to allowable annual emissions of carbon dioxide up to year 2100.

Following this, forecasts from the World Energy Council (WEC) regarding the availability of carbon dioxide neutral energy sources have been used to translate the acceptable emissions of carbon to a global maximal energy consumption per capita. The forecasts we have used assume an all-embracing global effort for renewable energy sources.

One can note that it is not realistic to, at least for the upcoming decades, lower the emissions of carbon dioxide by replacing fossil power production with expanding conventional renewable energy sources. Energy savings are the only possibilities of a short term carbon dioxide emission decrease.

Our conclusion is that, using powerful efforts, there is a possibility to avoid what we consider being unacceptable global climate changes. But the margins are slim.

References:
IPCC reports:
WGI/5th/Doc.2, Climate Change 1995: The Science of Climate Change
WGII/Sec.Ass.Rep., Impacts, Adaptation and Mitigation Options
WGIII/3rd/RS/Doc.2, Decision Making and Policy Action
World Energy Council, Energy for Tomorrow's World. Fuel Switching.
NUTEK, Energiläget 1995
Energiläget i siffror 1995
Klimatdelegationen/Naturvårdsverket, SOU1995:96, Jordens klimat förändras
AB Svensk Energiförsörjning, Fickfakta om Energi 1990
Arne Jernelöv, SOU1992:58, Miljöskulden

Introduction

In this PM we will, presupposing an arbitrarily posed limit for the environmental influences that we under no circumstances are willing to accept, try to clearly show the scientific demands this will pose on our future society. We will also try to present a scenario where these demands are fulfilled.

Most of the paper is based on the IPCC report 1994. The World Energy Council's paper Fuel Switching, and the swedish NUTEK's report Energiläget 1995, are used for supplementary data for calculations.

The Greenhouse effect

The Greenhouse Effect is a well known physical effect resulting from the fact that certain gases in the atmosphere, such as carbon dioxide, CFC's and methane, are transparent to visible light but are opaque to infrared radiation.

This means that the atmosphere stops the emission of heat from the surface of the earth. When the earth is in thermal equilibrium, the same amount of energy is emitted as heat as is received as solar radiation.

Millions of years ago, the atmospheric content of carbon dioxide was higher and consequently the equilibrium temperature was higher. Because carbon dioxide has been bound in the ground by plants, the average temperature of the earth has decreased to the level today.

When humans now dig up the coal that has been stored for millions of years and burn these fossil assets the equilibrium temperature increase. The temperature will not be stabilised for more than a hundred years due to the large thermal inertia of the oceans.

The mechanisms behind the effects are well known, but the climate is affected by many factors in an utterly complex interplay between accelerating and retarding effects which makes predictions complicated and uncertain.

The discussion about the greenhouse effect and the measures that should be taken has mainly concerned these uncertainties.

Anthropogenous emissions of carbon dioxide

It is established that the emissions of carbon dioxide from human activities are increasing the content of carbon dioxide in the atmosphere. Starting at 284 ppmv before the industrialisation, the carbon dioxide content has now increased to 358 ppmv.

Scientists are also certain that the increased carbon dioxide content in the atmosphere results in a decreased emission of heat. The radiation balance is perturbed to a new equilibrium state at a higher temperature, but the large thermal inertia of the system implies that hundreds of years will pass before this new state is established.

A difficult balance between economic development and climate

Out of today's population of the earth, many don't get their basic demands satisfied. Economic development is to these people probably the only way to a decent life without starvation and sickness. For many nations, consuming essentially no energy, a most likely requirement is an increased use of energy.

To limit carbon dioxide emissions and with economic means force the use of, in the short term, more expensive sources of energy is in this view a threat to the survival of these people. In a

longer perspective, however, a stable climate is a requirement for the development of the third world nations. It is these countries, with weak infrastructure and with no economic means of taking action, will be hit hard by bad harvests and drought.

This balance between economic development in the third world countries and the risk of global climate changes is very difficult. That, in combination with the scientific uncertainty characterising the estimates of the results of different levels of emission and the lack of accurate models to put a price tag on the climate changes, means that politicians and scientists have not been able to establish an absolute limit to which levels of stabilisation that are reasonable.

That humanity is unable to determine the effects of its environmental influences, or even to determine which results that are unacceptable, does not keep nature from posing strict limits to the effects resulting from a certain human influence. The terms of nature are not negotiable, and that we do not know these fully implies that we should be even more careful in our actions.

In this paper we will make a personal judgement of the environmental effects we regard as unacceptable and that consequently puts a defined, if not exactly known, limit to the effluents we can allow.

Our assessment of what are unacceptable results

Our opinion is that the influence on the climate cannot be of such a degree that we risk sudden, catastrophic changes of the climate with results in terms of human suffering, destroyed natural resources and political instability.

One example of such a change of climate is a change of the flow of the warm Gulf stream, which in contradiction to all global trends, would mean a *cooling* of the areas around the northern Atlantic. Such effects has been observed in the climate models, with other sudden changes of the ocean currents. Changes of climate leading to a geographic redistribution of the different ecosystems can in itself lead to an accelerating effect. Vast death of forests as a result of displacing the temperature zones can cause an additional emission of carbon dioxide of up to 200 GtC under several decades. Changes in the terms of the marine ecosystems are expected to give (for the moment not quantifiable) repercussions on the CO2 balance and the emission of other greenhouse gases. Another example of a catastrophic change of climate is the ceasing of the monsoons.

The direct costs could be determined afterwards, but the effects of huge population displacements or even war as a result of changes in climate are so uncertain that it probably is impossible to make an estimate in advance.

It is also unacceptable that we transfer the costs for our way of life onto coming generations. In Sweden it has been estimated that the costs transferred to our generation (1970's) is 260 billion kronor. [Jernelöv 1992]. And this debt is only based on the effects that could be corrected.

Even more unacceptable is that our generation initiates an irreversible process whose results coming generations cannot undo and where we cannot foresee the future consequences. Extermination of species, emissions of CFC's that harm the ozone layer for tens of thousands of years, and the destruction of the humus layer in dry areas resulting in spreading of deserts are current examples.

Our emissions should furthermore be limited at such a level that great changes in the ecosystems where whole biotopes disappear are avoided and flora and fauna are preserved locally. It is a value in itself that the environments where people live are preserved and that the biological variety is protected.

Our estimate of the highest acceptable atmospheric content of carbon dioxide

It is difficult to estimate the level of carbon dioxide that is acceptable to us. The task is complicated further since the effects depend on how fast the change occurs. The average trends will be distributed unevenly across the earth, and the regional and temporal variations in weather will increase. In historical times both temperature and the carbon dioxide level has been varying, but the changes have never taken place in such a short time as they do now.

IPCC establishes that stabilising the greenhouse gases at high concentrations corresponding to 650-750 ppmv CO2 markedly increases the risk of serious disturbances to the climate systems. In addition to the more or less predictable and progressive effects such as the raising of the sea level, redistributions of the vegetation zones, starvation and failure of crops, dramatic and sudden events such as the changes of the oceanic currents and the atmospheric circulation can occur. Concentrations such as these are thus disqualified as acceptable alternatives.

With this in mind, 550 ppmv seems to be a level that in some sense can be thought of as the highest acceptable, at the same time as it does not lead to a completely unrealistic further discussion. 550 ppmv will in a 200 year perspective lead to 0.5-1.5 degrees higher average temperature and 0.3-1.5 meters higher sea level. The rising of the sea level will however, in all but very favourable cases, continue well into the 2500's.

As examples of the effects this "acceptable" change of climate will have one can mention a shifting of the vegetation zones of about 150 km towards the poles, or to 150m higher elevation. With this will come a different composition of the ecosystems and widespread forest death.

The deserts are feared to become oven hotter, and "billion dollar storms" become more common. Diseases such as malaria will increase their range of distribution and many important crops lessen their productivity.

The raising of the sea level of 1 meter will, for a land such as Egypt, result in a loss of 12-15% of the arable areas and millions of people will lose their homes. In the industrialised world, hundreds of billions of dollars will be invested in protective measures against floods and storms, while the poor nations will be badly affected.

The allowed level of *carbon dioxide* is affected by the assumptions regarding the other greenhouse gases (CH4, N2O etc.). An optimistic assumption that the emissions of other greenhouse gases are practically frozen at today's level results in an allowed carbon dioxide concentration of 475 ppmv.

What are the allowed emissions?

A stabilisation level of 475 ppmv carbon dioxide implies that the anthropogenous emissions of carbon in the form of carbon dioxide in a long term (year 2300) will have to decrease from today's 7 GtC/year to 1.3 GtC/yr (to 19%). If radical measures are taken, the carbon dioxide emissions can be allowed to increase over a grace period to 7.5 GtC/yr in 2010, in order to decrease from there on to 4 GtC/yr in 2100 and down to the asymptotic level of 1.3 GtC/yr. This is the 475 ppmv stabilisation scenario by IPCC.

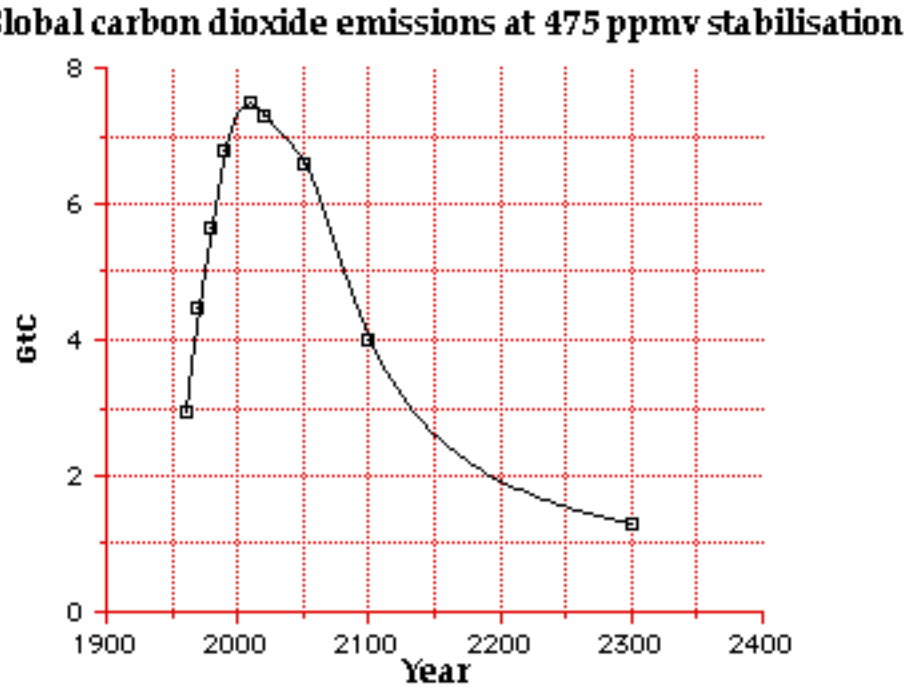

Diagram 1: Allowed global carbon dioxide emissions per year for a stabilisation at the 475 ppmv CO_2 concentration level.

Decrease in energy consumption

We have now constructed a scenario to manage a stabilisation of the greenhouse gases at a level corresponding to 550 ppmv carbon dioxide. The actual carbon dioxide level required is 475 ppmv.

The decrease in carbon dioxide emissions are even more pronounced expressed as fossilised fuel per capita since the population of the earth is expected to more than double, from 5.3 billion in 1990 to 11.3 billion in 2100.

Energy is here expressed as "tons of oil equivalents" (toe, 1 toe = 11.63 MWh). Our strategy has been to convert the carbon dioxide emissions to energy from fossilised fuels and from this calculate total allowed energy consumption, using certain assumptions about the availability of other sources of energy. The important quantity is available total energy per capita, which in some sense determines the living conditions of the individual.

For the years 1960-1980 we have used data from NUTEK regarding the global energy usage in different forms. From these we have, for completeness, calculated historic emissions and energy consumption per capita.

For the years 1990-2100 we have, based on the maximum allowed emission mentioned above, calculated available energy from fossilised fuels by assuming a certain mixture of fossilised fuels from the most ecological and optimistic scenario of WEC. This means an increased usage of gas and oil instead of coal. Coal is the most CO2 intensive fossil fuel, oil emits 80% and gas 60% as much CO2 for a given amount of energy.

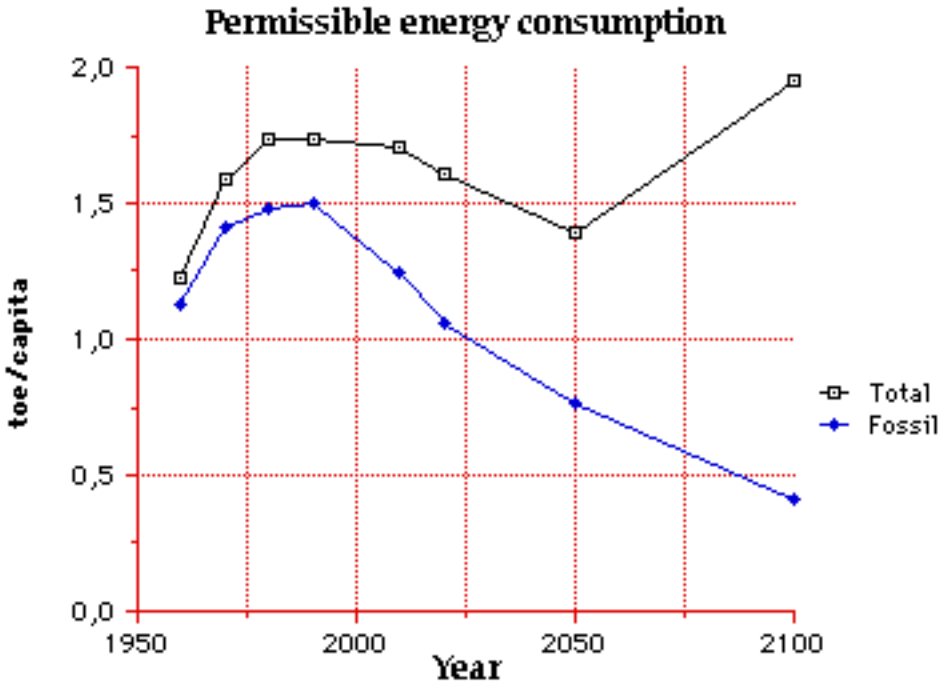

Diagram 2: Allowed global energy consumption per capita for a stabilisation at 475 ppmv CO_2 concentration, total and in the form of fossilised fuels. Note the break in the trend for the total amount in the year 2050.

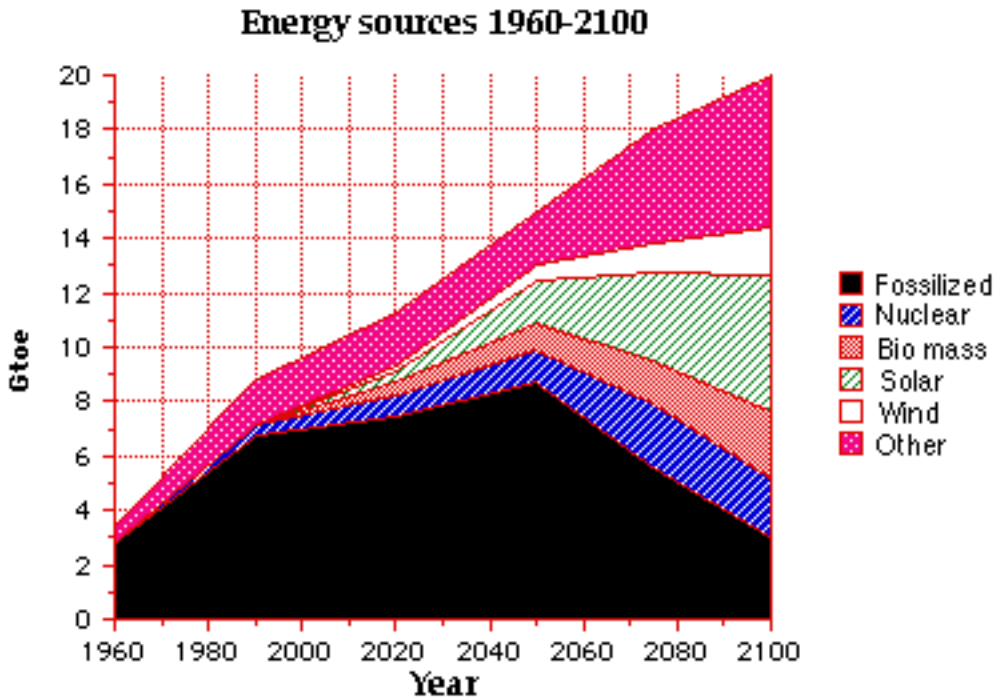

Diagram 3: WEC's ecological scenario with a massive development of renewable energy sources. This leads to a stabilisation at approximately the same CO_2 concentration as our scenario (IPCC), but the time evolution is different.

The fossil fuel energy has then been the basis of an estimate of the total allowable energy consumption per capita. For the years 1990-2020 the calculation has been done from the relative amount of fossilised fuel as estimated by WEC, and from 2050-2100 the estimated absolute amount of available carbon dioxide neutral energy from WEC. Se diagram 2.

The sharp break in the line of diagram 2 in the year 2050 is the result of a massive development of renewable energy sources in WEC's scenario. In the year 2100 10 Gtoe are estimated to come from biofuels, solar and wind energy, in comparison to the total energy consumption of 8.8 Gtoe today. Se diagram 3.

Worth noting is that in the models for energy consumption, electric energy has been converted to the approximately 2.5 times as great an amount of heat required to produce it.

Conclusions

Studying the plot of available energy per capita in diagram 2, it looks pretty good. We will have to save energy up to the year 2050 when the development of renewable energy sources will take care of the situation.

One should keep in mind that our scenario is a maximally optimistic estimate and requires a basic change of course of our society. In the worlds of WEC:

"If the world is to follow a course compatible with [our scenario], then a major change of direction is required. This will require policies to accelerate energy efficiency gains, encourage energy conservation, promote the diversification of the energy supply base, support the faster diffusion of acceptable new renewable energy schemes, assist in the financing of energy development and the efficient application of advanced technology, invest in cleaner energy provision and processing, and a wide range of demand-side measures."

Discussion

How reliable are then our predictions of necessary limits to the global use of energy? The uncertainty in the acceptable carbon dioxide emission and the effects on the climate are probably smaller than the uncertainties lying in the socioeconomical and in some sense technological predictions for the energy production more than a hundred years ahead.

In a historic perspective the progress of society, and thus also the energy supply, has been regularly disturbed by crises, such as the depression in the 30's, two world wars and the economic revolution in eastern Europe. Crises will continue to affect the progression even in the future.

Epilog - a just distribution

How the emissions are to be distributed between the nations is a political question. Carried to an extreme, it is hard to imagine how the industrialised nations are to stop the third world nations from increasing their emissions unless they themselves want to lower theirs. Morally right is, of course, that in the long term every human has the same right to the global resources.

So, what kinds of sacrifice will we have to do? President Bush made his classical remark "The American way of life is not negotiable!" during UNCED in Rio in 1992. Today, however, many are aware of the fact that we will have to take our western way of living under consideration.

Maybe the technical development will allow the same consumption of resources despite big savings in energy. Or maybe we will consume cellular phones, computer games and collect art instead of

using classical energy demanding consumer goods such as cars and dryers. This would decrease our use of resources without lowering our standard of living.

A just global distribution of earth's resources can be seen as a utopia, but also as a requirement for a sustainable development.

References:

IPCC reports:
WGI/5th/Doc.2, Climate Change 1995: The Science of Climate Change
WGII/Sec.Ass.Rep., Impacts, Adaptation and Mitigation Options
WGIII/3rd/RS/Doc.2, Decision Making and Policy Action
World Energy Council, Energy for Tomorrow's World. Fuel Switching.
NUTEK, Energiläget 1995
Energiläget i siffror 1995
Klimatdelegationen/Naturvårdsverket, SOU1995:96, Jordens klimat förändras
AB Svensk Energiförsörjning, Fickfakta om Energi 1990
Arne Jernelöv, SOU1992:58, Miljöskulden