ENERGY AND CLIMATE: WHAT DO WE KNOW? AND WHAT WHALL WE EXPECT?

Burning of fossil fuels constitutes the main source today of greenhouse gases and it is also the principal vector of anthropic action on the climate. But the relationship between energy and climate is far more complex that it seems initially. Climate response to disturbance of the Earth's radiating balance brings some complex retroaction mechanisms into play. Forecasting is thus difficult, nonetheless since scientific knowledge is advancing constantly. But an increasing number of authorities and business companies are now trying to assess the challenges that lie ahead, especially in the field of energy. Where does science stand today and how can we use the available knowledge?

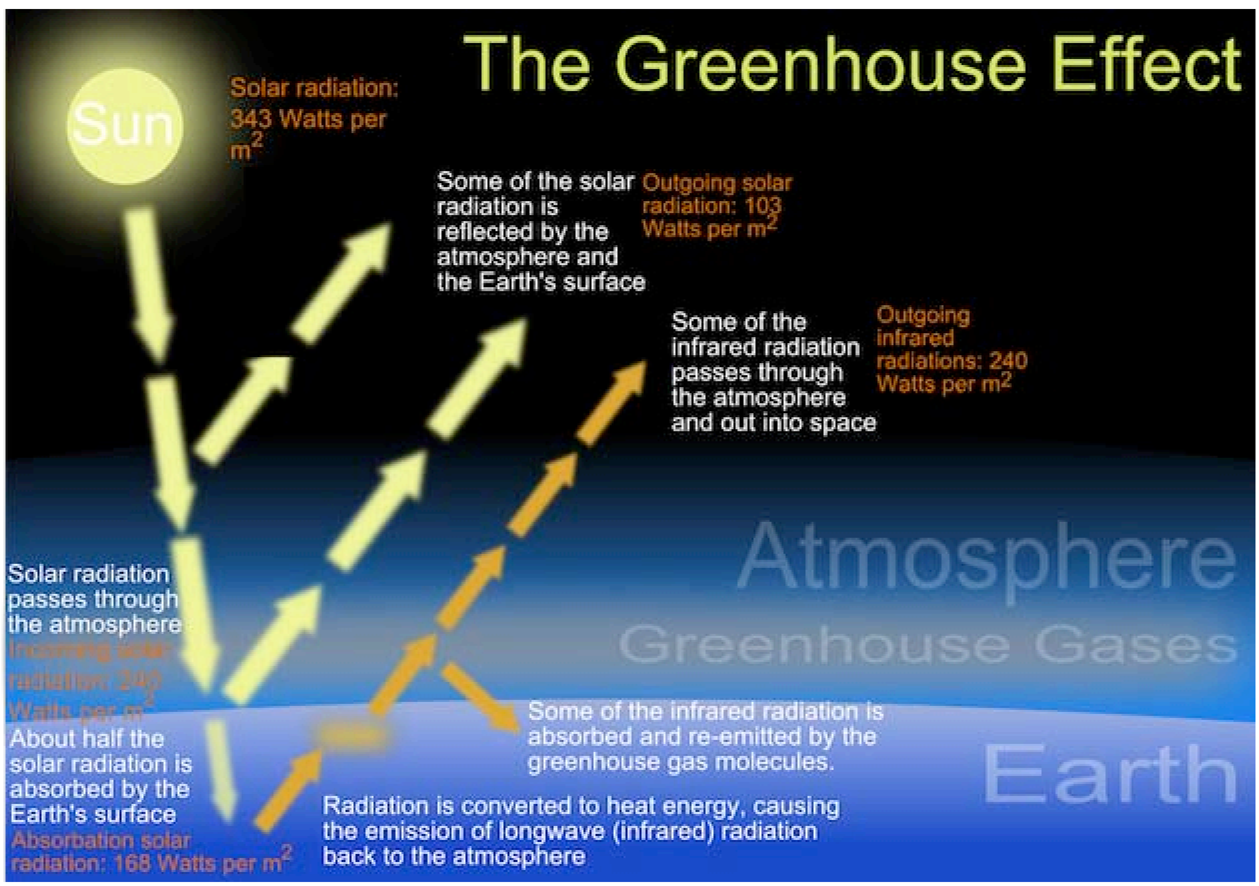
Extraction mining, transport and combustion of fossil fuel sources produces not only CO2 but also other greenhouse gases, such as methane (CH4) as well as fine particles, some of which cool the atmosphere (sulphates) while others (soot) warm the air. Combustion of biomass also has an effect on climate change through the impact, on one hand, of combustion on matter (releasing GHGs and particles) and, on the other, in connexion with deforestation policies when the biomass is collected from non-renewable forest-land. We must necessarily take into account the combined effect of these factors if we wish to compare climate impacts due to various energy sources.

Mother Earth is a complex machine

Our planet Earth can be seen as a thermal machine that intercepts solar energy and transforms part of this radiation into heat, atmospheric movements or rainfall. Mankind has, in the course of time, also become a major player. We manipulate quantities of energy such that we too have become important actors in terms of global balance.

I am not just referring to the fuel we burn in our cars or in our factories, but also and quite simply to subsistence: our food comes from photosynthesis and foodstuff procurement is therefore also an energy-related issue. Mankind also contributes to modification of the planet's energy equilibrium by consuming the fossil fuels such as oil, coal or gas accumulated during millions of years, their origin lying in photosynthetic transformation and storage of the Sun's energy. The net effect of burning fossil fuels, deforestation and kiln production of cement, currently represents an annual injection of some 11 gigatonnes of carbon each year. Admittedly, one half of these emissions is absorbed by natural wells formed by the oceans, vegetation and the top-soils. This leads to increased acidification of the oceans. But the other half comes as additional to previous emissions to the Earth's atmosphere, which seriously modified its composition. The increase of carbon dioxide in the atmosphere has increased by 40% since 1750. Concentration of methane has increased by 150% during the same period of time. This corresponds to a major change in atmospheric composition, compared with that observed over the past 800 000 years – by measuring the gas composition of air bubbles trapped in sample taken from the Antarctic ice-shields.

These changes in the concentration levels of GHGs have a major effect on our climate. The Figure below schematically represents how the atmosphere functions, viz., letting a large majority fraction of solar radiation through, thereby heating up the continents and the ocean surfaces. The energy from the continents and the oceans then heats up the lower atmosphere by contact, which in turn radiates in the infra-red (IR) to partly heat up the next lower atmospheric layers and partly, in reverse, the planet's surface and finally lets part escape into space. Under stable climatic conditions, the amount of solar energy absorbed in this cycle is equal to the amount of IR energy that escapes into space. The more the GHG concentrations levels rise, the more efficient they become to trap IR energy, therefore reducing the amount of IR that escapes into space and it is this phenomenon that leads to increased heating of the planet's surface and of the lower atmospheric layers. An increase of GHG concentrations therefore generate an accumulation of energy in the climate system leading to changes in ocean temperatures, surface air temperatures, changes in water precipitation cycles and occasionally to some extreme events (heat waves, very heavy rainfall), ice melting and increased height of the sea surfaces.



Thus our energy consumption contributes to the global warming measured by meteorological and oceanographic data, also known as "climate change" to underline the fact that over and above the global warming observed, there are also changes in other features (the water cycle, atmospheric circulation streams, ocean acidification, the level of the seas, extreme events). Contrary to a preconceived idea, is not the heat from combustion processes that changes the climate (an effect that can be felt clearly on a local scale, e.g., in cities in the winter period, but this is negligible on a global scale), but the green-house effect caused by certain gases emitted into the planet's atmosphere.

Over time, the Earth's climate has undergone important fluctuations, as it responds to changes in atmospheric composition, spanning several geological eras, or to changes in the Sun's nuclear activities, or to cyclic changes of the Earth's orbit round the Sun, or arising because of major volcanic activities. For similar geological or orbital characteristics, it is now possible to compare today's changes with the natural climate changes that occurred over the centuries or millenaries that preceded the industrial revolution. Paleo-climate recordings show that global warming over the past 30 to 50 years, the rising sea levels as well as the melting of the Arctic sea ice are exceptional in the observable context of the past 1 400 years.

Climate response to disturbance of the Earth's radiating balance brings some complex retroaction mechanisms into play. The main mechanisms among these – amplifying the atmospheric warming phenomenon, is for instance that a warmer atmosphere can hold more water vapour (and this vapour adds to the greenhouse effect), or that cloud distribution counts (again increasing the warming effects), to the effects of melting snow cover or sea-ice replaced by darker areas which absorb more solar radiation than white areas). The moderating factor comes from deep-ocean heat energy storage, and this represents 93% of the extra energy in the climatic machine. Ocean originating heat is then transferred to the near atmosphere, and effects the level of the seas and oceans with long term consequences (the scale being several centuries).

One final point here: a climate that changes will lead to changes in the capacity of the oceans' and continental surfaces capacity to capture a significant fraction of the carbon dioxide arising from human activities. For a similar level of emissions, climatic change will be all the more important if the carbons wells prove less efficient, or if the melting of the Arctic snow/ice cover/sea ice leads to a release of high amounts of greenhouse gases into the atmosphere.

Climate change is taking place in multiple retroactions, which scientists are busy modelling, beginning with endeavouring to gain a better understanding of physical laws and a simplified representation of small-scale processes such as cloud formation. Let me just, at this point, clarify an ambiguity: the assessment of future climate risks in no way relies on extrapolating figures/phenomena from past 'series' of events. Digital climate models are built from atmospheric circulation models used for weather forecasts (ocean, atmosphere, including the water cycle, but include atmospheric chemistry, the carbon cycle, ice-caps and sea ice, interactions plants/atmosphere....). These climate models are tested continuously in regard to their capability to represent the climate functionalities, the retroactions, past changes at various time-scales, confronting the models with series of data (palaeo-climates, meteorology, measurements from space, etc.). The uncertainties (error margins) associated with these digital models can be analysed in regard to the initial status of the climate (for example, the initial state of the ocean), or by having certain loosely constrained parameters in the model vary, or by systematically comparing the 40 or so climate models which have been developed to date, in different research laboratories round the world. Each climate model generates a so-called internal variability, that relates to the interactions between circulation of ocean currents and the atmosphere, as well as a response to perturbations of the Earth's radiation balance, whether the interactions be natural (activities of the Sun or by volcanoes) or linked to human activities. Comparisons of the simulations involved – taking these factors and observations into account – are essential to estimate the cause(s) of the observable climate change(s).

Climate change sciences form a lively area of academic research, with major progress – in land and sea observations or by remote detection sensors (and studies of past climatic conditions) – in our understanding of the underlying processes and in digital modelling of today's climate, of past climates or into scenarios for future evolution of the climate, corresponding to various scenarios of the atmosphere's composition in its relationship with human activities.

Considering the thousands of scientific papers published every year, it is very difficult to have a full overview of the state of knowledge in this field. This was why, given the challenges and stakes for many countries related to climate change and the consequences, a single structure was set up in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP). The new structure, the Intergovernmental Panel on Climate Change (IPCC) was assigned the mission to produce regular assessment reports on our state of knowledge relating to climate change. These reports are drafted by hundreds of scientists, based on readings of paper produced by their peers. Several editing stages by the science communities contribute to the critical synthesis that is the end-result.

September 2013 saw publishing the IPCC 5th Assessment Report on the state of our knowledge (Working Group 1). It follows suite to 4 previous Reports (1991, 1995, 2001 and 2007). The conclusions of each Report evolve as our scientific knowledge base advanced, and the Full Reports (cf. cit. situ supra) include an analysis of the verifiable points, identifying the main areas of uncertainty and analysing the main controversies. One specific feature of these reports is the very accurate degree of confidence associated with each conclusion, taking into account a qualitative assessment and, where possible a quantitative (probabilistic) assessment of the data available to the reporters.

So, having taken this explanatory precaution, let me now enter into the heart of the subject and examine more closely some of the mechanisms at play.

CO2 gas and fine particles: what exactly are we emitting and with what consequences?

Certain human activities contribute considerably to CO2 emissions unto the atmosphere. Noteworthy here are deforestation campaigns, cement kiln production and combustion of fossil fuels. Agriculture and industry also contribute to emission of other GHGs such as methane (CH4), nitrous oxide (N2O) and chlorofluorocarbons (CFCs). Over and above this, the combustion of fossil fuels or biomass also leads to release of pollutant particles, the aerosols.

The effects of these emissions are not comparable. GHGs and aerosols change the Earth's radiation balance in two ways: they trap the infrared radiation in the lower layers of the atmosphere (where the greenhouse effect takes place) and also reflect back into space part of the Sun's radiation. The GHGs, such as CO2 contribute to the former phenomenon above. We estimate today that more than one half of the increase in the greenhouse effect is due to released CO2 into the atmosphere. In contradistinction, the radiation impact of aerosols, on average, turns out to be negative. Their main effect is to reflect solar radiation back into space, either directly or by contributing to cloud formation. GHGs mix rapidly with the other atmospheric gases and have a long life expectancy in the atmosphere. We are talking here of around 20 years for methane, and much longer for CO2, 20% of the today's emissions will still be affecting our climate 1 000 years from now.

The densities of aerosols in our atmosphere are characterised by a high spatial heterogeneity (concentrated round large metropolitan built-up areas), with a short life barely exceeding several days, notably because of rain leaching. However, certain particles, for example, those contained in soot resulting from coal combustion tend to contribute to warming the atmosphere. The dual conclusion is that, while the effect of GHGs can be estimated accurately, there still remains a large error margin when it comes to identifying the exact effect of aerosols, but with an undisputed majority warming greenhouse effect, i.e., a positive net heat balance.

Coming back to the energy sector and to the climatic impact associated with various sources, we must take into account possible effects to due leak releases (methane) and to the net impact of aerosols and GHGs. Electricity produced from coal-burning leads to the highest amount of CO2 emitted, per unit of energy produced and moreover, if there are no constraining standards, can seriously lower the quality of local air because of the aerosols released.

How will such emissions evolve? GHGs due to deforestation have stabilised over the past decade, due to part compensation between the deforestation and the reforestation campaigns and to natural forest growth, on abandoned agricultural land or in the northern regions. By way of contrast, emissions due to consumption of fossil fuels and to production of cement have increased considerably: +1% per annum between 1990 and 2000 and +2.9% between 2002 and 2011. This recent trend is due mainly to increased coal consumption on a global scale. Since yr. 2005, the emissions from emerging and developing countries have exceeded those of the industrialised countries, China now being the first CO2 emitter in the world, followed by the USA, by the European Union, by India, Russia and Japan. The level of emissions per inhabitant due to use of fossil fuels depends on the energy procuring mix of each country. Thus, for Saudi Arabia, Qatar, the USA, Canada and Australia, it is largely in excess of 12 tonnes/inhabitant; for various countries in the EU, South Africa, South Korea, China or Russia, the figure falls to between 5 and 12 tonnes/inhabitant; and falls to less than 5 tonnes/inhabitant/year for Brazil, India and for mots developing countries. To complete this picture and acquire an accurate idea about the total GHGs emitted, we must include the other gases (converted into CO_2 equivalent) as well as changes in land and soil utilisations.

The distribution of ‘national’ sources contributing to global warming in France is as follows: 73.4 % due to CO_2, 11.9 % to CH_4, 11.3 % to N_2O and 3% for other gases. Recent evolutions relate to a decrease in coal burning and emission of CO_2, to an increase in consumption of natural gas (methane in residential housing) and in road haulage and to an increase in gas leaks in air conditioning and refrigerant gas circuits. On average, the CO_2 emissions in France amount to about 6.8 tonnes/inhabitant annual (cf. 9.6 tonnes for other gases). In addition, we must include emissions released in manufacturing processes of imported products, which in the final addition come to the figure of 12.6 tonnes of CO_2 equivalent/inhabitant/year.

From emissions to forecasting

Now let us look more closely at climatic forecasting models. The variability factor we can observe in the climate depends on natural radiative disturbance (release of aerosols, for example, that originate in volcanic eruptions or in variations in the Sun’s activities), man-made (GHGs and aerosols, uses of land) and finally the internal variability of the ocean-atmosphere system (for example when the Pacific El Niño current affects Western American coasts). Observations of current climate change reveals several significant trends: a rise of approximately 0.85°C at the Earth’s surface since 1900, a modification in the vertical atmospheric temperature gradient, an increase in atmospheric humidity, a more significant warming of the continental land masses than in the oceans (this is especially true in the Arctic ice-cap region) which translates into a withdrawal of snow-cover and ice-covers areas, increased frequency of heat waves and more intense rainfall; the above features are coherent with the theoretical analyses that have been drawn from modelling the impact of climate change on the concentration of GHGs in the atmosphere. They have led to the conclusion that there has been a dominant impact of human activities on the observed changes in global or regional climates, on rising sea levels, on more intense extreme events (high heat waves, very heavy rainfall) over the past 50 years.

Digital climate models are also used to assess the risks relate to future climate changes. A large number of research laboratories are building climate models (some 40 located round the world) have recently carried out a set of standardised simulations integrating various earlier climate scenarios, going back into history and another set of scenarios to integrate possible future revolution due to human activities. These scenarios correspondent to low or moderate variations of radiation trapped in the atmosphere (2.6 W/m^2, i.e., an additional disturbance factor similar to what has happened since the pre-industrial era to today), but also to strong variations (up to 8W/m^2, i.e., a fourfold increase in the radiation impact of human activities on the climate). These values correspond to CO2-equivalent concentration levels running from 490 to over 1 300 ppmv CO2.

What we must emphasize here is that the ‘low’ level scenario corresponds to stabilisation of global CO2 emission within the next 20 years, followed by a sharp drop, eventually reaching zero emission in the second half of the 21st century. The ‘high’ level scenario corresponds to a steady increase in CO2 emissions for some 2/3 of the 21st century. Recent trends are in line with the high level scenario. Comparing various climate models for a given scenario allow us to verify the robustness of the results or the error margin we can associate with each model.

So, what do these results teach us? Firstly, that the climate change only becomes significantly different, scenario by scenario, after approximately 30 years. In fact, expected climate change in the coming 3 decades already integrates the climate's response to the past perturbations. The differences of emission levels of GHGs (and scenarios) are deterministic to climate change beyond 2050, with a low temperature rise value (less than 2°C compared with the pre-industrial era) only for the low level scenario and a high level heating (close to 5°C with respect to the pre-industrial value) for the highest level scenario. All these models model an intensification of the phenomena already observed: melting of the sea ice-caps in the Arctic, more powerful water cycles (precipitation), increased intensity of heat-waves, rising sea levels, large scale modification of air streams (monsoons, low pressure zones) towards the poles, acidification of the oceans ...

The time scale for the consequences of CO2 emissions into the atmosphere is particularly long. Approximately 50% are captured by the oceans (which therefore acidify), surface soils and plants. It should be noted that the efficiency of various carbons wells might decrease if the climate gets hotter.

Thus, the oceans play a buffer effect: in the same way as they can and do absorb a large fraction of the CO2, they also store (more than 90%) of the surplus climatic energy. Very small fluctuations in the exchanges between oceans and the atmosphere modulate the rhythm at which global warming is taking place, decade by decade. Seen in this perspective, oceans also play a memory function that will make climatic changes and their consequences be with us for a long time to come. As a case in point, the rise in mean sea level, in the high level scenario, could be of the order of

90 cm above the pre-industrial level by 2100 and somewhere between 1 and 3 metres by 2300.

Finally, we see that future climate changes are mainly connected to CO2 emissions. This results is embodied in the objective finally adopted by various governments at the Copenhagen Summit, viz., a rise in temperature of less than 2°c with respect to pre-industrial values, with compatible emissions in terms of quantity; If we take into account the impact of the other GHGs and a pre-industrial time reference, in the middle of the 19th Century, the limit – if we are to attain this objective – is 790 GtC maximum. Over this specified period, the past cumulated amount of carbon released was 515 Gt and if we look at current emission rates, the limit will be reached in between 20 to 30 years.

By contrast, how will climate change affect offer and demand for energy?

On average, the winter season demand for energy for heating purposes in the temperate zones may decrease, whilst retaining the principle of being able to meet peak demand if a really cold spell occurs. In reverse, the demand for air condition energy could rise steeply because of the increased risk of heat waves.

As far as energy production is concerned, several effects can be anticipated. Changes in the water cycle and melting of mountain glaciers can affect, for example, the capacity to produce hydro-electric power. The capacity for renewal of biomass (used to generate heat or bio-fuels) can also be affected by global warming and their interaction with alongside evolution of the quality of ambient air. There are very large degrees of uncertainty associated with evolution of small-scale spatial events such as hurricanes or tempests with which energy production systems are faced as are electric transmission networks. The surface wind speeds associated with the strongest hurricanes known could well increase. The impact of global warming on flow and temperature of surface water (rivers and coastal waters) could affect the capacity to cool thermal or nuclear power stations.

Generally speaking, the future impact of climate change on production and consumption of energy could be summarised in one word: increased vulnerability for certain specific infrastructures and, beyond that by extrapolation, for the systems in which they are embedded. We can observe that both in major industrial sectors as well as in local authorities, there is a growing level of awareness of these risks. Infrastructure managers, of course, are in the front line, alongside the politicians of those areas that have already been damaged and made fragile by previous climatic events (floods, drought and erosion).

Coastal zones, if there are local populations and infrastructures, are especially vulnerable when the danger is that of rising sea levels and submersion. And certain elements in the current response to climate change could in the long term create new areas of vulnerability. For example, the planned programme expansion to install renewable energy sources (and increase their fraction in the future global energy mix) notably wind and solar power generation, reinforces the need for accurate weather forecasts in order to manage the intermittent supply characteristic of renewables producing electricity. Climate research centres are developing diagnostic protocols on the based on short term (several decades at most) and long-term (50-100 years) climate change forecasts to enable the policy decision-makers and the industrialists of the various sectors involved to assess possible impacts and prepare themselves for the changes.

In Denmark, home insurance policies are now indexed on the risks for climate change. Major reassurance companies such as SCOR, Munich Re or Swiss RE publish analyses that take these new factors and considerations into account.

Classic risk assessment models have already lost their relevance. Up till now, in order to manage a flood risk management, the reference values were those of the decade and centennial flood levels, viz., values from the past. Global warming now introduces a new regime of uncertainty forcing us to imagine events that never “occurred” before. For example, the case of track deformation of a high-speed train route during an unprecedented heat wave. Vulnerability studies are becoming commonplace and translate – following the moment of high drama at the Copenhagen Summit (Dec., 2009) and the first awareness of the leaders and delegates present – into a second wave of awareness, this time of a more pragmatic nature.

Certain countries, such as the United Kingdom, are to the forefront of vulnerability studies that bear principally on questions of procurement and supply. In the industrial sectors, certain groups have begun analyses as to their vulnerability with respect to their subsidiaries. In a more general manner, the variety of situations that may occur is conducive to sharing experience and know-how. Thus, the French, part of whose national territory could be affected by more frequent heat-waves, could learn from the Spanish who have successfully come to grips with this sort of event.

Simulations of future climate evolution provide a set of elements that will prove useful when it comes to building adaptation strategies. The very notion of “climatic services” emerging in various climate modelling research centres from integrates the implementation of specific diagnosis protocols that correspond to the needs of the actors (industrialists, insurance companies, territorial and local authorities...). The needs are specific: for example, an industrialist in the energy production sector will be less concerned about evolution of mean temperatures, and more by the number of days above or below a given threshold value.

The main impact of global warming on energy procurement/production issues will obviously relate to choices among possible sources, which themselves are already under constraint in those countries who have politically decided to move ahead with an energy transition policy, by the desire to respond to climate change and to limit its impact. For the time-being, it is difficult to predict the scale or order of magnitude of the changes which will depend a lot on multiple factors most of which will come to bear in the short term – starting with politics. These options will therefore necessarily involve political decision-making processes and on this point, climatologists can only throw light on certain aspects of the debates.

The example of bio-fuels shows identification of priorities in the energy field requires a largely interdisciplinary analysis. If we limit our reflections to the direct link between climatic and energy related issues, there is no real limit to satisfy the need to producing bio-fuels. If, however, we take into account the impact on food procurement, on conservation of bio-diversity, or the structural differences between Northern and Southern hemisphere countries, we can see that bio-fuel agro-production runs into considerable limitations, which cannot be settled by scientific expertise alone, inasmuch as they also involve decisions of justice.

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