



## Climate Change and Sustainability

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There is overwhelming scientific evidence behind the statement pointing out that human activities have already caused significant global warming. More than ten thousand peer-reviewed climate change articles have been published in the last couple of decades; less than one percent of these articles deny the warming is occurring, or that it is caused by humans. The Earth's climate is a complex system, and consequently projections of the average surface temperature increase in the future are uncertain; nevertheless, scientific research continues to demonstrate that there is a significant probability that this increase could reach five or more degrees Celsius towards the end of the Century if the release of greenhouse gases, coming mostly from burning fossil fuels, is not substantially limited in the near future. A change in climate of that magnitude would most likely have catastrophic consequences for human civilization.

### The climate of our planet

Basic science has established quite clearly how the Earth's climate functions. Even if climate has experienced significant transformations in the past, these usually took place during tens of thousands of years, and were caused by factors such as massive volcanic eruptions, or periodic changes in the geometric parameters of the Earth's orbit, such as its ellipticity or the inclination of the Earth's rotation axis. It turns out that the climate has been exceptionally stable during the last twelve thousand years – the so-called "Eocene" geological epoch, thus enabling the development of human civilization. In contrast, climate variables such as the average surface temperature and the distribution and intensity of precipitation have changed substantially in recent decades, giving rise to what is known as "climate change".

The sun is practically the one and only source of energy for our planet. This energy arrives in the form of electromagnetic radiation, predominantly as visible light. Approximately one third of this energy is reflected back to space by clouds, deserts and snow, and the rest is absorbed by the oceans and by land. Since the Earth attained thermal equilibrium millions of years ago, it emits back to space the same amount of energy as it receives from the sun, mainly in the form of infrared or "thermal" radiation. During the 19th Century it had already been established experimentally what is known as the "black-body radiation law", that connects emitted radiation with temperature; according to this law, in the absence of the atmosphere the average surface temperature of our planet should be about -18° Celsius. The actual temperature is, however, closer to +15° Celsius, a value that has enabled the evolution of life as we know it; the reason is that the atmosphere functions as a blanket, increasing the average surface temperature by about 33° Celsius.

Thus, it turns out that the atmosphere plays a vital role establishing the actual surface temperature. About 99% of the atmosphere is made of nitrogen and oxygen, and the rest is mostly argon, an inert gas. These gases are transparent to visible radiation, thus permitting energy from the sun to reach the Earth's surface. They are also transparent to infrared radiation, and hence if only nitrogen, oxygen and argon were to be present in the atmosphere, it would not function as a blanket; however, it contains small amounts of certain gases that do absorb infrared radiation, which are the ones responsible for raising the surface temperature by 33° Celsius. These are the so-called "greenhouse" gases (GHGs): they include water vapor, whose concentration varies greatly, but is about 0.25%, on the average; carbon dioxide (about 0.04%), and other trace gases such as methane, and nitrous oxide, whose concentrations are measured in parts-per-million. Water vapor absorbs roughly three fourths of the infrared radiation emitted by the surface, and carbon dioxide most of the rest. The concentration of water vapor is highly variable, and depends crucially on the temperature; as a consequence, if carbon dioxide would somehow be removed from the atmosphere, the average temperature would clearly decrease, causing the water vapor to condense and eventually to return to the Earth's surface as liquid water, snow or ice, thus eliminating the "blanket" function of the atmosphere and decreasing the surface temperature by 33 or more degrees Celsius. For this reason, carbon dioxide is known as the "thermostat" of the planet.

## **Understanding climate change**

During hundreds of thousands of years, the amounts of these gases in the atmosphere has remained relatively stable. However, since the beginning of the Industrial Revolution, in the late 19th Century, human society started to burn fossil fuels such as coal and oil, and the atmospheric concentration of carbon dioxide began to increase markedly, and has now reached more than 400 parts per million, a level that had not existed in several million years. In the same fashion, the atmospheric concentration of methane has more than doubled in recent years, also as a consequence of the activities of society. In other words, human activities have modified very significantly the composition of the atmosphere in terms of its greenhouse gases. The average surface temperature of the planet has increased by about one degree Celsius during the same time period, although the main change has taken place during the second half of the 20th Century. At first sight this change does not appear to be large, but it is very significant considering that the average temperature had decreased by only about 0.5° Celsius during the past eight thousand years. On portions of the planet, such as at high latitudes, the temperature change has reached as much as 3° Celsius; this explains why the amount of Arctic ice in the summer months has decreased enormously in recent years.

Because, as mentioned above, the Earth's climate is a complex system, scientists are cautious associating, for example, the observed chemical composition of the atmosphere with the observed temperature changes. Nevertheless, the Intergovernmental Panel on Climate Change (IPCC), a voluntary association of climate scientists, concluded in its fourth report, published in 2007, that the probability that human activities are responsible for the observed temperature change is 90%; in its most recent report, published in 2015, the same probability was estimated as 95%. In other words, it is possible that the temperature increase observed during the same time period as the change in composition of the atmosphere is a mere coincidence, but this conclusion is extremely unlikely.

## **Extreme events**

The scientific community is investigating whether the recently observed changes in the characteristics of the climate, which are mainly rises in the intensity, duration, and frequency of events such as hurricanes, floods, droughts, and heat waves are connected in some way to human activities. In view of the fact that relatively few such studies had been carried out in the past, the community had maintained a very conservative attitude related to the connection between those so-called "extreme events" and human-induced climate change. The relevant question is not whether such events would have occurred or not in the absence of climate change, but rather whether their intensity has increased. Consider, for example, heat waves: a recent study, based merely on temperatures measured by satellite at middle and low latitudes indicates that the probability of occurrence of an extreme heat wave has increased tens of times in the last half century. Yet another study examined six extreme events, including droughts and floods; the conclusion was that the intensity of five of them was indeed increased by climate change. Even more recent studies conclude that the intensity of hurricanes is indeed being affected by climate change, while others conclude that the damage caused by many forest fires has also increased significantly.

It is, thus, possible to conclude that many worrisome consequences of climate change are already taking place, and one can anticipate that as the average surface temperature continues to increase extreme events will occur more frequently, with important consequences for the well-being of human society. One expects, for example, a reduction in the productivity of agriculture, placing global food security at risk. On a longer time-scale, increase in sea-level rise, which is already well documented at present, will pose large risks to the coastal population in many parts of the planet.

## **Is it possible to successfully address climate change?**

It is possible to reduce the climate change risks mentioned above, but it represents a large challenge for society: it would be necessary to reduce the emission of GHGs very significantly. The goal is to limit the average surface temperature rise to two degrees Celsius, which is the result of an estimation of plausible limits to prevent dangerous interference with the climate resulting from human activities.

To achieve this goal, it would be necessary to reduce GHGs emissions more than 50% before the year 2050, requiring a multitude of measures. The most effective would be an international agreement to place a cost on the emission of GHGs, which would thrive a profound change in the generation and use of energy. Such a measure would also require to provide resources to developing countries so that they could impose the necessary measures, without affecting their economic development.

There is no simple means of achieving the desired goal in reducing emissions; energy efficiency measures are not sufficient by themselves, and it is necessary to develop economically feasible technologies to generate renewable energy. Fortunately, solar and wind sources have become affordable in recent years, thus

enormously facilitating the desired outcomes. Among other measures, it will eventually be necessary to use electric vehicles and to greatly reduce the use of fossil-fuel vehicles.

### **Climate change and the economy**

A key question is whether the desired changes will be economically feasible. The production patterns employed in most developed countries have followed the logic of minimizing production costs and maximizing income, transferring a portion of the costs to the environment, as is the case of emitting wastes to the atmosphere, rivers, lakes and oceans, or of using natural resources without taking into account their limits. As time elapses, such short-term savings imply a sizable increment in the production costs for future generations.

In general, a free economy is based in market forces, to the benefit of buyers and sellers. But, if there are failures in the market forces, there are costs that economic agents place on others that are only paid by future generations; these represent the so-called “externalities”. One way to deal with them is to place regulations that limit the behavior that imposes costs on others, amounting to the “internalization” of such costs. We can consider emissions of carbon dioxide and other GHGs as externalities, which implies that society needs to implement policies to disincentive such emissions. Furthermore, it is important to educate society so that it develops the appropriate culture required to implement such measures. The governments of some countries, such as Sweden and Australia, have already imposed industrial tariffs on carbon dioxide emissions.

### **Costs of mitigation vs costs of inaction**

As recently as five years ago, economists considered that measures to reduce GHG emissions by 50% by the year 2050 would cost approximately 1% or 2% of global GDP, and that the costs of not implementing such measures would be significantly larger. These conclusions were emphasized, for example, by the Stern Report, one of the most influential economic studies published so far, generated as a request from the U.K. Government by Sir Nicholas Stern, of the London School of Economics. More recently, the price of electricity generated with renewable resources such as solar and wind energy has dropped significantly, due to technological advances, so that from an economic perspective these energy sources now compete favorably with fossil-fuel generated energy. Even though the cost of electricity generated by coal-fired thermoelectric plants remain low, these plants are now rapidly becoming obsolete in view of their large damaging impact on air quality, as has been demonstrated in various countries, particularly in China.

In a recent paper Sir Nicholas Stern indicates how the price of inaction regarding mitigation of GHG emissions has been grossly underestimated by most economic models, and that the damage to future generations cannot be measured solely on economic terms; their quality of life is at stake.

### **Game of roulette**

One way to explain the uncertainty of the impacts climate change might have in the future is to make an analogy with a game of roulette. The Joint Program for Climate Change of the Massachusetts Institute of Technology has illustrated the results of their calculations, carried out with very sophisticated models of the global climate and of the global economy, simulating two roulettes that indicate the probabilities of given temperature changes towards the end of the Century for two different scenarios: the first one assumes that there is no change in the current tendency to generate GHG emissions (the business-as-usual scenario), and the other considering that efficient measures are implemented to reduce such emissions, for example, by means of an international agreement. The most worrisome aspect of the simulation is that for the business-as-usual scenario there is a probability of more than one in five that the surface temperature will increase five or more degrees Celsius. Should that result materialize, the world as we know it would largely disappear. Sea levels would rise by at least 10-15 meters, perhaps slowly, but unavoidably, affecting large urban populations. Many regions in the Sub-Tropics would turn into inhabitable deserts, causing massive migrations; and massive extinction of biological species would adversely affect ecosystem services that human civilization depends on.

### **Conclusion**

It is clear that the effects of climate change are already taking place. If society reacts urgently and decidedly, we are still on time to avoid unnecessary costs and potentially catastrophic consequences that would imperil economic development and would seriously damage ecological systems in our planet. A logical conclusion of all these findings is that society confronts a large threat, and thus it is very important to modify its activities to limit the interference with the Earth's climate. This amounts to carrying out a second Industrial Revolution.

A transition towards efficient energy generation systems with low GHG emissions requires new investments as well as the deployment of innovative large-scale technologies. This represents a window of opportunity in the frame of a new economic development era. The solution requires a compromise of all sectors of society: academia, governments, opinion leaders, local and multinational enterprises, and society at large. It is necessary for all nations to implement measures to reduce GHG emissions. It is essential for developing

countries to participate as well; perhaps some of them will require financial assistance from the developed world. In any event, there are many so-called “win-win” measures that do not require assistance, many of which have important side benefits, such as the improvement of air quality.

It is clear that climate change is already affecting the entire population of our planet. Science alone does not tell society what to do; economic, social and political considerations need to be considered, and ultimately, we all have an ethical responsibility towards the progress of civilization. To continue with the business as usual scenario, that is, ignoring the required restrictions on GHG emissions, would be highly irresponsible towards future generations, as they should be able to enjoy a quality of life at least as good as the one we have at the present time.