Climate Change

Impacts and Mitigation/Adaptation Perspectives

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Introduction

Giampaolo Cutillo

Let us not forget that the World Meteorological Organization (WMO) was instrumental, together with the United Nations Environment Programme (UNEP), in the creation of the Intergovernmental Panel on Climate Change (IPCC), with the aim of providing governments at all levels with scientific information that they can use to develop climate policies.

Before diplomacy and negotiations, there are facts and data to be gathered, complex scenarios that create a solid scientific basis enabling policymakers to make predictions and formulate appropriate reactions.

As UN Secretary-General António Guterres recently recalled, human-caused climate disruption is now damaging every region. Each increment of global heating will further increase the frequency and intensity of extreme weather events, and we need early warning systems to protect us against increasingly extreme weather and climate change.

We know that the UN has tasked the WMO to lead the efforts to achieve this goal within five years and to present an action plan at the next UN Climate Change Conference in Sharm El-Sheikh, Egypt,[1] and we applaud their efforts in this challenging and vital undertaking.

If I may expand a bit, I would like to go a step further and say that the freedom of science is crucial to shape a democratic culture and the behaviours needed to maintain and renew democratic processes.

Only education and science enable society to understand increasingly complex contemporary challenges, and to provide workable solutions to problems.

The Covid-19 pandemic has shown how science can and should come to the rescue of governments as they seek policies that strike

[1] The 27th session of the Conference of the Parties (COP27) of the United Nations Framework Convention on Climate Change (UNFCC) took place in Sharm El-Sheikh, 6-20 November 2022.

the right balance between public health needs and fundamental freedoms. At the same time, it has worryingly shown how casting doubts over science, spreading pseudo-scientific information, and instilling scepticism about the integrity of scientists can quickly fray the fabric of society.

The same goes with the other major challenges we are facing, which are central in today's discussion: energy transition and climate change. Undermining the freedom and integrity of science is a short-sighted, dangerous strategy, with dire consequences for humanity as a whole.

I would like to recall what the IPCC states in its most recent report, whose second part was released in February 2022: "Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a livable and sustainable future for all".[2]

While this second part focuses on the impact of climate change, the latest contribution looks at climate mitigation and confirms the urgency to act. In order to have a 50% chance of meeting the 1.5 scenario, global greenhouse-gas emissions will have to peak in the next three years, by 2025, and fossil fuels will have to be phased down at unprecedented scale and speed.

In all this, we cannot ignore that our economies and societies, already hit by the pandemic, are now facing the most serious political, military and humanitarian crisis in Europe since World War II – a conflict that radically changes the geopolitical, strategic and security framework against the backdrop of an emergency (that of climate change) which is no less disruptive.

In this context, already characterized by an unprecedented rise in energy prices, the need to ensure our energy security now adds to the challenges related to the structural transformation of our economies to tackle global warming.

As of now, we have to disengage the EU as a whole from the current, excessive dependence on Russia's fossil fuels.

Energy diplomacy shows all its crucial importance at this stage. At the national level, we are resolved to accelerate energy diversification, seeking alternative supplies and strengthening collaborations with reliable partners in the Mediterranean and beyond. Developing these collaborations is an investment in our common

[2] *Summary for Policymakers*, p. 33, in IPCC, *Climate Change 2022: Impacts, Adaptation and Vulnerability*, 2022 (https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf; https://www.ipcc.ch/report/ar6/wg2/).

stability and future shared prosperity, in a region rich, even more than in gas and oil, in inexhaustible natural resources for renewable production.

We must remember that the energy transition is the only long-term solution for our energy security and for the freedom of our countries from the dependency on fossil fuels.

Accelerating the clean energy transition remains therefore our common strategic goal for the autonomy and resilience of our energy systems. The national security paradigm has been a great mobilizing force, greater perhaps than the knowledge of impending global climate catastrophe.

The idea of renewables representing "freedom energy" is likely to trigger a further, unprecedented level of focus and spending on clean energy.

The good news is that, according to the latest part of the IPCC report I was citing before, a lot of what is needed is underway.

The study shows that between 2010 and 2019, prices of green alternatives to fossil fuels have plunged, with the costs of solar power and lithium-ion batteries falling by 85%, while the cost of wind energy dropped by 55%. Solar panels and wind turbines can now compete with fossil-fuelled power generation in many places, and the deployment of green technologies has increased significantly.

Accelerating the clean energy transition means accelerating the fulfillment of our strategic autonomy, our independence and resilience. It also leads to additional GDP growth, employment and social inclusion.

From the European Green Deal to the Fit for 55 package of measures, to the most recent RePowerEU, Europe has created a series of tools for a sustainable and zero-emission future, setting the goal of climate neutrality by 2050, while reaffirming Europe's global leadership in the fight against climate change.

In that regard, in 2021, as G20 Presidency and partner of the UK for COP26, Italy made an important contribution to reinforcing the need to keep the increase in global temperature within the threshold of 1.5 Celsius degrees.

We are committed to preserving our legacy, making the most of the fleeting window of opportunity that we still have in order to build on our progress, without returning to anachronistic and destructive patterns.

Also from this point of view, war is the most incoherent and anachronistic thing that can exist, a disheartening sight in the eyes of the girls and boys who are peacefully fighting to save the planet, and whose vision and values of the future we are committed to bringing forward.

Lectio Magistralis

Petteri Taalas

I would like to discuss some material from what the World Meteorological Organization (WMO) has compiled concerning climate science and disasters and what the most recent Intergovernmental Panel on Climate Change (IPCC) report shows. This recent IPCC report was published in three phases: the physics one on 6 August 2021, the impact report on 27 February 2022, and on 4 April 2022, the mitigation part of the report. I will discuss the most recent findings from those reports.

Since 2016, I have been leading the WMO, which is the UN specialised agency on weather, climate and water; practically all of the UN members are also our members. In 2023, we are celebrating our 150th anniversary. We are not as old as the Accademia Nazionale dei Lincei, but we are the second-oldest UN agency, having been established in 1873 as the International Meteorological Organization for the free exchange of data and the standardization of global meteorological instrumentation. Our work is very much done by our members, and Italy is one of our important members. We also deal with hydrological services and academic institutions, and we have opened our doors to the private sector. We are managing such a huge amount of data nowadays that it's important that, for example, Microsoft- and Google-type data providers become more active members of our family. As we have just heard from the previous speech, we are the second founding father of the IPCC, and we are also hosting the IPCC.

I'm personally a member of Secretary-General António Guterres' climate core group, and he has just given us a mandate to prepare a major early-warning service package for the next Conference of the Parties (COP27). I will meet the COP26 President, Alok Sharma, in Geneva, and I'm going to visit Egypt in the coming weeks to discuss this with them; they are also very enthusiastic about this initiative.

We have been setting global observing systems, consisting of ground-based observations, satellite measurements, and balloon-borne aircraft vessel measurements, and we also monitor the

global status of greenhouse gases. We have carried out major reforms over the past years; we are now looking at the Earth as a unity instead of dealing with weather, climate, water and oceans as separate items. We are happy to see a merging of services to discuss the hazard early-warning services. We have established two new scientific bodies, and we are getting advice from leading scientists on the future of our field, how the world may look ten to twenty years from now. That's the Scientific Advisory Panel and Research Board. We also have the services body for the sciences, and the private sector is becoming more and more important for us. We have a very active role in communicating the results of climate science, as I am doing today. Our meetings have become fewer, and we are paying more attention to the outcome of our meetings. We have plenty of partner organizations in the UN family, and we have joined forces with many of them. We are also supporting less developed country members with our expertise.

We have a very nice planet to live on, at the right distance from the Sun; we have the right composition of gases; we have water and we have oxygen in the system. But we have started changing the system. The temperatures globally have visibly changed. We have reached 1.1 to 1.2 degrees warming so far, and we have been breaking records year by year. In Italy, the European record was broken last year with 48.8 degrees in the southern part of the country. Maps displaying the variation in temperature show that the Arctic and the northern continents have been warming the most, and we also have some cooling, especially south of Greenland and Iceland; the so-called Gulf Stream, which brings warm air from the Caribbean towards Europe, has slowed. And this is a reflection of the melting of Greenland's glaciers.

We are not breaking the temperature records year by year; we have this El Niño/La Niña year, we break records. The last strong El Niño year was 2016; thereafter we have seen more of these La Niña years, but when the next El Niño year comes, we will already be fairly close to the 1.5 degree limit, the lower limit of the Paris Agreement. As I said, southern Italy broke the all-time European record; last year we also broke the all-time Canadian high in western Canada, and we have seen three years in a row of 38 degrees at the Arctic Circle in the Russian arctic. So those are all indications of climate change, and we will certainly see such records broken also in the future.

If we compare what has happened in the past hundred years, our situation is quite unique, since for the past 2000 years (which we can reconstruct by using indirect methods, along with estimations of what has happened in the past few hundred thousand

years) we have already exceeded that variability range, the ice age variation range.

We have broken records in many greenhouse gases, carbon dioxide, methane and nitrous oxide, year by year. What has happened to methane is a bit of a mystery; we don't fully understand all the sources of methane, and also we have a limited understanding of the sinks of carbon dioxide, especially through the oceans. The Covid era led to a drop in emissions in 2020 by 5.4%, but the lifetime of carbon dioxide is so long that this kind of one-year anomaly doesn't change the big picture. And since then, we have almost returned to the 2019 emission levels.

We have an idea of the relative importance of greenhouse gases behind observed warming so far; of these, carbon dioxide is responsible for two-thirds of the present warming, and methane is responsible for one sixth. Methane's life is only 11 years, while the impact of carbon dioxide stays in the atmosphere for hundreds of years, so that's the most important challenge that we have ahead of us.

I will quickly mention the carbon budget, or what has happened since 1850 with carbon. By far the greater percentage comes from the impact of fossil fuels, and a smaller amount from land-usage change, especially deforestation. About a quarter of the emissions go into the oceans, a quarter go into the land, and the rest remain in the atmosphere. Clearly, fossil-fuel use is dominating the picture.

We have stored more than 90% of the extra heat in the oceans, and the oceans have become warmer at various different depths. This is observed everywhere. We have also changed the chemical composition of the sea waters, since oceans act as a carbon sink, and now they have become more acid; according to estimates, they are at their most acid level in 26,000 years.

As for sea-level rise, twenty years ago we used to have about 2 millimetres per year sea-level rise, and recently we exceeded 4 millimetres per year. This boost is very much coming from the accelerated melting of glaciers. There is also a component coming from the thermal expansion of the sea water, but the situation is a bit striking. The IPCC has estimated what's going to happen to the sea-level rise by the end of this century, and of course it depends on emissions, but in any case we expect to see between half a metre to one metre of sea-level rise by the end of the century. By the end of next century it may be up to two metres if we reach the Paris 2 degrees target, while if we don't reach this target, we might see up to a seven metre sea-level rise. One of the negative facts of climate science is that we have already exceeded 400 ppm

of carbon dioxide, which means that the melting of glaciers won't stop even if we stop emissions. So that will be a long-term challenge that may be with us for the coming hundreds of years.

In English-speaking countries, we speak about 'global warming'; that's a little misleading, because the biggest impacts of climate change are felt through water and changes in the precipitation. We can see what has happened to rainfall amounts in recent decades as compared to the early decades of the last century; for example, Africa, Southern Asia and parts of Latin America have become drier, and the high latitudes, especially in the Northern Hemisphere, have seen an increase in rainfall amounts.

As far as glacier melting is concerned, we can see that there has been a boost in glacial melting, and as I said, this may continue for the coming centuries, which may have major negative impacts on the fresh-water availability in many rivers in all continents. We have seen the biggest changes in the Arctic, and that's because of this melting of snow and ice from the region, and both spring and autumn sea-ice coverages have been shrinking. We have melted already more than 70% of the sea-ice mass; so-called multi-year ice has disappeared from the Arctic.

In 2021, we also saw several disasters worldwide. There were severe flooding events in India, China, and also in Germany, and heat waves were also fatal in North America, in Canada and the USA. We have seen droughts in Africa and Asia, and also one hurricane which caused about 64 billion dollars of damage in the USA. There is already science showing that these two events, for example, would not have been possible without the impact of climate change – the heat waves in Canada and California, and also the flooding event in Germany, which caused 200 casualties. In Germany's case, this demonstrated that collaboration between meteorological and hydrological services didn't function optimally; if there had been better cooperation, we wouldn't have seen those 200 casualties.

Rome is hosting the Food and Agriculture Organization (FAO), which estimates what is happening to global food security. In the long run, we have seen a decrease in food insecurity, but in recent years we have started seeing an increase again. There is a climate component behind that; Covid has also had an impact, and most likely this Ukraine crisis will even further have a dramatic impact on food security worldwide.

During the past twenty years, more than half of the global population has faced major natural disasters. About two billion inhabitants have faced a flooding event, 1.5 billion a drought event, and about 700 million a tropical storm event. According to the

IPCC report which was published in February, these disasters have become more frequent, and they have a bigger impact than before. The economic losses have grown five-fold since the 1980s. We can see the disasters that have led to the biggest amount of casualties; we can see especially flooding and drought events hitting several less-developed countries, with up to 300.000 casualties. Thanks to improved early-warning services, we have been able to see a decrease in those numbers. But if we look at the economic losses, there we have seen a dramatic increase, and the most expensive ones have been in tropical storms, hurricanes hitting the USA, and flooding in China and Thailand, for example; but if we divide those with the sizes of the respective economies, the small economies have suffered the most. In the Caribbean, we have seen Gross Domestic Product (GDP) losses up to 800% a year, in Dominica, for example, in 2017. And in African countries we have seen GDP drops between 15 and 20% after flooding or a drought period.

In North America, South America, Europe, Africa and Australia we have seen a global increase in heat extremes, excluding in the southern part of South America. We have also seen increases in flooding risk, especially in the Eurasian continent and some parts of Africa; North and South America have also been facing an increase. We don't have enough observed data from many regions to say what has happened to them; we have to enhance our observing systems.

As far as drought risks are concerned, the Mediterranean region is one of those where we have started seeing an increase in drought events; this is also very much the case in the Middle East and also in several parts of Africa and Eastern Asia.

The Working Group II report in February also demonstrated where we have the most climate-vulnerable regions; Africa and also the southern part of Asia and some parts of Central America are the most vulnerable regions according to the IPCC.

If we look at the various climate risks, which are very much related to the Sustainable Development goals, we can see that Africa has practically all of the vulnerabilities that can be imagined; Asia, some of them; and Europe, many fewer than the other parts of the world.

The International Monetary Fund (IMF) has estimated what kind of impact the current one-degree warming has had on the global economy; the Southern Hemisphere and tropical, low-latitude areas are strongly negatively affected, and only the high-latitude areas of the Northern Hemisphere have gained; it's had a productive impact on temperatures and rainfall amounts, and less

energy for heating is needed. Whereas the southern part of the world has suffered.

The IPCC published its *Global Warming of 1.5 °C* report in 2018, where they demonstrated that, for the welfare of mankind and the biosphere, 1.5 degrees would be the desired outcome. If we are to reach that goal, as we just heard from the Ministry, we should bend the emission growth during the coming five years, and then we should become carbon neutral by 2050. To reach 2 degrees we have twenty years more time to bend this emission growth curve, and then we should become carbon neutral by 2070.

The good news is that we are no longer heading toward 3 to 5 degrees warming, which was the message of the IPCC report in 2014. So some progress has been made. I will come back to that issue later on.

The Working Group I report from August demonstrates what is supposed to happen to rainfall amounts, and especially soil moisture, which very much drives the agriculture conditions. Whether we suppose 1.5 degree warming, 2 degrees warming or 4 degrees warming, in all these cases, for example, the Mediterranean region is going to be drier, and this will be a challenge for agriculture. The same is true for both Americas, the southern part of Africa and also the eastern part of Asia and Australia. And that to me is the main concern related to climate change: what's going to happen to the global agricultural conditions, and how we will feed the growing population. If we go to 4 degrees warming, the problem will become fairly dramatic. For example, the Amazonian region could become a desert in that case.

That's why we have created the global Water and Climate Coalition, to pay attention to this water challenge, and that's going to be endorsed by the COP27; water will be one of the hot topics of the next climate conference. If we look at the hot spots globally, we can see the Mediterranean, the Middle East, Southern Asia, Central Asia, Eastern Asia, and also both Americas which are at risk in that sense. If we overlay the water challenge and the population-growth challenge, we can see that Africa is clearly facing a major challenge, especially since they're going to see four billion inhabitants by the end of this century. Also the Middle East and South Asian countries are going to be challenged from that perspective.

According to estimations of world resources, we have an idea of what would happen to the global crop yields if we reached 3 degrees warming; and we can see that most parts of the world would suffer, and those areas which may benefit from these changes are not the most suitable for agriculture, so that would mean that we would have difficulties in feeding the global population.

Consider what has happened to greenhouse gas emissions during the past thirty years up to the end of 2019. Carbon dioxide is the dominant one; this is followed by land use, then methane, nitrous oxide and fluorinated gases. We know fairly well what the consumption of fossil fuels is like, but the land-use part is very unknown; there is a fairly wide range of uncertainty, and that's why we have from the WMO side a new initiative to improve the greenhouse gas budget monitoring system. There are also some uncertainties concerning the sources of methane, as is also true for nitrous oxide.

As far as world emissions are concerned, Eastern Asia is clearly the dominant source, then North America, and Europe is only contributing 8% of the emissions, which demonstrates that Europe alone cannot solve this problem. We have to get these East Asian countries on board; that means China, India, Vietnam, and Indonesia, where emissions have been growing fairly rapidly recently.

If we overlay the impact of fossil-fuel use from different regions historically onto the land-use challenge, we can see that Europe has mainly been responsible for the fossil-fuel part, but if we go to Asia, Africa and also Latin America, there has been quite a big contribution coming from deforestation. This demonstrates that no region is innocent when it comes to the current climate problems. In Western countries, we have used the most fossil-fuel resources, but deforestation has also had a major impact, and we should bring a stop to it in the Amazonian region, Africa and Southern Asia, as for example in Indonesia. These areas are very much responsible for this.

The good news, as my colleague from the Ministry has already noted, is that the prices of renewable energy have been dropping dramatically, especially photovoltaics and wind; the price of electric batteries and electric vehicles has also been dropping. It is fairly encouraging to see that these things are becoming affordable, and they are even attractive for investors.

The IPCC has estimated the pathways toward 1.5 or 2.0 degrees, and what would happen if we do not change our behaviour enough. They have also estimated what are the most economically attractive ways to be successful in climate mitigation, and the top two are solar and wind energy. There are certain very low-cost investments needed for success. For example, in the transport sector, we have electric vehicles, electric bikes and public transportation and so forth. Nuclear energy is also a powerful way to fight against climate change, but it's a bit expensive. That's one of the challenges that we are facing here.

The IPCC have also estimated how much money is needed for successful climate mitigation, and where additional investments are needed. Especially in the developed world and Eastern Asia, one needs to invest much more to be successful in climate mitigation. That's also the challenge for European countries. We clearly have to invest more financially to be successful in mitigation.

This is the problem in a nutshell: at the moment, 85% of the energy that we use for energy production, industry and the transport sector are based on coal, oil and gas, and only 15% is based on nuclear, hydro and renewables. We should invert those numbers in the coming decades to be successful in climate mitigation. In many countries, we should also build more nuclear energy – in countries like China, India, and perhaps Germany, it's very difficult to meet that need through solar and wind alone. That's one of the challenges ahead of us.

The European Commission has been reasoning on how to become carbon-neutral by 2050. In the EU, power production is the biggest source of carbon, with transport at number two, and industry number three; then we have for example methane coming from agriculture, and also residential sources, especially from the northern parts of the European Union. Carbon sinks play a role, especially the forests, and this is important, but it's not the big picture. So far we don't have much ground to hope for carbon-removal technologies, so that's still a fairly marginal aspect of the problem according to the European Union's reasoning. They currently think that if we reduce emissions by 90%, the rest will be taken care of by carbon sinks and slight carbon-removal technologies.

One of the facts behind this challenge is that at the moment many of the products that we consume, including our mobile phones, and many other things, are produced in China, where the backbone of energy is coal-fired energy. But we are the ones who are very much consuming those products in Europe, and also in North America and Japan.

If we consider the flows of fossil energy, we see that so far we have been very much using Middle Eastern and Russian fossil energy, and it's very likely that European countries will reduce the consumption of Russian fossil energy dramatically as a consequence of this war. But we may use a bit more from Middle East sources of energy, and also from other sources. In the long run, I expect that we will reduce the consumption of fossil energy in general as a consequence of this war. For the coming years things may look somewhat different, but five to ten years may look already fairly positive from that perspective.

Finally, some good news: we have seen thirty-two countries which have reduced their emissions during the past fifteen years, although their economies have been growing. These are mostly European countries and developed countries, but this demonstrates that there is not an automatic link between emission growth and economic growth.

So far we are not heading towards 1.5 to 2 degrees warming; we are moving toward the 2.5 to 3 degrees range, although the Glasgow COP Conference was partly a success story; the G7 countries and the European Union in particular were able to make pledges that would keep us on the 1.5 degree pathway, but the big Asian economies were not ready to do so, so far.

Finally, some political dimensions. The main concern from my perspective is going to be what's going to happen to global agriculture. We have plenty of regions which will suffer because of this change. It was already shown a long time ago that it is much cheaper to mitigate climate change than to live with its consequences, and that's of course still valid. We have to invest now, and the benefits will be seen in the long run. What's going to happen to oil- and gas-dependent economies – of course, Russia is a very urgent case, because of the war – but also what's going to happen to the Arabic economies in the long run, if the world stops using fossil energy?

Africa is clearly a challenging region. The economies of many African states are highly dependent on rain-fed agriculture. That's also their employment, and that's also their life-and-death issue. If this population growth up to 4 billion takes place, it's going to be a total mess.

In Europe, the southern part of Europe will suffer. We will have less rainfall here, and higher temperatures. The immigration potential also affects the whole of Europe, but the southern part of the continent has especially felt this.

Discussion *

Petteri Taalas, John Shine, Giorgio Parisi
and Wolfango Plastino

Wolfango Plastino: *Is climate change a real problem or just natural variability we have seen in the history of Earth?*

Petteri Taalas: It has been very much debated in the past whether climate change is real, and it has been said that we have seen natural variability in the past. And that's very true. The geometry between the Sun and the Earth has varied, and it has caused, for example, ice age variation. We have also seen warm periods in the past, but this is now the first time that manmade impact on climate has been seen. The theory of the impact of greenhouse gases on climate is physically very solid. It's been shown that this is a scientific fact.

John Shine: Climate change is a very real challenge. Global mean surface temperature has increased by 1.1 degree since the beginning of the industrial period. In the late 19th century alone, there has been a steady documented rise in global temperatures, now well outside of anything we could call natural variability. We are at 1.1 degrees now, and we've seen the impacts worldwide. Even with current international commitments, we are likely to shoot past the 1.5 degrees before the end of the century. And even holding to a temperature below the Paris Agreement target of well under 2 degrees, things still look highly uncertain.

Giorgio Parisi: Let me speak about the global average temperature on the entire Earth, over a period of one year. It's clear, as we have seen by the charts that have been presented before, that sometimes we have an increase of 10% in one part of the planet,

* The text below is the full transcript of the roundtable that followed the *Lectio Magistralis* by H.E. Petteri Taalas, Secretary-General of the World Meteorological Organization of the United Nations.

and in other parts of the planet we have a decreasing temperature. So the important thing, the thing that is most solid and most reliable, is the temperature average over all the world.

Now, we know that this quantity changes from year to year, by just over a tenth or two tenths of a degree, and fluctuates around an average. One year it is higher, and one year it is lower. This is just the fluctuation from one year to the next. On top of this fluctuation, there are some long period trends. For example, the temperature that we have now is more or less slightly higher than the temperature during the Altithermal Period on the Earth, which was some 8000 years ago. And this Altithermal Period was likely the warmest period in the last 100.000 years.

We have seen, in recent years, essentially more than one degree of temperature change in one century. And this is a staggering increase of temperature, one which is unprecedented. Indeed, if we go back to the Altithermal, from the Altithermal on, the temperature dropped as little as two tenths of a degree every 1000 years. And we have just recovered all the descent that happened from the Altithermal to nowadays in 8000 years, and we recovered it in only a single century. So things are changing very fast, much faster than in the past, without any other apparent reasons, such as volcanoes and so on. That is important, because we know that we have a varied change in temperature due to volcanic eruptions, due to meteorites, and similar things; but we have seen nothing which could justify, on the basis of natural causes, this type of variability; it is unprecedented.

Wolfango Plastino: *What are the biggest risks caused by climate change so far and in the future?*

Petteri Taalas: We have built many of the big cities worldwide in low-lying coastal areas. That's the case in China, India, Vietnam, Thailand, and in some African cities. Many European cities are located in low-lying coastal areas. The same is true for several North American cities. So that's going to be a challenge, while at the same time urbanization is happening. And then we expect to see intense tropical storms in wider areas than we used to have in the past. For example, this spring we have seen record-breaking cyclones hitting Madagascar. There have been altogether five cyclones with severe flooding impacts affecting Madagascar. And as I said already in my presentation, I'm mostly concerned by the impact on global food production and capacity, and what's going to happen in the less-developed world in that respect.

And then, the melting of glaciers is going to endanger the availability of fresh water. The Himalayan glacier affects the amount of water in Indian and in Chinese rivers; here in Europe the Alpine glaciers are the origin of several rivers; in North America, the Rocky Mountains have a similar impact, and in South America the Andes. So that's one of the long-term challenges: how to get enough fresh water for human beings, for industry and for agriculture.

John Shine: Worldwide, we're seeing growing impacts of climate change on the frequency and the intensity of extreme weather events and climate-related disasters. We are witnessing their impacts on supply chains and primary production, their impacts on human health. Heatwaves, droughts, cyclones, floods, fires – all are increasing in intensity.

In Australia, we've recently seen many climate-related disasters, including major continent-scale bush fires, heavy cyclones, extensive coral-reef bleaching on the Great Barrier Reef, and record-breaking floods. The town of Lismore was completely inundated in March 2022 with what was described as a one-in-five-hundred-year flood. But then again at the beginning of April we had another major flood in that town. These have had devastating impacts on people's lives.

In the future, these disasters are almost certain to become more intense. Impacts on human systems will become more and more marked, with health effects becoming more pronounced and prevalent. Our economic systems will probably be fairly seriously disrupted, and food security may be compromised.

I mentioned the Great Barrier Reef in Australia, which is actually unlikely to survive if global temperatures rise above 2 degrees. But ecosystems that we rely on for clean air and water, crop pollination, pest control and other services, will all be disrupted and severely altered.

Giorgio Parisi: I think that most of the important points have already been covered. Let me stress that we have seen a sea-level rise of more or less thirty centimetres in the last thirty years, and this trend gives no sign of decreasing. Maybe it won't increase for the moment, but it's clear that, in the long run, this might be an extremely dangerous problem for coastal areas, like Venice in Italy.

Now, I think that the other point that has already been stressed is that extreme events, like floods, hurricanes and so on, will become more and more frequent. And this is clear. One of the big

effects of global warming is to increase the atmospheric circulation from the equator to the North Pole, and this will increase the kinetic energy in the atmosphere. That obviously carries more energy, and there will be a situation which may include a great heat wave coming from the South, or a great cold wave coming from the North, and thus extreme events will become more and more frequent. And we know that when we have an extreme event of one kind or another, it is clearly extremely dangerous, especially because sometimes these extreme events are associated with catastrophic rainfall.

One problem that I think may prove the greatest danger is the unpredictable change in the pattern of rainfall. You have seen that in some parts that were supposed to have more rain, there, for any number of reasons, we actually see less rain. And clearly this is a terrible danger for agriculture. It is not easy to relocate agricultural activity from one country to another. In the Altithermal Period, the Sahara area was occupied by a big lake, and the Chad Lake is what remains of it. But if we had more increase in the rains in the Saharan and central-African regions, and we had a stop to the monsoons in India and China, it is clear that the latter would be a huge disaster that is not mitigated by the former.

I think that one other big risk of climate change is that, actually, due to the action of man, the natural environment is more fragile, because the regions of natural resources are decreasing. We see most of Europe is no longer in its original natural state, and so the change of temperature is going to cause the extinction of an impressive number of species. We have all the seen tendencies that are leading toward a mass extinction, the traces of which will remain in the future for hundreds of millions of years from now.

Wolfango Plastino: *What are the main factors behind the observed climate change?*

Petteri Taalas: What we also saw in my presentation is that deforestation has had an impact, and that's also something that we should stop. We should try to grow more forests, at the expense of deforestation. But carbon dioxide is the main problem, with methane as number two and nitrous oxide number three. Deforestation, especially in the Amazonia region and some parts of Africa and some parts of Southern Asia, should be stopped as well.

John Shine: Greenhouse gas emissions are far and away the biggest factor. Emissions from power generation, our cities, the

transport sector, agriculture and land use. The physics of this has been very well documented for a generation now. These gases trap heat from the Sun in the atmosphere, causing environmental warming.

Giorgio Parisi: It's clear to me and to most of the people who have deeply studied this problem that human behaviour is the main factor; it is mainly responsible for this climate change, through the effect coming from the emission of huge quantities of CO_2 into the atmosphere, and also methane from livestock, from agriculture practices; these two gases have a strong greenhouse effect. Now we are setting deforestation on top of this, as we have all just mentioned. And on this point there is presently no doubt that the increase of CO_2 (just to put things in their simplest form) is strongly correlated with the increase of temperature. The temperature increase which we have seen was predicted, albeit with a large margin of error, forty years ago, by two climatologists who have won the Nobel Prize in 2021 together with me (*ed. note*: Syukuro Manabe and Klaus Hasselmann). Now, there have been accurate models which have been made, the margin of errors have been extremely reduced, and the human origin of climate change is certain beyond any reasonable doubt.

Wolfango Plastino: *Do we have the means to solve the problem, and what are they?*

Petteri Taalas: The good news, which is also coming from this most recent IPCC report, is that we have the means to be successful in climate mitigation, and the price of those solutions have become lower. We can stop using fossil energy in the energy sector and replace it with nuclear, hydro, solar and wind energy. In transportation, we have a growing amount of electric vehicles on the market; their prices have been dropping, and I'm convinced that they will drop further during the coming years. We can also consider using some biofuels, and it's likely we will also have hydrogen as a new available solution.

In our everyday diet we are eating a bit too much meat, and to produce that meat we have been using 70% of our farmland for feeding the cattle. The deforestation of tropical rainforest areas is also connected; one of the reasons behind that is that we produce, for example, soybeans for cattle. We could eat a little bit less meat, and that would also be a good solution. And also there are energy saving solutions like heat pumps, which could be part of the solution.

John Shine: We need to decarbonize the electricity supply and transition away from fossil fuels. We need to couple that with electrified transport and energy systems, removing fossil fuels from these systems as well. We need to improve energy efficiency in all sectors, and provide support for low-energy options in design and building. We also need to deploy carbon-reduction technologies at scale, and we need to continue to research options for carbon sequestration and negative emissions. We need to preserve and expand existing carbon sinks, especially things such as mangroves and forests. The IPCC has given us a roadmap. They've given us a comprehensive description of the problem, and have highlighted what the solutions are. We need to follow this roadmap.

Importantly, though, we also need to make sure that we adapt while we go. We are already living in a changed climate, and we need to prepare for much further change. What we can't do anymore is sit on our hands and wait for a better solution – one which costs less or doesn't inconvenience so many people. If we don't make the hard choices that we need to now, the climate will make them for us.

Giorgio Parisi: I would say in a nutshell that the cure is clear: we should reduce the greenhouse effect. We should reforest. This can be done either by the exploitation of renewable energies, energy saving and the reduction of some consumption, like meat, as was stressed before, which would, in some sense, go together with the improving of our health; because in many, many countries, like Italy, we do eat too much meat.

Generally speaking, I would say that we are facing a huge problem that needs decisive interventions, not only in this direction, to stop the emission of greenhouse gases, but also in scientific investment. We must be able to develop new technologies to conserve energy by transforming solar energy or other kinds of energy into fuels; we should have non-polluting technology based on renewable resources. Not only must we save ourselves from the greenhouse effect, but we must also avoid falling into the terrible trap of exhausting our natural resources. Energy saving is also an issue that should be tackled in a decisive way. And we should somehow stop using too much heating in the winter and too much cooling in the summer.

We have to block climate change in a successful way, and the price incidentally connected to this will engage humanity for many, many years. It will require a monstrous effort by all people. It's an operation with a colossal cost, both financial and social, with changes that will affect our lives. The political powers must

ensure that these costs are accepted by all, and that those who have used the most resources must contribute more in order to affect the bulk of the population as little as possible. The cost must be distributed fairly and equably among all countries, and the countries that currently use the most resources must make the greatest effort.

Wolfango Plastino: *Is the destruction of mankind and our planet likely, or just science fiction?*

Petteri Taalas: We have to keep in mind that we are not foreseeing the end of the world, neither for human beings nor for the biosphere. But the higher the warming rate is going to be, the more negative impacts we will see and the more difficult it will be for us as human beings. It will also be more difficult for the biosphere.

We need to keep in mind that the media sometimes likes horror stories, and we may have got the impression that we have this kind of apocalyptic view of the future. The scientific proof based on these climate models doesn't show that. But it has clearly shown that the lower the warming rate, the better things will be for the welfare of mankind, and with these higher numbers we will see lots of unrest globally. That will be the source of various crises. For example, one reason behind the so-called Arab Spring, which led to changes of the government in Tunisia, Libya, Egypt and the still ongoing war in Syria, was severe warming, which doubled food prices, and led to the unemployment of the agricultural population. That kind of crisis will become more frequent unless we are able to limit the warming to safe numbers.

John Shine: Well, the planet will survive, and humanity will undoubtedly continue. But the threat to a stable worldwide civilization is very real. Imagine if severe climate disturbances meant that we could no longer maintain uninterrupted international communications, or we couldn't get the water to irrigate stable crops, or we couldn't distribute those crops due to damaged transport infrastructure.

The social impacts of extreme weather events are well known. These have been enormously costly, in terms of both people and infrastructure. As they escalate, it will become harder and harder to keep people safe and secure. Governments cannot afford to ignore science. They must invest in the technology, policy and actions that will address the causes. The changes needed are enormous, and of

course, if we'd started forty years ago, we'd be forty years ahead now; that didn't happen. But the good news is, we have the science and we have the technology. We have the knowledge. We do know what we need to do, and we do know we need to do it now.

Giorgio Parisi: I think that our planet is extremely resistant. We have seen a lot of much more difficult periods, and the mass extinction of species has happened in the past many, many times. I think that the problem is ours; we should avoid ending up like the dinosaurs.

Now, I think, as has been mentioned, that the greatest danger is that climate change may cause very strong international tensions. It's clear that a billion climate migrants are not manageable. If we have to relocate billions of people, that cannot happen in a peaceful way. And now nuclear war is a much greater danger than climate change, but the effects of climate change may trigger nuclear war if the situation or relations among states become more and more strained.

I also have to mention that there might be the danger of falling into a Catch-22. We need to combine the actions of all countries of the world to combat climate change, and this may not happen if climate change itself has just created very strong tensions between nations. So, for this reason, it is extremely important to act as fast as possible, before this political increase of tensions between countries becomes too frequent.

It's clear what I'm thinking of. If we have a drought problem, a lack of rain in India and other regions, and we have to relocate people from India, one of the most populous countries, into the Northern hemisphere, as for instance into Siberia and Canada, this cannot be easily done, and therefore it would be a problem. We have seen what happens when there are tens of millions of migrants; it's clear that when there are billions, it won't be possible to take them in. So we should act now.