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“SCIENCE, RISK AND THE PRECAUTIONARY PRINCIPLE”

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I. SUMMARY

Science has greatly improved the condition of humanity. It has contributed to the rise in global well-being. It has helped to meet the major challenges facing human societies, and there is every reason to hope that it will continue to do so. However, some of the applications of research lead to serious and irreversible risks for both individuals and the environment and, consequently, for the world in which future generations will have to live.

Fortunately, advances in research are also helping to identify, pre-empt and protect against these risks. The precautionary principle thus aims to take advantage of these scientific findings to take protective measures, without waiting until we are able to precisely quantify the extent of the perils we may face. There is therefore tension between the progress of knowledge, the technological developments that such findings bring about and the awareness of the risks they entail.

The precautionary principle stems from the 2004 Environment Charter, enshrined in the French Constitution in 2005. Its scope has gradually been broadened from the environment to health. Its historical and philosophical origins lie in the concepts of prudence, prevention and precaution. However, while prevention relates to proven risks, the precautionary principle relates to counterfactual risks, which are not yet proven by observation but can nonetheless be foreseen.

Risk assessment is based on the results of the work of expert researchers who are consulted by public authorities before a decision is taken. Given the margin of uncertainty inherent in scientific research, the complexity of the problems addressed and the importance of the human, social and economic issues at stake, these experts must have a multidisciplinary approach, proceed in complete transparency, avoid conflicts of interest with the industrial groups involved and, generally speaking, comply with the rules of scientific integrity. Furthermore, these researchers must be attentive to the reactions of their fellow citizens, who may sometimes find it difficult to grasp the reality of the potential risk posed by certain technologies, and make excessive use of the precautionary principle. However, some citizens may, on the contrary, be the informed discoverers of real, as yet unidentified hazards and their voice should be heard.

We wish here to consider, with discernment, the moral responsibility of researchers themselves with regard to risks arising from the application of their work. It is clearly sometimes difficult to appreciate the consequences of some innovative research, for example in the field of genetics, digital technology or artificial intelligence. Indeed, research projects such as these often involve risks that have not yet been fully explored, whether they could affect our personal lives or the evolution of society as a whole. It is therefore important to take into account both the scientific aspects of the precautionary principle and the ethical issues that its application may pose, whether societal, economic or political.

Finally, from a legal point of view, the precautionary principle raises questions about the indirect responsibility of scientists when judges request their expertise. The legal status of scientific evidence, in the presence of uncertainty or debate, should then give rise to in-depth reflection, in which scientists should be more closely involved than they are today. COMETS sees this as an opportunity to bring together researchers on the one hand and legal players on the other.

Recommendations are made both to research institutions and their employees.

II. FORMAL INTERNAL REQUEST

Although science has considerably improved the condition of humanity, its applications give rise to both hope and mistrust, as they entail major risks not only for individuals but also for their environment, and ultimately for the survival of the human race. Fortunately, advances in research are also helping to assess and pre-empt such risks. The precautionary principle finds itself therefore in the tension between the progress of knowledge, technological developments and awareness of the risks they entail.

Born a quarter of a century ago, the precautionary principle was inspired by the reflections of Hans Jonas, a key ethical philosopher of the 20th century who, in his major work "The Imperative of Responsibility" first published in German in 1979[1], urges us to adopt a heuristics of fear. This approach recommends taking into consideration the risks posed to future humanity by current technological developments, even in the absence of scientific evidence determining the precise extent of the danger. After being articulated at the 1992 Rio de Janeiro Earth Summit[2], the precautionary principle was incorporated into French legislation in 1995[3]. It was then reaffirmed in 2004, with slightly different wording, in the Environment Charter[4], which was itself incorporated in the preamble to the French Constitution in 2005.

Over the years, the precautionary principle has gradually been extended from the field of the environment to that of public health, in particular following the contaminated blood scandal and the ‘mad cow’ crisis. It is increasingly referred to today when addressing various technologies outside the environment and health sectors, such as digital technologies.

If applied appropriately, the precautionary principle can be very useful to avoid major and irreversible damage in the long term. It occasionally echoes concerns or even fears felt by citizens, whether or not these are based on rational grounds. It can also serve as an alibi for some politicians to cover up their lack of scientific and technological knowledge, thus blocking much-needed decisions or, on the contrary, pushing for irrelevant ones. Finally, it can discourage the boldness of some innovators in the name of presumed risks for the future that are not yet borne out by fact. Difficulties arise from the tension between advances in knowledge and the implementation of preventive measures, decided in the name of the precautionary principle, but taken in total or partial ignorance of scientific knowledge.

This Opinion will begin by recalling the historical and philosophical origins of the concepts of prudence, prevention then precaution. We shall first analyse how science often allows us to foresee the potential danger in the technologies it has inspired, without being able to eliminate all risk. We shall then show how citizens' anxieties can, on the one hand, be a source of excessive calls for the precautionary principle, yet, on the other, reveal very real threats.

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[1] *Hans Jonas, “Das Prinzip Verantwortung” published in English by the University of Chicago Press (1 June 1984) as “The Imperative of Responsibility”.*

[2] *The United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil in June 1992.*

[3] *Act No. 95-101 of 2 February 1995, known as the Michel Barnier Act, on the reinforcement of environmental protection. “Lack of certainty, in the light of current scientific and technical knowledge, shall not delay the adoption of effective and proportionate measures to prevent a risk of serious and irreversible damage to the environment at an economically acceptable cost”. (English translation approved by COMETS).*

[4] *Where the occurrence of damage, although uncertain in the light of scientific knowledge, could seriously and irreversibly affect the environment, public authorities shall ensure, in application of the precautionary principle and within their areas of competence, that risk assessment procedures are implemented and that provisional and proportionate measures are adopted in order to pre-empt the occurrence of damage”. (English translation approved by COMETS).*

The analysis will then focus on the responsibility of researchers regarding the risks involved in the potential applications of their work. We shall then consider how to establish a constructive exchange between researchers, decision-makers and citizens. Finally, we shall examine the uses of the precautionary principle and the constraints it imposes on politicians, researchers and their institutions.

III. ANALYSIS

A. Origins of the precautionary principle

1. Science, uncertainty and prudence

The early Greek philosophers[5] tried to free human thought from myths and religious beliefs. They argued that the world could be understood through observation and questioning, not through the passive acceptance of fables and dogmas. The third century BCE and the Alexandrian school saw the first real measurements of the world around us[6], but also an awareness of the imprecision of these measurements. In discovering that it is possible to get close to the 'truth', the Greek 'physicists' and 'engineers'[7] also realised that it was impossible to fully know the ultimate truth. The Greek philosophers also proposed a definition of the concept of 'prudence'[8], which is the ability to deliberate successfully before making a decision. The precautionary principle thus refers back to its early origins through the established link between the uncertainty inherent in knowledge and the prudence involved in a decision.

The development of modern science from the 16th century onwards stemmed not only from the ever-present need to understand the world in which we live, but also from the need to solve the many problems faced by the 'engineers' of the time (artillery, navy, lifting and pumping machines, then steam engines, etc.). Many of the concepts that inform modern science thus have their roots in both the understanding of nature and the need to develop new technologies. A series of remarkable successes have helped give humanity the impression that we can explain, predict and control everything through science[9]. The 19th century saw the development of the application of science on an industrial scale with its attendant economic challenges. At the same time, we began to deplore the harmful effects accompanying this development, such as health risks (pollution, asbestos, lead, etc.) and adverse effects on the environment (air pollution, soil contamination, etc.). Fundamental science and its technological applications are closely linked and cannot therefore be dissociated in the debate on the precautionary principle. Applying the precautionary principle to scientific research can thus be defined as applying this principle to the technologies that scientific research helps to produce.

Although science and technological developments in the 20th century have contributed to a considerable improvement in living conditions and an unprecedented increase in life expectancy, society is gradually becoming aware of the harmfulness of certain technologies resulting from science. The development of

[5] *There was no really clear distinction at that time between philosophy and science.*

[6] *Aristarchus of Samos (in the third century BCE) determined the relative diameter of the Moon and the Earth, the Earth-Moon distance in relation to the diameter of the Moon, and the Earth-Sun distance (much underestimated) in relation to the Earth-Moon distance. Eratosthenes of Cyrene (died ca. 192 BCE) succeeded in measuring the diameter of the Earth, which made it possible to put numbers on all the distances determined by Aristarchus.*

[7] *In Alexandria, experiments were carried out on metals and dyes (which later became known as chemistry), while different types of machines and instruments were also developed (which became known as technology).*

[8] *Aristotle, "Nicomachean Ethics", Book 6, Chapter 5. "...This is why we regard Pericles and those like him as prudent men, because they are in a position to see what is good and advantageous for themselves and for others; and we believe them to be capable of successfully directing the affairs of a family, and those of a state..."*

[9] *For example, in 1846 Urbain Le Verrier investigated a slight anomaly in the trajectory of Uranus and predicted the existence and characteristics (mass, orbit, position) of a previously unknown planet. Neptune was discovered shortly afterwards and found to have the characteristics calculated by Le Verrier. In a session of the academy, Arago stated that Mr Le Verrier "saw the new star at the end of his pen".*

weapons of mass destruction during the first and second world wars has left a lasting impression[10]. After World War II, considerable economic development and the globalisation of trade led to a growing awareness of the actual or potential dangers of technologies in the fields of health, the environment, climate and biodiversity. Günther Anders[11] even spoke of 'Promethean shame' when referring to the dangers of technology. The view that humans are changing the planet is now widely shared. Some even consider that we are entering a new era in the history of Earth, the Anthropocene[12]. Society is becoming aware of the risks not only on a local and short-term scale for individuals, but also on a long-term, large-scale basis for the survival of humanity and the planet, as illustrated by the premonitions of science fiction.

2. Initial actions

Despite the rapid development of science and its technological applications, it seemed obvious for a long time that the planet could withstand massive, systematic exploitation of its resources and that the environment—greatly deteriorated—could spontaneously regenerate resources on its own. However, after several human and environmental tragedies between the late 1950s and the 1980s[13], people realised that societies cannot be subjected to anarchic technological development indefinitely. Politicians have successively proposed various responses in order to protect the environment.

The first response was the 'polluter pays' principle. Enshrined in the Single European Act, it was adopted by the OECD countries as early as 1972 and defined as the financial responsibility of the polluter for preventive and control measures imposed by the public authorities to keep the environment in an "acceptable" state. Assuming the cost of remediating damage a posteriori should drive any rational party to reduce potentially harmful effects a priori. However, even if the 'polluter pays' principle can solve local and specific environmental problems, it becomes inapplicable when the damage is imperceptible, diffuse or noticed late, or when the cost of repair is too high. This is even more true when the harm done has become irreversible.

Once people began to consider the possible irreversibility of the harm caused by technology, the focus shifted to the need for *preventive* action[14]. However, this assumes that science is able to foresee with *certainty* and *precision* the level of environmental damage and all its consequences. However, such a level of knowledge and information is not always available to science. Thus, in the fields of chemical pollution, the notions of *hypothetical risk* and *threat* have emerged, involving scientific predictions based on *uncertainty* and *probability*[15]. The uncertainties concern above all the geographical extent of potential damage, the lifespan and reactivity of the pollutants with the environment, the time frame of their effects (e.g. for greenhouse gases) and their reversible/irreversible nature (e.g. deterioration of the ozone layer)[16].

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[10] Chemistry leading to weapons such as poisonous gas but more especially physics (and secondarily chemistry) leading to nuclear weapons.

[11] Günther Anders, "The Obsolescence of Man", originally in German: https://libcom.org/library/obsolescence-man-volume-i-part-two-%E2%80%9C-world-phantom-matrix-philosophical-considerations-r

[12] The term was first coined by Paul Crutzen, winner of the 1995 Nobel Prize in Chemistry. Although the Anthropocene Working Group (of which Crutzen is a member) of the International Stratigraphic Commission has proposed its recognition, the Commission—which establishes precise scientific criteria for the definition of geological ages—has not so far adopted it (https://www.nature.com/articles/d41586-019-01641-5). The idea of such a new age is now widely circulated, particularly in the human and social sciences.

[13] For example, the industrial accidents at Seveso in Italy (1 July 1975) and Bhopal in India (3 December 1984).

[14] The catastrophic incident at the AZF site in Toulouse led to an in-depth review, which resulted in the "risks" Act of 30 July 2003. This law consolidates preventive actions in several areas. Technological Risk Prevention Plans (PPRTs) organise the co-existence of hazardous industrial sites and neighbouring areas in French regions.

[15] These notions emerged in particular following observation of the destructive effects of PCBs (polychlorinated biphenyls or Pyralene, which are toxic, ecotoxic and reprotoxic) and DDT (dichlorodiphenyltrichloroethane, an ecotoxic insecticide that is a persistent organic pollutant) on biodiversity, and of CFCs (chlorofluorocarbons) on the ozone layer.

[16] It should be noted that to assess the level of uncertainty, scientists rely heavily on numerical simulations based on sophisticated models using the results of a multitude of measurements as their input.

3. Preventive actions, precautionary principle and innovation principle

a. Preventive actions

There is no very precise definition for a prevention principle. It is better to talk about *preventive actions*. This means that public authorities have a duty to enforce measures to avoid or reduce the damage associated with the proven risks that certain technologies may pose to society. Proven risks are confirmed by scientific findings—even if they include uncertainties—so their existence is not or no longer in doubt. In France there is a Higher Council for the Prevention of Technological Risks known as the CSPRT. Founded in 1976 under the name CSIE, its remit at first covered only "classified installations" for the protection of the environment[17], but its scope was extended in 2011. It is now a consultative body that assists the ministers responsible for classified installations for the protection of the environment and nuclear facilities. In 2018, for example, the CSPRT spoke out to limit the red sludge discharged by industry into the Mediterranean Sea, as it is known to damage the marine ecosystem[18].

b. Precautionary principle

Preventive actions are justified when the risks entailed by certain technologies are clearly identified for today's world. Sometimes the uncertainties are too great, however, for science to be able to assess the risks that will affect tomorrow's world. These are referred to as counterfactual risks as they are not based on observed facts. This is how the precautionary principle, which concerns potential and hypothetical threats for the future, originated. The idea behind this principle is that uncertainties should not delay the adoption of measures to avoid or slow down probable environmental degradation in the long term. Through the scientific dimension of the concepts of uncertainty and probability, the precautionary principle can be seen as an adaptation to the planet, to present-day humanity and to future generations, of the notion of "prudence" that Aristotle advocated for the city (albeit without suggesting taking action in the face of uncertainty over counterfactual risks for which experience acquired over time is not sufficient).

In 1976 the West German government, aware of the environmental damage caused by acid rain, called for precautionary action, arguing that it was unacceptable to wait for precise and quantified scientific forecasts before taking preventive action. Other major issues concerning the state of the planet then required the attention of public authorities. The Vienna Convention on the Protection of the Ozone Layer, as adopted by 28 countries on 22 March 1985, recognises the need for increased international cooperation to limit the risks that human activities may pose to the planet's ozone layer. The first explicit mention of a precautionary principle appears in June 1992 with the Rio Declaration on Environment and Development, which is not yet legally enforceable. Principle 15 includes the following wording: *"Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."* This declaration was followed by several reports.

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[17] Act No. 76-663 of 19 July 1976 on classified installations, now Art. L. 512-5 and L. 512-10 of the Environmental Code. The term "classified installation" applies to any industrial or agricultural operation likely to create risks or cause pollution or nuisances, particularly for the safety and health of local residents.

[18] In an Opinion issued on 13 February 2018, the CSPRT called for an end to the exemptions on iron discharge limits, and for the discharge thresholds for aluminium, arsenic and COD (chemical oxygen demand) to be halved. As a result, the CSPRT recommended that the prefectoral decree of 28 December 2015, which had granted ALTEO important exemptions concerning the chemical content of discharges into the sea, be amended.

In France, the precautionary principle entered domestic law through the Barnier Act of 1995 in these terms, which add the concepts of proportionality and acceptable cost to satisfy the demands of the state's financial backers:

“Lack of certainty, in the light of current scientific and technical knowledge, shall not delay the adoption of effective and proportionate measures to prevent a risk of serious and irreversible damage to the environment at an economically acceptable cost”.

Then the precautionary principle was first integrated into Article 5 of the Environment Charter (2004) then incorporated into the preamble to the French Constitution (2005)[19]. Its scope has gradually been broadened to include the health sector.

Public authorities shall ensure, through the application of this principle in their areas of responsibility, the implementation of risk assessment procedures and the adoption of provisional and proportionate preventive actions that must furthermore be taken at an economically acceptable cost. The two concepts of proportionality and economically acceptable cost considerably enhance the definition of the precautionary principle, while at the same time coming into tension with the principle itself, especially with regard to cost. However, this tension makes them imprecise and subjective, and their difficult assessment depends very much on the context, the acceptability of risk by the population, the priorities of the governing regime, the pressures exerted by promoters of the technologies in question, etc. They may also depend on the hierarchy of ethical values: does the duty to save human lives at a very high cost, as in a health crisis, outweigh the need to save the economy?

c. Differences between prevention and precaution

There is therefore a major difference between precaution and prevention[20]. In order to avoid or minimise technological risks for the future, the measures applied by public authorities call for prevention in the case of risks that have been proven, through experience, to cause harm able to be assessed according to current procedures. Preventive actions are therefore required. This is not the case when applying the precautionary principle. Here, the decision is not based on scientifically proven risks, as in the case of prevention, but on scientifically assessed potential risks that can be used to distinguish between different risk scenarios for the future. This is an unconventional scientific situation resulting from the great complexity of the subject and its multifactorial nature, which requires an assessment approach that calls on multiple and participatory skills, that is open to criticism and that can be revised. It should be noted that in the absence of scientific proof, the precautionary principle is unique in that, unlike prevention, it does not imply a formal obligation to take a decision. It is therefore the precautionary principle and not preventive actions that should be implemented if a risk is only foreseen but not proven with any certainty. It was thus in the name of the precautionary principle and not with reference to prevention that in October 2020, the Danish Minister of Agriculture ordered the slaughter of millions of battery-farmed mink, after it was discovered that some of them were carriers of a mutated form of SARS-CoV-2 and that the mutated virus had been transmitted to twelve people. The precautionary principle was invoked here, based on the hypothetical but unproven threat that a mutation of the coronavirus from mink to humans could compromise the effectiveness of a future vaccine[21].

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[19] After its adoption by Parliament in 2004, the text was submitted to the Congress of the French Parliament in Versailles on 28 February 2005. The Charter was then adopted and promulgated on 1 March 2005 and incorporated into the preamble of the Constitution of 4 October 1958 that founded the Fifth Republic.

[20] See, for example, the article by Robert Delorme in Le Monde of 23 September 2010: “Prévention ou principe de précaution ? Une question insoluble scientifiquement” [Prevention or precautionary principle? A scientifically unsolvable question]

[21] Press release from the French National Academy of Medicine and the French Veterinary Academy, 5 November 2020.

But sometimes the line between prevention and precaution is blurred and risks that were initially foreseen without any certainty may subsequently be proven once their effects have clearly materialised. An example is the ban on hydraulic fracturing ('fracking') used for shale gas exploration and development activities (Jacob Act of 2011), based on a debate involving scientists, the economic sector and citizens[22]. In fact, the ban could have been the result of preventive actions, as the threats to the environment had already been identified by 2011. However, this risk was not quantified and the debates on the ban constantly appealed to the precautionary principle.

There are also cases where prevention, justified by the knowledge of definite risk, is artificially transformed into the precautionary principle by a clever semantic twist aimed at bringing into play the fact that public authorities are not obliged to take preventive measures. Such tricks may be the result of pressure from industrial lobbies involved in the dangerous technologies in question: they buy time by casting doubt on the risks, sometimes with pseudo-scientific arguments, before bans are imposed that will disadvantage them. For example, the ban on asbestos in public works was postponed for several decades due to poorly substantiated arguments, such as those concerning the small risk of low doses (see § C4).

d. Innovation principle

Not all industries are in favour of the precautionary principle. Many believe that this principle can slow down the innovations that result from advances in research, in the name of alleged risks for the future that have not yet been established by facts. In this respect, the innovation principle is sometimes put forward alongside the precautionary principle, with which it is more or less in direct opposition. The concept of the innovation principle was introduced and discussed at an OPECST day of reflection on 5 June 2014, which brought together representatives of major companies, MEDEF, the IESF association for French engineers and scientists as well as the French Academy of Technologies. Following their discussions, OPECST declared itself in favour of making innovation a legislative principle: in 2015, it proposed that the so-called "Macron Act" be accompanied by an amendment introducing the innovation principle, yet with a rather vague definition[23]. Some MPs disagreed with this proposal to reduce the scope of the precautionary principle, which they considered particularly detrimental to environmental protection.
The innovation principle has not yet been given a legislative status in France, but the concept periodically comes up in political debates. It made a discreet entry into European legislation in 2018 and appears in the preamble to the European Horizon 2020 programme, in a form vague enough not to call into question the precautionary principle[24].

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[22] *See Act No. 2011-835 of 13 July 2011. It should be noted that the damage caused by fracking (pollution of the water table, mini-earthquakes), appears to be confirmed by a recent English scientific study and is still being researched.*

[23] *This is how the principle of innovation is referred to in the amendment by MPs Jean-Yves Le Déaut and Anne Yvonne Le Dain for the OPECST in 2015, proposing to add an Article 41B to the law, amending the French Research Code: "Art. L. 131-1: In the exercise of their respective powers and, in particular, through the definition of their purchasing policy, public and private persons entrusted with a public service remit shall promote, implement for the fulfilment of their tasks and support all forms of innovation, understood as all new solutions in terms of the supply of goods, services or works capable of meeting needs that cannot be met by solutions that are already on the market. As such, they are committed to monitoring contemporary forms of innovation, including those emanating from small and medium-sized enterprises".*
The amendment, which was accepted in the first reading in Parliament, was finally rejected by the Senate and not adopted as law.

[24] *https://www.lemonde.fr/planete/article/2018/12/16/le-principe-d-innovation-entre-dans-la-loi-europeenne_5398455_3244.html*

B. Scientific risk assessment

Risk assessment is based on the work of expert researchers. They may be consulted by public authorities to assess the potential risk of developing a technology, or conversely the damage that would be caused by not using it. This can lead to the establishment of standards (e.g. on the use of plastic packaging), or to decisions being taken in a health or environmental crisis situation. It is therefore important to understand how science can shed light on threats and potentially on how to overcome them.

1. Experts' imperfect approach to truth

The greater the complexity of the questions asked and the longer the time frame of the predictions, the greater the margins of uncertainty in the research findings. Researchers are often required to work as part of multi-disciplinary expert groups whose diverse skills complement each other. They then pool information of relevance based on their respective areas of competence in order to be able to give an overall opinion.

These expert groups address issues that have multiple parameters. One example is estimating climate change, which is the result of interrelated processes in which the various components (oceans / atmosphere / Earth / Sun, etc.) interact and have a knock-on effect on each other. Scientists do not believe that there is always a straightforward link between cause and effect, unlike most of the general public and some politicians who naturally tend to associate an effect with a single cause. The way scientists assign margins of error to their predictions is not always properly understood. Moreover, the complexity of the phenomena involved requires experts to factor in the various, and sometimes divergent, points of view on the reality they are investigating. This usually includes economic, cultural and societal aspects that can be understood in greater depth thanks to the multidisciplinary nature of expert groups, as in the case of the IPCC[25] for example.

It should be noted that the results of such work always reflect the state of knowledge at a given time. However, knowledge is likely to change or may even be refuted at a later date. Experts may have their own reading of very complex phenomena and therefore their own interpretation. Indeed, interpretation has a lot to do with the uncertainty surrounding results and therefore the impossibility of obtaining an absolute truth.

2. Importance of time and space scales

The precautionary principle is based on the assessment of risks that are difficult to evaluate because the uncertainties vary according to whether one is looking at the short, medium or long term, and whether the scale is local or global. In the case of the climate, for example, risk prediction takes into account interactions between natural climate fluctuations, driven largely by processes within the climate system, and the extent of greenhouse gas emissions. The uncertainty of natural fluctuations is unavoidable, whereas the uncertainty of fluctuations in greenhouse gas emissions depends on societal developments: it can therefore potentially only be assessed in part, but justifies the application of measures under the precautionary principle. The degree of uncertainty in predictive models thus differs according to time and space scales. There are many uncertainties on a long-term scale (end of the 21st century), and forecasts are not very accurate because they depend to a large extent on the worldwide policy adopted today in response to global warming. The impact will be global, affecting the entire planet. In the shorter term, e.g. for the next ten years, change

[25] *IPCC: Intergovernmental Panel on Climate Change, set up in 1998 to provide detailed information on the state of scientific, technical and socio-economic knowledge on climate change, its causes, potential impacts and coping strategies.*

depends partly on natural climate fluctuations and the uncertainties of models depend more on local conditions. However, the clear trend already points to accelerated global warming.

In the field of health, the risks associated with new treatments are assessed according to the practice at a given time and are properly monitored through the pharmacovigilance system. However, monitoring is hampered by the a priori uncertainty as long as these treatments have not been tested over a long period of time, since harmful side effects may appear belatedly. It should be noted that in the medical field, uncertainty is inherent in the development of new compounds and drugs, and reference is generally made more to the benefit/risk ratio for the pharmaceutical group concerned than to the precautionary principle, which concerns society[26]. Thus, in view of the emergency created by the SARS-CoV-2 pandemic and taking into account this benefit/risk ratio, the stages leading to the marketing of vaccines were shortened.

3. Expert researchers' responsibilities

The risk assessment of a technology, when recommended by a party such as the Government, a parliamentary commission, a regional council or a regulatory agency, requires the scientific expert appraisal to be free from any bias due to conflicts of interest. These may arise when, for example, expert researchers enter into research contracts with companies (funding effect). Examples are given in a previous COMETS Opinion[27], which cites a case where, during a state enquiry into air quality, one of the scientists consulted failed to declare his financial links with an industrial group responsible for pollution. Experts have to guard against pressure from external interest groups such as economic lobbies. This requirement is particularly crucial for expert appraisals commissioned by national or international regulatory agencies. Over time, this requirement has increased, especially when it concerns industrial products (e.g. food, medicines, cosmetics and plant protection products) and the exploitation of natural resources (biodiversity, environment, mining resources, etc.)[28].

When they are consulted by a political entity in an emergency situation such as a natural hazard warning or a health crisis, the expert researchers may be forced to somewhat shake up the methodological standards of scientific expertise due to time constraints. The COVID-19 pandemic has provided some examples: in the name of emergency pragmatism, some researchers published their work while bypassing the requirements of the scientific process and the usual procedures, in particular the reliability and transparency of the methods used, the critical peer review of publications and the absence of conflicts of interest[29]. The media and social networks have amplified public statements about the widespread use of treatments not validated by current standards of scientific integrity[30]. While the primary objective of medicine is to save lives, it must be remembered that this objective can only be based on reliable research using controlled clinical trials and meeting the same criteria of reliability as other areas of research. The ethics of biomedical research, i.e.

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[26] *See (in French) https://www.lemonde.fr/sciences/article/2015/03/31/principe-de-precaution-et-innovation-medicamenteuse_4606696_1650684.html. This analysis shows that in terms of irreversibility, the harm is less for drug effects than for many other technologies.*

[27] *COMETS Opinion no. 2019-39 "Interests and conflicts of interest in public research". Let us recall the importance of the Declarations of Interests to be filled in honestly by the experts.*

[28] *These agencies aim to guarantee their neutrality in the face of pressure by setting up ethics committees that investigate the interests of their expert researchers. They also keep an accurate account of their hearings with industrial lobbies, scientific expert groups and the government entities requesting the appraisal.*

[29] *See COMETS Opinion no. 2020-42 "Scientific communication during a health crisis" soon to be published*

[30] *See the joint press release by COMETS and the CNRS's Scientific Integrity Office (MIS) published on 16 April 2020 "Research during a health crisis: ethical debates and observance of scientific integrity".*

compliance with the ethics of experimentation and scientific integrity, guarantee both the absence of harm and the effectiveness of treatments and thus the trust that society can place in its scientists[31].

4. Transparency and vigilance

It is important to make it clear to all (the political entity that requested the appraisal, the media and citizens) that scientific reports are an aid to decision-making, but that the responsibility of the expert group is limited to ensuring their accuracy and comprehensiveness. It should be noted that they are just one link in the decision-making chain, which itself involves multiple criteria. This reality was regularly demonstrated during the 2020 public health crisis: the COVID-19 scientific council set up by the French government in March 2020 produced successive reports at the request of politicians. These reports were intended to be made public[32], and council members discussed their content with the media. Some of their recommendations could lead to the invocation of the precautionary principle, for example the lockdown applied to citizens, given the major uncertainties concerning the pandemic's progression[33].

Researchers need to be particularly careful about how their reports are used so that wrong decisions are not attributed to them, as was the case with the Italian seismologists consulted on the possibility of an earthquake at L'Aquila in 2009[34]. The report of a group of experts is often taken up and commented on by the media and social networks. The group's rapporteur must clearly state the margins of uncertainty of the expert appraisal and communicate them with all the transparency that the task entails. To ensure that the media do not distort the conclusions of the report, it is important to make uncertainties clear and to respond to queries in an instructive manner.

In some cases, it may be the responsibility of scientists to issue warnings even before being called upon as experts by public authorities. In the event of a crisis, they are responsible for firmly conveying—primarily to their supervising authorities—their assessment of threats as soon as they become aware of them. It may thus be considered that at the start of the COVID-19 crisis, the alert could have been raised sooner in France, given that the pandemic had already begun in China, therefore providing an earlier warning of the seriousness of the looming public health crisis.

More generally, care should be taken in academic circles to pursue work on potential risks, whether to health or in any other area. Sometimes whole areas of research cease to be funded because they are considered outdated or lacking in creativity, so strong is the imperative to always produce something new on trending topics in order to obtain contracts. Thus, many proficient virology teams were denied sufficient resources to continue their work on coronaviruses at a high level a decade before the appearance of SARS-CoV-2[35], thus slowing down the possible progress towards a treatment for the pandemic. There are many examples of this

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[31] *See, for example, Emmanuel Hirsch, The Conversation 27-03-2020 "Quels principes éthiques en temps de pandémie ?" [What ethical principles apply during a pandemic?]*

[32] *All the Opinions published by the French COVID-19 Scientific Council are available on the website of the Ministry of Health and Solidarity.*

[33] *One example is the recommendation for preventive and targeted self-isolation in the publication of 14 December 2020*

34 *Their oral consultation gave margins of uncertainty about the possibility of such a disaster, but those in charge did not take these into account; instead, they concluded that there was no risk. When an earthquake actually struck, there were many victims among the non-evacuated population. The seismologists were blamed by the families of victims and had to undergo a trial that lasted several years. This example is discussed in COMETS Opinion no. 2013-27: "Natural Hazards, Expert Appraisals and Crisis Situations". Arguably, the situation would have been different had the seismologists consulted taken more care to ensure that their report was not distorted once they had handed it in to the decision-makers.*

[35] *One example is Bruno Canard, senior CNRS researcher in the "Architecture and Function of Biological Macromolecules" laboratory in Marseille, whose work on RNA viruses since 2004 has led to spectacular progress in understanding their reproduction. However, from 2006 onwards, his team's funding fell sharply, as donors' priorities shifted to other issues. The researcher said in an article in Le Monde on 29 February 2020: "A lot of time has been wasted in finding medication for the coronavirus".*

in other areas of research such as the environment, where the trade-offs between benefits and counterfactual risks have not been properly weighed up by decision-makers—in this case research institutions and agencies—and trust in the competence of researchers has not been sufficiently taken into account.

C. Context of the precautionary principle

1. Cultural context of the concept of precaution

The risks of an innovation may not be perceived in the same way by researchers, the media and the general public. What may appear to the researcher as irrationality on the part of the public may actually be a cultural misunderstanding. Indeed, every culture is based on beliefs deeply rooted in what is often called 'tradition'. What appears obvious to the researcher may be experienced as a challenge to this culture.

Scientists may perceive the relationship between living beings and their environment in a way that is incomprehensible to some of humanity. This is the case, for example, among Amazon natives, for whom nature and culture are related to each other in a systemic continuity alien to science[36]. For the Achuar and many peoples of the Amazon and other continents, animals and certain inanimate beings possess a 'spirit', intentions, feelings, language and morals; in short, a culture that does not fundamentally differ from those of humans. It is just their "physical envelope"—their body—that distinguishes the two.

In Fiji, it is difficult to conduct research on overfishing in order to delineate marine protected areas because Fijians believe that fish hide from fishermen who have not observed collective codes. Furthermore, they believe that certain species of fish belong to certain clans. One clan may lend its schools of fish to another village to feed guests at a ceremony, for example. If that fish species later becomes scarce in the reef of its home village, it will be said that those who were lent it forgot to return it[37]. It is therefore understandable that Fijians do not see the need to apply a precautionary principle to marine protected areas.

Irrational beliefs affect even the very foundations of our culture of scientific thought. In the 19th century, it was recommended not to take the train because you could go mad from seeing the landscape go by so fast and because passengers' lungs could burst when the train entered a tunnel. There are still many urban legends circulating today recommending precautions that are difficult to accept[38], such as those that women should take to avoid becoming pregnant outside of sexual intercourse. There is even a widespread rumour that it is possible for them to be impregnated simply by sharing bath water with a man[39]. This is also an argument used to discourage them from frequenting swimming pools. Compulsive rituals and obsessive avoidance strategies are even practised in the name of prudence to ward off imaginary risks in everyday life. Precaution can thus lead to behaviour that is far from scientific logic. Such behaviour has even allowed

[36] *Philippe Descola, "Par-delà nature et culture" [Beyond nature and culture], Paris, Gallimard (2005)*

[37] *Elodie Fache & Simonne Pauwels (2020), "Tackling coastal 'overfishing' in Fiji: advocating for indigenous worldview, knowledge, and values to be the backbone of fisheries management strategies", Maritime Studies https://doi.org/10.1007/s40152-020-00162-6*

[38] *See the publication by Véronique Campion-Vincent and Jean-Bruno Renard, sociologists: "100% rumeurs. Codes cachés, objets piégés, aliments contaminés…la vérité sur 50 rumeurs extravagantes" [100% rumours. Hidden codes, booby traps, contaminated food... the truth about 50 outlandish rumours], Paris, Payot, 2014*

[39] *https://sante.journaldesfemmes.fr/fiches-sexo-gyneco/2506122-tomber-enceinte-sans-rapport-sans-penetration/#tomber-enceinte-sans-rapport-idees-recues*
https://www.cnews.fr/monde/2020-02-25/selon-une-responsable-indonesienne-les-femmes-pourraient-tomber-enceintes-dans-les

anthropologists to advance the concept of 'risk rituals', bringing irrational precautions closer to religious exercises[40]. One’s perception of the precautionary principle cannot help but be influenced by these specific systems of representation.

2. Cognitive bias in risk perception

When a discussion on the possible application of the precautionary principle to a technology is initiated at the request of public authorities, sometimes following an alert, the scientists consulted may find themselves out of step with the concerns and opinions of the population of which they themselves are citizens. There are many reasons for misunderstandings.

Some cognitive biases may distort people’s perception of risk. As early studies have shown[41], humans tend to overestimate very low probabilities and underestimate very high probabilities. Thus, some parents who refuse to have their children vaccinated may not consider that measles poses a much greater threat than the extremely low risk of complications from the vaccine[42]. Other biases may lead to a lack of knowledge about results obtained in foreign countries. Misleading historical shortcuts can distort the view of current events: for example, the risks of COVID-19 are assessed in relation to those of previous, yet very different, pandemics. Awareness of the actual risks occurs only in stages and with some delay: a pandemic is often poorly assessed at the outset because contamination—which is exponential by nature—is not understood as long as the statistics remain low. Impatience and the desire for reassurance sometimes make us over-react. Moreover, we can understand scientific arguments, such as those warning about global warming, without really assimilating them and grasping the consequences ("it's true, but still..."), especially if they call into question our habits.

In extreme cases, and particularly in crisis situations, public opinion can be manipulated by rumours or fake news inspired by conspiracy theories or attempts at political destabilisation, which are massively disseminated. Based on unscientific assertions, fake news ends up winning over a large proportion of public opinion and reaches a critical mass enabling it to be self-sustained through social media. An example of this is the absurd chemtrail theory, which claims that aircraft contrails are caused by the deliberate spraying of chemicals, a theory that has been utterly refuted by science without the slightest uncertainty[43]. Despite this, a study published in a Nature journal in 2017 revealed that 30-40% of Americans surveyed believe in the chemtrail theory[44]. No country is untouched by this contagious conspiracy theory[45]. When confronted with distressing events, we would prefer to refuse to believe in chance and find explanations by resorting to a causal relationship (for example, that SARS-CoV-2 was manufactured by such and such an individual for the purpose of mass destruction...).

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[40] *Sarah E.H. Moore and Adam Burgess (2010) “Risk rituals?”, Journal of Risk Research, first published on 05 October 2010. https://www.tandfonline.com/doi/abs/10.1080/13669877.2010.505347*

[41] *M.G. Preston and P. Baratta (1948) “An experimental study of the auction-value of an uncertain outcome”, American Journal of Psychology, 61, 83-193*

[42] *Of the 14,600 cases of measles in France in 2017 (including 37 deaths), 87% were not vaccinated.*
According to the French institute for prevention and health education, INPES, the incidence of complications from the MMR vaccine (encephalomyelitis) is 1 in 1 million cases.

[43] *This conspiracy theory emerged in 1996. It is especially supported by far-right groups but has been taken up uncritically by people on all sides.*

[44] *“Solar geoengineering and the chemtrails conspiracy on social media”. D. Tingley & G. Wagner (2017) Palgrave Communications / DOI: 10.1057/s41599-017-0014-3. It should be noted that the survey is limited in scope as it covered only 1,000 people.*

[45] *Thus chemtrails were the subject of a question to the National Assembly by the MP for the Hautes Alpes, Joël Giraud; Question No. 42050 of 12/11/2013*

Researchers are not always able to address irrational fears (and they themselves must be wary of not being susceptible). Epidemics of symptoms, or rather of "perceived symptoms", are amplified by the media coverage of a hazard, even if it is unproven or even totally fictitious, as in the case of ailments caused by Linky smart electricity meters[46]. Some sections of the media are attracted to doom and gloom, others to the sensational, which makes it all the more difficult for scientists, who need to be rigorous and educational in their explanations.

In response to irrational public fears, researchers may find themselves in a deadlock when they fail to convince the majority of people of the facts they have established scientifically. Although essential, fact-checking techniques often have a mixed impact on challenging misconceptions on social media. Opinion is rarely changed once the public's mistrust has been instilled ("There's no smoke without fire"); the ad hoc rebuttal approach is not very effective. The discrepancy between the scientific assessment of a risk and its perception by citizens cannot be addressed solely through the didactics of a science that is supposed to explain and protect. You have to face the objections in return and try to understand how fear can take hold.

It is important not to underestimate the fact that the public's perception of risk can be the result of political manipulation and have democratic implications. Citizens have sometimes learned, often at the expense of their health, that doubt can be deliberately maintained by the companies concerned, for example on the harmful effects of asbestos or tobacco[47]. In some situations, however, it is the citizens who have first-hand knowledge that scientists can confirm, such as those of associations bringing together local residents who suffer from the toxic emissions of chemical plants[48]. In the health sector, patient associations provide information on the potential side effects of certain medicines. Thus, AIDS patients, including the activist association ACT UP, have made progress in understanding the disease.

Citizens are also legitimate whistleblowers when they make public authorities aware of the need to implement the precautionary principle. They are often the first to identify foreseeable threats that could result from local, economically-driven policies that directly affect them. The subsequent debate is relevant as long as it is based on rational grounds. This is often the case in ecology-related areas, for example when land-use developments are likely to have a significant impact on biodiversity and aquatic environments. The precautionary principle can be raised by affected residents when infrastructure standards are being applied. It is therefore necessary that the voice of the people be heard.

It should be noted that the precautionary principle is not perceived and applied in the same way throughout the world. Many countries, in addition to China, are carrying out genetic research that raises ethical questions (see the examples provided in § D1). Similarly, concerns about nature protection are not universally considered to be vital. Moreover, it must be emphasised that the management of science-based technologies for the common good is highly dependent on political regimes. Misconceptions are sometimes amplified by statements made by government leaders. Somebody with an authoritarian executive power, such as the President of Brazil in 2020, may assume the right to impose their own interpretations on ongoing research, contradicting the conclusions of the most competent scientists.

3. Excessive application of the precautionary principle

[46] *It should be noted that the public's reluctance to use Linky smart meters is also due to concerns about intrusion and control of their private lives.*

[47] *See, for example Naomi Oreskes and Erik M. Conway "Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming" Bloomsbury Press, 2010.*

[48] *See, for example, the article by Michel Callon and Pierre Lascoumes in The Conversation of 22 May 2020.*

Decision-makers can hide behind the precautionary principle when the potential of a hazard is not quantifiable and the absence of risk cannot be proven based on the current state of science. Deciding to apply the precautionary principle appears legitimate if the risk, even if very small, creates a high potential for long-term harm. However, in some cases the precautionary principle is applied on the basis of alleged risks that it is very difficult to prove do not exist. It is often impossible to prove that a new instrument, process or product will never have any dangerous effect[49]. And it sometimes happens that remaining uncertainty, even though it is extremely small, can justify banning or postponing the development of a product or technology indefinitely on the basis of the precautionary principle. This is particularly true in the health sector, where active ingredients always have side effects that are difficult to quantify until they have been tested on a large sample of the population: a precautionary policy in this case would be tantamount to saying that new medicines should never be introduced, which would be absurd.

Ultimately, if one considers that no risk is acceptable and that the motto "when in doubt, assume the worst" should be followed to the letter, excessive precaution may paralyse technological development and the economy[50]. Public authorities may thus be led to take overcautious decisions when under pressure from poorly informed public opinion. Some municipalities are pushing back the installation of 3G and 4G relay antennas to the limits of their boundaries, despite reassuring statements from ANSES[51], the French Agency for Food, Environmental and Occupational Health & Safety[52].

Increasingly sensitive measurement techniques can lead to an overestimation of risks that in fact do not exist, because making a measurement means giving figures, and it is the figures that inspire fears even when they are well below the danger threshold. The application of the precautionary principle in such situations can then lead to costly decisions without any real benefit for society, or even stimulate imaginary conspiracy mongering. A well-known example is the ‘discovery’ in 2000 of an abnormal level of radioactivity on the beaches of the Camargue region in southern France[53]. This information, relayed by the mainstream media[54], led some to suspect that the Marcoule nuclear power plant had illegally dumped radioactive waste on these beaches. The local economic consequences were immediate (for tourism, rice producers, etc.). Yet this radioactivity is entirely natural and has long been known to geologists[55]. The media's subsequent discretion—or even failure to debunk the initial information—means that even when the truth is established, unease and fear remain firmly in the public mind.

[49] For example, CERN was sued in the Federal Court of Hawaii on the grounds that the large hadron collider (LHC) could produce a black hole that would engulf the Earth. Although such an apocalypse is a fantasy, scientists could not provide (or did not want to waste their time providing) absolute proof that it was absurd. It should be noted that the plaintiffs did not exactly appeal to the precautionary principle but only raised the alarm.

[50] *See Gérald Bronner and Etienne Géhin "L'inquiétant principe de précaution" [The worrying precautionary principle] PUF (2010)*

[51] Since 2002, ANSES has been asked on several occasions to draw up a scientific assessment based on knowledge from international publications on the possible health risks associated with mobile telephony. After reviewing and analysing more than 1,000 studies—most of them thorough—on the health risks of radio waves, ANSES has clearly established that a distinction must be made between the low risks of relay antennas and those of mobile phones, which are considerably higher. It should be noted that some of ANSES’s positions were criticised because not all its experts had declared all their possible relations of interest with operators.

[52] It should be noted that the NIMBY ("not in my back yard") effect can also play a role in the reactions of certain decision-makers who, although convinced of the "scientifically proven" harmlessness of radio waves, take into account the reluctance of their fellow citizens to see a relay antenna from their windows...

[53] This 'abnormal' level of radiation is, however, four times lower than that to which passengers on a flight from Paris to San Francisco are exposed, for example.

[54] This information was relayed, for instance, on the 8 o'clock news of television broadcasting channel TF1 on 2 April 2000.

[55] A. Rivière, Weekly reports of the sessions of the French Academy of Sciences, 241 (1955) 964. This radioactivity is due to the presence in these sands of particles of monazite, a mineral rich in radioactive elements such as uranium and thorium.

However, the precautionary principle can have a stimulating effect on research. The difficulty in establishing it is that it must be based on rational arguments about the risks involved without being able to determine the exact extent of those risks. Researchers may have an incentive to propose alternative ideas for risky technologies, or more generally to fill in knowledge gaps about the risks of certain technologies that concern their citizens. One example is the very strict statistical studies that have been progressing over the last ten years on the health risks resulting from exposure to radiation from relay antennas, often referred to under the precautionary principle (see above). These studies have partly helped to reassure the public and are currently being pursued through research into electromagnetic hypersensitivity (EHS). Popular beliefs or fears can thus ultimately be marginalised and trust rekindled by scientific findings when these become more precise, better explained and more difficult to circumvent.

4. Legitimate application of the precautionary principle

However, it should not be concluded from the above that the precautionary principle is always used too frequently. There are, on the contrary, situations where its application is appropriate and its non-application harmful.

An example of the legitimate application of the precautionary principle is provided by the European REACH[56] system, which came into force in June 2007 and consists of a series of regulatory safeguards against the potential hazardousness of new chemicals. This is the organised implementation of a European policy integrating the precautionary principle that potentially concerns 60,000 chemical substances. Before being adopted, this decision aroused a great deal of fear on the part of the chemical industry, counterbalanced by pressure from various NGOs. The implementation of this precautionary principle requires the cooperation of scientists from public bodies, including those from the human and social sciences, for the assessment of "acceptable" risks in relation to chemicals[57]. It involves assigning different statuses to different types of product. The implementation of the REACH Regulation is an ongoing process. It can be noted that the risk induced by each substance is unique, as the same chemical compound has a different reactivity, and therefore a different risk, depending on the size of its individual particles[58]. However, there is no doubt that the application of the precautionary principle under the REACH Regulation is globally justified and beneficial for people’s health and for the environment.

On the other hand, a counter-example is provided by the non-application of preventive measures against asbestos for a century after the first warnings about its health hazards dating back to 1906 in France[59]. The delay in banning asbestos was based on pseudo-scientific doubts planted by lobbies asserting that low doses

[56] *REACH, an acronym for registration, evaluation, authorisation and restriction of chemicals, is a regulation issued by the European Parliament and the Council of the European Union that updates European legislation on chemicals and implements a single integrated system for registering, evaluating and authorising thousands of chemicals.*
[57] *See COMETS Opinion no. 2009-19 – “The role of the scientific community in the debate on chemicals”*
[58] *Nanoparticles are sometimes wrongly associated with health risks. It is important to distinguish between different types of nanoparticles: metallic nanoparticles and inorganic compounds may pose risks, while organic nanoparticles, such as the lipids used in the new COVID-19 vaccines, do not pose any threat.*
[59] *From 1927 onwards, the respiratory problems of certain asbestos workers were established and, from 1950 onwards, asbestos was implicated in certain bronchopulmonary cancers, pleural mesothelioma and pulmonary fibrosis (asbestosis). In 1975, researchers at the Faculty of Sciences on the Jussieu campus in Paris discovered that their buildings were insulated with asbestos and took action. In 1977, the State set up a so-called 'reasoned' health policy on the use of asbestos, without banning it. The management of this policy was delegated to an informal group known as the Standing Committee on Asbestos, which brought together representatives of the asbestos industry in particular. The official ban on the use of asbestos in France only dates from 1997.*

of inhaled asbestos are safe for the respiratory tract. This catastrophic delay in the decision led to the deaths of thousands of people who contracted pleural cancer in buildings containing asbestos. This could have been avoided or at least limited if preventive action had been taken decades earlier. This major health scandal, which is now well documented, is explained by the multiple pressures that led to the reluctance of politicians to take the risks into account[60].

On an even more general scale, let us mention the vast study entitled "Late lessons from early warnings: science, precaution, innovation" commissioned in 2001 and renewed in 2013 by the European Environment Agency (EEA)[61]. This is a retrospective study of cases where the application of the precautionary principle was deemed unjustified or excessive by the public authorities, in situations where there was a suspicion of risk in a wide variety of areas ranging from pollution threats to food safety or disease outbreaks. Many international contributions were sought for this study, which broke cases down into "false positives" (where the regulation applied proved unnecessary)[62] and "false negatives" (where the absence of preventive action led to clear damage even though hazard warnings had been issued). Of the 14 cases studied, 12 were identified as "false negatives"[63]. The authors of the EEA report drew 12 valuable lessons for improving public decision-making methods and concluded that fabricating doubt about the reality of risks is often a deliberate strategy to undermine the precautionary principle in decision-making.

D. Ethical limits to research practices

Scientists themselves must question the potential risks of their research in areas ranging from the private sphere to public health, the environment or the economy. Thanks to "academic freedom"[64], they enjoy a great deal of latitude in the choice of their research subject, although this must comply with the values of tolerance and objectivity. It should be remembered that this freedom comes with no less responsibility[65]. They are able to set self-imposed limits on their experiments. It must be admitted that some researchers, believing themselves to be working primarily to improve the well-being of humanity, are in fact playing at being the sorcerer's apprentice, like the hero of Goethe's very popular poem.

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[60] *See Le Monde's article (in French): "L'amiante : un scandale sanitaire sans procès" [Asbestos: a health scandal that never stood trial], 20 July 2019. https://www.lemonde.fr/planete/article/2019/07/20/face-a-l-echec-des-instructions-penales-des-victimes-de-l-amiante-adoptent-une-autre-strategie-judiciaire_5491411_3244.html*

[61] *EEA "Late lessons from early warnings", volume II, 2013, article by Steffen F Hansen and Joel A Tickner "The precautionary principle and false alarms, lessons learned".*

[62] *Of the 88 cases studied, only 4 were considered as "false positives" after the fact, for which the application of the precautionary principle was pointless and costly for society, e.g. the vaccination of 50 million Americans in 1976 against the virus of an influenza variant that caused only a few deaths and never turned into a pandemic. In all the other cases, the application of the precautionary principle was justified after the fact.*

[63] *One example is dibromochloropropane (DBCP), a pesticide used in agriculture in the United States since 1955 against worms that damage tropical fruits. In 1970 it was proven, after repeated warnings, that workers who sprayed these products had fertility problems. Better controlled today in the United States, the product continues to be sold and used in Latin America, the Philippines and African countries.*

[64] *Article L. 952-2 of the Education Code based on the Savary Act of 1984 amended by the Research Planning Act (LPR) no. 2020-1674 of 24 December (Art 15). This Act currently guarantees academic freedoms in France: "Faculty members and researchers enjoy full independence and complete freedom of expression in carrying out their teaching duties and research activities, providing that they respect the principles of tolerance and objectivity, in keeping with university traditions and the provisions of this Code. Academic freedom... is exercised in accordance with the constitutional principle of the independence of academic staff."*

[65] *See COMETS Opinion no. 2018-35 on freedoms and responsibilities in academic research.*

1. Research whose consequences are difficult to assess

First of all, there is the problem of the potential risk that certain experiments may entail for those who carry them out or for those around them. One example is research on highly pathogenic biological agents carried out in ultra-secure P4 laboratories: given all the precautions taken, the risks of contamination of workers and of spread in the community are kept as low as possible, but they cannot be considered non-existent[66].

More generally, it is not always possible to foresee all the consequences of experimentation in new and intellectually challenging fields of research. Serious questions arise in the field of biology and medicine. The CRISPR/cas9 technique, or genetic scissors, opens up many fascinating possibilities, such as the simultaneous modification of several genes in the genome[67]. It was even awarded the Nobel Prize in Chemistry in 2020[68]. Applied to a human being, it can have several types of objectives, some therapeutic, others aimed at improving the species. Thus one of the laudable aims of gene therapy is to reduce the likelihood of a serious disease. However, the CRISPR/cas9 technique has unpredictable effects and there is a risk of affecting several functions by altering one particular gene. In addition, genetic scissors are used for "gene drives", a mechanism used to modify any sexually reproducing living being in such a way that this modification is propagated to all its descendants and thus to an entire population[69]. In this way, certain insects can be made less virulent in their ability to transmit disease. Applied to humans, gene drives entail uncertain but serious risks of irreversibly modifying the human species; it is a form of eugenics and its prohibition is fully in line with the precautionary principle. In China, the birth of twin babies with CRISP-modified DNA in 2018 led to an international outcry against this breach of ethics[70].

The consequences of much genetic research are difficult to assess. For example, the creation of chimeric embryos by implanting human cells into an animal embryo has been authorised in Japan since 2019. The stated aim is to humanise animal species in order to develop organs that can be transplanted into humans so as to alleviate the shortage of human organs. Now being discussed in France with a view to their authorisation under bioethics laws[71], such manipulations are the subject of questions identified by the Council of State, some relating to health safety, others more hypothetical concerning the blurring of boundaries between species. They raise serious ethical concerns about the alteration of the natural ecosystem of which humans are a part[72].

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[66] *Blamed by some for the emergence of the COVID-19 pandemic, the P4 laboratory in Wuhan was finally exonerated by the World Health Organization. At a press conference on 21 April 2020, a WHO spokeswoman stated that "all available evidence suggests that the virus has an animal origin and is not manipulated or constructed in a lab or somewhere else".*
[67] *See the report of JY Le Deaut for the OPECST available at https://www.senat.fr/rap/r16-507-1/r16-507-11.pdf.*
[68] *Nobel Prize in Chemistry 2020 awarded to Emmanuelle Charpentier and Jennifer Doudna.*
[69] *Gene drives generate mutations that are passed on from one generation to the next and can circumvent the laws of natural reproduction. The CRISPR/Cas9 genome editing tool was used to delete a gene from the genome of Anopheles gambiae, the main vector of malaria in humans. However, these methods raise questions about the possible consequences of such manipulations on the whole natural ecosystem.*
[70] *See (in French) https://www.huffingtonpost.fr/2018/11/26/crispr-polemique-apres-la-naissance-de-bebes-aux-genes-modifies-en-chine_a_23601100/*
Note that the scientist responsible for this research was subsequently imprisoned in 2019 by the Chinese regime.
[71] *Article 17 of the bioethics bill authorises the creation of "animal-human" embryos and their transfer to females. A special Senate committee had Article 17 deleted on 5 February 2020, but the French National Assembly reinstated it on 31 July 2020.*
[72] *See Boris Cyrulnik "les embryons-chimères, une folie au nom de la liberté de la recherche" [chimeric embryos, foolishness in the name of freedom of research] in the Psychology special issue of "La Vie", October 2019.*

Other research has the potential to endanger our planet through its large-scale applications. One example is climate engineering to better control global warming. The idea is to tailor negative-emission technologies, but their associated risks call for a precautionary approach (e.g. fertilisation of the oceans with iron can cause, among other harmful consequences, anoxia i.e. a reduction in oxygen levels in the water). At the same time, research is being carried out into modifying the planet's albedo ("parasol effect") by spraying water or sulphate aerosols into the upper atmosphere, which could be irreversibly damaged (see Annex 1).

However, researchers are naturally trained to push fundamental research on 'their' subject as far as possible. Some even think that "anything that can be done will be done" anyway. Should they not, however, subscribe to the precautionary principle to avoid any dangerous deployment of their results on a completely different scale than the laboratory? Such questions arise in many areas of research. The areas that are particularly sensitive are those that involve societal transformations. For example, in some third world countries the development of a particular cultigen (i.e. a plant species that has been deliberately altered or selected by humans) can lead to social changes that can endanger entire communities. Some teams from the French agricultural research centre for international development, CIRAD, have thus developed the habit of collectively discussing the potential risks of a development project following on from their research before even deciding to submit it for funding.

2. Economic and political interests in high-risk research applications

Technology development is a political issue. The examples given above indicate that researchers and engineers are not the only ones responsible for inappropriate or even potentially dangerous applications of their work. Political figures may give precedence to priorities linked to electoral criteria or prestige strategies. Players often assess the benefit-risk balance in different ways. In addition, powerful economic interests may intervene in the choice of high-risk research, whether at national or, more often, international level.

The history of nuclear power in France provides an example. Without reviving the debate on the risks related to nuclear weapons, a debate that has mobilised some of the world's citizens since the Second World War, it is worth recalling that some researchers have long been reticent about the production of nuclear energy. Some IN2P3[73] research physicists sounded the alarm at the start of the major industrial production programmes in the early 1970s. These researchers, members of the GSIEN[74], clearly emphasised at that time that reactor safety was imperfect and that the question of waste was unresolved and worrying. These concerns are still reflected today through the activists of citizen associations such as "Sortir du nucléaire" or "Négawatt", many of whose members are scientists.

Let us also revisit the issue of global warming mitigation, where strong industrial interests are involved in negative-emission technologies and techniques. The Shell company funded the first research on ocean seeding, which was nevertheless considered extremely dangerous. Today, the resurgent research on solar radiation modification is strongly driven by military and industrial interests, although there are serious risks of an irreversible large-scale change in the Earth's atmosphere, and social acceptance is low. Unable to

[73] *IN2P3: Institut National de Physique Nucléaire et de Physique des Particules [the French national institute for nuclear and particle physics], founded in 1971. It brings together all the laboratories and research platforms working in these fields in France.*
[74] *See "Electro-nucléaire DANGER", Seuil, collection Combats (1977), written by the Groupement de Scientifiques pour l'Information sur l'Energie Nucléaire (the GSIEN association of scientists for information on nuclear energy). The GSIEN became known as a notoriously anti-nuclear group.*

impose a moratorium on such research, UK authorities have established a minimum set of guiding rules on geoengineering research known as the Oxford Principles (see Annex 1).

In the sphere of agronomy, a great deal of research is being carried out to improve yields, fertilise the soil and eliminate pests. The applications of this research are governed by regulations that reflect the precautionary principle. The interests of various farmers' associations and industrial lobbies prompt them to impose limits or, on the contrary, push back those established by governments, which can give rise to heated political controversies that are widely covered by the media[75]. Despite serious and irreversible threats that have been clearly identified, in some cases economic interests take precedence over the protection of people's health, a situation that is all the truer in the case of remote populations whose economic survival depends on industrial or agricultural lobbies[76]. The research organisations involved are rightly concerned about the ethical aspects of work in these areas[77].

The dangers posed by certain industries to people and our planet often have an international dimension. These problems arise, for example, in the massive exploitation of natural resources of strategic metals (rare earths, lithium, etc.) necessary for our modern technologies. They are used in the composition of certain systems intended for ‘low-carbon’ energy (such as wind turbines or batteries), or in the design of mobile phones and digital tablets. Awareness of the upcoming shortage of these strategic metals is worrying, even if it is moderated by recycling practices that make sustainable exploitation possible. Added to this are the risks to workers related to widespread exploitation by mining companies and the dangers caused by massive pollution of the ecosystems in mining regions. Western countries have stopped exploiting their mineral resources for reasons of cost and pollution, which is mainly a matter of preventive measures and secondarily the precautionary principle. It should be noted that they have delegated the dangers involved to countries that are less scrupulous or whose economies depend on these operations.

3. Limiting individual freedoms

The digital technologies and artificial intelligence sector, whose research is currently enjoying rapid development, has applications whose risks have not yet been fully explored. We foresee that research developments in this area will have far-reaching consequences for both our personal and public lives. Given the novelty of these technologies and the radical social and political transformations they entail, it is difficult to look into the future. What is being built? What is being destroyed?

Thanks to advances in artificial intelligence, for instance, ever more sophisticated methods are available to identify faces in a crowd, whether in a video or a photograph. Identifying people from an image can be very useful for indexing multimedia databases, authenticating yourself when accessing your computer or bank account, or conducting an investigation after a terrorist attack for instance, when a judge asks you to analyse

[75] Examples include the use of glyphosate (the active ingredient of Roundup) marketed by Monsanto (now owned by BASF), as well as neonicotinoids for sugar beet cultivation.

[76] Another example is chlordecone, an organochlorine insecticide used for several decades against the banana weevil. Acknowledged as dangerous for soil contamination and groundwater pollution, chlordecone was banned in France in 1990 but continued to be used in the French Caribbean until 1993. It is responsible for a high rate of prostate cancer.

[77] INRAe (national French institute focusing on research in the areas of agriculture, food and the environment), CIRAD and IFREMER (national French institute focusing on oceanographic research) have a joint ethics committee which, in its June 2019 Opinion, discusses the ethical implications for research of the major international objectives on sustainable development and climate. This Opinion analyses "interculturality or how to take into account the different cultures and practices related to social groups in the application through research of agreements expressed in a universal form". It also looks at the governance of research and the practices of researchers.

data from surveillance cameras. However, there is a huge potential for misuse. It is to be feared that the massive use of these technologies to track everyone's movements will reduce individual freedoms to come and go at will or to meet with others. If you can be recognised in the street, for example, it is possible to see who you were with and who you talked to.

There have been many other attempts to use artificial intelligence technologies with damaging consequences, such as detecting sexual orientation, as a social psychology team at Stanford University[78] claims to be doing, or identifying an individual's ethnicity, as is being done in China to identify Uighurs[79], or identifying 'delinquent minds' in children at an early age. This is in line with Cesare Lombroso's infamous essay "The Criminal Man", published in 1876[80]. The reactivation of the principles of physiognomy, which are known to have had disastrous effects in the 19th century, should however lead to a strong framework for research characterising human groups without the consent of all the members of these groups.

The risk is that these technologies will be used irresponsibly, resulting in threats to privacy that must be vigorously guarded against. When there is no uncertainty about their devastating effects, a preventive policy should clearly be put in place without delay. To apply the precautionary principle to certain uses, they would have to be shown to be unpredictable, unquantifiable and irreversible for future generations. It should be added that these legitimate concerns do not relate to fundamental research itself, which appears to be very generic, but to the implementation of problematic applications.

Digital technology can also be used to track people's movements and contacts through various mobile phone applications, as was the case in 2020 in some Asian countries to contain the COVID-19 pandemic. In France, the "StopCovid" application, which became "TousAntiCovid" from autumn 2020, have both been strongly recommended by the public authorities in an attempt to break the chains of transmission of the pandemic[81], without fully overcoming the reluctance of some citizens who see this as a limitation on their freedom of movement. Nevertheless, despite the fears and objections expressed in France and elsewhere in Europe, such contact tracing applications, which are both transparent and audited by competent authorities such as the CNIL, are a far cry from the mass surveillance carried out in China, where everybody's movements and daily activities are monitored without their knowledge. This is a large-scale system of moral coercion which is reflected in the establishment of a score, or 'social credit', granted by the state to each citizen and based on a 'capital of points' which can be increased or decreased[82]. Such an "Orwellian" control of privacy strongly conflicts with our ethical attachment to individual freedom. Indeed, it is contested by opponents of China's dictatorial regime. It should be noted that democratic states are not immune to such control or manipulation, but it is less obvious.

There are other dimensions of digital technology that might require application of the precautionary principle. This is true of some neurocognitive technologies. It is worth noting that brain-computer interfaces could help with rehabilitation after strokes and other brain injuries, remedy disabilities, or even enable people with locked-in syndrome to communicate with the rest of the world. These potentially beneficial applications are to be welcomed. Similarly, deep electrical stimulation using neural implants can treat the symptoms of some

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[78] *Yilun Wang and Michal Kosinski, "Deep Neural Networks Are More Accurate Than Humans at Detecting Sexual Orientation from Facial Images," Journal of Personality and Social Psychology 114: 2 (2018): pp 246–57, accessible at: http://dx.doi.org/10.1037/pspa0000098*

[79] *See the dossier published in Nature, vol. 587, 19 November 2020.*

[80] *In this essay, Lombroso argues that criminality is significantly more common among individuals with specific physical characteristics, demonstrating the innate nature of some behaviour. He thus stands in opposition to sociological approaches arguing that deviations are the consequence of a person's social environment.*

[81] *The TousAntiCovid application was rolled out on 22 October 2020 as an update of the StopCovid application. It was approved by the French data protection authority, CNIL. The assessment of its use by citizens and its effectiveness is still to come.*

[82] *See, for example, the article (in French) in Le Monde of 16 January 2020: https://www.lemonde.fr/idees/article/2020/01/16/le-credit-social-les-devoirs-avant-les-droits_6026047_3232.html*

forms of Parkinson's disease. On the other hand, businessmen like Marc Zuckerberg or Elon Musk[83] (through Neuralink, a company he set up for this purpose) are planning to use neurocognitive technologies to increase human cognitive capacities and, above all, to intrude into our innermost being using electronic devices that are supposed to directly access our thoughts. If this were to happen, the consequences would be terrifying because of the dangers of thought police and various forms of coercion. It therefore appears that, even if projects of this kind—along with those leading to transhumanism[84]—have very little chance of success, they should be examined in the light of the precautionary principle[85] (OECD report).

Similarly, some technologies (such as 6G) could have harmful effects on the planet's equilibrium in the long term, given the energy consumption they would entail. Here again the risks should be investigated and the precautionary principle could be applied.

In summary, we have discussed here ‘Janus’ technologies with two sides, one potentially beneficial to society, the other posing threats to individual freedoms. These threats, which are established to a greater or lesser degree depending on the country, need to be specified and, where relevant, should lead to the implementation of a prevention policy; some of them may also justify recourse to the precautionary principle when effects that are both unforeseeable and irreversible for future generations are identified.

Generally speaking, digital technologies—which are not new—raise ethical issues that are currently being discussed in numerous dedicated ethics committees. It is worth recalling the specificity of data mining methods which, when applied to personal data, allow the merging of all kinds of confidential information on individuals. New vulnerabilities related to identity theft and the hacking of personal data are emerging. The risk is that personal data are likely to be exploited for commercial[86] or political purposes. This is the case with the countless items of information on people’s behaviour provided free of charge to Google, Apple, Facebook, Amazon and Microsoft (collectively known as GAFAM), the web giants that generate colossal traffic on the internet with their billions of users. Each one has a different role, but all of them make billions of dollars in profit—that allow them to grow even bigger—from the data provided free by their users, without these users realising that they are being monitored, and without counterbalancing the interests of these private companies that do "behavioural marketing". A key issue is to make citizens aware of these profit-making practices.

Actually, as far as the monitoring of behaviour is concerned, the advances in digital technology are not the only ones that raise questions. Behavioural sciences (cognitive sciences, psychology, economics or behavioural marketing), for instance, are building powerful tools to circumvent cognitive biases and thus steer individual and collective behaviour. Very large companies and governments use researchers to support them in direct applications of these tools. There is nonetheless a fine line between simply guiding the construction of choices and manipulating them in a way that compromises the autonomy of individuals and organisations[87]. How far are researchers ethically justified in venturing into these areas without taking precautions?

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[83] Nick Statt, “Elon Musk Launches Neuralink, a Venture to Merge the Human Brain with AI,” The Verge (March 27, 2017), accessible at: https://www.theverge.com/2017/3/27/15077864/elon-musk-neuralink-brain-computer-interface-ai-cyborgs

[84] https://www.academie-medecine.fr/wp-content/uploads/2021/02/Rapport-20-06-Interfaces-cerveau-machine-essais_2021_Bulletin-de-l-Acad-.pdf

[85] https://www.oecd.org/sti/emerging-tech/recommendation-on-responsible-innovation-in-neurotechnology.htm

[86] In March 2018, the British company Cambridge Analytica allegedly retrieved data from 50 million Facebook users, allowing for behavioural microtargeting of potential Donald Trump voters.

[87] While Canada has integrated clear ethical principles into its behavioural policies, this is not the case for many other countries, including democratic ones. See https://horizons.gc.ca/wp-content/uploads/2018/11/bi_ethics_summary_fr_0.pdf

E. The precautionary principle, researchers and the law

In civil courts, implementation of the precautionary principle appears difficult because the concept of risk is found in different forms in civil liability law. By its very nature, the precautionary principle looks to the future and concerns the political debate by involving decision-makers and scientific players. In law it only concerns the judge when decisions have been taken. Referral to the civil court presupposes the existence of either actual damage or a risk of damage, provided that it is certain or at least foreseeable. In civil liability, risk has become a new basis for liability since the 20th century, thus complementing fault-based liability. However, it is only the suspected and by nature incalculable risk that can give rise to the application of the precautionary principle due to uncertainties in the scientific arguments, which must nevertheless be as rationally based as possible.

When the precautionary principle is raised in court, it is usually when challenging decisions taken by politicians or industrial players. However, researchers may be indirectly concerned when a scientific expert appraisal has been requested by a judge.

The judges may then adopt different attitudes towards the appraisal[88]. They can refuse to get involved in scientific controversy, though this is rare. This was the case, for example, with the case law of the Lyon Court of Appeal on the "danger" of the proximity of relay antennas, where the judge refused to form an opinion on the scientific report submitted and noted that the alleged danger was not sufficiently proven[89]. On the other hand, the judge can take for granted an indisputable scientific truth when the scientific fact is obvious. This was the case, for example, with a court decision which asserts that “in the state of knowledge, the origin and danger of asbestos for human health was fully identified and known”[90]. A third, quite frequent, situation is when the judge adopts the opinion expressed by an expert during the trial. This requires the judge to understand the scientific analysis (which implies that he or she can also refute it), which is then assimilated and translated into legal terms. Thus, still in the case of relay antennas, judges have cited and summarised a large number of published scientific expert appraisals to reject the proximity of relay antennas as a cause of physiological disorders in the population[91].

However, the judge may also completely disregard the expert's opinion, which seems regrettable, and in this case use only the raw scientific data (the facts) of the appraisal. In the field of health, this may be the case when good medical practices are described not in the scientific literature, but in legal texts such as the Public Health Code, or a ministerial order[92]. At the appeal level, judges systematically assess the facts, including scientific facts, in relation to a particular case: taking into account the scientific evidence before them, they consider causality to be either established or not for that case. An extreme situation is when judges do not hesitate to take a particular stand in a scientific controversy dominated by uncertainty, thus acting as "real scientists". In such cases, the decisions of several Courts of Appeal may be different even if the facts are the same. This is typically the case in litigation over the link between the hepatitis B vaccine and the later onset of multiple sclerosis, where the judges' analysis of causal relationships is akin to true scientific reasoning. Either the judge uses a *reductio ad absurdum* argument, eliminating all possible causes (the patient's history,

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[88] *E. Verges and L. Khoury, “Le traitement judiciaire de la preuve scientifique” [The judicial treatment of scientific evidence], Les cahiers de droit, (2017), 58, 383. https://doi.org/10.7202/1041010ar*
[89] *Court of Appeal, Lyon, 3 February 2011, no. 09/06433: Juris-Data no. 2011-002705.*
[90] *Court of Appeal, Rennes, 22 June 2012, no. 10/04672: Juris-Data no. 2012--018965.*
[91] *Court of Appeal, Aix-en-Provence, 24 June 2011, no. 09/18929: Juris-Data no. 2011-014016.*
[92] *This is the case, for example, of the conclusion of medical malpractice related to the combination of a tuberculosis test and a BCG vaccine, the practice of which is governed by a ministerial order. Court of Appeal, Aix-en-Provence, 29 February 2012, no. 10/04437: Juris-Data no. 2012-004869.*

predispositions, etc.) in order to deduce that the vaccination was the sole cause of the disease[93], or he or she considers that the absence of manifestations of the disease prior to the vaccination is of "little probative value" and rejects the causal link between multiple sclerosis and the hepatitis B vaccination, as the proof cannot be provided by negative facts[94]. The Court of Cassation can thus validate two apparently contrary decisions, because it merely checks that the reasoning used is correct and does not review the judge's characterisation of the facts examined.

To summarise, the attitude of judges towards scientists is quite variable in trials where the precautionary principle is raised. They reach the conviction that a fact is proven by an intellectual representation requiring scientific analysis of the factual situation. Since the precautionary principle refers to potential, unproven risks, judges who call on the expertise of scientists have a great deal of latitude when forming a conviction and making judgements. The judicial treatment in tort law of scientific evidence in the presence of uncertainty or debate is a subject for further reflection, in which scientists should be involved. This would be an opportunity to bring the research sector and legal players closer together.

In court cases, judges do sometimes cite the precautionary principle, their role being to monitor its proper application. However, the legal measures resulting from the application of this principle may be very different depending on whether the political authorities have decided to act or not. Acting without delay can mean adopting legal acts subject to judicial review, funding a research programme, or informing the public about the negative effects of a product or technology, for instance. The party concerned may then be required to provide evidence of the absence of danger. Conversely, failure to act can lead to liability (particularly civil or criminal liability). In conclusion, it should be remembered that such decisions come under the exclusive moral obligation of the judiciary. However, any scientists consulted also indirectly assume their responsibility to inform the judges through their expert appraisal, in complete independence and as rationally as possible.

F. Conclusion. Responsibilities, ethics and the precautionary principle

The risks of technologies subject to the precautionary principle can be described as counterfactual in that they are not based on the observation of past facts but can be shown to be probable in the future despite not corresponding to proven facts. As a result, many consider these risks to be either implausible or so unlikely that it may be too costly to take adequate measures to address them. Precautionary policies relating to these counterfactual risks come up against multiple pitfalls analysed in this Opinion, not least of which is the manipulation of the beliefs of some citizens who do not believe in scientists' conclusions. Indeed, many cognitive biases affect people's perception of risk and are consolidated in particular by communication over social media. On the other hand, there is pressure to avoid application of the precautionary principle when too many economic interests are at stake. This principle then appears as a barrier to the endless development of new technologies as it is subject to the economic dictatorship that reigns throughout the world, regardless of the regime. This is why the precautionary principle is repeatedly attacked and needs to be defended, even though it is now well established in French law.

This Opinion develops an analysis of the need to use the precautionary principle in many situations to protect the future environment, health, biodiversity and freedoms. The definition of this principle requires the measures adopted by decision-makers to be economically acceptable. It is difficult to define exactly what this

[93] *Court of Appeal, Lyon, 22 November 2007, no. 06/02450.*
[94] *Court of Appeal, Orléans, 31 October 2011, no. 12/-20903: Juris-Data no. 2013-010739.*

concept means, which should be assessed on a case-by-case basis and is constructed from the estimation of a reasoned benefit-risk balance. Choices are based on the priorities given to prevailing values at the time of the decision. During a pandemic, for example, the population's health may be considered more important than saving jobs, and the choice made by the authorities may have a huge but accepted economic cost.

It is therefore important to consider how the precautionary principle is implemented and to question the role of the various players involved: politicians who make the decisions, scientists who enlighten them, users who inform or criticise them, not forgetting judges who enforce the measures decided upon. The need to take into account public opinion is an ethical issue difficult to put into practice and that depends on the subject matter, especially as citizens must be informed because they cannot form an opinion otherwise. The solution found for health and life sciences is the organisation of public debate by France's consultative committee on bioethics, CCNE, which includes citizen-users, patient associations and other representatives of civil society. Based on this model, ethics committees could be set up in other areas, such as climate change, or ethics colleges that could be part of an enlarged CCNE, as with the National Pilot Committee for Digital Ethics (CNPEN) set up in 2019.

The precautionary principle is directly linked to politics and therefore has its place in the Constitution. As for the role of scientists, it is clear that even if they do not bear the brunt of the decisions to be taken, they have a large share of responsibility. They have a key role to play in assessing the as yet unproven risks of certain technologies and in identifying the issues for which the precautionary principle should be applied. They bring their knowledge, itself accompanied by uncertainties. They are not the only parties involved: their expertise is combined with the constraints of market laws and with national or international policy strategies.

Let us come back to the wording of the 1995 Barnier Act (see above): "*Lack of certainty, in the light of current scientific and technical knowledge, shall not delay the adoption of effective and proportionate measures to prevent a risk of serious and irreversible damage to the environment at an economically acceptable cost*". This obviously assumes that all scientific knowledge has been mobilised. All staff involved in fundamental and technological research should contribute to the discussion on applications of their work, in their respective fields of expertise and based on sound data. The objective is to achieve rational, shared progress as the foundation for preventing risks—especially long-term, irreversible risks—ultimately driven by an ethic of responsibility concerned with protecting human beings, wherever they are from, and preserving a future for humanity.

IV. RECOMMENDATIONS

1. The precautionary principle, initially established for the environment and then extended to health, is now applied in many technological fields. Scientists have a role to play in the debate that is needed to develop the scope of subsequent applications.

2. Discussions could be supported by studies on the precautionary principle itself, which could thus be the subject of research programmes. This would be an opportunity to develop relations between scientists and legal professionals in order to develop the concepts of prevention and precaution, and how they are applied.

3. During a public consultation on the ecological or health risks of a technology, scientists must use their knowledge to shed light on the issues at stake, without ignoring any margins of uncertainty.

4. In order to better organise the public debate on technologies in areas such as digital technology or climate change, COMETS suggests that consideration be given to the creation of ethics committees along the lines of the CCNE or possibly within an enlarged CCNE with colleges such as the CNPEN.

5. Where there is uncertainty or debate about application of the precautionary principle, scientists should be encouraged to think carefully about the way that scientific evidence is treated in civil liability law. Such deliberations should involve legal players.

6. Apart from any official consultation, scientists have a duty to alert the authorities when they become aware of risks that could justify application of the precautionary principle in their field of competence.

7. Scientists consulted by a party as experts under the precautionary principle must transparently disclose any interests that might interfere with their expert appraisal.

8. The expert appraisal of the scientists called upon to address issues that may be relevant to the application of the precautionary principle must be collegial, open to the concerns of civil society and attentive to any information that civil society may be able to provide.

9. Scientists consulted as experts under the precautionary principle cannot be held responsible for the decisions taken by the party that commissioned them. They must ensure that the findings of their expert appraisal are accurately presented to the public and the media.

10. As part of their foresight mission, the Scientific Councils of the CNRS Institutes (CSIs) should be encouraged to reflect on the risks posed to the environment and to citizens by research conducted in their field. They could, if necessary, discuss the matter with COMETS, or even request—through the appropriate channel—that the committee study the ethical aspects of the matter.

11. Researchers must also, at their level, consider the risks arising from their work. They can thus consult the CNRS ethics adviser to help them position themselves in relation to current ethics texts. We encourage them to submit the problem to the Institute concerned, which will then organise a scientific analysis of the problem if necessary and open up the ethical dimension to which COMETS can contribute.

V. ANNEXES

ANNEX 1: Climate engineering. Negative CO_2 emissions and reducing albedo

The objective of limiting the increase in the average temperature of the atmosphere due to global warming to within 2°C of its value in 1850 naturally leads to the development of climate engineering techniques known as negative-emission techniques and technologies (NETs). Most of them have an attendant risk that prompts application of the precautionary principle. NETs should not be confused with other projects to seed the atmosphere with aerosols in order to mitigate the effects of warming (parasol effect) by changing the albedo.

I-Examples of NET projects

a) **The most popular among companies is bioenergy.** The principle is to use the combustion of wood (or pellets) to make ethanol, and then capture the CO_2 emitted by the process and bury it in geological faults. However, the surface area of forest required is such that up to a third of the world's agricultural land would have to be used, putting food resources and biodiversity at risk. Finally, very recent studies raise the issue of water stress for water-intensive techniques.

b) **Reforestation**: very popular with large industrial, transport and service companies. However, forests pose their own problems: trees grow so slowly that they will not be effective quickly enough; extending forests would be to the detriment of agricultural land; and forests themselves could become carbon emitters because they are more fragile under the effects of global warming. Specialists much prefer to stop deforestation.

c) **Ocean fertilisation**: whether by calcium carbonate or its chemical derivatives (to stimulate the direct removal of atmospheric CO_2 by the ocean) or iron (to stimulate the development of algae and thus the sequestration of CO_2 through biological activity), these projects are as unrealistic as they are potentially dangerous. The first would quickly result in a shortage of mineral resources, the second in anoxic waters (oxygen being consumed by bacteria that destroy dead organic matter) requiring repeated injections of oxygen on a permanent basis.

d) **Projects to capture the CO_2 emitted by industrial facilities** and transport it by pipeline to geological sites are also on the rise. There are currently 19 such "industrial plants " in the world, with another 50 under construction. The energy costs and emissions generated by such facilities do not currently compensate for the flow of carbon trapped and the number of storage sites is limited; however, the side effects estimated to date are not insurmountable and the research carried out is less risky, a priori, than the projects mentioned above.

II-Modifying solar radiation

Protocols propose injecting aerosols into the atmosphere to create a giant 'parasol' around the planet. Over the oceans, water may be sprayed into the atmosphere by injector ships to increase the reflectivity of marine clouds. Sulphate aerosols have also been proposed. Developed by British teams between 2010 and 2012, the SPICE project was quickly halted due to controversy, while the Russians have gone further, practising geoengineering field research by injecting aerosols from helicopters at 200 m altitude.

This short-term solution would buy time to implement effective mitigation techniques, but raises a major ethical issue. The cost of injecting sulphate aerosols over 15 years—including R&D—is huge. These solar radiation management techniques are similar in people's minds to weather modification techniques, whose practice is accepted and ongoing in many countries, although its effectiveness is far from proven.

III-Basis of considerations on a possible framework for geoengineering: the Oxford Principles

Several research consortiums have attempted to establish principles to guide geoengineering. The "Oxford Principles" may be cited here[95]:

- Principle 1: Geoengineering to be regulated as a public good

"While the involvement of the private sector in the delivery of a geoengineering technique should not be prohibited, [...] regulation of such techniques should be undertaken in the public interest by the appropriate bodies at the state and/or international levels". (It should be noted that private experiments on iron fertilisation or any other climate engineering projects fall outside this principle);

- Principle 2: Public participation in geoengineering decision-making

This principle is about transparency. "Wherever possible, those conducting geoengineering research should be required to notify, consult, and ideally obtain the prior informed consent of, those affected by the research activities. The identity of affected parties will be dependent on the specific technique which is being researched—for example, a technique which captures carbon dioxide from the air and geologically sequesters it within the territory of a single state will likely require consultation and agreement only at the national or local level, while a technique which involves changing the albedo of the planet by injecting aerosols into the stratosphere will likely require global agreement".

- Principle 3: Disclosure of geoengineering research and open publication of results

"There should be complete disclosure of research plans and open publication of results in order to facilitate better understanding of the risks and to reassure the public [and decision-makers] as to the integrity of the process. It is essential that the results of all research, including negative results, be made publicly available". This principle is in line with the debates on scientific integrity (see the COMETS recommendation on this subject). Disclosure of results is not part of the private research culture either. Furthermore, the journals should be free of charge, which is not the case and thus hinders the dissemination of results;

- Principle 4: Independent assessment of impacts

"An assessment of the impacts of geoengineering research should be conducted by a body independent of those undertaking the research..."

- Principle 5: Governance before deployment

"Any decisions with respect to deployment should only be taken with robust governance structures already in place, using existing rules and institutions wherever possible".

[95] *Source: Oxford Geoengineering Programme http://www.geoengineering.ox.ac.uk.*

ANNEX 2: Legal evolution of the precautionary principle

In 1979[96], in "Das Prinzip Verantwortung", published in 1984 as “The Imperative of Responsibility”, the German philosopher Hans Jonas wrote that the enormous power conferred on humankind by technoscience constitutes a problem to which humanity must respond with a new form of responsibility that would prevent people from undertaking any action that might endanger either the existence of future generations or the quality of future existence on Earth.

Discussions will be used to progressively develop the precautionary principle, the need for which has been affirmed worldwide in conventions and treaties, as well as in "Declarations", "Reports" and other European communications[97].

The precautionary principle continues to evolve in France by its incorporation into various national texts (code, acts and charters), such as:

- the Barnier Act No. 95-101 of 2 February 1995, which provides a definition: “the precautionary principle, according to which lack of certainty, in the light of current scientific and technical knowledge, shall not delay the adoption of effective and proportionate measures to prevent a risk of serious and irreversible damage to the environment at an economically acceptable cost”[98].

- The precautionary principle is directly related to other French Codes, notably the Rural Code, the Town Planning Code and the Commercial Code, because of the links between their activities and environmental risks. It complies with the provisions of the constitutionality block (principles of the Environment Charter in particular) and the conventionality block (European directives and international treaties relating to the environment).
  Article L110-1 II 1 of the Environment Code expressly refers to the precautionary principle, which it defines by taking up the definition of the Barnier Act[99] while incorporating four major principles into the Rural Code[100]: precaution; preventive and corrective action; the polluter pays; and citizen participation.

A simple general legal principle, the precautionary principle has seen its binding force reinforced by the Environment Charter, discussed and adopted by Parliament in 2004 before being submitted to Congress in Versailles on 28 February 2005. Environmental law was then enshrined in the Constitution. It recognises the fundamental rights and duties relating to protection of the environment. Its extension in case law to health (the 'contaminated blood' case) is easily understood in view of its interface with the environment. Affirming that everyone has the right to live in a balanced and healthy environment, it includes the following key principles:

- Everyone has a duty to take part in the preservation and improvement of the environment (citizen participation).

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[96] *It should be remembered that the French Ministry of the Environment was founded in 1971*
[97] *The Vienna Convention for the Protection of the Ozone Layer of 22 March 1985 (signed by 28 countries and enforced on 22 September 1988), The Maastricht Treaty of 7 February 1992 (enforced on 1 November 1993), the Rio Declaration of 3-14 June 1992.*
[98] *Definition enshrined in Article L200-1 of the French Rural Code, which the Act created.*
[99] *The precautionary principle, according to which lack of certainty, in the light of current scientific and technical knowledge, shall not delay the adoption of effective and proportionate measures to prevent a risk of serious and irreversible damage to the environment at an economically acceptable cost.*
100 Article L200-1

- Everyone must, under the conditions defined by law, prevent the damage they are likely to cause to the environment or, failing that, limit its consequences (prevention principle).

- Everyone must help repair the damage they cause to the environment, under the conditions defined by law (polluter pays principle).

In Article 5, the Charter expressly refers to the precautionary principle[101]: “Where the occurrence of damage, although uncertain in the light of scientific knowledge, could seriously and irreversibly affect the environment [and the health sector, as in the case of contaminated blood and 'mad cow' disease], public authorities shall ensure, in application of the precautionary principle and within their areas of competence, that risk assessment procedures are implemented and that provisional and proportionate measures are adopted in order to pre-empt the occurrence of damage*”.*

The text therefore does not take up the definition of the Barnier Act and the Environment Code but retains the notion of uncertain damage.
It expresses the rights and duties of every citizen in Articles 2 to 4, while it places the responsibility for implementing appropriate measures solely on public authorities[102].
As part of the risk assessment procedures and the adoption of interim measures, the authorities will thus be required to use scientific expert appraisals as provided for in Article 7.

The Constitutional Council clearly recognises the constitutional value of the precautionary principle in Decision No. 2016-737 DC of 4 August 2016 on the law for the recovery of biodiversity, nature and landscapes.

Finally, the creation of a standing council[103] on the precautionary principle could be considered. This council would bring together all the stakeholders concerned, and scientists could participate and assist in the debate on the evolution of the precautionary principle, its scope of application and its use. A more specifically legal approach would be to create a Legal Observatory of the Precautionary Principle, bringing together scientists and lawyers, allowing both to become aware[104] of existing problems and possible liability issues.

* * *

[101] This is combined with the principles of prevention and reparation in Articles 3 and 4, but also with the obligations of education and training in Article 8 and research in Article 9.
[102] This turns the precautionary principle into a principle of action (assessment procedures as well as provisional and proportionate measures).
[103] Like the CCNE, France’s National Consultative Ethics Committee for health and life sciences, created in 1983.
[104] And perhaps to take responsibility for the effects of its evolution.

VI. GLOSSARY OF ABBREVIATIONS OR ACRONYMS USED

ANSES: *Agence Nationale de Sécurité sanitaire de l'alimentation, de l'Environnement et du Travail* [French Agency for Food, Environmental and Occupational Health & Safety]
CCNE: *Comité Consultatif National d'Ethique pour les sciences de la vie et de la santé* [France's National Consultative Ethics Committee for health and life sciences]
CFC: Chlorofluorocarbon
CIRAD: *Centre de coopération internationale en recherche agronomique pour le développement* [French Agricultural Research Centre for International Development]
CNIL: *Commission Nationale de l'Informatique et des Libertés* [France's National Commission for Data Protection and Liberties]
CNPEN: *Comité National Pilote d'Éthique pour le Numérique* [National Pilot Committee for Digital Ethics]
COD: Chemical oxygen demand
CRISPR: *Clustered regularly interspaced short palindromic repeat*
CSPRT: *Conseil Supérieur de Prévention des Risques Technologiques* [Higher Council for the Prevention of Technological Risks]
DBCP: Dibromochloropropane
DDT: Dichlorodiphenyltrichloroethane
EEA: *European Environment Agency*
EHS: Electromagnetic hypersensitivity
GSIEN: *Groupement de scientifiques pour l'information sur l'énergie nucléaire* [an association of scientists providing information on nuclear energy]
IESF: *Ingénieurs et scientifiques de France* [an association of French engineers and scientists]
IFREMER: *Institut Français de Recherche pour l'Exploitation de la Mer* [French institute focusing on oceanographic research]
IN2P3: *Institut National de Physique Nucléaire et de Physique des Particules* [the French national institute for nuclear and particle physics]
INPES: *Institut National de Prévention et d'Education pour la Santé* [French institute for prevention and health education]
INRAe: *Institut national de recherche pour l'agriculture, l'alimentation et l'environnement* [French institute focusing on research in the areas of agriculture, food and the environment]
IPCC: Intergovernmental Panel on Climate Change
LHC: *Large hadron collider*
MEDEF: *Mouvement des Entreprises de France* [the largest employers' union in France]
MIS: *Mission pour l'Intégrité Scientifique* [the CNRS's Scientific Integrity Office]
MMR: Measles, Mumps, Rubella
NET: *Negative-emission technique/technology*
NGO: Non-Governmental Organisation
NIMBY: *Not in my back yard*
OECD: Organisation for Economic Co-operation and Development
OPECST: Office Parlementaire des Choix Scientifiques et Techniques [French parliamentary office for evaluating scientific and technological choices]
PCB: Polychlorobiphenyl
PPRT: *Plan de Prévention des Risques Technologiques* [Technological Risk Prevention Plan]
REACH: *Registration, Evaluation, Authorisation and restriction of CHemicals*
RNA: Ribonucleic acid
SPICE: *Stratospheric Particle Injection for Climate Engineering*
WHO: World Health Organization

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