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The anthropogenic climate change hazard: role of precedents and the increasing science-policy gap[1]

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Abstract—There are some parallelisms and similarities since the 1960s in the identification, attribution, scientific communication, and the subsequent initial policy setting processes of the acidification, ozone layer depletion, and climate change hazards. The anthropogenic factors behind the latter one were hypothesized well before the discovery of the cause-effect relations of the two other problems; nevertheless, later on the policy approaches to address the "acid rain" and "ozone shield" issues served to some extent as precedents for building up the international climate policy mechanisms. The analysis of these knowledge and policy development cases is of particular interest in light of the widening climate change science-policy gap, whilst efficient international policy and legal regimes have been built up for tackling the acidification and ozone depleting phenomena. Concerning the global climate policy regime, the consideration of its progress covers the time period since the early 1970s by 2015 when its most recent building block was adopted.

Key-words: acidification, ozone layer depletion, climate change, environmental precedence, science-policy gap

"*Let us suppose that the climate changes by one degree during a century, which anyway could be considered as a tremendous change, but nowadays would we be able to detect such a change?*" (*Róna*, 1909)

"*The globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 [0.65 to 1.06] °C, over the period 1880 to 2012.*" (*IPCC*, 2013–2014)

[1] This paper is the extended and updated version of the author's presentation at the Hungarian Academy of Sciences.

1. Introduction

<u>Phases</u>. Various factors were leading to the almost simultaneous intensification of the scientific research activities and the first general international policy reflections by the late 1970s on emerging large-scale atmospheric hazards, namely, the acidification, the ozone layer depletion, and the climate change problems. The formulation of the evidence-based hypotheses on their anthropogenic drivers, sources of the atmospheric emissions, and possible implications was relatively shortly followed by ascertaining the cause-effect relations and the adoption of increasingly rigorous international agreements only for the acidification and ozone depletion problems. It has happened differently for the climate change issue. In general, the earlier chronologies of these scientific and policy-making processes were segmented and separately analyzed from different perspectives (e.g., in the case of acidification by *Levy*, 1995; the ozone layer policy history by *Morrisette*, 1989; the development of climate change policy regime by *Gupta*, 1997 and *Bodansky*, 2001). The parallel and partially interlinked science-driven policy-making for these three atmospheric problems is studied in this paper through the following phases: (i) the "*inception phase*" by the late 1970s associated with the detection of these hazards, the scientific search for their cause-effect relations, and the initial political reactions; (ii) the verification and the "*international policy setup phase*" by about the turn of the 20th century, which is characterized by reaching much higher confidence level in the attribution of these hazardous phenomena to certain anthropogenic factors affecting the natural mechanisms and also by the development of the relevant international policy regimes; and (iii) the following "*divergent phase*", when the effective solution of the acidification and ozone layer hazards was already on track, meanwhile the science-policy gap was widening for the global climate change problem. The "inception phase" actually coincides with the birth of a new and prosperous branch of atmospheric sciences, namely the air chemistry (*Mészáros*, 1981), which is *inter alia* dedicated to the subjects of those atmospheric processes, the interrelated science-policy aspects of which are considered in this paper. More generally, the evolution of the international environmental cooperation and the adoption of numerous multilateral agreements were closely linked to the progress in environmental science in its entirety, the "scientization" as it was called by *Brauch* and *Sprong* (2011), and to the changes on the global political scene in the second half of the 20th century (*Clark et al.*, 2001; *Faragó*, 2006).

<u>Precedents</u>. The policy-setting cases for acidification and ozone depletion served in some degree as precedents during the early period of the elaboration of the international mechanisms for tackling global climate change. This effect was profoundly justified because of some similarities in the socio-economic drivers, the applicability of the general principles of international environmental cooperation, the most typical response options (abatement/mitigation policies),

and the specific situations of the various country groups. But, it turned out rather soon, there were considerably distinct aspects of the climate change policymaking that could not be overcome at such a pace, as it occurred for the two other environmental issues. These aspects stem from the complexity of the climate system *per se*, and also from the multiplicity, particular technology aspects, and the inertia of those economic sectors, which contribute to the escalation of this global problem. Therefore, the two above-mentioned precedential policy processes could have productive effects (directly or indirectly) only for a while on development of the international climate policy architecture. In course of time, this diversion became even more apparent as the science-policy gap was rapidly widening in terms of the improved scientific knowledge and the increasingly inadequate level of the overall climate policy responses.

<u>*The beginning*</u>. The human-induced climate change hazard was hypothesized and the acidifying air pollution problem was already noticed well before the middle of the previous century. Notably, the possibility of global warming caused by fossil fuel combustion was raised at the end of the 19th century (by *Arrhenius* in 1896 and by *Chamberlain* in 1899). Based on a limited set of surface temperature data series and information on "artificial production of carbon dioxide" from fossil fuel combustion available that time, *Callendar* (1938) asserted that global warming had begun and provided a draft assessment for its rate. In terms of the acidifying air pollutants, the harmful effects of emissions from a Canadian metal smelter on the neighboring areas of the USA can be mentioned as an early case of such a transboundary pollution. These effects were observed from the 1920s and resulted in an international conflict between the two countries. The conflict was settled by an arbitration procedure without any deep theoretical analysis of the pollution propagation, and the decision simply referred to the "injury by fumes in or to the territory of another state (..), when the case is of serious consequence and the injury is established by clear and convincing evidence" (*UN*, 2006). As a matter of fact, these environmental hazards together with the ozone layer problem became prevalent several decades later, when rapidly increasing attention was paid to them by the scientific community, their genuine mechanisms could be discovered, and the first concrete recommendations were formulated for their mitigation. That is why we focus on the parallelism and certain similarities of these scientific and policy-making processes from the mid-20th century.

<u>*Drivers*</u>. Before turning to the above-mentioned phases of detection and management of these atmospheric problems, some of those common *socio-economic drivers* are highlighted, because of which these hazards started to manifest themselves at a quick pace in the post-WW2 era, and in turn, the late 1960s and early 1970s marked the beginning of more focused scientific research nearly simultaneously in these environmental issues and the subsequent initial

international political reactions. The post-war economic recovery followed by an economic boom in the OECD (formerly OEEC) countries, the rapid reconstruction and development in Eastern Europe from the 1950s, and the socio-economic changes in many developing countries went together with growing demand for natural resources and increased pollution in very diverse forms. These environmental pressures were significantly enhanced by the global population explosion and changing consumption patterns. The growth in the key economic sectors (energy, transport, agriculture, such industrial activities as metallurgy, chemical industry, etc.) was inadvertently leading to the intensification of large-scale atmospheric and other environmental problems (water pollution, loss of biological diversity, deforestation, chemical hazards, waste streams). Moreover, there are rather evident reasons that explain why these three atmospheric hazards were drawing increased attention with almost the same time lag, namely, the time period needed by these accumulating environmental pressures for exceeding some critical thresholds. Of course, other factors were also essential in this regard, like the fast development of environmental monitoring technics, systems and networks, methodologies, numerical models, and the international scientific cooperation.

2. Simultaneous knowledge development on emerging atmospheric hazards and the initial policy reactions

"The combustion of coal, oil, and gas (..) results in the discharge into the air of sulphur dioxide, carbon dioxide, carbon monoxide, oxides of nitrogen (..) Little is known, e.g., of what happens to our most common pollutant, SO_2, once it has been discharged into the atmosphere." (*PSAC*, 1965)

"It is recommended that in establishing standards for pollutants of international significance, Governments take into account the relevant standards proposed by competent international organizations (..) in planning and carrying out control programmes for pollutants distributed beyond the national jurisdiction." (*UNCHE*, 1972)

The massive atmospheric emission of disparate pollutants from human activities since the mid-20th century have triggered the increased interest of the research community to see whether these environmental pressures would lead to extensive adverse effects. Besides revitalizing some earlier conceptions or developing new ones in this regard, it was clear that first of all, sound environmental observations were necessary for reliable scientific investigations and conclusions. The International Geophysical Year (IGY) in 1957–58 offered a good opportunity to launch regular and internationally standardized environmental measurements. The data series from these measurements, the assessments of sources and volumes of airborne emissions, and the clarification of the relevant biogeochemical cycles greatly contributed to knowledge development concerning climate change, acidification, and ozone layer depletion by the late 1970s (i.e., during the above mentioned "inception phase"). As a consequence, these and some other emerging environmental hazards were acknowledged by policymakers, and the initial coordinated responses were agreed upon at their international meetings in 1972 (Stockholm) and 1975 (Helsinki). In this context, the atmosphere plays a particularly important role: "air pollutants move quickly and cover greater distances than do pollutants in watercourses or the marine environment. The atmosphere is in fact the planet's largest single shared resource" (*Kiss* and *Shelton*, 2007).

2.1. Systematic observations and initial findings

Observing atmospheric CO_2 changes. The hypothesis on the possibility of human-induced climate change could be better tested from the mid-20th century, when the after-war economy boost and industrial development resulted *inter alia* in rapidly growing fossil fuel based energy production. *Revelle* and *Suess* (1957) described it as a dangerous process and insisted on having more precise measurements and assessments: "Present data on the total amount of CO_2 in the atmosphere, on the rates and mechanisms of CO_2 exchange between the sea and the air (..) are insufficient to give an accurate base line for measurement of future changes in atmospheric CO_2. An opportunity exists during the International Geophysical Year to obtain much of the necessary information." As a follow-up, the rate of increase of the anthropogenic CO_2 emissions and atmospheric concentrations was re-assessed in 1958 (*Callendar*, 1958; *Bolin* and *Eriksson*, 1958), and accurate measurements of the atmospheric CO_2 started at the Mauna Loa Observatory in the same year. It was confirmed soon that this value had annually a "small but persistent increase" (*Keeling*, 1960). Based on that discovery, the USA President's Scientific Advisory Committee formulated its opinion that the changing chemical composition of the atmosphere *may* lead to a significant change of the climate already by the end of that century (*PSAC*, 1965).

Concerns about the SO_2 releases. The same period of time marked the increased attention to man-made atmospheric discharges of various pollutants, their transport and deposition, with a particular focus on the sulfur cycle (*Eriksson*, 1963). Similarly to the case of the carbon-dioxide, it became evident that for the sake of more accurate assessments, first of all systematic monitoring was necessary. The European Air Chemistry Network (EACN) was established in the middle of 1950s and substantially extended during the IGY. This issue was also raised on the other side of the Atlantic (*PSAC*, 1965): "The combustion of coal, oil, and gas in our homes, vehicles, and factories results in the discharge into the air of sulphur dioxide, carbon dioxide, carbon monoxide, oxides of nitrogen, and partially burned hydrocarbons. (..) Many of these pollutants released unintentionally or as a by-product are long-lasting, come from a multitude of sources, and are subject to transportation over great distances in air, water, or living organisms. All three characteristics make them very difficult to control. (..) The problem of air pollution calls for much research."

Systematic observations of O_3. It is noteworthy that the Global Ozone Observing System also started its operation in 1957 in the framework of the IGY (*WMO*, 2014). Initially it was based on an existing international monitoring network; afterwards, it was gradually extended, internationally standardized, and two decades later complemented with satellite measurements. Initially, the measurements were made from the ground, however, their series did not show any considerable trends by the 1970s.

2.2. Evidence-based identification of cause-effect relations

CO_2 emissions. The growing observational network, the Global Atmospheric Research Programme (GARP) from 1967, and the first simple global climate models (developed by *Manabe* and *Wetherald* in 1967, by *Budyko* in 1969, and by *Sellers* also in 1969) provided more information on the global climate system. It made possible better (conditional) assessments of the potential consequences of the steadily increasing CO_2 releases from fossil fuel combustion together with other greenhouse gas emissions. These developments were reflected in the scientific communication already in the early 1970s. According to *Keeling* (1970), the increasing human population in the 21th century "along with their other troubles, may also face the threat of climatic change brought about by an uncontrolled increase in atmospheric CO_2 from fossil fuels." *Bolin* and *Bischof* (1970) have derived estimates of the atmospheric CO_2 for the forthcoming decades by accepting certain assumptions, for instance on further rates of global fossil fuel combustion. It is remarkable that their estimate was 371–378 ppm for the year 2000, which proved to be very close to the factual value of 370 ppm obtained at Mauna Loa Observatory as the annual average for 2000 with its peak monthly value of 372 ppm in May that year.

SO_2 emissions. Those years became also memorable for understanding the transboundary "sulfur problem". The evidence-based hypothesis on the long-range transmission of airborne acidifying pollutants was raised by *Odén* (1968) by studying the series of precipitation chemistry measurements from the EACN. Systematic analyses by a couple of North-European researchers (supported by the Scandinavian Council for Applied Research) offered more arguments on this matter and resulted in setting up the international Cooperative Technical Programme to Measure the Long Range Transport of Air Pollutants by the OECD in April 1972 (*OECD*, 1977). These efforts were assisted by the establishment of the Background Air Pollution Monitoring System (BAPMoN) in 1970 and by a multi-annual programme on the Biogeochemical Cycles under the aegis of the Scientific Committee on Problems of the Environment (SCOPE) of the ICSU (*Svensson* and *Soderlund*, 1976). The tentative observational data and analytic studies confirmed the assumption on the long-range transport of those pollutants. Similarly to the CO_2 releases, the increasing fossil fuel combustion was primarily "blamed" for these emissions and their harmful

effects on ecosystems. Based on these studies, the Swedish experts decided to present this issue as a case study to the UN Conference on Human Environment to be held in June 1972 (*Bolin et al.,* 1971, 1972). Because of substantial scientific uncertainties and other reasons, representatives of a few key Western European emitters strongly denied the idea of the long-range atmospheric transmission of these pollutants (i.e., the possibility that pollutants from their sources can reach Scandinavian regions).

CFC emissions. The potentially harmful human effects on the stratospheric ozone layer have also piqued the interest of the research community just in the same time period. This quasi-coincidence was obviously triggered by the socio-economic drivers mentioned above (economic growth, technological progress, new production and consumption patterns, etc.). The recognition of the possibility of endangering the ozone layer did not stem from actual observations, but from theoretical studies. In the early 1970s, two specific human activities were identified as those, which can directly interfere with natural factors in controlling the ozone content in the lower stratosphere. *Crutzen* (1970) revealed that the nitrogen oxides emitted from the surface may influence the ozone photochemistry in the stratosphere, but the sources of these nitrous oxides remained unclear, that is, where those originate from (in respective volumes) and how they reach high-level altitudes. In retrospect, it seems so evident that the stratospheric supersonic transport aircrafts (SST) were named as important anthropogenic causes of this problem, since they directly released nitrogen oxides up there (*Johnston*, 1971). One year later it turned out that the NASA's space shuttle operations using solid rocket boosters of the Space Transportation Systems (STS) caused high amount of hydrogen chloride emissions in the stratosphere that might also contribute to the ozone destruction (*Stolarski* and *Cicerone*, 1974). Assumptions on the SST and STS as the main dangers for the ozone layer did not prove valid (the overall amounts of these emissions could not explain an extensive ozone depletion); nevertheless, those ideas were catalyzing very intense scientific research in this area. The attention was turned to the halocarbons when their very stable chemical property, persistence, and accumulation in the atmosphere was discovered (*Lovelock et al.*, 1973). The invention of chloroflourocarbons resulted in a breakthrough, *inter alia*, in the refrigerator industry and a boost of the production of these halocarbons from the 1950s. It was a crucial milestone in the scientific recognition, when *Molina* and *Rowland* (1974) demonstrated that these synthetic chemical compounds (notably, $CFCl_3$ and CF_2CL_2, i.e., CFC-11 and CFC-12) are responsible for the increasing volumes of chlorine in the stratosphere and in turn, for the ozone depletion. They also had a clear argument for the still missing detection of the "thinning" of the ozone layer by these halocarbons: it could not be "immediately felt after their introduction at ground level because of the delay required for upward diffusion up to and above 25 km."

2.3. *First international policy reactions*

Other preconditions. Therefore, the period of the late 1960s and early 1970s was crucial in the identification of the human causes for all the three large-scale atmospheric hazards, as it was indicated above together with demonstrating some common factors behind these processes and the parallelism of these discoveries. In spite of the considerable scientific uncertainties, the first general policy responses were already agreed upon internationally during those years. Besides the strengthened environmental observing systems and the increased concerns of the scientific community over the rapidly growing environmental pressures from different human activities, there was another important precondition for that progress, notably, the favourable geopolitical situation or more specifically, the global political atmosphere of the *détente* (*Clark et al.*, 2001; *Faragó*, 2006). This condition was essential in general for the initiation of international deliberations on the increasing environmental risks and eventually, for achieving consensus on the basic principles of cooperation and the initial concerted actions. The general tone was set by a UN resolution (*UNGA*, 1968), according to which: the General Assembly decided to convene the United Nations Conference on the Human Environment (UNCHE) in 1972, in particular because of "the continuing and accelerating impairment of the quality of the human environment caused by such factors as air and water pollution (..), which are accentuated by rapidly increasing population and accelerating urbanization". Among the various intensifying environmental problems (including those associated with the extraction of natural resources, chemical pollution, etc.), special attention was paid to the atmosphere-related ones, since primarily these could induce dangerous large-scale transboundary or even global ecological and socio-economic impacts.

UNCHE outcomes. Because of conflicting political and economic interests of various country groups (in Europe and also between the developed and developing countries) and the still rather limited scientific knowledge on the environmental issues concerned, the preparation of the UNCHE and its outcome documents was exceptionally complicated (*Engfeldt*, 2009). Eventually, that event could be considered as the first historical milestone in global environmental cooperation. The most important provisions of the adopted documents in relation to the subject of this study clearly demonstrate that the initial international political reflections were quite similar and rather cautious in terms of the anthropogenic factors of these large-scale atmospheric hazards (*UNCHE*, 1972). First of all, it was agreed that the relevant *monitoring systems* should be further developed, notably by setting up a global network of stations "for monitoring properties and constituents of the atmosphere on a regional basis and especially changes in the distribution and concentration of contaminants" (recommendation 79/b), and more specifically, by properly monitoring the environmental effects of energy use and production, including "the environmental levels resulting from emission of carbon dioxide, sulphur dioxide, oxidants, nitrogen oxides (NO_x), heat and particulates, as well as those from releases of oil and radioactivity" (r. 57/a). (The "oxidants" in this listing, supposedly was an implicit compromise wording already referring to ozone.) Reference was also made to the importance of the internationally coordinated *research programmes* to learn more on the causes and the possible impacts of air pollution and climate change (r. 57/b, r. 79/d) and to understand better "the causes of climatic changes whether these causes are natural or the result of man's activities" (r. 79/d). Beyond that, the very general principles and objectives were also agreed on the *mitigation policies*, which aim "to minimize the release to the environment of toxic or dangerous substances" (r. 71), to plan and carry out "control programmes for pollutants distributed beyond the national jurisdiction" (r. 72), and to bear "the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction" (principle 21). The adoption of the recommendations and principles by the conference can be considered as the beginning of the modern era of international environmental cooperation marked by strengthened science-policy links and numerous multilateral agreements: "The Stockholm Conference had immense value in drawing attention to the problem of environmental deterioration and methods to prevent or remedy it. The Conference was global both in its planetary conception of the environment, and in its view of institutional structures and world policies." (*Kiss* and *Sheltin*, 2007)

Sceptics. The histories of the three atmospheric topics considered here had also something else in common in those years, namely, the appearance of *counter-positions and sceptical views* by rejecting with counter-arguments or by simply denying the possibility of significant human influence on the natural processes in question. In general, scepticism in natural science is an important methodological approach; however, in these cases besides questioning the validity of the attribution of these hazards at least partially to some human activities and referring to differing scientific arguments, the denial of the hypotheses was sometimes seemingly backed by particular economic interests. For the acidification and ozone depletion problems, such a reminder might be pertinent in view of the recurrent debates on degrees of certainty and confidence in the context of anthropogenic climate change and the justification of the precautionary approach in policymaking. When in the early 1970s the hypothesis on the transboundary air pollution causing acidification in the North European countries was reaffirmed by Scandinavian experts, the possibility of such long-range transport was refused by many West European representatives, as recollected by *Seip* (2001): "British and Norwegian authorities came in conflict on the acid rain issue particularly since Great Britain was the largest contributor of acidifying deposition in Norway". Even after that the above-referred OECD project resulted in convincing observational information on this issue and the need for international regulation was raised in 1978, the initiative to draw up a convention on the reduction of sulphur dioxide emissions was "battered by delegations of the EEC countries, especially by France, the United Kingdom and the Federal Republic of Germany. In the course of the discussion, the United Kingdom's delegation expressed unequivocal doubt about the validity of the hypothesis of the transboundary character of acid rain" (*UNECE*, 2004b). Similarly, in the early 1970s, there were strong opponents of the SST and STS theories either by raising clear-cut and correct scientific thoughts (e.g., about negligible amounts of NOx emissions by SST and STS) or clearly representing some economic interests (in connection to the supersonic transport airplanes by the "Brussels Group" as documented by *Engfeldt*, 2009 and *Hamer*, 2002). After 1974, the scientifically much more established discovery of the ozone-depleting potential of CFCs was heavily challenged by the concerned industry groups: "both manufacturers and users of CFCs opposed any effort to regulate CFCs in aerosol spray cans. They questioned the validity of the theory, pointing out the uncertainties and noting the lack of supporting evidence" (*Morrisette*, 1989). Concerning the global climate change hazard, in the 1960s and early 1970s, both the theories on forthcoming global cooling (the beginning of a new glacial period) and on human induced global warming were promoted and communicated in parallel. This course has changed considerably when the scientific assumptions, evidences, and results were critically assessed in 1979 by the (first) World Climate Conference and by the Ad Hoc Study Group on Carbon Dioxide and Climate in the USA. The declaration of the Conference (*WMO*, 1979) and the report of the Group (*Charney et al.*, 1979) already focused on the global warming scenarios caused by increasing atmospheric CO_2 amounts from fossil fuel combustion, deforestation, and land use change. The "sceptical era" was generally overcome by about the late 1980s for the acidification and ozone depletion problems, but it has been prolonged for the climate change hazard for some understandable reasons.

The Helsinki process. The focus on the environmental problems was strengthened in the broad context of international cooperation and security. Formally, the Helsinki process leading to the 1975 Conference on Security and Co-Operation in Europe (CSCE) was a pan-European initiative yet of global significance. The negotiations have culminated in the adoption of the Final Act in 1975, which incorporated a chapter dedicated to the enhancement of environmental cooperation. This chapter of the document was not only reconfirming the most essential provisions of the UNCHE (e.g., the responsibility for transboundary and global environmental degradation, importance of preventive measures for the avoidance of environmental damages, development of environmental monitoring networks), but it stated more concretely the necessary steps regarding the acidification and the climate change problems. Obviously, the more definite formulation was made possible by the specific regional dimension of the CSCE (devoted to the East-West relations and the pan-European cooperation). In terms of these two atmospheric issues, there were already affirmative references to the *transboundary pollution* and to the *anthropogenic factors* (as compared to the "cautious" recommendations by the UNCHE). Accordingly, the participating States agreed (i) to develop an international programme for the monitoring and evaluation of the long-range transport of air pollutants, starting with sulphur dioxide and with possible extension to other pollutants; for the "desulphurization of fossil fuels and exhaust gases, pollution control of heavy metals, particles, aerosols, nitrogen oxides, in particular those emitted by transport, power stations, and other industrial plants; systems and methods of observation and control of air pollution and its effects, including long-range transport of air pollutants" and also (ii) to study the changes in climate "under the impact of both natural factors and human activities" (*CSCE*, 1975). The ozone layer issue also became a delicate topic during the preparations for the CSCE, as the discovery of the ozone-destroying effect of the CFCs was published in June 1974 (*Molina* and *Rowland*, 1974), and already in December that year, the U.S. House of Representatives held a hearing on this matter. Presumably, the U.S. representatives raised this theme during the international expert meeting in Oslo in December 1974 (*US-DoS*, 1974), where the proposals for the environmental chapter were discussed for the CSCE.

Consequently, in the late 1960s and early 1970s besides some other environmental problems, not only the scientific awareness and communication were significantly strengthening more or less simultaneously for the three rapidly emerging atmospheric hazards, but already these issues were addressed internationally by the policymakers. These *initial policy recommendations* agreed upon at the high-level meetings in 1972 and 1975 concentrated on the development of the environmental monitoring systems and the promotion of the international research cooperation in these areas in order to better understand the processes, their natural and anthropogenic drivers, the potential adverse impacts. Moreover, the general need for controlling the emissions of the relevant pollutants was also indicated but without any concreteness and targets. Already a few years later, the specific policy-planning started and some very concrete first measures were taken: a World Plan of Action on the Ozone Layer was adopted in 1977 by the UNEP; between 1977 and 1979 the non-essential use of CFCs were banned in the USA, Canada, Norway, and Sweden; the negotiations on controlling transboundary air pollution began at the end of 1978 under the UNECE auspices; and some policy-related aspects were already raised in connection with different climate change scenarios at a conference held in 1978 at IIASA.

3. Setting up the international response policy regimes

(On the policy regime of the 1979 Convention on Long-Range Transboundary Air Pollution:) "As a precedent, the regime has contributed to the adoption of global treaties and rules on air pollution." (*Byrne*, 2015)

"*The Montreal Protocol (..) offers the precedent of international negotiation and agreement on global environmental problems.*" (*Morrisette*, 1989)

From the late 1970s, the research activities were intensified, the cause-effect relations were much better identified, the basic international mechanisms and response policies were formulated and gradually advanced for all the three large-scale atmospheric issues. The international policy framework established for the acidification and ozone layer problems served to some extent as precedents for the climate change negotiations. In the following, several key precedential components of both the pan-European acid rain policy regime and the global policy architecture for the ozone layer problem are highlighted; then the analogous features and building blocks of the international climate change policy settings are presented in order to demonstrate (*mutatis mutandis*) the "re-use" of the previously agreed and proved procedures.

3.1. Precedent-setting regional agreements to combat transboundary acidifying pollution

Reaffirming the acidification hazard. The long-range transport of the acidifying pollutants was profoundly ascertained in the late 1970s as much more observational data and improved numeric models became available. In this regard, the European Monitoring and Evaluation Programme (EMEP) played an important role owing to the systematic collection and provision of standardized atmospheric chemistry data from 1977 onward. The "acid rain" problem started to receive higher political attention internationally when the report of the above mentioned OECD programme was published in 1977 with the following conclusions (*OECD*, 1977): "Man-made emissions of sulphur dioxide in Europe are derived mainly from combustion of sulphur-containing coal and fuel oil. (..) The programme has confirmed that sulphur compounds do travel long distances (..) in the atmosphere and has shown that the air quality in any one European country is measurably affected by emissions from other European countries." This was an important catalyst to the international policy negotiations, but the real push for general acceptance of the need for urgent abatement measures was that when the long-range atmospheric transport of pollutants and the acid rains generated by them were made responsible for the extensive forest degradation in Germany (*Hinrichsen*, 1983). *Ulrich* (1983) categorically stated that the "emissions of strong acid formers like SO_2 and NO_x leads to the poisoning of the ecosphere (..) The only environmental factor for forest which has been changed is the 'chemical climate' by air pollution. There is therefore no doubt that this change is the driving force for a development in the ecosphere which is characterized not only by tree and forest die-back, but also by the acidification of waters and by disappearance of species at an increasing rate. The data about load, carrying capacity and visible damage are more than enough to claim a rapid and considerable reduction of air pollution to avoid a possible ecological catastrophe". It was followed by a significant expansion of the atmospheric chemistry observational network, refined assessments of sulphur emissions from different sources, and further development of the transport models, which altogether produced much clearer information on the widespread scale of this pollution problem, and on its anthropogenic factors (*Mylona*, 1993). The stages of science development and its influence on strengthening the acid rain policy regime are presented in detail by *Levy* (1995), *Menz* and *Seip* (2004), and also in the analytic review of the 25 years of the Convention on Long-range Transboundary Air Pollution (*UNECE*, 2004b). These studies demonstrated that the international policy-making from the 1980s closely followed and adequately reflected the advancement of "acidification science" with the adoption of increasingly ambitious targets and emissions reduction commitments for all relevant pollutants in order to minimize their harmful effects.

The acid rain policy regime. The Helsinki conference (1975) and the conclusion of the OECD programme on the Long Range Transport of Air Pollutants (*OECD*, 1977) were followed by launching in 1978 the negotiations on a pan-European agreement on transboundary pollution. Both the basic scientific and political prerequisites existed for that motion. As regards the latter, the visit of G. H. Brundtland, the Norwegian prime-minister to Moscow in 1978 and the bilateral consent on the importance of this matter proved to be one of the most significant political factors for the start of the multilateral negotiations. Eventually, the Convention on Long-Range Transboundary Air Pollution (CLRTAP) was adopted in Geneva in November 1979 and afterwards, in the succeeding two decades, it was complemented with a series of protocols on monitoring, on abatement of sulfur and nitrogen emissions, and on reduction of the adverse impacts. The *international acid rain policy regime* comprises of the provisions of this set of legal instruments, the agreed targets and policies together with the means of implementation introduced by a series of the Parties' decisions. We restrict our focus to the acidifying air pollutants (AAPs), however, from the early 1990s, this pan-European cooperation was broadened to cope more generally with transboundary air pollution, including abatement policies for VOCs, heavy metals, and POPs, and taking into account the harmful "multi-effects" of all these pollutants.

The framework agreement. The 1979 convention was a *framework type legal instrument*, as it was only demonstrating the general political consensus on the environmental risk caused by air-borne pollutants, however, without determining any particular obligations for the Parties on controlling the emissions of the AAPs. One reason for that was the still considerable level of uncertainties, so that implicitly, a precautionary approach was adopted by "recognizing the existence of *possible* adverse effects, in the short and long term, of air pollution including transboundary air pollution" (*UNECE*, 1979). Thanks to rapid verification of the transboundary movement of these pollutants and their adverse impacts, the precautionary approach was soon replaced by very concrete preventive measures in the first sulphur protocol in 1985, as the Parties already expressed their concern "that the present emissions of air pollutants *are causing* widespread damage" (*UNECE*, 2004a). Afterwards, more stringent legally binding emission reduction obligations were included in a series of subsequent protocols. It has meant a *stepwise or gradual strengthening* of the targets and obligations, which ultimately resulted in the very effective management of this environmental problem.

Quantified emissions control commitments were formulated by means of defining the reference levels (base years) and the limitation or reduction targets (*UNECE*, 2004a): in 1985 the 30% emission reduction for sulphur by 1993 compared to its 1980 level; in 1988 the stabilization of the NOx emissions or transboundary fluxes generally by 1994 at the level of 1987; more ambitious reduction levels in the second sulphur protocol in 1994. Eventually, the 1999 Gothenburg protocol took into account the combined adverse effects and set even more stringent reduction targets for all relevant pollutants: 65% for SO_2, 44% for NOx, 17% for NH_3 by 2010 below their 1990 emission levels. (This protocol was further amended later.)

Some differentiation was demanded by the countries as the required level of emissions reduction was gradually raised, so that the countries' different situations could be acknowledged in relation to: the responsibility for and contribution to this common environmental problem; the adverse effects; the abatement costs; and/or their capabilities to control these emissions. Such a differentiation of the commitments was introduced on a *country-by-country basis* when more ambitious reduction targets for sulphur were agreed in 1994, and also when the comprehensive "multi-pollutant and multi-effect" protocol was adopted in 1999 (*UNECE*, 2004a). According to this last protocol, country-specific reduction commitments were set for sulphur, nitrogen oxides, and ammonia (and also for VOCs).

Joint implementation was permitted by the 1994 protocol, according to which two or more Parties could jointly fulfil their emissions reduction commitments (if it seemed to lead to cost savings). As a matter of fact, the use of this option would actually mean *emission trading* between the Parties in such a way that the "host Party" undertake additional reductions to be accounted for the "donor Party", which pays for those "transferred" emission units, but not directly for any project resulting in those extra emission reductions. In reality, this instrument was never used, as the Parties could not agree on the specific conditions and rules of its application.

The active science-policy interaction was essential for the development of proper policies and mechanisms in this international cooperation. A close relation was established between the convention-related organs (primarily, the main governing organization, i.e., the Executive Body) and those international institutions (the Steering Body of the EMEP, Meteorological Synthetizing Centres), which regularly delivered information to the negotiators on the new observational and research results. Moreover, the Parties set up their own permanent working groups with the mandate to evaluate the scientific and technological developments, and if necessary, to recommend additional measures (Working Groups on Strategies, on Effects and on Abatement Techniques).

Enforcement. At last, we refer to the *compliance mechanism* that included procedures and institutional arrangements (Implementation Committee), which were adopted within the 1994 and 1999 protocols and aimed at reviewing the fulfilment of commitments and supporting the Parties to comply with them. It was a soft enforcement instrument, as the emphasis was on providing assistance to the Parties concerned, and actually, no sanctions could be proposed at all against a Party, which was found in non-compliance even with the emissions control obligations under the CLRTAP and its protocols.

3.2. The ozone layer policy regime as a global precedent for the climate policy mechanisms

Ozone science development. Contrary to the acidification problem, the scientific recognition of the ozone layer depletion hazard did not start with the actual observation of this dangerous phenomenon, but with the scientific cogitation in early 1970s about those substances, their anthropogenic sources and chemical reactions which could influence the stratospheric ozone. The potential risk of modification of the ozone layer by human activities was reconfirmed by reports (published by WMO, UNEP, U.S. NAS), which summarized the growing body of scientific results on this matter, and starting from 1977, these triggered the decisions to ban or at least to reduce the "non-essential use" of the CFCs in some countries. The UNEP undertook the international coordination from 1977 based on the "World Plan of Action for the Ozone Layer", and in 1981, the decision was made to begin drafting a global convention to protect the ozone layer (*Morrisette*, 1989). Understandably, concrete commitments could be adopted only after 1984, when the stratospheric ozone hole above the Antarctica was discovered and the assumptions on the role of CFCs in the ozone destruction were confirmed (*Farman et al.*, 1985). The thorough analysis of various ozone depleting substances (ODS), their chemical mechanisms, varying status of the ozone layer, and the adverse impacts of its depletion, as well as, the technological search for the "ozone friendly" chemical compounds were leading to gradual strengthening of international policy responses. Below, we turn only to some of those key elements of this international policy regime, which directly or indirectly served as precedents for the climate policy negotiations and their outcomes. A few of these elements somehow replicate those instruments at global level which were developed for the pan-European acid rain policy regime, whilst others were specifically introduced, for instance, to facilitate effective participation of the developing countries in the common endeavour to cope with this global hazard.

The gradual approach to the ozone layer depletion problem was similar to that for the acidification, namely this global issue was also addressed by the international community in a stepwise manner starting with a *framework type convention* (*UNEP*, 1985), which was followed by a protocol (*UNEP*, 1987) and a series a subsequent amendments and adjustments. Extension of the list of the controlled substances and setting new reduction targets occurred due to advancement in ozone science and technology (development of the substituting chemical compounds). The 1985 Convention emphasized only the importance of the *precautionary measures* and accordingly did not include any concrete immediate quantified objectives, but contained only a future oriented provision: "The Parties shall take appropriate measures (..) to protect human health and the environment against adverse effects *resulting or likely to result* from human activities which *modify or are likely to modify* the ozone layer" and named those hazardous substances which at that stage were "thought to have the potential to modify the chemical and physical properties of the ozone layer". As the discovery of the ozone hole was communicated shortly after concluding the convention, the negotiations were speeded up, and the 1987 Montreal Protocol (MP) already determined quantified reduction targets for the production of some ODS. The subsequent amendments and adjustments (*UNEP*, 2012) substantially extended the list of controlled substances and set more stringent reduction obligations for the Parties.

The basic commitments were formulated as required *quantified reduction rates* to be reached by some deadlines compared to a reference level (1986). In the 1987 Montreal Protocol, the longest term target was defined for 1999 and it aimed at a 50% reduction for the most "prominent" substances (five types of CFCs) by that year and beyond. For other substances (halons), a *stabilization obligation* was accepted, namely, the requirement that their national production volume should not exceed the reference level. In response to the increasing awareness of the ozone layer thinning danger and the ozone depleting potential of those substances, already in 1990, the deadlines for the 50% reduction target were moved backward to 1995, and it was agreed to fully phase-out the use of these synthetic chemical compounds from 2000. The further amendments and adjustments by 1999 did not only extend the lists of the substances, tightened the deadlines, and increased the reduction rates (ultimately referring to a consumption and production level that "does not exceed zero"), but also for many ODS even banned import from and export to the countries which were not Parties to the MP.

Some differentiation in terms of the controlling commitments were agreed already in 1987 in favour of the developing countries with relatively low level per capita ODS consumption. With this provision, the apparently less responsibility for the ozone depletion hazard and also the developmental needs of these countries were recognized. This group of countries became entitled for a ten years delay for the compliance with some of the Protocol's key obligations. The subsequent amendments and adjustments regularly turned back to and refined the terms of this differentiation.

Trading with production quotas and joint implementation as optional complementary instruments were defined by the 1987 Montreal Protocol. Under specific circumstances, the former one was an option for any two Parties according to which those could trade in a portion of production of some ODS, as long as the aggregated level of their productions would not exceed the sum of production limits set out for those Parties (*UNEP*, 2012). This opportunity was used by Australia and New Zealand in 1997. The joint implementation or *joint fulfilment* mechanism in principle could be applied by a group of countries, such as the members of the European Community.

Science-policy relations were of high significance for this matter, as well, especially for evaluation of the effectiveness of the agreed commitments and for provision of advices about additional, more ambitious targets, based on the advanced knowledge on the ozone depleting mechanisms and abatement options. For this purpose, expert panels were established with the mandate to provide scientific and technological assessments and proposals (Panels for Ozone Scientific Assessment, Environmental Effects Assessment, Technology and Economic Assessment).

Enforcement. A comprehensive procedure was put in operation for the evaluation of the occasional *non-compliance* of the Parties regarding the implementation of their commitments under the MP. The elaboration of this mechanism began in 1990, it was adopted in 1992, and substantially widened in 1998 (*UNEP*, 2012). It included detailed proceedings and an institutional component (Implementation Committee). Basically, recommendations were made for the Parties which were found in non-compliance with the control or the reporting obligations, moreover, financial means could be offered as assistance to achieve compliance. Beyond that, in principle, more serious measures could also be taken, such as the suspension of the rights of a Party to trade with production quotas, however, the use of the sanctions was generally avoided (*Sarma*, 2005).

A financial instrument was initiated in 1989 by the Parties to the Montreal Protocol "to recognize the urgent need to establish international financial and other mechanisms to enable developing countries to meet the requirements of the present and a future strengthened Protocol, thereby addressing the ozone depletion and related problems" (*UNEP*, 2012). Its operation started on an interim basis in 1990, but already two years later it was made final. This Multilateral Fund received financial contributions from the "non-developing countries", that is from the developed countries and the "countries with economies in transition" (EiTs) with a clear understanding that without such an instrument and technological support, the majority of the developing countries (DCs) would not be able to reduce and gradually phase out the ODS. In 1990, the financial assistance for capacity building was considered by the DCs as a condition for implementation of the control measures by them. The agreement on financial contributions involved that the Central and Eastern European countries (that is the EiTs) also became donors, whilst they started to face serious problems to fulfil their own obligations under the MP. Ultimately, it was the Global Environment Facility (GEF) that offered some financial assistance to these countries for meeting the ODS controlling targets.

<u>A specific condition for entry into force</u> (EiF) of the Protocol is also noteworthy, and essentially it was replicated for the international climate change policy regime with more or less similar justification. In general, it is customary to set a reasonable threshold number of acceding countries that should be reached for a multilateral agreement for its coming into force. (In this respect, "becoming a Party" in broad sense requires the deposition of the instrument of ratification, acceptance, approval, or accession.) In the case of the MP, one more essential condition was added, according to which it would enter into force provided that at least eleven such instruments had been deposited by countries "representing at least two thirds of 1986 estimated global consumption of the controlled substances". Determining such a bottom line for the aggregated reduction volume of the ODS consumption by those countries guaranteed the effectiveness of the implementation of this agreement. It was evident that the objectives of the MP could not be reached without the active participation of the "big consumers" of the ODS. Those years, the USA and the European Community together were responsible for more than half of the global consumption, while the large group of the developing countries only for about one seventh of that total amount (*UNEP*, 2005).

3.3. Replication of some precedential features in the international climate policy setup

<u>Policy-relevant climate science: the outset</u>. A new period started in the scientific understanding of and the elevated concern over the climate change hazard from the late 1970s. What was known and also the remaining knowledge gap concerning the cycles of the greenhouse gases (GHGs) and the effects of their increasing atmospheric concentrations were summarized

inter alia in the *Charney* report (1979) and at international level, by the (first) World Climate Conference (*WMO*, 1979). According to our timeline terminology, the Conference's declaration properly reflected the end of the "inception phase" and the outset of the next phase for ascertaining the validity of the earlier assumptions on this complex issue: "Carbon dioxide plays a fundamental role in determining the temperature of the earth's atmosphere, and it appears plausible that an increased amount of carbon dioxide in the atmosphere can contribute to a gradual warming of the lower atmosphere, especially at high latitudes (..) but the details of the changes are still poorly understood". During the following decade, the expanding observational systems, the improved global climate models, as well as the synthetization of the multidisciplinary research results in the framework of the World Climate Programme and the programmes of many international organizations (ICSU, UNEP, WMO, IIASA, etc.) substantially contributed to the fast science development on climate variability and change (*Faragó*, 1981, 1991). In the second half of the 1980s, a series of international meetings were devoted not only to the discussion of the new scientific achievements, but also to the possible actions to mitigate this hazard. Experts reviewed the state-of-the-art of climate change science at the meetings held in 1985 and 1987 (Villach, Bellagio), which were followed by international conferences between 1988 and 1990 (Toronto, The Hague, Nordwijk), where already scientists and policymakers exchanged views on the probable adverse consequences and the policy options (*Bodansky*, 2001).

Climate change policy regime. The year of 1988 can be seen as the actual beginning of construction of the international climate change policy regime with several exceptionally important developments: the first proposal for a concrete GHG-emissions control target was formulated at the Toronto meeting, the IPCC[2] was established as the main channel of scientific information to the policymaking community, and the UN resolution was adopted on the "Protection of global climate for present and future generations of mankind" (*UNGA*, 1988). The findings of the first IPCC report in 1990 were essential motivations for the outcomes of the 2nd World Climate Conference and also for a further UN resolution at the end of that year, which were leading to the international negotiations from 1991 and ultimately, to adoption of the global agreement on climate change in 1992. The foundations of the policy regime defined by this UN Framework Convention on Climate Change (*UNFCCC*, 1992) were later on considerably complemented by the Kyoto Protocol (KP) in 1997 and by a series of decisions enframed in the Marrakesh Accords (MA) passed in 2001 by the Conference of the Parties (COP). The Convention was enacted in 1994, the Protocol's entry into force occurred ten years later, after which the terms of a

[2] Intergovernmental Panel on Climate Change

new round of negotiations were discussed in 2005 (Montreal) and agreed in 2007 (Bali Action Plan) on the continuation of the KP for the post-2012 period and the elaboration of a new global agreement. Eventually, (i) the KP was "prolonged" in 2012 by its Doha Amendment (DA) with new emission reduction commitments for the industrialized countries (ICs) for the 2013–2020 period, and (ii) a new universal legal instrument was adopted at the end of 2015. The latter one is the Paris Agreement (PA), which is also under the UNFCCC likewise the Kyoto Protocol and its Doha Amendment, but the PA is elaborated as a complex set of mechanisms and procedures for the post-2020 period with various general obligations *for all Parties*. (As a matter of fact, the PA established and defined only the "skeleton" of those mechanisms and procedures so that the concrete rules of their operation ought to be defined in the forthcoming years. Unfortunately, it is also valid for the Parties' concrete commitments: in particular, the PA does not include any concrete global and country level emissions control targets with the respective deadlines, and such nationally determined targets will be regularly determined, updated/upgraded, and communicated later.) Henceforth, we devote our attention to some of the *substantial components of the international climate policy architecture*[3]*, which had their precedents in acid rain and ozone layer policy regimes* (*Table 1*). Some of these elements appeared in other contemporary multilateral legal instruments, however, the influence of the policy mechanisms of the two other large-scale atmosphere-related environmental processes was especially prominent for the climate change issue. As the protocols on sulphur and nitrogen emissions were finalized in 1985 and 1988, respectively, and the Montreal Protocol on ozone layer protection was concluded in 1987, the fresh experiences on compromise-settings within those negotiating processes had also their reflections on the climate negotiations launched at the beginning of 1991.

[3] The present discussion of the international climate policy regime takes into account some key components of the Framework Convention, the Kyoto Protocol, the Marrakesh Accords, the Doha Amendment, some decisions by the Parties, and the Paris Agreement.

Table 1. Evolvement of the international policy regimes since the late 1970s and some of their analogous features (introduced by the acid rain and/or ozone layer regimes and replicated in the climate change policy settings)

	Acid rain policy regime	Ozone layer policy regime	Climate change policy regime
	1978- negotiations ***1979: "framework" Convention***	1977: World Plan of Action on the Ozone Layer (UNEP)	1979: World Climate Conference
1980-	***1985: Helsinki Protocol (sulphur)*** ***1988: Sofia Protocol (nitrogen)***	1981- negotiations ***1985: "framework" Convention*** ***1987:Montreal Protocol** (MP)*	1988: Toronto Conference 1989: Hague and Nordwijk Conferences
1990-	1994: Oslo Protocol (sulphur) 1999: Gothenburg Protocol (GP) (multi-pollutants)	1990-1999: Amendments and Adjustments of the MP	1990: 2nd World Climate Conf. 1991- negotiations ***1992: Framework Convention** (UNFCCC)* ***1997: Kyoto Protocol** (KP)* (completed with the 2001 Marrakesh Accords)
2000-	2012: Amendment and Adjustment of the GP	2007: Further adjustment of the MP	2005/2007/2011- new rounds of negotiations (Montreal, Bali, Durban) 2012: Amendment of the KP (Doha) ***2015: Paris Agreement** (PA)*

Feature and building block	Acid rain policy regime	Ozone layer policy regime	Climate change policy regime
Stepwise approach: gradual strengthening of the mitigation obligations	"framework" convention followed by protocols and a series of decisions	"framework" convention; its concretizing protocol followed by amendments, adjustments	framework convention; protocol (and decisions) and its amendment; a new, framework type "global" agreement (2015)
Mitigation obligations: quantified targets	quantified emissions control targets (AAPs)	quantified production control targets (ODS)	KP: quantified emissions control targets (GHGs); PA: nationally determined targets/efforts
Differentiation: differentiated obligations (for response policies and measures)	country-by-country targets (1994 Protocol)	MP: longer term compliance period for the developing countries	KP: concrete mitigation targets for ICs PA: targets to be communicated later; general reference to actions, enhanced efforts by DCs
Flexibility instruments: for cooperative fulfilment	joint implementation (1994 Protocol, but w/o rules)	joint fulfilment; trading with volumes of ODS-production	KP: joint implementation; trading with emission allowances; PA: cooperative mechanism/approach
Science-policy interface: institutional arrangements	expert level working group on effects, EMEP Steering Body	expert panels on strategies, effects, etc.	expert level body on scientific advice and close link with IPCC
Financial mechanism: for assisting developing countries		Multilateral Fund (1990-) (GEF to assist EiTs 1992-)	GEF climate portfolio (1996-); Green Climate Fund (2010-)
Compliance mechanism: for the facilitation and enforcement of implementation	facilitative mechanism (1994-)	facilitative mechanism, incl. potential sanctions (1992-)	KP: compliance mechanism, incl. potential sanctions (2001-) PA: facilitative mechanism
Conditions for entry into force: aggregated indicator		MP: threshold for aggregated production by the ICs	threshold for aggregated emissions (KP:) by the ICs, (PA:) by all Parties

Phased approach. Similarly to the acid rain and ozone layer policy regimes and for analogous reasons, the climate negotiations resulted in *gradually strengthened outcomes* by starting with a framework convention in 1992 and continuing with some more ambitious commitments and actions from 1997 on. In this case, such a stepwise approach was justified not only by slowly dissipating scientific uncertainties (e.g., on the forcing factors or the possible future behaviour of the system), but also by the prolonged discussions on the differentiated responsibilities for this global hazard and the considerable inertia of the key GHG emitting economic sectors. The responsibility was and remained a critical question, since it stemmed from the huge differences in the historical and gradually varying GHG emissions and in the consequent shares of the countries in the increase and excess of the atmospheric concentrations of these gases. Despite the framework character of the 1992 convention (according to its title and general substance), yet it contained an important commitment on emissions control by the industrialized countries, *viz*. the stabilization of their emissions by 2000 compared to the 1990 reference level (as a default baseline, while EiTs were entitled to have some flexibility in this regard). It was followed by the 1997 Kyoto Protocol already with a moderate emissions reduction commitment by almost the same country group, and by the 2012 Doha Amendment of the KP with even more stringent emission reduction obligations, but for a considerably smaller group of the industrialized countries. The particular *quantified emission limitation and reduction objectives* (QELRO) and commitments (QELRC) were defined in the 1997 KP and later in its 2012 amendment on a country-by-country basis similarly to the 1994 (second) sulphur protocol. Contrary to that approach, the 2015 Paris Agreement did not include any quantified mitigation target, but (i) it only concretized the ultimate objective of the Convention by referring to 2 °C and 1.5 °C as the critical limit values for the global average surface temperature increase above pre-industrial levels; and (ii) for the temperature goal, it included a rather general roadmap for the overall emissions control, i.e., to *reach global peaking of GHG emissions as soon as possible and to undertake rapid reductions thereafter*, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of GHGs in the second half of this century (in other words, to reach decarbonisation or zero net GHG emissions). As their contributions to the global response to climate change, the progressive quantified emissions control targets by the PA's Parties will be nationally determined and communicated later.

Differentiation. The concept of the common but differentiated responsibilities (CBDR) was unanimously accepted as the guiding principle for this policy regime. In particular, it meant the acknowledgment of the differences in the above-mentioned historical GHG emissions. Its consequence was the strong *differentiation of the obligations between the developed and developing countries*. In this regard, the countries' respective capabilities and national circumstances were also considered as important factors. This approach was clearly reflected in the emissions controlling provisions of the KP and DA, which set legally binding quantified *commitments* for the industrialized countries[4] (ICs) and referred to the mitigation *actions* of the developing countries (DCs) in line with the key preambular paragraph of the Convention: "Noting that (..) per capita emissions in developing countries are still relatively low and that the share of global emissions originating in developing countries will grow to meet their social and development needs". Moreover, the developed countries were also expected to undertake the provision of financial and technological assistance to the DCs in order to build and enhance their capacities for the assessment of emissions, development of climate response policies, and preparation for the adverse climatic impacts. The Paris Agreement repeated such a distinction, namely, by referring to emission reduction *targets* of the ICs and mitigation *efforts* of the DCs to be nationally determined, however, already encouraging the DCs to set also emissions control targets at a later stage. Some differentiation was also provided for other components of this policy regime (e.g., for the national communications on emissions and measures).

An international emission trading system was established by the KP in 1997. It was initiated by the USA by referring to its efficient internal (federal) SO_2 allowance trading scheme. Moreover, the *joint implementation* instrument was introduced as another flexibility mechanism, by means of which one industrialized country could transfer emission reduction units (quotas) originating from a project to another such country that partly or fully financed the project. In international terms, the KP's trading system was somewhat similar to the bilateral trading option for CFC production quotas under the 1987 MP, however, there was a very limited practical utilization of the latter one. A joint implementation option was agreed for the sulphur emissions by the 1994 protocol to the CLRTAP, but as it was indicated above, that was never used by any Parties in lack of the agreed rules for its application. Nevertheless, these two international precedents and operation of the above mentioned federal scheme in the USA provided useful background for the elaboration of the terms for those two supplementary mechanisms of the climate change policy regime. (The Clean Development Mechanism of the KP realized a very much different, innovative approach.) Because of significant differences in experiences and positions on such flexibility instruments, only the general provisions for the *market-based and non-market cooperative mechanisms* were included in the Paris Agreement, which applicability depends on when and how their terms and concrete procedures will be determined.

Science-policy relations. The state-of-art scientific knowledge closely motivated the rapid progress in the acid rain and ozone layer policy regimes, and some dedicated institutional arrangements were made in both cases to

[4] We use the term of "industrialized countries" (ICs) for the group of the developed countries and the countries with the economies in transition, which are listed in the Annex I of the UNFCCC and referred to also in the Annex B of the KP.

systematically channel the new observational and research information to the negotiators (through working groups and expert panels). These experiences have contributed to setting up the relevant institutional mechanisms for an interactive science-policy dialogue to assist the climate negotiations. For this purpose, the role and functions of a permanent advisory body were already defined by the 1992 Convention[5], and a close working contact was maintained with the IPCC. The periodically published assessment reports of the IPCC had significant influence on the multilateral negotiations and their outcomes: e.g., the conclusions of the 1990 first report on the Convention (1992), the outcomes of the second report in 1995 on the Kyoto Protocol (1997), and the policy relevant scientific assessments of the fifth report (2013/2014) on the elaboration and adoption of the Paris Agreement (2015).

Enforcement. A comprehensive mechanism was elaborated for the evaluation of occasional *non-compliance* of a Party with its commitments under the KP, which rules were adopted only in 2001 (as part of the Marrakesh Accords). The lessons from such instruments established earlier were taken into account, as well as, the very complex nature of reporting on the GHG emissions, various climate policies, and measures by the Parties, and as a consequence, the elaborateness of the KP's mechanism went well beyond that of the compliance systems for the acid rain and the ozone layer policy regimes: "The Kyoto Protocol has thus given rise to a non-compliance procedure, which is among the most elaborate and innovative of its kind, while the Compliance Committee (..) is one of the most powerful and independent committees of its kind established by an environmental convention" (*Maljean-Dubois*, 2010). For the sake of enforcement, one possible *sanction for non-compliance* could lead to the temporal suspension of the eligibility of a Party for using the KP's flexibility mechanisms. This option reminds a similar opportunity within the ozone layer policy regime, however, with more serious implications in the case of the KP. Recently, a more cautious formula was included in the Paris Agreement obviously because of the universal nature of certain obligations: a mechanism for the *facilitation of implementation* of and *promotion of compliance* with the provisions of the PA and the relevant committee with *only facilitative and non-punitive functions* (which concrete terms of reference should be determined later).

Financial assistance for the developing countries was considered as a crucial prerequisite for their participation in the common global climate protecting endeavour, so that the financial mechanism was established and outlined already in the framework convention, which operation was undertaken by the Global Environment Facility (GEF). Primarily, it aimed to assist the developing countries and, to a less extent, the countries with economies in

[5] "A subsidiary body for scientific and technological advice is hereby established to provide the Conference of the Parties (..) with timely information and advice on scientific and technological matters relating to the Convention." (UNFCCC, Art. 9.1) The author of this paper was elected as the first chairman of that body (SBSTA), and in that capacity (*ex officio*), he was also the member of the Bureau of the COP.

transition. In a sense it was comparable to the Multilateral Fund for the Montreal Protocol together with the support from the GEF to the EiTs. Moreover, such a similarity became even more apparent when the COP of the climate convention established its "own" Green Climate Fund in 2010 to channel financial resources to DCs to support their mitigation and adaptation related actions.

A specific condition for entry into force (EiF) has guaranteed that the KP could have its legal power only if the key "players" become Parties to it. This idea was similar to the special EiF criteria of the Montreal Protocol. Besides the requirement of having already at least 55 ratifyers, there was an additional condition, namely, this group of the Parties had to incorporate industrialized countries (ICs listed in Annex I of the Convention), which accounted in total for at least 55 percent of the total CO_2 emissions for 1990 of all the ICs. This very high threshold can be better understood by taking into account that in 1990 the Russian Federation and the USA together were responsible for more than half of that total. (Of course, this situation has profoundly changed when the USA pulled out of the Protocol.) The Paris Protocol formally repeats the similar 55–55 condition for its entry into force, however, because of its global nature, not exclusively the ratifying industrialized countries' emissions will be added up to meet the 55 percent emission threshold, but the annual emissions of all the ratifyers (those from the group of the developing countries, as well).

In sum, important precedential features of the acid rain and the ozone layer policy regimes had their positive effects on the construction of the climate change policy architecture, however, as it will be demonstrated below, after a while, the evolvement and effectiveness of the climate change policy mechanisms considerably diverged from those for the two other atmospheric issues.

4. Increasing science-policy gap in addressing the global climate change hazard

"The production and consumption of the majority of harmful ozone-depleting chemicals has been successfully phased out, in both developed and developing countries." (*UNEP*, 2012)

"Noting with grave concern the significant gap between the aggregate effect of Parties' mitigation pledges (..) and aggregate emission pathways consistent with having a likely chance of holding the increase in global average temperature below 2 °C or 1.5 °C above pre-industrial levels." (*COP Decision 2/CP.18*, 2012)

Effectiveness of acid rain and ozone layer policy regimes. When the 1997 Kyoto Protocol entered into force in early 2005, it was the general expectation that the international treatment of the climate change hazard will somehow follow the examples of the relatively rapid and effective development of the international policy mechanisms for tackling the "acid rain" (more generally, the long-range air pollution) and the ozone layer depletion problems. Due to the increasingly stringent measures, the emissions and transboundary transmissions of the AAPs have drastically dropped in the pan-European region. In the same way, thanks to gradually enhanced provisions of the MP, the production, consumption, and atmospheric release of an ever expanding group of ODS was taken under control, eventually many of these substances were phased-out and substituted by "ozone-friendly" ones for various applications. In these cases, the rapidly enriching knowledge base has had its decisive effect on policymaking besides many other supportive factors.

The climate change science-policy paradox. Contrary to the above cases, a growing gap could be observed primarily between the actual levels of the globally aggregated GHG emission reductions and the level of reductions that was from time to time recommended by the large group of scientists backing the work of the IPCC, the UNEP, and various international academic organizations. Since 1990, the IPCC has regularly published science-based assessments, *inter alia*, on those levels of global emission reductions, which would make possible, with certain degrees of confidence, the avoidance of dangerous human interference with the climate system. These were accompanied by evaluation of the mitigation potential of the economic sectors and by recommendations for specific mitigation and adaptation policies ("climate-friendly" measures in various sectors, sustainable forest management, opportunities for increased climate resilience, etc.). In addition to that, the UNEP issues Emissions Gap Reports (EGR) since 2010, and the scope of its reports is the comparison of the theoretical emissions reduction pathways for remaining below the presumably still safe global temperature increase limits with the actual, agreed, or pledged global emission reductions. In this section of the paper, the increasing deviations of the international policy responses from these science-based advices and the key factors of these deviations will be discussed. We consider the evolution of the science-policy interplay in terms of the influence of growing scientific awareness about the global climate change hazard on the international climate policy cooperation for the last four decades. This process was more or less analogous to those for the acidification and ozone depletion hazards for about two decades, however, for various reasons, there is a widening science-policy gap concerning especially the abatement or mitigation targets since the turn of the century in case of the climate change problem (*Table 2*). This is a *climate change science-policy paradox*, i.e., the contradiction between the increasing knowledge level on an environmental problem and the aggregated effect of the actions to cope with that problem. There are other forms of paradoxes embedded in the climate policies as contradictory feedbacks (*Fölster* and *Nyström*, 2010; *Jordan et al.*, 2012).

Table 2. Timeline of climate change science-policy relations
(S: short-term emissions control, L: longer-term emissions control; /1990 or /2000 is the reference year; "emissions" refer to GHG-emissions; * is for the "2°C limit" after 2007)

	Emissions control targets: science-based recommendations*	**Emissions control targets: policy approach or commitment**
1985-	1985 Villach; 1987 Villach, Bellagio S) stabilization of ICs emissions L) stabilization of the atmospheric concentrations	1988 Toronto; 1989 The Hague, Nordwijk, UNEP S) 20% reduction or stabilization of the ICs emissions by 2005 L) stabilization of the atmospheric concentrations
1990-	1990-1992 IPCC AR1 (1990 WG-III, 1992 Supplement) S) stabilization of ICs emissions L) stabilization of the atmospheric concentrations	1992 UNFCCC S) stabilization of ICs emissions by 2000 (/1990) L) stabilization of the atmospheric concentrations 1994 The Convention enters into force (EiF)
1995-	1995 IPCC AR2 S) reduction of ICs emissions L) stabilization of global CO_2-emissions within several decades followed by substantial reductions (/1990) 2001 IPCC AR3 S) reduction of the ICs emissions beyond KP levels L) stabilization of global emissions within few decades	1997 Kyoto Protocol (KP) S) 5% reduction of the ICs emissions by 2012 (/1990) L) reference to the ultimate objective of the Convention (stabilization of the atmospheric GHG concentrations) 2001 Marrakech Accords completing the rules for the KP 2004 Protocol's special EiF criteria are fulfilled (EiF: Febr. 2005)
2005-	2007 IPCC AR4 S) stabilization of global emissions within 10–15 years; 25–40% reduction of ICs emissions by about 2020 (/1990) L) global emission reductions: at least 50% by 2050; 80–95% reduction of the ICs emissions by 2050 (/1990) 2010 UNEP-EGR S) increase of global emissions: less than 17% by 2020 (/1990)	2005 Mandate for dialogue on long-term actions (Montreal) 2007 Mandate for negotiations on future actions (Bali) 2009 Copenhagen Accord (CA), a general reference to IPCC AR4; S) peaking of global and nat'l emissions "as soon as possible" according to CA: "Cancun pledges" by countries in 2010 2010 UNEP-EGR S) global effect of "pledges": 30–40% increase by 2020 (/1990) 2012 Doha Amendment to the KP S) 18% reduction of the ICs emissions by 2020 (w/o 5 ICs) (/1990)
2013-	2013-2014 IPCC AR5 S) emission peak years for all regions in 2010-2020; ca. 30% reduction of ICs CO_2-emissions by 2030 (/2010) L) 40-70% global emission reductions by 2050 (/2010) 2014, 2015 UNEP-EGR (scenarios from IPCC AR5 database) S) increase of global emissions: less than 14% by 2030 (/1990)	2015 INDCs by Oct 2015 (UNFCCC, 2015[1], UNEP-EGR, 2015[2]): S) global effect of INDCs[1]: 37–52% increase by 2030 (/1990) S) global effect of INDCs[2]: 40–54% increase by 2030 (/1990) 2015 Paris Agreement S) global peaking "as soon as possible" L) zero net emissions in the 2nd half of this century

4.1. *The scientifically recommended and the actually accepted levels of mitigation responses*

Initiatives for the climate change policy regime. The scientific community started to urge the policy measures on the climate problem from the mid-1980s. The conclusions of the 1985 Villach conference included the following recommended actions based on the assessment of the climate change hazard (*Villach*, 1985): "Governments (..) should take into account the results of this assessment in their policies on social and economic development, environmental programmes, and control of emissions of radiatively active gases. (..) Major uncertainties remain in predictions of changes (..) Nevertheless, the understanding of the greenhouse question is sufficiently developed that scientists and policy-makers should begin an active collaboration to explore the effectiveness of alternative policies and adjustments." As a follow-up, two expert-level meetings already focused on concretizing the policy areas which, according to the joint meeting report, should cover both the limitation and adaptation strategies. The priority actions for the former one included the re-examination of long-term energy strategies, reduction of deforestation, and increase of forest area, moreover, the limitation of the growth of non-CO_2 GHGs in the atmosphere. The report also suggested the examination "of the need for an agreement on a law of the atmosphere as a global commons or the need to *move towards a convention* along the lines of that developed for ozone" (*WMO-UNEP*, 1988). These science-based suggestions strongly motivated the outcomes of those conferences, which took place in 1988 and 1989 with the participation of many government representatives, as well. Their policy-oriented declarations included already some quantified proposals for emissions control and some other actions (afforestation, controlling other GHG emissions, international financial means, etc.). In this regard, the key points by the Toronto conference (1988) were as follows: *stabilization* of the atmospheric concentrations of CO_2, for which emission reductions of more than 50% would be necessary for long-term, and as an initial global goal, the reduction of emissions by approximately 20% of 1988 levels by the year 2005 should be achieved. The high-level meetings held in The Hague and Nordwijk in 1989 emphasized the need of *urgent stabilization of the emissions by the industrialized countries* (ICs) as a first step. The UNEP Governing Council reiterated a similar requirement for all the emissions of carbon dioxide and other greenhouse gases at its meeting in 1989 (Nairobi). As we see, these *international policy reactions were in line with the science-based recommendations at least with those that concerned the most immediate actions* (emission stabilization, launching negotiations).

Stages of mitigation policy development. From the early 1990s, the negotiations generally resulted in the shorter term mitigation obligations for subsequent decadal periods. The 1992 convention comprised of emission stabilization objectives for the ICs at the 1990 level by 2000. The 2007 Kyoto

Protocol set reduction obligations for them with the targets expressed as the annual averages for the 2008–2012 period. The Doha Amendment in 2012 defined new emission reduction commitments for a "shrunken" group of ICs by 2020. The negotiations on a new global instrument started about a decade ago and its preparations became more concentrated after 2012 with the intention to reach a deal on more ambitious actions for the post 2020 period. After 2009, many countries communicated their pledges and intentions with more or less concrete national targets for 2030 or some other target date. Eventually, that new agreement was concluded at the end of 2015, however without any concrete emission reduction "roadmap". The negotiations during all these stages could rely on inputs from the research community. The series of assessment reports of the IPCC from 1990 and the Emission Gap Reports (EGR) by the UNEP from 2010 presented scenarios with global emissions estimates, aggregated emissions of the industrialized countries, and relevant emission pathways, adherence to which could guarantee with some chance to stay below the 2 °C global warming limit. In order to demonstrate the changing science-policy gap, we now compare the science-based global emission recommendations with the global targets from the above-mentioned legal instruments or with aggregated effects of the countries' "pledges" provided at the later stages of this negotiating process.

The Convention. The IPCC published its first report in 1990 and issued supplemental assessments in early 1992. These reports included scenarios for GHG emissions control, and specifically, the IPCC's third working group (on the response strategies) provided initial evaluations on the feasibility of meeting the different quantitative targets. Besides a general reference to the urgency of the *stabilization of these emissions*, the 1990 and 1992 reports made clear that "in the near term, no significant progress in limiting global emissions will occur without actions by the industrialized countries. Some countries have already decided to stabilize or reduce their emissions". The rationality for a phased approach was also pointed out (*IPCC*, 1990–1992): "The IPCC recommends a programme for the development and implementation of global, comprehensive and phased action for the resolution of the global warming problem under a flexible and progressive approach." The existing uncertainties and the need for further in-depth studies warranted the carefulness of such formulations, i.e., the inadequacy of information available at that stage to make sound and detailed policy analyses. These complex IPCC messages had their equally cautious imprints on the ministerial declaration of the Second World Climate Conference (November 1990, Geneva) and also on the outcomes of the international negotiations, which culminated in adoption of the UN Framework Convention on Climate Change (UNFCCC). The convention included (i) short term obligations, such as the *emission stabilization commitment for the industrialized countries* (listed in the Annex I) by 2000 at the default 1990 reference level (base year) and a general provision for all Parties (i.e., also for the developing countries) to elaborate their national climate change programmes; and (ii) the long-term ultimate objective of the *stabilization of atmospheric GHG concentrations* at a level that would prevent dangerous anthropogenic interference with the climate system (*UNFCCC*, 1992). Obviously, both the scientific and policymaking communities wished to have some more time for getting more information on the climate change process, its expected impacts, and on the technical and economic feasibility of stronger policies. The Convention entered into force in 1994, and some years later it had a universal membership. Afterwards, the implementation and adequacy of this agreement was regularly discussed during the annual sessions of the Conference of the Parties (COP).

<u>The Protocol</u>. The next comprehensive assessment of the IPCC was completed in 1995 (*IPCC*, 1995). The refined scenarios for CO_2 *concentration stabilization* were linked to the relevant *emission pathways,* and it was made clear that even if global CO_2 emissions were maintained at then levels, they would lead to a nearly constant rate of increase in atmospheric concentrations for very long time. It was deduced that only the urgent halting of the emission growth followed by a systematic decrease of these emissions could lead to presumably still safe stabilization levels of the atmospheric GHG concentrations. More concretely, for instance, it was indicated that the 450 ppmv CO_2 stabilization scenario could be achieved only if global anthropogenic CO_2 emissions returned to the 1990 levels within approximately 40 years from that time, and dropped substantially below those levels subsequently. It was also clear from these scenarios and the related assessments that in order to achieve that global emission peaking, the industrialized countries had to commit themselves to considerable emission reductions (by taking into account their higher historical emissions, i.e., the CBDR principle). The new round of negotiations started in 1995 (based on the so-called "Berlin Mandate") and eventually those were leading to the preparation of the Kyoto Protocol (KP) and its adoption in 1997. The Protocol set an average 5% reduction obligation for the group of the industrialized countries (Annex I Parties) compared to the 1990 level of their emissions, to be achieved in the period of 2008–2012. *Although it was much lower than the GHG reduction levels stemming from the scientific evaluations, nevertheless, it was considered as a moderate but important short-term first stage in a stepwise approach.* In a sense, it still followed to some extent the initial phases of the acid rain and the ozone layer policy regimes. The detailed rules for some of the critical components of the KP were approved in 2001 (Marrakech Accords), and at last the KP came into force in early 2005 (already w/o the USA but thanks to the ratification by the Russian Federation in 2004, which was a decisive act in view of the specific EiF condition).

<u>Coming to a standstill</u>. In the meantime, the IPCC's third report was issued in 2001 and had some catalytic role on deliberations on the future climate policy cooperation that began in 2005 (after the KP entered into force). Based on that report, it was evident that for stabilizing the atmospheric CO_2 concentrations

e.g., at 450 ppmv level, the *global emissions should reach a ceiling within a few decades* and already on short term, it "may require emission reductions during the period 2008 to 2012 in Annex I countries that are significantly stronger than the Kyoto Protocol commitments" (*IPCC*, 2001). Contrary to the essence of these conclusions, in 2005 (Montreal) the Parties could hardly reach consensus even on the formats and general objectives of dealing with the post-2012 period. It can be considered as the beginning of a rapidly widening gap between the global climate change science and the international policy responses. At least, the dispute on formalities of the future negotiations and their general directions could be resolved in 2007, and the clear-cut messages of the fourth IPCC report had some influence in that regard (*IPCC*, 2007). The report, especially, its part contributed by the third working group of the IPCC, clearly stated that: (i) keeping the 2° C objective within reach requires stabilization of the atmospheric concentration of GHGs in line with the lowest stabilization level assessed, i.e., 450 ppmv CO_2eq; (ii) this will assume that the *global GHG emissions peak within the next 10 to 15 years*, and then those are substantially *reduced at least by 50% below 1990 levels by 2050*; and (iii) the groups of the industrialized (ICs) and the developing countries (DCs) contribute to those short and long-term CO_2eq reduction goals in line with their different shares in the overall emissions. These pertinent short and long-term reduction targets *in 2020 and 2050 for the ICs are 25-40% and 80-95%*, respectively, while for the DCs their contributions were suggested as follows: substantial deviation of the emissions from baseline by 2020 in some developing regions and substantial deviation from baseline in all developing regions by 2050. These science-based assessments were indirectly cited in the 2007 negotiating mandate (Bali), however, after two years of intense deliberations instead of agreeing on new targets and commitments, the only concrete product of the Copenhagen summit (2009) was that the delegates took note of an accord that included indications for: *deep cuts in global emissions*; *peaking of global and national emissions as soon as possible*; *quantified economy wide emissions targets by the industrialized countries by 2020*. While these general provisions were not complemented with any concrete goals, all Parties were invited to submit their "pledges": quantified economy wide emissions targets for 2020 by the Annex I Parties and further mitigation actions by the non-Annex I Parties. These submissions were reviewed at next COP session (Cancun), and the total effect of these "Cancun pledges" was also compared with the emission pathways consistent with a "likely" chance of meeting the 2° C threshold (*UNEP*, 2010). The results of this gap analysis demonstrated the need to *limit the growth of overall emissions by 2020 to a maximum of 17% in contrast to the 30-40% range of the global emission increase* that was deduced from those pledges and the four policy scenarios (a combination of the unconditional and conditional pledges with "lenient" or strict rules of compliance).

"Prolonging" the Kyoto Protocol as a transient solution. We now turn our attention to the legally binding deal, which was arranged in 2011 and finalized in 2012 as an amendment to the KP by extending it to a second commitment period. This Doha Amendment (DA) included quantified emission limitation or reduction commitments (QELRC) by a group of the industrialized countries with the target year of 2020. The aggregated unconditional commitments equalled to 18% emission reduction, however, already five industrialized countries did not take part in this deal, namely: Canada, Japan, New Zealand, Russia, and the USA. Many participants of the deal indicated also a conditional higher emission reduction target (e.g., the EU-28 a 30% reduction besides the unconditional 20% target). If one were combining the emissions control "low pledges" of those five countries (e.g. 4% below the 1990 level by the USA) with the unconditional commitments by the ICs inscribed in the DA, then such a virtual aggregated target would result in a less than ten percent reduction by 2020 below the 1990 level by all the ICs (listed in the convention). Whatever would be the exact estimate for this whole group, *the aggregated target for 2020 could mean a significant decline from the science-based emission reduction range for the ICs that was derived in the 2007 IPCC report*. Moreover, the DA covered only about 15% of the global GHG emissions (*Sterk*, 2012), since it did not address the goals of the above mentioned five ICs, neither the actions by the DCs by 2020. Therefore, it remained unclear, how the overwhelming majority of the countries plan their concrete measurable, reportable, and verifiable mitigation and other climate related policies and measures. Nevertheless, the Doha Amendment is an essential achievement: without its adoption, apparently, no progress could be achieved at all in the parallel negotiations of a new global instrument.

New policy-relevant scientific assessments. The year of 2013 brought about a new stage both in the communication of new scientific results and the international climate policy cooperation. The first part of the fifth report of the IPCC was published in 2013 and it was followed by other volumes of the report in 2014. The statements on the human interference with the global climate system, on the scenarios of its future state, and on the expected impacts reflected a much higher level of confidence. Comprehensive information was also provided on the possible mitigation and adaptation strategies. Regarding the future emission pathways, besides the general indications of the need for substantial emissions reductions over the next few decades and for near zero net anthropogenic emissions by the end of the century, more concrete GHG emission reduction assessments were given for 2050 and some estimates only for the CO_2 emissions for 2030. The apparently most essential statement on the mid-century global emissions was as follows: "Emissions scenarios leading to GHG concentrations in 2100 of about 450 ppm CO_2eq or lower are likely to maintain warming below 2° C over the 21st century relative to pre-industrial levels. These scenarios are characterized by 40% to 70% global anthropogenic GHG emissions reductions by 2050 compared to 2010." For the same warming threshold (actually, for the relevant range of long-term CO_2eq concentration scenarios, i.e., for 430–530 ppm CO_2eq), regional emissions peak years were derived by means of different models, and CO_2 emission reductions in 2030 over the 2010 levels were also presented in the report (*IPCC*, 2013–2014). According to these calculations, *the peak years for all the regions were set between 2010 and 2020 in order to be in line with the above-mentioned scenarios; therefore, the global emissions ought not to grow after the end of the present decade*. But what might be much more informative for the negotiators, those were the assessments of the transient mitigation efforts by the regions (which lead to those 430–530 ppm CO_2eq scenarios in 2100): "The contribution of different regions to mitigation is directly related to the formulation of international climate policies. In idealized implementation scenarios, which assume a uniform global carbon price, the extent of mitigation in each region depends most heavily on relative baseline emissions, regional mitigation potentials, and terms of trade effects. (..) In general, emissions peak in the OECD-1990 sooner than in other countries with higher baseline growth. Similarly, emissions are reduced in the OECD-1990 countries by 2030 relative to today, but they may increase in other regions, particularly the fast-growing Asian and MAF regions." The concrete quantitative estimates (for the 430–530 ppm CO_2eq scenarios) suggest *the average 32% regional CO_2 emission reductions in 2030 below the 2010 emission levels for the group of the ICs* (the OECD members in 1990 and the EiTs), 35% reduction in average for the Latin-American region, and show a range of emissions control rates around zero (i.e., stabilization) for the Asian region and the MAF (Middle East and Africa). The above assessments offered important orientation values for the ongoing negotiations. The overall scale of these most recent emission-related figures for the 2° C criterion seems to be even more demanding than the ones from the previous assessments, in particular for the industrialized countries as a whole. By using the same scenarios from the IPCC database, the UNEP report (*UNEP*, 2014) offered even more relevant information for the gap assessments, namely the *global GHG emission levels in 2030* "for a likely chance of staying within the 2 °C limit" following a least-cost pathway from 2020 which are: 42 $GtCO_2$eq (range: 31–44), or *+14% relative to 1990 emissions and –14% relative to 2010 emissions*. The use of 1990 default reference year and emissions level is essential not only for comparability purposes (with former assessments and commitments), but also for realizing the very significant actual changes, which clearly demonstrate the inadequacy of the existing policy responses since the early 1990s. Before turning to the most recent "offers", let us compare these theoretically critical thresholds with the actual data: *global emissions have grown since 1990 by more than 45%* and were approximately 54 $GtCO_2$eq in 2012 (*UNEP*, 2014).

International climate policy cooperation beyond 2020. Now the basic question is that, how and to what extent these new science-based assessments were taken into account in the course of preparation and finalization of the new agreement adopted in 2015 for the post-2020 period. The too general, unquantified emissions control "roadmap" and the requirements of the Paris Agreement for all the Parties to communicate later their concrete emission-related contributions were already mentioned above and obviously, these provisions are not applicable at these stage for any science-policy gap assessment. The "recommended" global emissions reduction pathways presented by the IPCC or the UNEP would be valuable for top-down distribution approaches (based on the common but differentiated responsibilities), but as a matter of fact, the negotiations were again centered around a bottom-up process (likewise the KP and the DA). As a matter of fact, the majority of the countries (or country groups in the case of the EU) individually formulated and communicated their possible emissions control targets beyond 2020 in the framework of the "intended nationally determined contributions" (INDC). Obviously, the consideration of the aggregated global levels of these (unconditional and conditional) quantified national targets for 2030 or 2050 is especially important in light of the "reasons for concern" depicted by the IPCC in its latest report. The synthesis of these intended contributions submitted by October 2015 represented three quarters of Parties to the Convention and 86 percent of global emissions in 2010, and the aggregate effect for 2030 would be 56.7 (53.1 to 58.6) $GtCO_2eq$ in 2030 (*UNFCCC*, 2015). In relative terms, these estimates would mean 11–22% increase of the aggregated emissions in 2030 in relation to the 2010 level, or *37–52% increase in relation to the global emission level in 1990*. A rather similar assessment is derived in the Emission Gap Report (*UNEP*, 2015), namely, 54 $GtCO_2eq$ (range: 52–57) for 2030, which corresponds to *46% (range 40–54) relative increase compared to the 1990 level*. These clearly indicate a huge deviation from those targets which were considered necessary theoretically, and it means a further significant increase in the science-policy gap in tackling this hazardous global environmental process.

4.2. Some basic factors behind the difficulties with the climate change policy regime

There are several factors which may explain the complications with the international climate change policy-making. Their nature and significance can be better understood in a comparison with the acidification and ozone depletion cases. Four distinctive problematic areas are mentioned below; however, there are obviously other more or less critical ones, which should be taken into consideration to make the international policy regime more responsive to the climate change challenge.

The operation of the global climate system governed by internal and external, natural and anthropogenic factors seems to be much more complex than the mechanisms of the acidification and ozone layer depletion processes. As a consequence, the detection of the present climate change signal and its attribution to different drivers (forcing factors) is rather problematic because of the relatively low *climate change signal-to-noise ratio* (where the "noise" is the climatic variability in this context) and because of the diverse interactions and characteristic timescales of natural and human-induced contributions to the GHG cycles and to the impacts of the changing climatic conditions. The problem of signal-to-noise ratio also appears in the climate modelling (*IPCC*, 2001); moreover, it necessitates careful approach to climate impact assessments and adaptation strategies as the impacts of the short-term and long-term processes overlap (*Czelnai*, 1980). The complexity of the system, in particular, the problems related to the detection of the global climate change signal are clearly manifested in a more prolonged and slower decrease of the *scientific uncertainty level* concerning the anthropogenic influences on the climate system and in turn, a longer time length between the improved degree of scientific knowledge and the agreements on the related international policy frameworks. That timespan was about one decade in case of the acidification and ozone depletion problems, but it took several decades for the climate change issue (with regard to the time periods between the confirmation of the adequate attribution hypotheses and the adoption of the first multilateral legal instruments).

The substantial historical differences in responsibilities of various countries and country groups for the emerging climate change hazard have been a crucial factor together with their *differing vulnerabilities, capabilities, socio-economic problems, and interests*, in influencing the international negotiations. The recognition of the mutual interdependence was the most important motivation ("push factor") to seek common ways and means for the solution of the three environmental problems discussed in this paper, but the above mentioned differences mattered much more seriously to the global climate policy-making case compared to the other two atmospheric problems.

All key economic sectors somehow have their part in the climate change problem as GHG emitters and/or bearers of the impacts: energy sector, transport, various industrial activities (e.g., metallurgy, cement production), agriculture, forestry, healthcare, water management, nature conservation, etc. This means that for all these sectors and socio-economic activities efficient mitigation and/or adaptation policies should be developed at all levels. Therefore, it necessitates *economy-wide* national measures, while many of these policy areas have essential international dimensions in our globalized world. Sectoral policy-making is especially challenging for those areas that are characterized by substantial *inertia*, which is typical of fossil fuel based energy and transport systems (also because of the so-called "lock-in" effects); to some extent, such inertia characterizes certain agricultural and industrial activities, as well. This situation was somewhat simpler for the other two environmental problems, especially in case of the ozone layer policy regime.

Technologies. At last, availability and effectiveness of the *abatement and control technologies* should be noted. For the acidification problem, relatively cost-effective emission source-oriented and end-of-pipe "technological fixes" could be shortly developed, such as the desulfurization of coal, crude oil or natural gas before their further utilization, the flue gas desulfurization technologies (which provide gypsum, a widely used material), or more generally, the industrial scrubbers for the AAPs, moreover, the catalytic converters for vehicles to reduce nitrogen emissions. The phase-out of the ODS and their replacement with "ozone-friendly" substitutes have become appropriate to cope with the ozone layer depletion hazard, which were accompanied by the disposal of the ODS from their surplus stocks or those recollected from various appliances. With the GHGs, in general, the situation is much more difficult, since there are no such relatively simple, cost-effective, widely applicable technological solutions. Some of the remarkable barriers to the existing carbon neutralizing technologies (including the so-called "negative emissions technologies", i.e., different land use, forestry related sequestration methods, or the rather controversial carbon capture and storage options) are referred to by *UNEP* (2014). Therefore, the gradual but comprehensive and environmentally sound *decarbonisation of the entire economic systems* based on sustainable production and consumption patterns, and parallel preparations for the already seemingly unavoidable changes can only be considered as the adequate strategy for tackling this global environmental problem.

5. Conclusions

The knowledge development and the initial steps in the international policy regime building in relation to the global climate change problem have been analyzed, as these proceeded parallel to the somewhat analogous processes for acidification and ozone layer depletion by the late 1970s. This synergy during the "inception phase" had some role not only in facilitating the enhancement of the global environmental observing systems and the international scientific cooperation, but also indirectly in conducting the relevant detection and attribution studies. With the rapid research progress on acidification and ozone layer depletion, the corresponding multilateral policy mechanisms were not only established and gradually strengthened within a relatively short time period, but some of their important features and building blocks served also as precedents or prototypes for the climate change policy architecture. But the climate change issue proved to be a much more complex problem, so the proper international policy responses could not be formulated so smoothly as it occurred for the other two large-scale atmospheric issues and their anthropogenic drivers. This kind of increasing asymmetry was also evaluated in this paper throughout the "international policy setup phase" by about the turn of the

20th century and the subsequent "divergent phase" for these environmental problems.

Some of the important factors behind this lagging of the climate change response policies were also mentioned, and none of them can be easily overcome. Yet, all those should be tackled adequately. The reason for this is clearly stated by the recent IPCC report (*IPCC*, 2013–2014): "Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread, and irreversible impacts globally (high confidence)." The directions of the further scientific research tasks are outlined by the IPCC and the World Climate Programme (i.e., its research component, WCRP); furthermore, an integrated concept is foreseen by the "Future Earth" programme, which is the ICSU initiative devoted to all key environment-related processes, their interactions, and possible future effects, including those associated with the climate change process. Concerning the science-based complex climate policy-making challenges, references were already made to the need of an economy-wide approach; however, it should be re-emphasized that the climate policy-making problem is not a self-contained one, but inherently linked to a large range of other challenges (e.g., addressing the unsustainable resource use and land management, increasing waste streams, loss of biodiversity). Anyway, in light of the already solid scientific achievements and the possibility of the abrupt and irreversible changes, accurate policy responses are necessary amid remaining uncertainties, as it was so formulated by Stephen H. Schneider, to whom the Synthesis Report of the latest IPCC assessment report was dedicated (*IPCC*, 2013–2014): "Policymakers struggle with the need to make decisions that have far-reaching and often irreversible effects on both environment and society with sparse and imprecise information. (..) Strictly speaking, a surprise is an unanticipated outcome; by definition it is an unexpected event. Potential climate change and, more broadly, global environmental change are replete with this kind of surprise because of the enormous complexities of the processes and relationships involved (such as coupled ocean, atmosphere, and terrestrial systems) and our insufficient understanding of them. (..) as the rate of change of CO_2 concentrations is one imaginable condition for surprise, the system would be less rapidly forced if decision makers chose to slow down the rate at which human activities modify the atmosphere. This would lower the likelihood of surprises." (*Schneider* and *Kuntz-Duriseti*, 2002). These ideas are even more valid in view of the latest observations and assessments. In principle, such an approach was reflected in the recently adopted new global deal, the Paris Agreement that stressed the need for an effective and progressive response to the urgent threat of climate change by reaching global peaking of greenhouse gas emissions as soon as possible and undertaking rapid reductions thereafter in accordance with best available science. But the setting of the relevant and concrete policy targets was postponed and consequently, as it was demonstrated in this paper, there is still a rapidly increasing science-policy gap in tackling this hazardous global problem.

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