Nuclear Power and Climate Change

A. Introduction

Global climate change has dominated the international environmental and energy agendas over the past two decades. Increasing scientific evidence indicates that anthropogenic emissions of greenhouse gases (GHGs), especially CO_2 emissions from burning fossil fuels in the energy sector, lead to changes in the atmosphere that alter the earth's climate. The impacts of climate change above the threshold value of a 2°C increase in the global mean annual temperature above the pre-industrial level are widely believed to be largely negative in key sectors such as ecosystems, agriculture, water supply and human health in most regions of the world. The double challenge for the world society will be to increase energy supply to support the socio-economic development of an increasing global population and to mitigate GHG emissions. This document presents the results of the most recent scientific assessment of climate change, the status of international negotiations to manage climate change, the potential contribution of nuclear energy to resolving the energy-climate challenge, and summarizes the main conclusions.

B. Climate Change Science

The *Fifth Assessment Report* (AR5) of the Intergovernmental Panel on Climate Change (IPCC) adopted a new approach to project anthropogenic climate change for the next few centuries. Abandoning the traditional pathway tracking changes from GHG emissions through atmospheric concentrations and radiative forcing[1] to climate attributes like temperature and precipitation, the new projections are based on alternative assumptions about radiative forcing values for the year 2100.

These new scenarios include four so-called representative concentration pathways (RCPs) for exploring the near and long term climate change implications of different pathways of anthropogenic emissions of all GHGs, aerosols and other climate drivers. The four RCPs depict approximate total radiative forcing values for the year 2100 relative to 1750 in the range 2.6–8.5 W/m2. RCP2.6 assumes strong GHG mitigation actions. Radiative forcing along this pathway peaks and declines during the 21st century, and leads to a low forcing level of 2.6 W/m2 by 2100. For RCP4.5 radiative forcing stabilizes by 2100. In contrast, the two high concentration pathways (RCP6.0 and RCP8.5) entail continued increase of radiative forcing beyond 2100. The RCPs served as inputs to more than 30 climate models participating in the Coupled Model Intercomparison Project Phase 5 (CMIP5) to assess the changes they trigger in the climate system globally and regionally [1].

Relative to the 1850–1900 period, the increase in global surface temperature is likely to exceed 1.5°C by the end of this century for all but the RCP2.6 scenario. Relative to the IPCC AR5 reference period (1986-2005), global surface temperature is expected to rise between 0.3°C and 1.7°C (RCP2.6) at the

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[1] Radiative forcing is the change in energy flux caused by drivers (natural and anthropogenic substances and processes that alter the Earth's energy budget). It is quantified in watts per square metre (W/m^2), and it is calculated at the tropopause or at the top of the atmosphere.

low end, and between 2.6°C and 4.8°C (RCP8.5) at the high end of the scenario spectrum. The low end of the range is associated with limiting the global mean temperature increase to less than 2°C.

Figure B-1 shows the baseline (without climate policy) and the RCP2.6 mitigation pathways for all GHGs included in the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) and for energy and industry related CO_2 emissions alone. The chart indicates an enormous mitigation challenge: total GHG emissions will need to start decreasing at a fast rate in less than a decade while energy and industry related CO_2 emissions will need to become negative beyond 2070. The latter will require a fast decarbonization of the energy system by adding carbon capture and storage (CCS) to a large fraction of fossil fuel and bioenergy use and drastically increasing the contribution of nuclear energy and other low-carbon sources to the global energy mix.

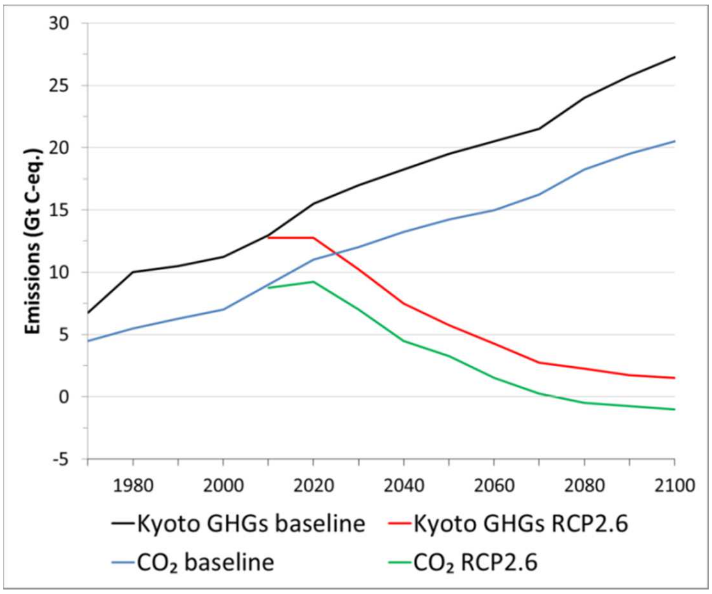

FIG. B-1. Baseline and RCP2.6 emissions paths of all GHGs included in the Kyoto Protocol and of energy and industry related CO_2. Data source: Ref. [2].

C. Global Climate Policy

The first step by the international community to address the climate change challenge was the UNFCCC, which was adopted at the Earth Summit in 1992 and entered into force in 1994. Article 2 specified its ultimate objective: “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”. The third session of the Conference of the Parties (COP 3) adopted the Kyoto Protocol to the UNFCCC in 1997, in which industrialized countries (listed in Annex I of the Convention[2]) made commitments to reduce their collective GHG emissions during the period 2008–2012 by at least 5.2% below 1990 levels. Since the United States of America (USA) has not ratified the Kyoto Protocol, the actual reduction is

[2] Annex I includes the member countries of the Organisation for Economic Co-operation and Development (drawing from the 1990 membership) as well as Belarus, Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, the Russian Federation, Slovakia, Slovenia and Ukraine.

expected to be only about 3.8% of the 1990 Annex I emissions. This reduction is far outweighed by increases of emissions in non–Annex I countries in the same period.

UNFCCC negotiations on the next steps started in 2005, but failed to produce an agreement on "long-term cooperative action" about mitigation, adaptation, finance and other issues by the 2009 deadline. COP 15 merely "took note" of the Copenhagen Accord that recognized "the scientific view that the increase in global temperature should be below 2 degrees Celsius" and provided a framework for voluntary GHG emissions reductions by 2020 but involved no firm commitments [3]. In 2011, COP 17 established the formal legal amendment for a second commitment period under the Kyoto Protocol (without which the world would not have an international agreement after 31 December 2012 limiting GHG emissions) and launched the Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP) with a mandate "to develop a protocol, another legal instrument or an agreed outcome with legal force under the Convention applicable to all Parties" for adoption in 2015 and to enter into force in 2020.

Progress towards the new agreement has been very slow over the two years after COP 17. The ADP mandate involves a fundamental change from differentiating developed (Annex I) and developing countries (non-Annex I) concerning their legally binding mitigation commitments under the Kyoto Protocol by calling for an agreement applicable to all Parties. COP 19 in 2013 demonstrated large gaps between the positions of developed and developing countries about the preferred legal character of the agreement and about the differentiation of obligations. The COP 19 decision on ADP invited all Parties "to initiate or intensify domestic preparations for their intended nationally determined contributions … towards achieving the objective of the Convention as set out in its Article 2 and to communicate them well in advance of the twenty-first session of the Conference of the Parties (by the first quarter of 2015 by those Parties ready to do so) in a manner that facilitates the clarity, transparency and understanding of the intended contributions, without prejudice to the legal nature of the contributions" [4].

As of early 2014, the ADP negotiations have been far from the level of detail at which Parties could consider approaches and mechanisms for implementing the new agreement. However, future outcomes of the discussions about frameworks for various approaches (new market, other market and non-market-based mechanisms) and the related accounting rules may affect the choice of technologies under the post-2015 agreement. The applicability of the Bonn Agreement and the Marrakesh Accords — which practically excluded nuclear energy from two international flexibility mechanisms (the clean development mechanism and joint implementation) of the Kyoto Protocol — in implementing the new agreement remains uncertain at this point.

D. Nuclear Energy in Climate Change Mitigation

If the new global mitigation agreement embarks on sweeping GHG reduction pathways calculated by the scientific community, the importance of energy technologies emitting small amounts of GHGs per unit of energy service provided will increase. Because of this heightened importance, emissions need to be accurately identified and assessed. The appropriate method to quantify the total GHG emissions is life cycle analysis (LCA), accounting for all GHG emissions from the infrastructure (from construction to decommissioning of power plants and all equipment) and the associated fuel cycle (from mining to final waste disposal).

LCA is defined as the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a production system throughout its entire life cycle. The LCA of an electricity production system reflects its high complexity, encompassing many processes within its chosen system boundary that contribute to the final product. Because of its importance in the decision making process and the possible consequences of errors, consistency and credibility are of the utmost importance in LCA. Aiming to enhance quality, but without prescribing specific methodologies, relevant ISO standards were introduced and currently present the norm for developing LCA studies, including GHG emissions of different electricity generation technologies.

Estimates of life cycle GHG emissions from electricity generation fuelled by lignite and hard coal vary in a wide range between 1000 and 1800 g CO_2-eq. per kW h around a median value of 1300 g CO_2-eq. per kW h for lignite and 1150 g CO_2-eq. per kW h for hard coal. Conventional gas fired power plants and modern combined cycle gas turbines emit considerably less GHGs: about 700 g CO_2-eq. per kW h and 400 g CO_2-eq. per kW h, respectively. Adding carbon dioxide CCS to fossil fired power plants, life cycle emissions would still remain high at about 200 g CO_2-eq. per kW h for coal and about 150 g CO_2-eq. per kW h for gas.

Figure D-1 presents GHG emissions for renewable energy sources and nuclear power. The median value of emissions from nuclear power (light water reactors) is estimated at 14.9 g CO_2-eq. per kW h, with a range of 13.5–19.8 g CO_2-eq. per kW h of generated electricity. The entire life cycle from uranium mining to waste disposal is taken into account in the underlying calculation. There are some regional variations around the global averages. The Japanese Central Research Institute of the Electric Power Industry (CRIEPI) calculated 19.5 g CO_2-eq. per kW h for pressurized water reactors and 20.2 g CO_2-eq. per kW h for boiling water reactors. Based on more precise studies, British, Swedish and Swiss nuclear power LCA studies have calculated considerably lower emissions, 4–6 g CO_2-eq. per kW h.

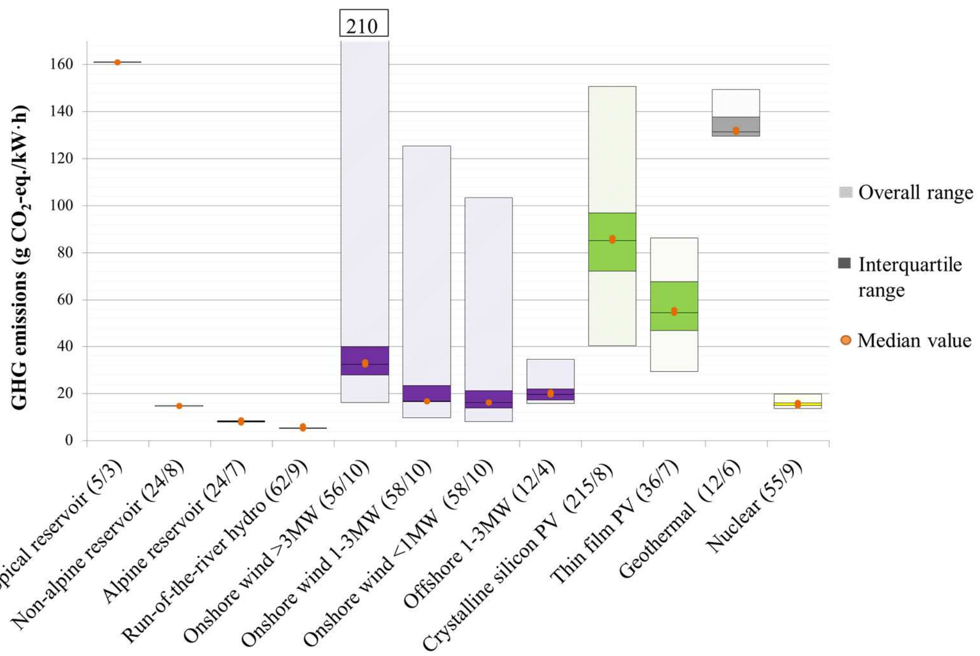

FIG. D-1. Life cycle GHG emissions from electricity generation: renewable technologies and nuclear power. The numbers in parenthesis indicate the number of LCA calculations and the number of global regions in which those locations can be found. The interquartile range includes half of the calculations around the median of the whole range. (Source: Ecoinvent [5])

Median values for solar photovoltaic (PV), compared to nuclear power, range between 4 times (54.5 g CO_2-eq. per kW h for thin film) and 6 times higher (85.2 g CO_2-eq. per kW h for crystalline silicon). Wind power GHG emissions are comparable with those from nuclear power up to the class of 3 MW(e) wind turbines (Fig. D-1). Above that, life cycle GHG emissions practically double, reflecting the higher use of energy and materials per unit of capacity for the construction of turbines with a capacity larger than 3 MW(e). Hydropower from alpine and non-alpine reservoirs, as well as run-of-river systems, also has comparable life cycle GHG emissions to nuclear power. Pumped storage systems show a very wide range (40.3–2004.6 g CO_2-eq. per kW h), depending on the carbon intensity of the electricity used to power the pumps that drive the water back to the reservoir for storage.

Life cycle GHG emissions from nuclear energy may well decrease in the future due to further improvements in: (a) uranium enrichment technologies, shifting from electricity intensive gaseous diffusion to centrifuge or laser technologies that require much less electricity; (b) the increased share of electricity used for enrichment based on low carbon technologies; (c) improvements in fuel manufacturing, such as higher burnup, which reduces emissions per kilowatt hour associated with the fuel cycle; and (d) extended nuclear power plant lifetime from 40 to 60 years reducing emissions per kW h associated with construction and decommissioning.

The very low CO_2 and GHG emissions on a life cycle basis make nuclear power an important technology option in climate change mitigation strategies for many countries. The figures demonstrate that nuclear power, together with hydropower and wind based electricity, remains one of the lowest emitters of GHGs in terms of g CO_2-eq. per unit of electricity generated. But what would be the share of nuclear energy in a mitigation portfolio based on its economic performance relative to other low-carbon technologies?

The International Energy Agency (IEA) of the Organisation for Economic Co-operation and Development (OECD) publishes a detailed energy technology assessment for the world every two years. *Energy Technology Perspectives 2012* (ETP2012) presents an in-depth survey of energy technologies and prospects for their evolution up to 2050. The report presents a reference case called the 6°C Scenario (6DS) in which current policies and trends are extended into the future. Two policy scenarios — the 4°C Scenario (4DS) and the 2°C Scenario (2DS), reflecting the policy targets of limiting global mean temperature increase to 4°C and 2°C, respectively — are evaluated, with an emphasis on the 2DS. The 2DS is consistent with the Copenhagen Accord of the UNFCCC. The 2DS stipulates an ambitious pathway along which global energy related CO_2 emissions peak before 2020 and decline to almost 50% of the 2009 level — that is, to around 17 Gt CO_2 — by 2050 [6].

According to the 2DS, the electricity sector will be substantially decarbonized by 2050. The contribution of various electricity generation technologies to this extraordinary development is presented in Fig. D-2. End use efficiency improvements, CCS and electricity production from nuclear represent the largest shares of the low cost mitigation opportunities within the power sector. CCS accounts for 3.3 Gt CO_2/year (18%) and nuclear about 3.2 Gt CO_2/year (17%) of the power sector's CO_2 reductions.

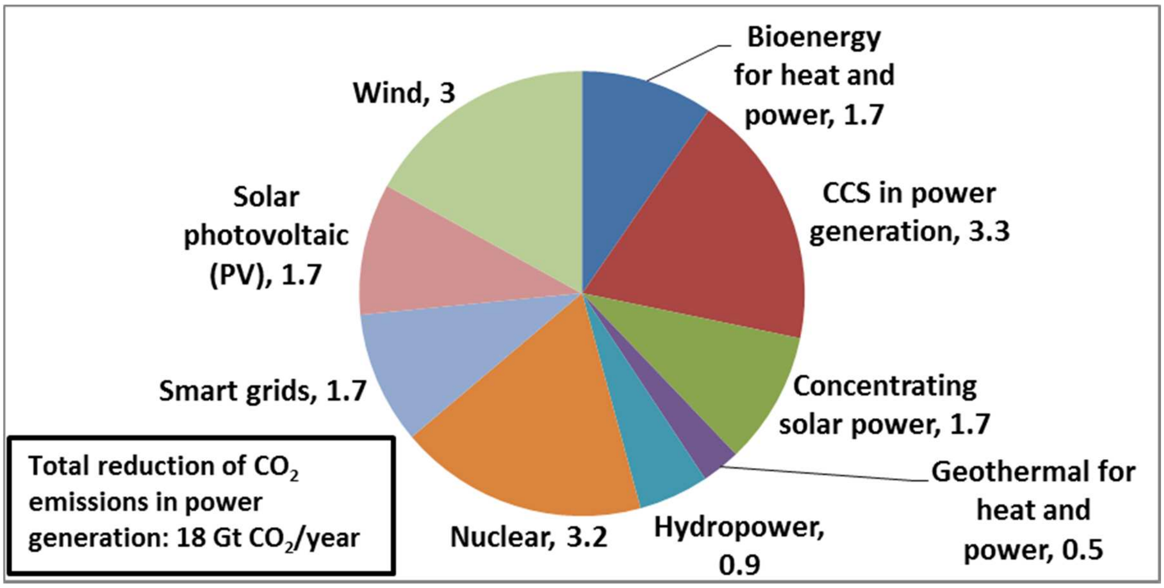

FIG. D-2. The contribution of mitigation options to CO_2 emissions reduction in the power sector in 2050. (Source: IEA [6])

The driving force behind CO_2 mitigation in the electricity sector is renewables, which is projected to grow to a 57% share of generation in 2050 in the 2DS. Nuclear energy is also a significant contributor to generation in the electricity sector in the 2DS with a 19% share by 2050, and CCS is close behind at 14%. ETP2012 also presents a high nuclear case combined with a 2DS, and in this scenario, nuclear reaches a 34% share by 2050, largely by crowding out some renewables and coal with CCS. According to ETP2012, this high nuclear scenario “reflects a world with larger public acceptance of nuclear power” and assumes average construction rates of almost double the 27 GW/year of the 2DS: 50 GW/year. This variant also assumes a larger nuclear fuel supply through recycling spent fuel and/or unconventional uranium sources.

E. Conclusions

Recent scientific evidence confirms that unconstrained emissions of GHGs from human activities would lead to considerable changes in the climate system of the earth with distressing impacts on ecological and socioeconomic systems. Global energy demand will keep increasing. However, in order to keep the increase in global mean temperature below 2°C relative to pre-industrial levels, GHG emissions should stop increasing within the next decade or so and then should fall substantially below the 2000 emission levels by the middle of the century. International negotiations to achieve the required emissions reductions have achieved modest results so far. Accomplishing the ADP mandate under the UNFCCC to establish a legally binding global agreement for reducing GHG emissions beyond 2020 is a fundamental element of international environmental policy.

Nuclear power belongs to the set of energy sources and technologies available today that could help meet the climate–energy challenge. GHG emissions from nuclear power plants are negligible and nuclear power, together with hydropower and wind based electricity, is among the lowest CO_2 emitters when emissions through the entire life cycle are considered. In a cost-minimizing mitigation portfolio, nuclear energy could account for about 17% of the total CO_2 emissions reduction in power generation in 2050. If the use of any low-carbon technology were restricted or if it were excluded from the mitigation mix, the costs would increase and the environmental effectiveness of mitigation policies would be reduced. Therefore, cost efficiency, environmental effectiveness and timely reduction measures are important factors to consider in the 2015 UNFCCC agreement on mitigation commitments and implementation mechanisms.

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