Climate Change and Nuclear Energy

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1. Climate change and greenhouse gas (GHG) emissions [1]

The Intergovernmental Panel on Climate Change (IPCC) confirmed in its assessment report [1] that the climate system has been warming due to human activities and that rate of warming has been accelerating over the past three decades. The global surface temperature relative to the pre-industrial level which has increased 0.85°C so far was projected to increase 4.3°C by 2100. IPCC made ominous projections that, without proactive and effective mitigation efforts, climate change would lead to severe, wide, irreversible and therefore unadaptable shocks on nature and human in the next century.

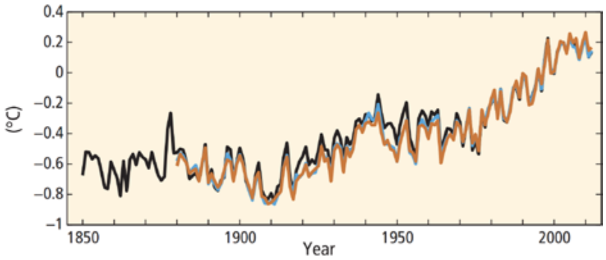

Fig. 1 Globally averaged surface temperature relative to the average over 1986-2005 [1]

IPCC pointed out that anthropogenic GHG emissions such as CO_2, CH_4 and N_2O are the main cause of global warming. Despite gradual adoption of climate change mitigation policies in many countries, the total annual GHG emissions are still increasing. IPCC estimated that anthropogenic GHG emissions should be reduced to 30~60% of 2010 levels by 2050 to maintain global warming below 2°C above pre-industrial temperatures (2°C scenario).

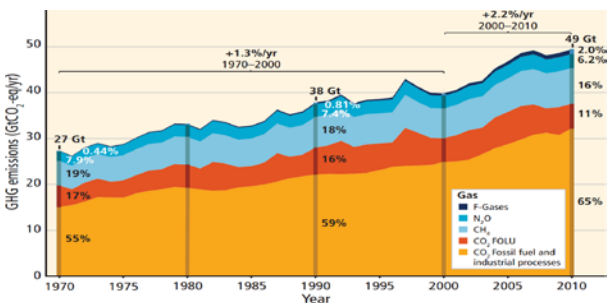

Fig. 2 Total annual anthropogenic GHG emissions [1]

2. The Paris Agreement

The United Nations Framework Convention on Climate Change (UNFCCC) organized its annual Conferences of the Parties in Paris in December 2015 (COP21) and adopted the 2015 Paris Agreement by consensus to strengthen the global response to the threat of climate change.

Each individual member country of UNFCCC was required to pledge the Intended Nationally Determined Contribution (INDC) during COP21, which became the nationally determined contribution (NDC) that a country should make to reducing GHG emissions, when the country ratified it. The actual contribution each member has made should be reported every five years and the new NDC for the next five years should be submitted. The new NDC should be more ambitious than the previous one (the principle of progression).

The International Energy Agency (IEA) evaluated the pledges of more than 190 countries presented to the Paris Agreement and concluded that such pledges would be far from being sufficient to meet the 2°C target on global warming. It was predicted that the CO_2 emissions would not decrease but rather increase at the reduced rate, even though all the pledges were assumed to be successfully implemented. [2]

(Korea submitted its INDC to the UNFCCC secretariat, targeting to reduce its GHG emissions by 37% by 2030 from the baseline scenario where additional mitigation action is not implemented. (BAU scenario, 850.6 $MtCO_2$-eq). 11.3 % of the pledged will be obtained from international carbon markets.)

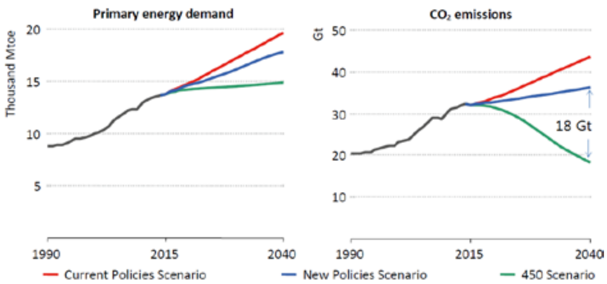

Fig. 3 Primary energy demand and CO_2 emissions [2]

3. GHG reduction scenario in energy sector [3]

Energy-related CO_2 emissions mostly caused by the combustion of fossil fuels are the majority of about 70% of anthropogenic and account for 32 Gt each year, 44% of which comes from coal consumption, and 35% and 20% come from oil and gas, respectively. Therefore, policies to reduce fossil fuel consumption are most efficient among policies for responding climate change. Strategic approaches to reduce the demand of energy, to improve efficiencies in energy production and use and to expand the low-carbon technologies in energy production are the key elements of these policies.

The International Energy Agency (IEA) laid out an energy system deployment pathway and an emissions trajectory consistent with the 2°C scenario [4]. The energy-related CO_2 emissions should be reduced to 15 Gt by 2050. This amount is equivalent to 47% of current emissions of 32 Gt and only 27% of the amount of 55 Gt of the BAU scenario.

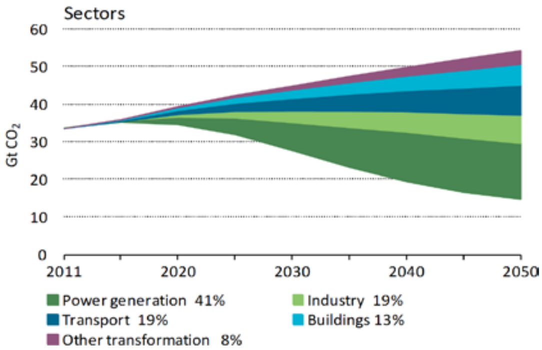

Fig. 4 Emissions trajectories in the energy sector [4]

To achieve this ambitious goal, IEA has developed a series of global low-carbon energy technology roadmaps covering the 21 most important technologies. As one of such roadmaps, the IEA/NEA nuclear roadmap was published in 2010 based on a hopeful scenario with 24% of nuclear share in world electricity in 2050. [5] This roadmap was updated in 2015 with a toned-down scenario of a 17% share by taking into account a number of unfavourable factors since 2010 such as the Fukushima Daiichi accident, the global financial and economic crisis, the shale gas boom, and the failure to set up functioning carbon markets. [6]

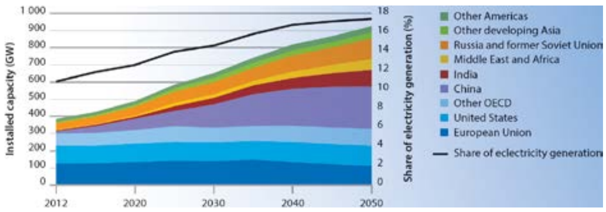

Fig. 5 Projected nuclear capacity with regional split [6]

4. Nuclear contribution to GHG reduction scenario [3]

Thanks to existing low-carbon technologies such as nuclear, hydro and renewables including wind and solar photovoltaics (PV), electricity is the sector where almost full decarbonization is possible. In fact, a virtual decarbonization of the electricity sector by 2050 is one of key underlying assumptions in the aforementioned IEA 2°C scenario. However, fossil fuels are still generating 63% of the world electricity in 2013 (41% by coal and 22% by natural gas) and emitting slightly less than 30% of total anthropogenic GHG emissions.

The largest low-carbon source of electricity is hydro with a 16% share of world electricity production. However, it is less likely that hydro will be a significant contributor to carbon emission reduction in coming decades because of limited resources and other environmental issues involved in hydro.

Renewables have dramatically increased their share in electricity generation with much hope in combating climate change and contributed 6% to global electricity supply in 2013. However, renewables cause difficult problems in matching supply with demand because of intermittency and variability in their daily and yearly availability. The necessity of residual generation systems to ensure reliability of supply increases costs at the system level. [7] Site issues such as large tracts of required land and rarity of the best meteorological sites are also barriers for their large scale deployment.

Another alternative is the carbon capture and storage (CCS). The CCS is a key assumption of the IEA 2°C scenario, contributing similarly to the nuclear contribution to reducing carbon emissions in the electricity sector only, but contributing twice more in the overall energy sector. Although much research has been made on it, its large-scale commercial deployment has been delayed and is still thought to be decades away from realization due to its performance, cost and social acceptance issues.

Nuclear is better than or at least comparable to renewables in terms of the lifecycle GHG emissions including direct and indirect emissions [8]. In addition, nuclear is cheaper than any other low-carbon sources in terms of levelized cost of electricity. [9] Thus, nuclear is the cheapest energy source to achieve the same emission reductions. IEA estimated that in 2012, nuclear producing 11% of global electricity supply avoided the CO_2 emissions of 1.7 Gt or 13% of total emissions in electricity sector, and that cumulatively since 1971, 56 Gt or 3 % of the world's cumulative post-industrial anthropogenic emissions has been avoided. [10]

According to the IEA 2°C scenario, a portfolio of low carbon technologies of electricity sector including nuclear, CCS, and renewables as well as electricity savings should altogether contribute to emissions reduction with their challenging shared goal in order to achieve a de facto decarbonization of the electricity sector by 2050. Nuclear energy plays a key role in the scenario by sharing a contribution of 15% to the cumulative CO2 emissions reduction relative over the period 2012-2050.

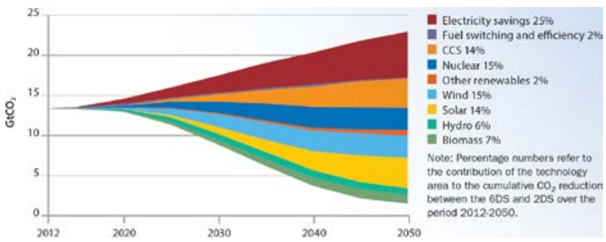

Fig. 6 Emissions trajectory in the power sector [11]

The new nuclear capacity is needed to be installed enough to contribute its share in emissions reduction. In the IEA/NEA nuclear roadmap, nuclear electricity generation is projected to increase its capacity from 390

GW in 2012 to 930 GW by 2050. (Fig. 5) China and India, rather than the other regions, will lead the majority of growth in nuclear capacity, although their current shares of the global nuclear electricity generation are small. The two countries will together contribute to approximately two thirds of the global capacity increase by 2050.

5. Benefits of nuclear cogeneration in GHG reduction

The IEA/NEA nuclear roadmap assumes that nuclear will contribute to only the electricity sector, as it has done so far. Noting that the 2°C scenario is not a prediction of what will happen in the future and consists of a tailored portfolio of low-carbon technologies with their barely achievable targets, the gap between the reality and the target is most likely to increases as time goes on. Nuclear may become necessary to bridge such a gap in the future by expanding its use to non-electricity sectors as well as increasing its share in electricity generation. Indeed, while CCS, for example, constituting the 2°C scenario with a significant proportion might not be commercially-available in decades, nuclear is a proven technology through its long history and a dispatchable technology to supply stable large-scale heat at any location and time.

By replacing fossil fuels, different types of nuclear reactors can supply heat only or heat and electricity over a wide range of temperature up to 1,000°C in all processes for district heating, sea water desalination, or production of petrochemicals, hydrogen, and synthetic fuels. Nuclear can provide steam and hydrogen in extracting and refining transportation fuel from large resources of heavy oils and bitumen in some countries, e.g., Canada. The feasibility of non-electric applications has already been demonstrated through decades of experiences with about 74 reactors around the world (about 17% of the world's fleet) providing either district heating, desalination or other forms of process heat.[12]

6. Nuclear contribution to pollution reduction [3]

Fossil fuel combustion also emits other pollutants such as particulate matter (PM) of various sizes, sulfur oxides, nitrogen oxides and volatile organic compounds, which cause severe impacts on agriculture and forestry as well as human life. The World Health Organization defined such air-borne pollutants as a serious threat to human health with high mortality of about 7 million deaths annually especially in developing countries such as China and India which use more coal with a high emission rate and have a relatively loose regulation on pollutants. [13] In particular, polluted smog of large cities caused by fossil fuel use in transportation and heating is a great stressful trouble for the government in choosing its policy options for economic growth.

Though a little air pollutants are released in its forehand fuel cycle, nuclear emits at least an order of magnitude less pollutants than fossil fuel energy sources. Therefore, replacing fossil fuels with nuclear in the energy sector results in the co-benefits of lower pollutants and CO_2 emission. Nuclear may also help China and India to abate their severe air pollution because the two countries are forecasted to have a majority of the world's new capacity in the future.

Table I Life cycle emissions in mg/kWh [14]

	Coal		Natural Gas		Bio-energy	Nuclear
	Hard coal	Lignite	Combined Cycle	Steam Turbine		
SO_2	530~7680	425~27250	1~324	0~5830	40~490	11~157
NO_X	540~4230	790~2130	100~1400	340~1020	290~820	9~240
PM	17~9,780	113~947	18~133	Insufficient data	29~79	0~7

7. Contribution to a 'well below 2°C' or a '1.5°C' emissions pathway [2]

The Paris Agreement stated that it aims to strengthen the global response to the threat of climate change by:

> "Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels."

In this statement, there are two targets to limit global temperature rise: 'well below 2°C' and '1.5°C'. Making its own definition of 'well below 2 °C' by shifting the probability of limiting the global temperature rise in 2100 to below 2°C from 50% to 66%, IEA provided an assessment of emissions reduction pathways for '2°C', 'well below 2°C' and '1.5°C' targets. For each of three temperature rise cases, one of the emissions trajectories which yield a required accumulated budget in the right side of Fig X is shown on the left side of the figure.

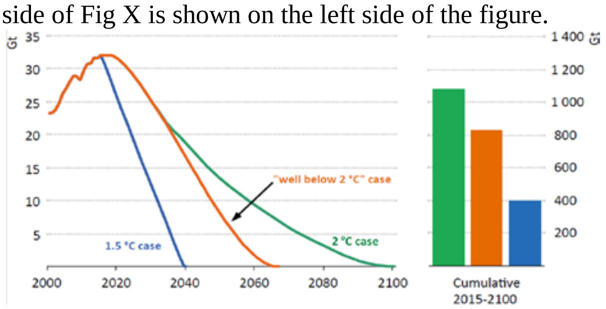

Fig. 7 Energy sector emissions budgets and trajectories [2]

The IEA pointed that it would be a formidable challenge to transform from the 2°C case to the 'well below 2 °C' case, although the difference in energy-related CO_2 emissions in 2040 is about 2 Gt between the two cases. According to their reasoning, this is because the sectors that can be easily decarbonized, for example, the electricity sector will have been already mostly decarbonized in 2040 and the required emission reductions must occur in the other challenging sectors. For the same reason, more non-electric energy demand needs to translate into electricity demand with, e.g., more electric vehicles assumed in more challenging scenarios. They estimated the additional electricity capacity would be 180 GW above the level in the 2°C case with 80% share of low carbon capacity.

Nuclear is a proven low carbon energy source instantly applicable to provide electricity and different types of industrial process heat. In the 2°C case, IEA estimated the heat demand for industry and building would be 5.3 Gtoe in 2040 and the resulting CO_2 emissions would be 7.3 Gt. Considering that 22% of the heat demand is assumed to be satisfied by renewables in the scenario, we also assume a nuclear share of about 20%. Then, this can result in the 2 Gt emissions reduction, which is the amount required additionally to move forward the 'well below 2 °C' case from the 2 °C case in 2040.

Limiting the temperature rise to 1.5 °C is much more challenging than the 'well below 2 °C' case. Energy sector net-emissions need to fall down to zero by around 2040. The electricity demand in 2040 would be doubled mainly due to fully electrified passenger and light-commercial vehicles. The entire energy sector would be almost decarbonized, but minimum CO_2 emissions, for example, from 10% of the electricity sector would not be able to be avoided. Natural gas, which is one third of the current level, and less than 40 mb/d of oil would still be consumed in the energy sector. Emissions that cannot be avoided need to be compensated by negative net-emissions caused by biomass use with CCS.

The IEA does not estimate how much CO_2 emissions should be reduced in what areas and in what ways to move to the 1.5°C target. Obviously, it is a hardly reachable goal even if we make all-round efforts. Rather than presenting quantitative figures, we can conclude that nuclear make a big contribution to the 1.5 °C target by filling gap that cannot be covered by all other efforts.

8. Conclusions [3]

It is a significant challenge to reduce CO_2 emissions drastically while supplying world energy demand to increase over decades due to economic growth especially in developing countries. Given limited hydro resources and delays in large-scale deployments of CCS, nuclear is an indispensable choice to reduce CO_2 emissions in the growing energy sector along with renewables. Considering that variability of renewables are often complemented by the carbon-emitting peak load plants that burn fossil fuels, nuclear needs to provide at least a robust and stable base load electricity in order to minimize CO_2 emissions in the electricity sector. In addition, a further contribution to the decarbonization of the energy sector beyond electricity can be made by the use of heat extracted from nuclear reactors for non-electricity applications.

Besides the difficulty in site selection, it takes a long time to build a new nuclear reactor with enormous upfront capital costs. In such an environment where the private sector is not likely to invest long-term funds to build new reactors, government support is essential to expand the nuclear role in the sustainable low-carbon energy system. In the design of future energy system, the similarities, differences and complementarities between nuclear and renewables should be understood and the value of nuclear as a dispatchable low-carbon technologies for the safe and reliable operation of the energy system should be recognized.

Supposed that the goal of the Paris Agreement to limit global warming to well below 2 °C is realized, nuclear is likely to become the most important future energy source which produces carbon-free heat and electricity. The Paris Agreement will provide a good opportunity to include nuclear in a flexible mechanism of the new climate regime which succeeds the Clean Development Mechanism (CDM) of the Kyoto Protocol. This allows full utilization of nuclear potential in reducing GHG emissions. To utilize nuclear as a powerful weapon in combating climate change, every effort must be made to draw a social consensus that nuclear is the most effective and safe means to reduce GHG emissions in the growing future electricity and non-electricity energy sectors. It is also important to understand the appropriate measures that a government can take to address social, institutional and financial issues related to expanding nuclear use in order to realize the Paris Agreement's goals.

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