Task Force 6
Accelerating SDGs: Exploring New Pathways to the 2030 Agenda

SMALL MODULAR REACTORS TO ACHIEVE SDG 7 AND NET ZERO EMISSIONS

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Abstract

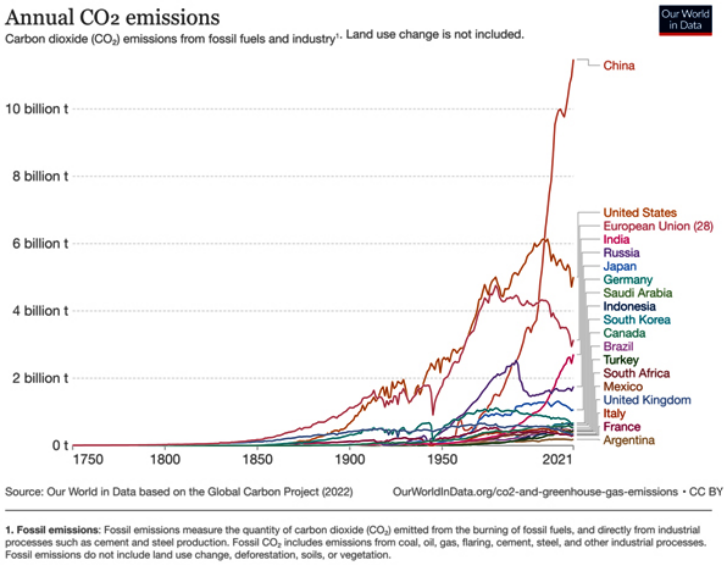
Decarbonisation of the electricity sector is critical to achieving global net zero, since the contribution of electricity to final energy consumption is expected to increase by 80–150 percent of the current level by 2050. The recent uptick in coal consumption in Europe despite the increase in solar and wind power indicates the criticality of firm low-carbon electricity resources for the deep decarbonisation of power generation along with grid stability and energy security. Rapid expansion of nuclear energy is critical since hydroelectric sources are limited by topography, besides social and environmental issues. Less nuclear power would make the journey to net zero more challenging and expensive. Several G20 countries are developing small modular reactors (SMRs) to supplement conventional nuclear power plants since SMRs can be installed in decommissioned thermal power plant sites by repurposing the site infrastructure. Leaders in SMR technologies must enable other G20 countries to accelerate SMR deployment at competitive costs.

The Challenge

1

The Intergovernmental Panel on Climate Change (IPCC 2023) has projected that global warming will exceed the 1.5°C-mark within this century if immediate actions are not taken to ensure deep greenhouse gas (GHG) emission reductions, starting this decade. The Sharm el-Sheikh Implementation Plan stresses "the importance of enhancing a clean energy mix, including low-emission and renewable energy, at all levels as part of diversifying energy mixes and systems, in line with national circumstances and recognizing the need for support towards just transitions" (UNFCCC 2023). However, the world is still dependent on fossil fuels for 82 percent of its energy supply (EI 2023). While the total electricity generated by solar and wind energy sources increased by 668 percent between 2010 and 2021, fossil-based power generation grew by 23.8 percent during the same period, while nuclear power (a major carbon-free source of electricity) stagnated (IEA 2022a). Thus, global CO_2 emissions from energy combustion and industrial processes reached an all-time high of 36.8 gigatonnes (Gt) in 2022, primarily due to an increase of 423 Mt in energy consumption (IEA 2023a). In 2021, the G20 members contributed 80 percent of CO_2 emissions from fossil fuel combustion and industries (Figure 1) (Ritchie et al. 2023).

Figure 1: Annual CO_2 Emissions of the G20 Members



Source: Ritchie et al. (2023)

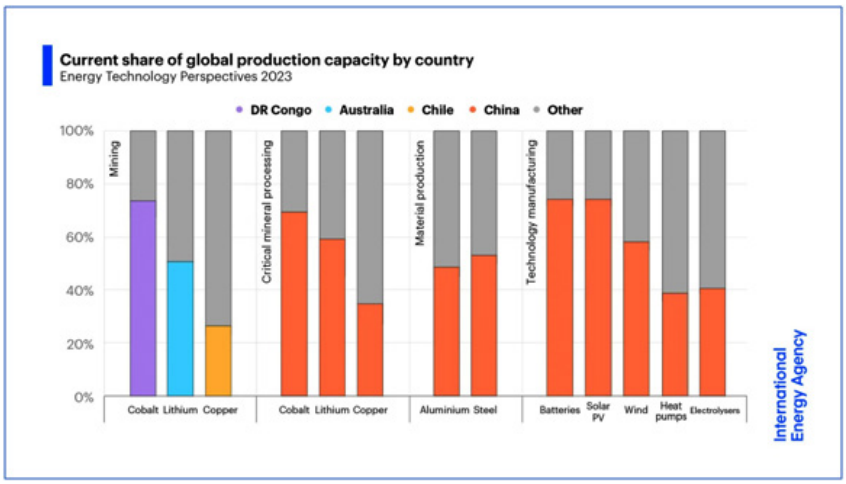
Battery-storage technologies and demand response are growing in capacity and capability and can play a substantial role in integrating variable renewable generators. While these options are effective in providing short-term flexibility and absorbing fluctuations on a per-minute or hourly basis, they are not suitable even for medium-energy storage. This is one of the key reasons for a wave of gas-to-coal switching in the European Union (EU) during the global energy crisis, which resulted in a year-on-year increase of 1.6 percent in CO_2 emissions from coal to an all-time high of 15.5 Gt in 2022 (IEA 2023a).

The International Energy Agency (IEA) defines energy security as the "uninterrupted availability of energy sources at an affordable price" (IEA 2023). While grid-scale battery storage can reduce the adverse impacts of intermittent Variable Renewable Energy (VRE) sources on the power grid for a few hours, Kim (2022) has sounded a note of caution on the affordability of energy from VRE sources. Specifically, the prices of wind turbines and solar photovoltaic (PV) modules increased by 9 percent and 16 percent, respectively, in 2021, compared to the prices in 2020. Further, the prices of batteries in 2022 have increased by 15–25 percent (depending on battery chemistry) over those in 2021 (IEA 2023b).

IEA (2023b) has also highlighted specific challenges related to critical minerals required for manufacturing batteries, including the long lead times and large capital investments for developing new mines and the need for enhanced compliance with environmental, social, and governance standards in mines and process plants located in certain geographies. Further, as shown in Figure 2, the top three producing nations control the entire global output of metals such as lithium, cobalt, copper, and aluminium, besides batteries and solar PV components. These materials are critical for integrating higher amounts of VRE sources.

Sustainable Development Goal (SDG) 7 "aims to ensure access to affordable, reliable, sustainable and modern energy for all." The achievement of SDG 7 is critical to the fulfilment of the 2030 Agenda for Sustainable Development and the Paris Agreement on climate change (UNEP 2021).

Figure 2: Share of Global Production Capacity of 'New Energy' Materials



Source: IEA (2023b)

Nuclear power plants (NPPs) generate 10 percent of the global electricity, helping avoid approximately 180 billion cubic metres of natural gas demand and 1.5 Gt of CO_2 emissions per year (IEA 2022b). Therefore, the rapid expansion of nuclear power is a reliable and efficient way to mitigate climate change and achieve multiple SDGs, since nuclear power can generate zero-carbon baseload electricity at affordable tariffs while providing myriad other benefits such as high-skill jobs in technology development, manufacturing, and operations, besides community development. Therefore, in IEA's Net Zero by 2050 scenario, nuclear power must be doubled from 413 GW in 2021 to 812 GW in 2050, with annual capacity additions reaching a record high of 27 GW per year in the 2030s (IEA 2022b).

NPPs use land very efficiently, and their grid integration costs are also much less than those associated with VRE sources, since they generate power in all kinds of weather and throughout the night. However, conventional NPPs have generally suffered from time and cost overruns, while some greenfield projects have faced challenges due to large capital requirements and adverse public opinion.

To avoid some of these disadvantages of NPPs, some G20 countries intend to construct Small Modular Reactors (SMRs) at retired coal-fired thermal power plant (TPP) sites (Walton and Morelova 2022). This also enables the countries to reap the benefits of reusing existing infrastructure like grid and water facilities without acquiring land beyond the existing site boundary. SMRs are designed with a smaller core damage frequency and source term compared to conventional NPPs and include enhanced seismic isolation. SMR designs are also simpler than those of conventional NPPs and include several passive safety features, resulting in lower potential for unsafe radioactive releases into the environment (Liou 2021). The amount of spent nuclear fuel stored in an SMR site will also be lesser than that in a conventional NPP using larger amounts of uranium fuel. Therefore, several studies have concluded that SMRs can be safely installed and operated in several TPP sites, which may not meet the stringent emergency planning zone requirements for conventional NPPs (Hansen et al. 2022).

Accelerating the deployment of SMRs under appropriate international safeguards by implementing a coal-to-nuclear transition at existing TPP sites will not only accelerate the attainment of net zero but will also ensure energy security, since uranium resources are widely dispersed, unlike reserves of lithium, cobalt, nickel, and rare earths, which are controlled by three countries (Grancea et al. 2023).

While the capacity of each module in an SMR cluster may be an order of magnitude smaller than a conventional NPP, the modular design of an SMR-based NPP ensures that each module can be operated independently of the other modules at the same site. The cost-effectiveness of SMRs depends on the deployment of multiple modules, with standard specifications suitable for serial manufacturing in factories before assembly at site. This is critical for cost reduction and time compression, since factory manufacturing minimises time and cost overruns that are endemic in conventional NPPs. SMRs leverage several factors to be more cost-effective than conventional NPPs. These include product design with standard features that can be installed in a variety of sites without the delays caused by modification; increased factory production and

reduced site construction work to reduce time overruns; experiential learning with serial manufacturing; and plant design simplification to facilitate efficient regulatory approvals (Stewart and Sirwan 2020). However, the accelerated deployment of SMRs faces the following key challenges, which can only be overcome through the joint and coordinated actions of the G20 leaders:

- Since SMRs are designed with inherent safety features, the Nuclear Regulatory Commission (NRC) in the US includes a provision for determining the size of the Emergency Planning Zone (EPZ) on a case-by-case basis for SMRs based on specific nuclear technologies and/or below a certain size (250 $MW_{thermal}$). On this basis, the US NRC agreed to limit the EPZ to the site boundary in the first SMR design to be approved by the NRC (Welter et al. 2023). However, other G20 countries have not approved any SMR designs or issued specific regulatory provisions for the approval of SMRs. Therefore, the installation of SMRs in countries other than their country of origin will be needlessly delayed while the nuclear regulator in each country completes its own review of the applications filed by SMR technology providers and project developers.

- The high capital investment for all NPPs, compounded by the high cost of capital in several developing countries, reduces the cost-competitiveness of carbon-free nuclear power compared to other baseload power generators unless the government provides suitable incentives in the form of grants or low-cost loans. Unfortunately, the strained finances of several G20 countries do not permit them to grant such incentives without the financial assistance of the developed countries, as per the Paris Agreement (UNFCCC 2016).

- Lack of progress on spent fuel reprocessing (to reduce radioactive waste) and long-term waste storage also clouds public perception of the growth potential for NPPs.

- Shortage of trained manpower to meet future requirements of the nuclear power sector (from construction and manufacturing,

to operation, maintenance, and inspection) must be overcome with time-bound and consistent efforts, or by carrying out a major portion of SMR manufacturing in India, which has the suitable human resources and infrastructure for manufacturing NPPs and SMRs.

The G20's Role

2

All parties to the Paris Agreement have agreed to promote international cooperation to mobilise more ambitious climate action and have recognised the urgent need to respond to climate change on the basis of the best available scientific knowledge (UNFCC 2016). The inevitable transition from coal-fired power generation to clean energy sources poses major challenges for all countries worldwide, and there is a widespread consensus amongst several G20 countries that solar and wind alone will be insufficient (Fell et al. 2022). Baik et al. (2021) and Sepulveda et al. (2018) conducted modelling studies of electricity grids in the United States and concluded that batteries and demand flexibility cannot substitute firm baseload low-carbon energy resources, and in deeply decarbonised electricity systems with significant shares of variable renewable energy, the additional availability of at least one baseload (firm) electricity generating technology can overcome reliability challenges and substantially reduce electricity costs.

Several G20 members are developing new nuclear capacity along with more renewables to meet the steep rise in electricity demand during the energy transition. Both the EU and the government of the UK have included nuclear energy as a part of their 'green taxonomy', while the US has announced tax credits for zero-carbon power plants (e.g., SMRs) commencing operations after 2025, with a 10 percent bonus if such a power plant is built in specified brownfield sites, including a retired coal-fired TPP (US DOE 2022).

In general, SMRs require low-enriched or high-assay low-enriched uranium, which must be continually supplied by all countries that possess uranium mines and facilities for such enrichment if the recipient nuclear facility is operating under strict international safeguards. This must be guaranteed by all G20 countries under suitable bilateral as well as multilateral agreements so that no civilian nuclear facility continuing to operate safely under the International Atomic Energy Agency (IAEA) safeguards is left stranded without adequate uranium fuel because of a dispute between two or more countries in an unrelated area.

To achieve the high nuclear energy targets in the Net Zero by 2050 scenario, annual global investment in nuclear

energy must rise to over US$100 billion in the 2030s—which is over three times the average of US$30 billion in the 2010s, falling steadily thereafter to US$70 billion in the second half of the 2040s (IEA 2022c). While climate change is a real global threat, it can only be tackled based on equity and according to the principle of 'Common but Differentiated Responsibilities and Respective Capabilities' (CBDR&RC), enshrined in Article 3.1 of the United Nations Framework Convention on Climate Change (UNFCCC), which was also reiterated in the Paris Agreement (UN 1992; UNFCCC 2016). As per Article 4.5 of the UNFCCC, developing countries depend on developed countries for financial resources and transfer of technology to meet their climate-change commitments, since human development and poverty eradication are the overriding priorities of developing countries (UN 1992).

International public financial flows to developing countries in support of clean energy was 35 percent less in 2021 than the 2010–2019 decade-long average, and less than half the 2017 peak of US$26.4 billion (UN 2023). This can only be corrected by the G20 leaders if they act in unison to counter climate change.

The process to obtain safety clearances from regulatory authorities for any new nuclear reactor design is a long and expensive one. Therefore, it is unproductive to repeat the regulatory process to approve SMR designs in each country if the same model is granted general design approval in another country. However, this is the current practice among atomic energy regulators, even though aviation regulators routinely accept the certification granted by the Federal Aviation Administration (FAA) for civilian aircrafts that fly thousands of passengers in a particular aircraft model countless times across hundreds of countries every day. This is another critical issue that the G20 leaders must address in their upcoming summit to enhance regulatory efficiency and reduce cost and time overruns of SMRs designed, built, and constructed as per standard designs licensed in their country of origin.

Recommendations to the G20

3

Nuclear power is currently the second largest source of zero-carbon electricity in the world after hydropower. Its growth potential, environmental performance, safety record, and dispatchability must be harnessed to ensure a secure and affordable green energy transition in G20 countries where nuclear power is accepted. Therefore, the following recommendations can be discussed and adopted by the G20 leaders during their upcoming summit in India to decarbonise the electricity sector and achieve SDG 7, along with energy security and global net zero:

- Delays in the coal-to-nuclear transition, even in countries already operating NPPs, are likely to result from overlapping and inefficient regulatory processes utilised by nuclear regulators in different countries. An efficient regulatory regime comparable to that in the civil aviation sector (which has even more stringent safety requirements) can be set up only if the G20 leaders direct their respective nuclear regulators to cooperate amongst themselves and with the IAEA in order to harmonise their regulatory processes and requirements and expedite the grant of statutory approvals for nuclear power projects with SMRs based on standard, universal designs. This is the biggest enabler for expediting the coal-to-nuclear transition in all countries that wish to use SMR technologies to achieve net zero in a reliable, secure, and affordable manner.

- The need for technology transfer, fuel security, waste reprocessing, and climate finance must be resolved by the leaders of the G20 countries during their upcoming summit to incentivise other member countries to expedite their coal-to-nuclear transition under international safeguards. Specifically, the developed countries in the G20 must absorb the one-time costs of research and development as well as design certification and ensure that SMRs are available and affordable for all developing countries in the G20. This is critical to address the urgent risks of global warming by ensuring the attainment of global net zero in an expeditious, secure, and affordable manner.

- Public perception of nuclear power must be changed by enhancing the transparency and timeliness of response from nuclear energy regulators. The G20 leaders can decide and implement a policy for enhancing public and timely dissemination of data related to the environment and public health around existing civilian reactors under international safeguards. Such timely and comprehensive disclosures will help remove any misgivings and promote public acceptance of nuclear power as a vital and reliable tool to fight global warming.

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