IAEA
International Atomic Energy Agency

Nuclear Energy for Net Zero

Accelerating Investment in Clean Energy Transitions

G20 BRASIL 2024
BUILDING A JUST WORLD AND A SUSTAINABLE PLANET

“Achieving sustainable economic development and averting the devastating consequences of unchecked climate change will require making use of all low carbon energy sources, including nuclear power...

Net zero needs nuclear power.”

IAEA Director General,
Rafael Mariano Grossi

1.5°C

All low carbon energy technologies, including nuclear power, are needed to maximize our chances of meeting the goals of the Paris Agreement.

Global mitigation scenario pathways show more nuclear electricity is needed to limit global warming to 1.5°C or 2°C. The United Nations Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report and the International Energy Agency (IEA) World Energy Outlook highlight an important role for nuclear energy — in combination with other low carbon energy sources — in transition pathways compatible with the goals of the Paris Agreement. Most low carbon pathways project a doubling or more of global nuclear electricity generation by 2050.

Nuclear heat and hydrogen can play an additional role reducing emissions in non-electric applications — for example, to decarbonize hard-to-abate activities in heavy industry and transportation. This additional mitigation potential of nuclear energy may not be fully reflected in current energy transition analysis and scenario pathways. In this context, the IAEA's **Atoms4NetZero** initiative is helping Member States to better analyse relevant nuclear energy technologies and applications to support effective climate action.

Unlocking and accelerating investment is critical for rapid deployment of nuclear energy. Nuclear energy has a proven track record of rapid deployment, including in recent projects, which is critical for urgently and economically decarbonizing the global energy system. Consistent climate, energy and investment policy frameworks that recognize the imperative for nuclear expansion for ambitious climate goals — embracing a wide array of financing approaches — in tandem with efficient markets, effective project risk management and multi-stakeholder cooperation, will be needed to accelerate annual nuclear energy investment to over US $100 billion to reach net zero. By enhancing the availability of finance in emerging markets and developing economies (EMDEs) in particular, these measures can help to deliver a just, inclusive or affordable transition.

Nuclear energy today is a key economic source of low carbon electricity and heat, helping to avoid more than one billion tonnes of carbon dioxide (CO_2) emissions annually while supporting energy system reliability, long term security and climate resilience [1]. Nevertheless, despite the contribution of nuclear and other low carbon energy sources, global greenhouse gas emissions remain well above the levels required to limit the global average temperature increase to below 1.5°C or 2°C — the key goal of the Paris Agreement (see Fig. 1). To avoid warming above these levels, the global energy system will need to transition to net zero CO_2 emissions by around 2050 (for 1.5°C) or soon after (for 2°C).

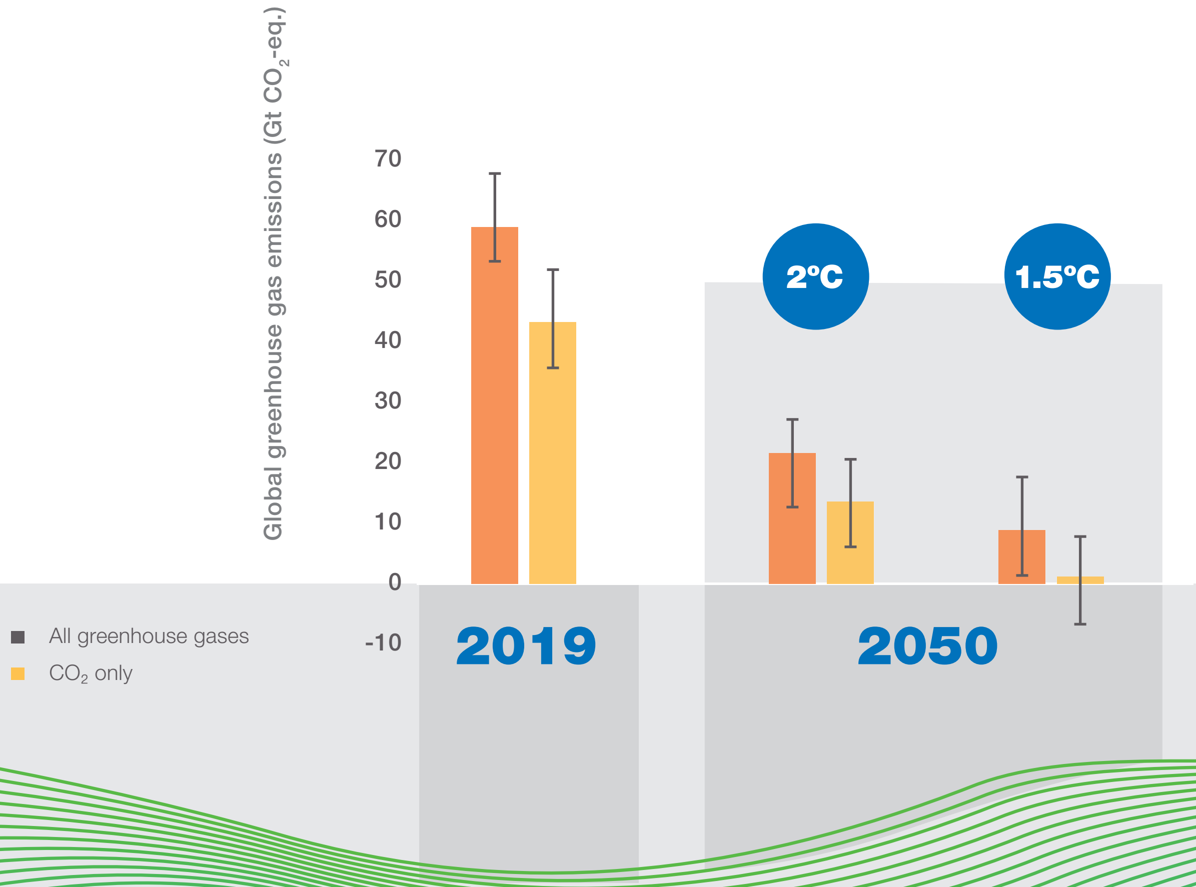


Fig. 1. Global greenhouse gas emissions, 2019 and estimated 2050 targets for 2°C and 1.5°C. Reproduced from Ref. [2] with permission.

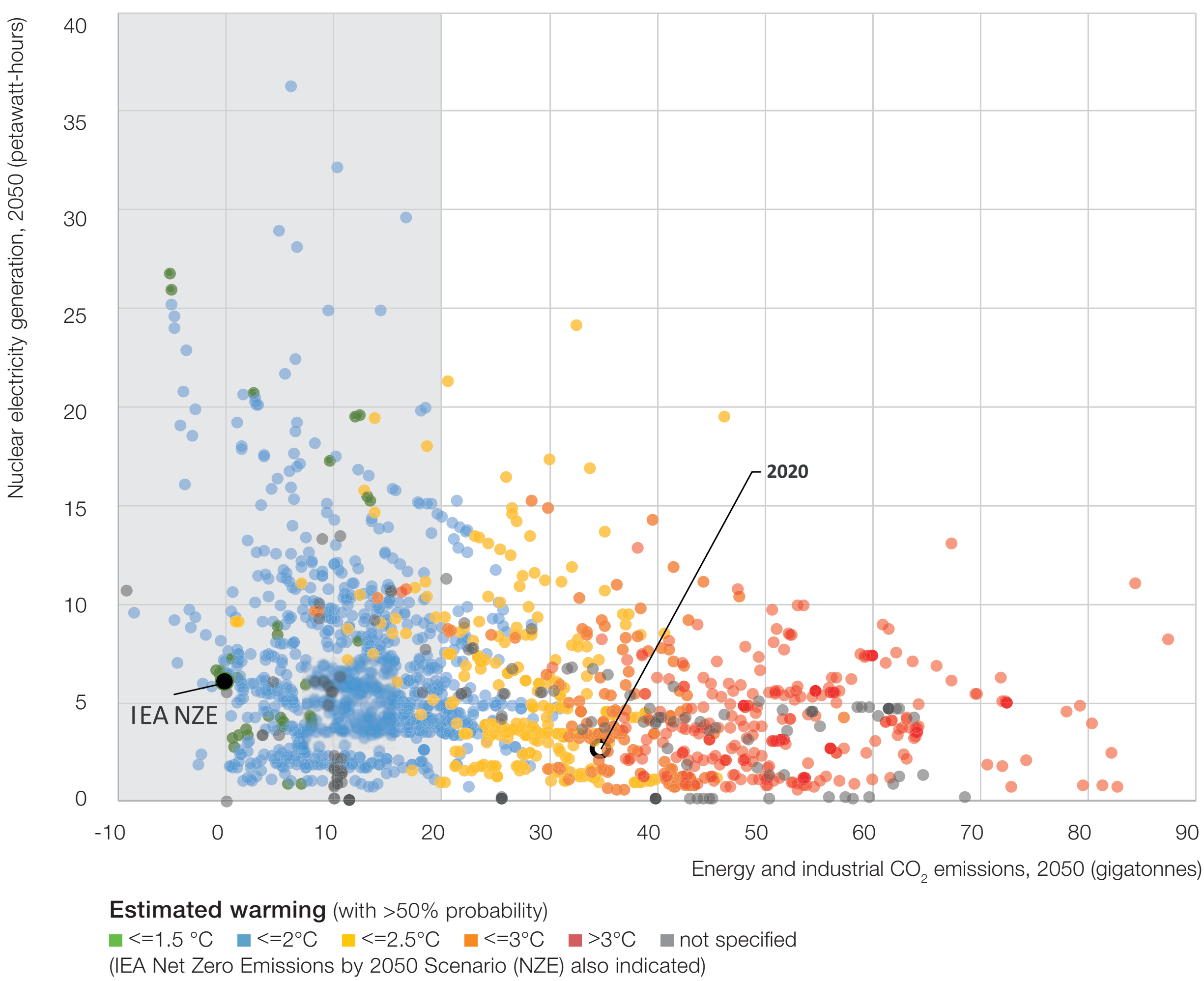
NUCLEAR ENERGY IN PATHWAYS TO NET ZERO

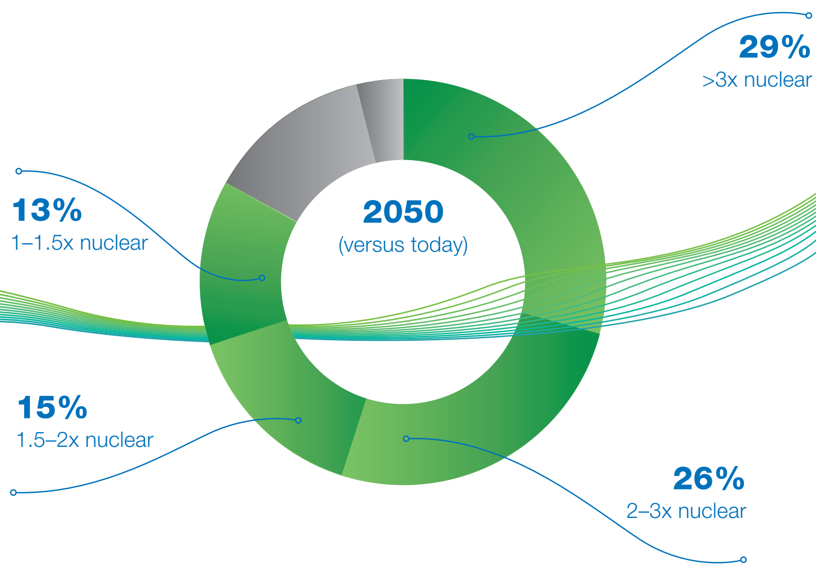
The IPCC compiled and assessed more than 3000 peer reviewed scenarios related to climate change mitigation as part of its Sixth Assessment Report published between 2021 and 2023 [2–5]. These scenarios cover a wide range of perspectives on energy transitions and provide extensive insights into the role of different low carbon energy sources in reaching climate change mitigation targets. The IEA has also published scenarios exploring pathways of global energy system development in their annual World Energy Outlook [6].

The contribution of nuclear energy varies widely across these scenario pathways. This is illustrated in Fig. 2 overleaf, which plots global nuclear electricity generation and energy related CO_2 emissions in 2050, with each dot representing a different scenario from the IPCC Sixth Assessment Report, coloured according to the projected level of warming (with >50% probability) [7][1]. For comparison, the 2020 level of nuclear electricity generation and energy emissions is plotted as a circle.

Angra Nuclear Power Plant, Brazil

[1] The full set of scenarios was filtered to select those reporting key variables for 2050, such as global energy related CO_2 emissions, electricity generation and others, corresponding to a subset of more than 1800 scenarios developed with around 30 model families (a model family includes different model versions based on the same underlying model [7]).





80%

of scenarios with emissions below 20 gigatonnes see an expanded role for nuclear electricity generation

Fig. 2. Global nuclear electricity generation and carbon dioxide emissions in the IPCC mitigation pathways, 2050 [2–5, 6, 8].

Overall, an increasing role for nuclear power by 2050 is seen across a significant majority of the scenarios, particularly in those that achieve substantial reductions in emissions in line with the goals of the Paris Agreement. For instance, more than 80% of scenarios with emissions below 20 gigatonnes of CO_2 in 2050 (roughly corresponding to limiting warming below 2°C) see an expanded role for nuclear electricity generation, with more than half projecting at least a doubling and around 30% projecting a tripling or more compared with 2020 levels (Fig. 2, pie chart). The IEA's Net Zero Emissions by 2050 Scenario also envisages more than a doubling of nuclear electricity generation [6].

Notably, the expansion of nuclear energy across many IPCC mitigation pathways exceeds the increase in the IAEA's high projection [9] (see Box 1) which is derived from a bottom-up, country by country and project by project assessment based on current market and policy trends. Fully capitalizing on the additional mitigation potential identified in the IPCC Sixth Assessment Report scenarios will likely require enhanced market and policy support to drive investment beyond the levels reflected in the IAEA projections. Additional efforts would also likely be needed to ensure global supply chains, human capital and other infrastructure are in place to support the high levels of nuclear deployment and generation seen in some scenario pathways.

BOX 1: **IAEA ENERGY, ELECTRICITY AND NUCLEAR POWER ESTIMATES TO 2050**

IAEA

The IAEA annually publishes projections of energy, electricity and nuclear power trends for the coming decades [9] based on a critical review of other international and national projections and estimates from national and international experts.

In 2023, for a third successive year, the IAEA revised up its projections of the potential growth of nuclear power to 2050, reflecting a shift in the global debate over energy and the environment: “Climate change is a big driver, but so is security of energy supply,” IAEA Director General, Rafael Mariano Grossi noted in October 2023. “Many countries are extending the lifetime of their existing reactors, considering or launching construction of advanced reactor designs and looking into small modular reactors, including for applications beyond the production of electricity” [10].

With the 2023 revision, the IAEA high case projection reaches more than 7000 terawatt-hours of nuclear electricity generation in 2050 (and 890 gigawatts of installed capacity), as shown in Fig. 3, which is relatively conservative compared with many of the scenarios in the IPCC Sixth Assessment Report in Fig. 2 (which reach up to more than 35 000 terawatt-hours). However, the IAEA projections are not intended to reflect the lowest or highest feasible future levels of nuclear generation, but rather reflect contrasting (but not extreme) assumptions on driving factors and current market and policy trends. The IPCC scenarios, on the other hand, help identify a larger mitigation potential that could be tapped with additional market and policy support for nuclear energy, above current trends reflected in the IAEA projections.

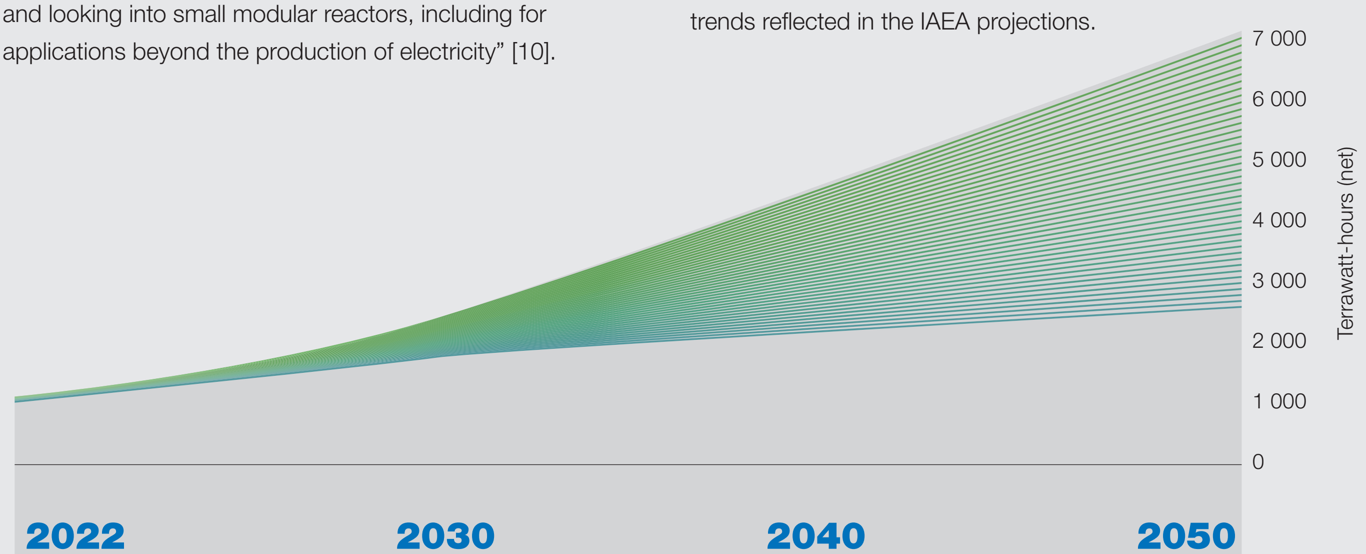


Fig. 3. Global nuclear net electricity generation in IAEA projections [9].

Turning to the broader energy transition, the IPCC mitigation pathways also highlight the need for a combination of nuclear power and other low carbon energy sources to reach the goals of the Paris Agreement. This is illustrated in Fig. 4, which plots the share of global electricity generation in 2050 from renewables against the share of nuclear generation across the full set of pathways. Again, each scenario is represented by a dot coloured according to the projected level of warming. Historical renewables and nuclear shares from 1971 to 2020 are also shown [8]. Figure 4 shows that the combined share of low carbon renewable and nuclear electricity generation is higher in scenarios with lower levels of warming. For example, most of the scenarios with warming of more than 3°C report a combined share between 20% and 40%, while those in line with the Paris Agreement's 1.5°C and 2°C goals report shares of 60% to 100%. In addition, practically all scenarios include both renewables and nuclear generation — with up to >45% nuclear and >95% renewable generation — which is consistent with nuclear energy's capacity to support the integration of high shares of renewables to achieve long term mitigation goals while strengthening climate resilience (see Box 2).

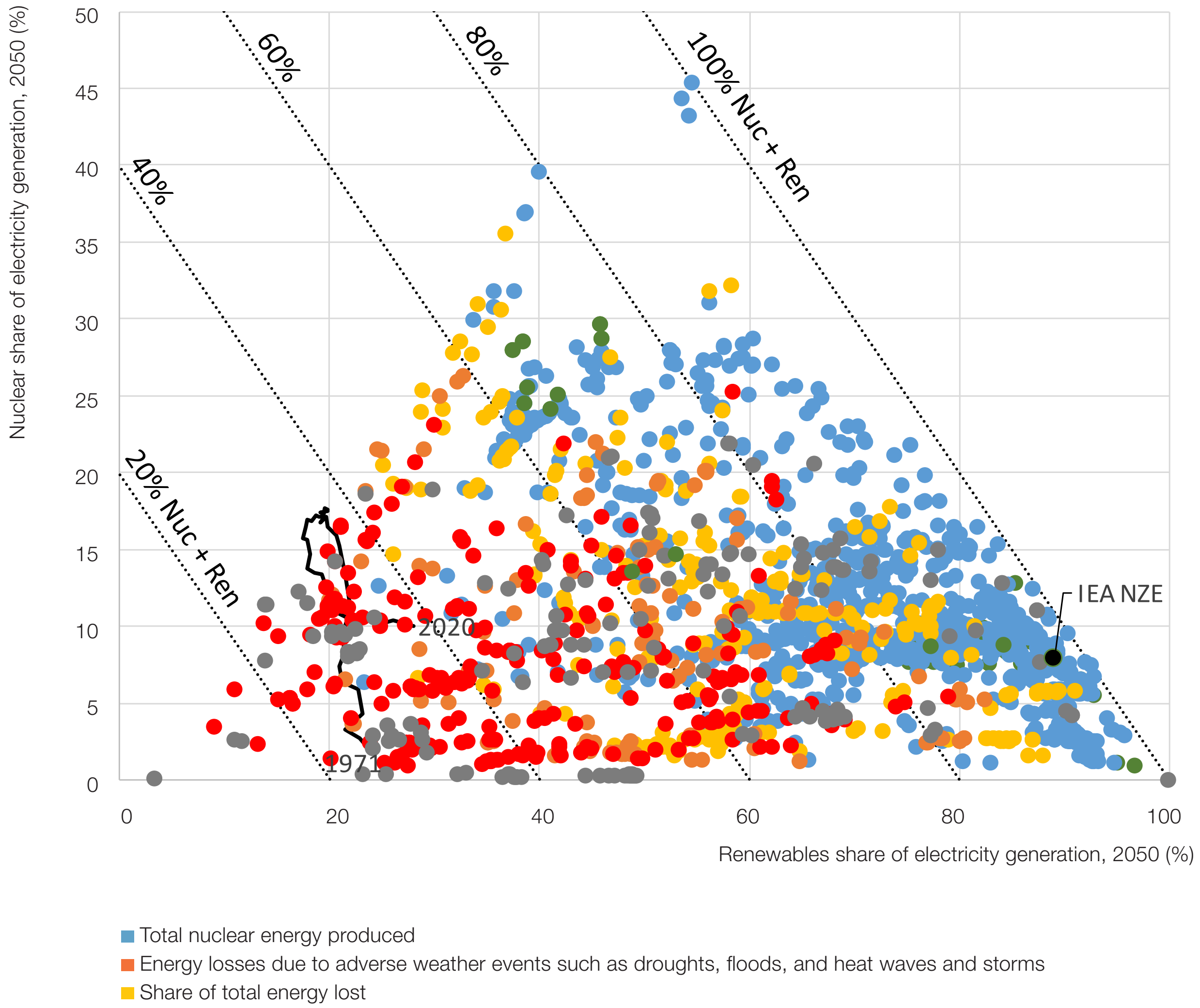


Fig. 4. Global shares of renewable and nuclear electricity generation in IPCC Sixth Assessment Report scenarios, 2050 [2–5, 8].

The IPCC mitigation pathways also highlight the need for a combination of nuclear power and other low carbon energy sources.

BOX 2: **NUCLEAR ENERGY FOR CLIMATE RESILIENT POWER SYSTEMS**

In addition to providing low carbon electricity, nuclear energy can facilitate the integration of high shares of renewables and support both long term energy security and climate resilience. In particular, the global nuclear fleet has proven to be robust in the face of extreme climate events such as heat waves, storms and droughts, making nuclear energy an excellent complement to other low carbon energy sources as climate risks increase. The resilience of the global nuclear fleet is illustrated in Fig. 5 [11], which shows reductions in nuclear output due to climate events rarely exceeded 0.5% throughout the period 2000–2022. Taking the example of France, despite record low river flow rates in spring of 2022 followed by the second hottest summer on record, production losses attributable to environmental factors were less than 0.2% of annual nuclear power production [12].

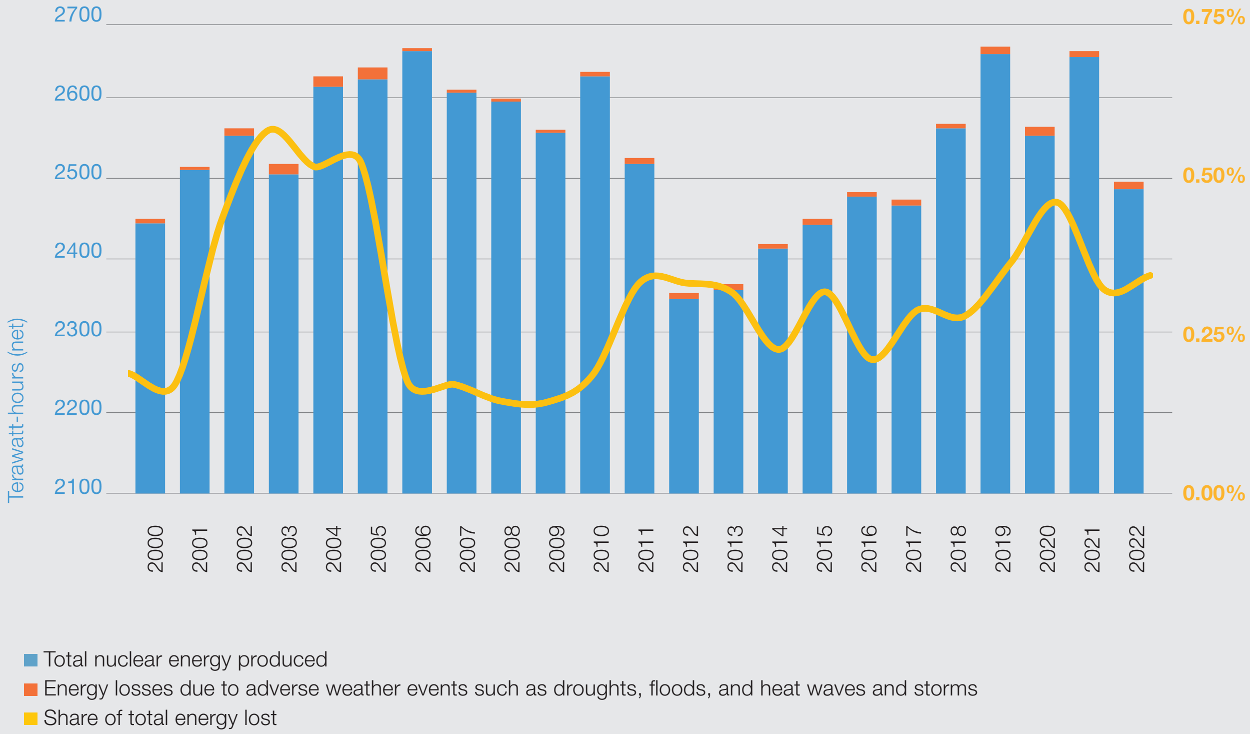


Fig. 5. Annual nuclear energy production and weather-related losses between 2000 and 2022 [11].
Note: Reflects data availability and reporting by IAEA Member States.

NUCLEAR ENERGY FOR HEAT, HYDROGEN AND OTHER NON-ELECTRIC APPLICATIONS IN MITIGATION PATHWAYS: AN OPPORTUNITY FOR THE NEXT GENERATION OF SCENARIOS

In addition to generating clean electricity, nuclear energy has the potential to provide heat and hydrogen that can be used to decarbonize processes and activities that are less suited to electrification. Examples of these so called hard-to-abate activities include processes in the steel, non-ferrous metals, cement and chemical industries, heavy transport and aviation.

Despite this potential, only a small number of scenarios in the IPCC Sixth Assessment Report include heat or hydrogen from nuclear energy, generally in negligible amounts (see Fig. 6) This may be explained by the very limited representation of relevant technologies and processes in most scenario models [7], suggesting that the role of nuclear heat and hydrogen may be underestimated in current analysis and mitigation scenarios. This presents an opportunity to further enhance the modelling of energy transition pathways, and with this in mind the IAEA launched the Atoms4NetZero initiative in late 2022 to support its Member States to better understand the potential of current and emerging nuclear energy technologies in developing their national energy strategies towards reaching net zero emissions (see Box 3).

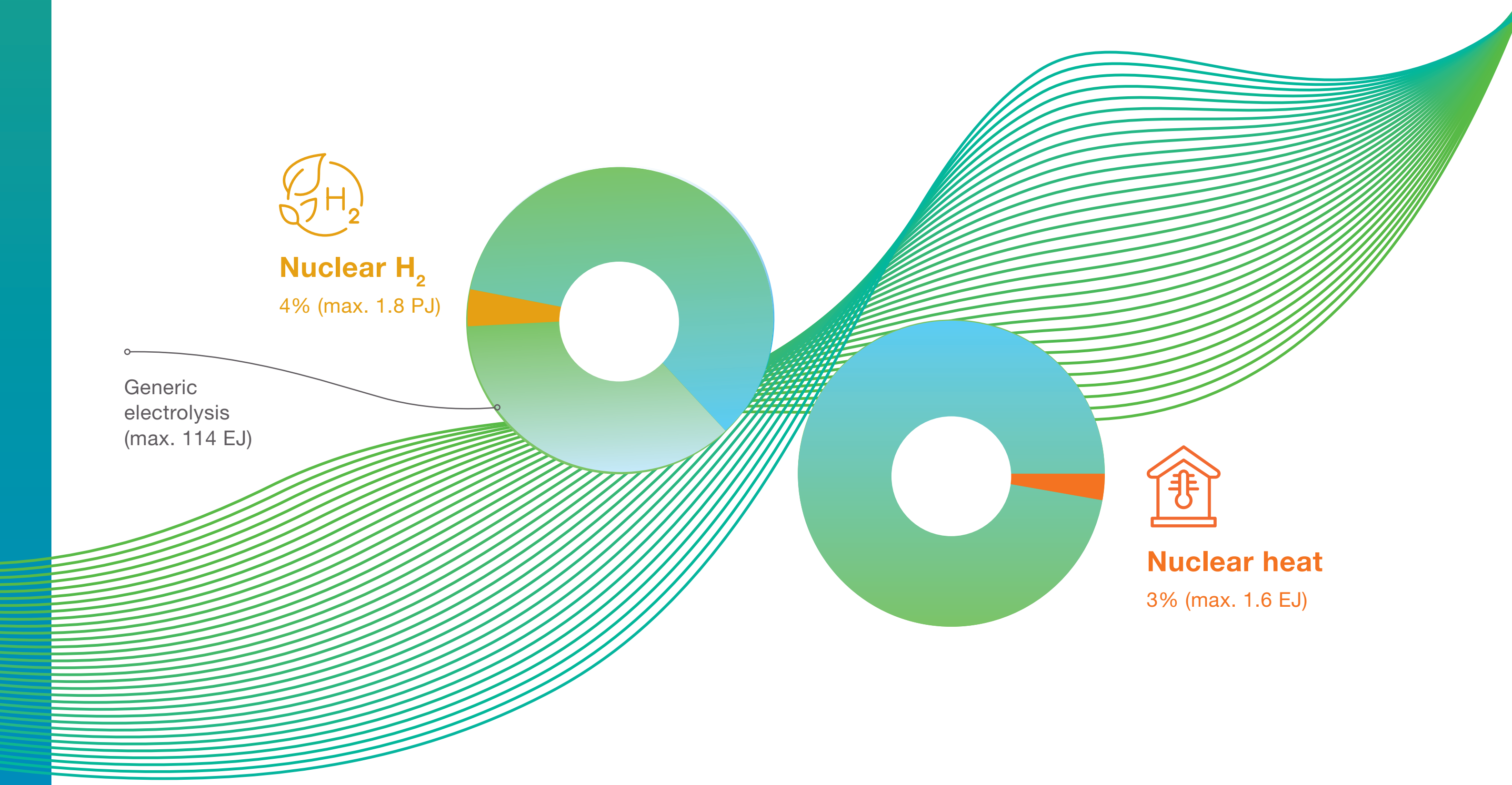


Fig. 6. Share of scenarios from the IPCC Sixth Assessment Report reporting nuclear hydrogen (H_2) or nuclear heat production in 2050 [2, 3, 7]. **Note**: The 2050 maximum nuclear H_2 and heat production levels across the scenarios are given in parentheses. PJ —petajoule, EJ — exajoule.

The IAEA launched the Atoms4NetZero initiative at COP27.

BOX 3: **SUPPORTING MEMBER STATES EXPLORE PATHWAYS TO NET ZERO: THE IAEA'S ATOMS4NETZERO INITIATIVE**

IAEA

At COP27 (the 2022 UN Climate Change Conference, held in Sharm el-Sheikh, Egypt) IAEA Director General Rafael Mariano Grossi announced the Atoms4NetZero initiative. Building on decades supporting Member States to develop capacity in sustainable energy planning, through this new initiative the IAEA is providing its analytical tools and expertise to help countries model how nuclear power can contribute to reducing greenhouse gas emissions to as close to zero as possible by 2050. The Atoms4NetZero initiative is helping countries assess the potential of innovative nuclear technologies, including small modular reactors, to support their long term strategies to decarbonize electricity generation and other carbon intensive sectors. The initiative will develop credible scenarios through the IAEA's analytical tools, including MESSAGE (the Model for Energy Supply System Alternatives and their General Environmental Impacts) which is used by more than 100 countries. Atoms4NetZero is one example of IAEA initiatives in energy planning tools, capacity building and regional cooperation, which can support the Global Coalition for Energy Planning under the G20 Presidency of Brazil.

ATOMS4 NET ZERO

Explore the Atoms4NetZero website.

REALIZING THE POTENTIAL OF NUCLEAR: ACCELERATING INVESTMENT FOR TRANSITIONS TO NET ZERO

Decarbonizing the global energy sector by 2050 or soon after to limit average global temperature increase to below 1.5°C or 2°C will require accelerated deployment of low carbon electricity generation technologies. In this context, nuclear energy has a proven track record of rapid deployment, adding low carbon electricity faster than any other technology across almost all countries (see Fig. 7). In much of the world, nuclear power projects continue to be delivered both economically and at speed, exemplified by the recent experience with the construction of the Barakah Nuclear Energy Plant in the United Arab Emirates — estimated to add over 400 kilowatt-hours of clean electricity generation per capita per year (a rate which would decarbonize the global electricity system by 2030). Even in countries that have experienced delays in constructing new first-of-a-kind nuclear power plants, the rate of deployment has also often outpaced the uptake of other low carbon sources [13].

Globally, historical deployments are more than sufficient to expand nuclear electricity generation in line with many 1.5°C and 2°C mitigation pathways. For instance, realizing the electricity mix in the IEA Net Zero Emissions by 2050 Scenario [6] would require gross annual additions less than half the historical peak deployment rate shown in Fig. 7. However, the global deployment rate in recent years (2016–2020) has been around 3 to 4 times slower than required.

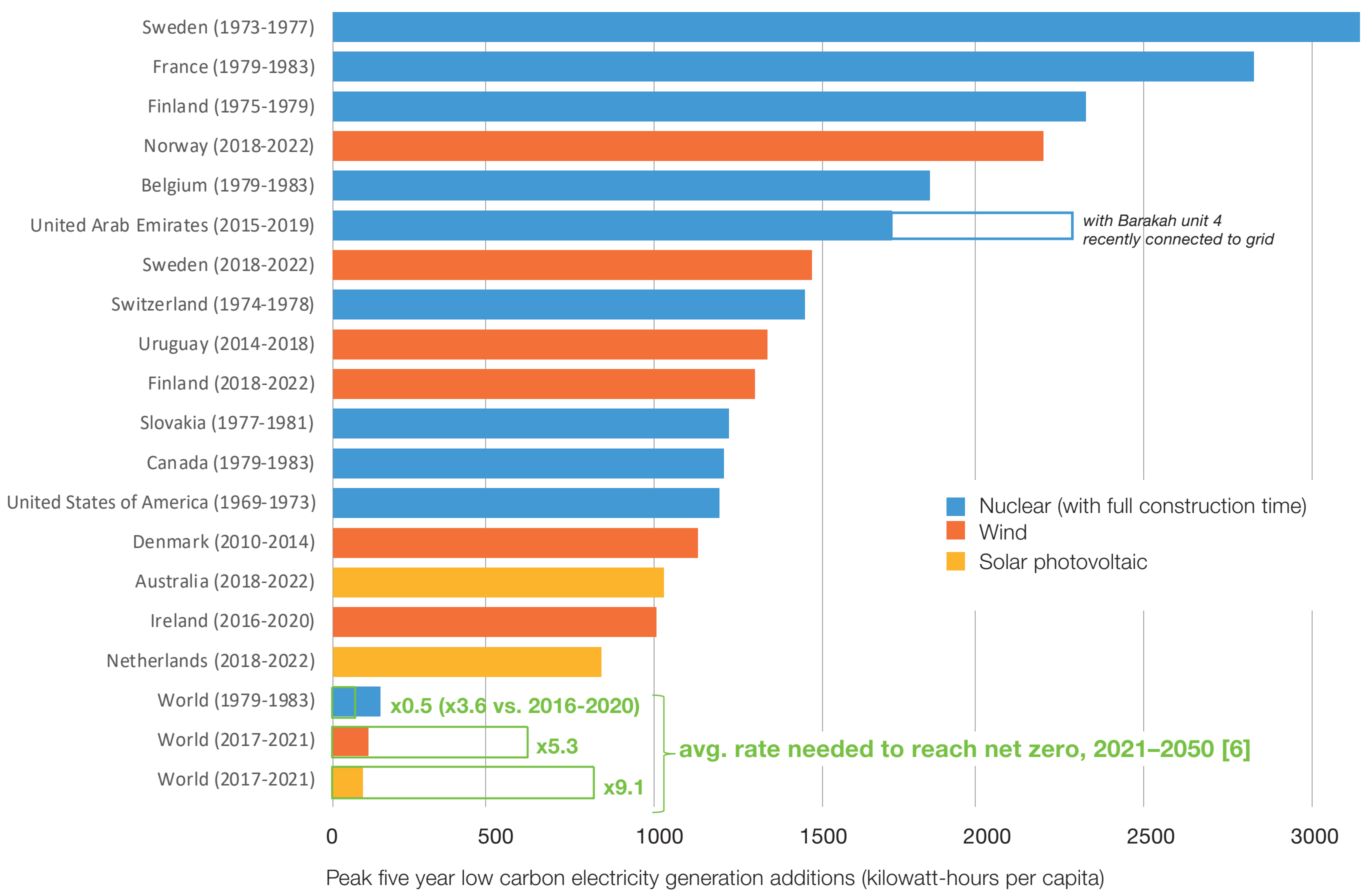


Fig. 7. Peak additions of low carbon electricity generation, kilowatt-hours per capita over five years [8, 11].

Note: Additions are averaged over the entire period from construction start to grid connection/commercial operation. For wind and solar photovoltaic generation, this is assumed to be one year or less. For nuclear power, the actual dates of construction and grid connection/commercial operation are used. Transparent bars indicate the estimated average deployment rates needed to realize the 2050 electricity mix in the IEA Net Zero Emissions by 2050 Scenario [6].

To unlock the potential of nuclear energy, efforts are therefore required to accelerate global investment and deployment rates from current levels. For instance, the IEA identifies the need for a rapid increase in annual nuclear energy investment to over US $100 billion by 2030 to reach net zero, from around US $40 billion per year during 2016–2020, amounting to more than US $2 trillion through to 2050 — split roughly equally between advanced economies and EMDEs [1].

Increasing recognition worldwide of the role of nuclear energy in meeting ambitious climate targets, reflected in the outcomes of the first Global Stocktake under the Paris Agreement [14] and national commitments (see Fig. 8), provides an important impetus to accelerate investment. However, the world runs the risk that current market and policy environments may be incompatible with mobilizing the scale of investment required for net zero, as Simon Stiell, Executive Secretary of the United Nations Framework Convention on Climate Change stated: “We need torrents — not trickles — of climate finance” [15]. This is especially the case in EMDEs, requiring concerted international efforts to enhance the availability of finance for accelerating the deployment of nuclear and other clean energy sources. To respond to this challenge, it is critical to align policy, regulatory, infrastructure and other measures to ensure efficient operation of both energy and investment markets, while embracing a wide array of financing sources and approaches, including those used traditionally to deliver bankable nuclear power projects (such as government and vendor finance) as well alternative and emerging sources of private, multilateral and green finance. This entails adopting consistent investment criteria and frameworks (such as sustainable investment taxonomies, see Fig. 8) — nationally and internationally, including by multilateral financial institutions — to guide investment (and avoid arbitrary barriers). Other key elements include ensuring regulation and project approval processes are aligned with the need for urgent climate action and that energy markets provide appropriate incentives for long term investment. Barriers to investment can also be reduced with measures to manage clean energy project risks (such as through long term contracts and regulated tariffs), facilitate coordination and cooperation across different levels (e.g. public–private sectors, emerging–developed economies) and support emerging low carbon new technologies [16, 21]. The combination of a supportive policy environment and improved access to finance is particularly crucial for scaling up clean energy investment in EMDEs.

Sanmen Nuclear Power Station, China

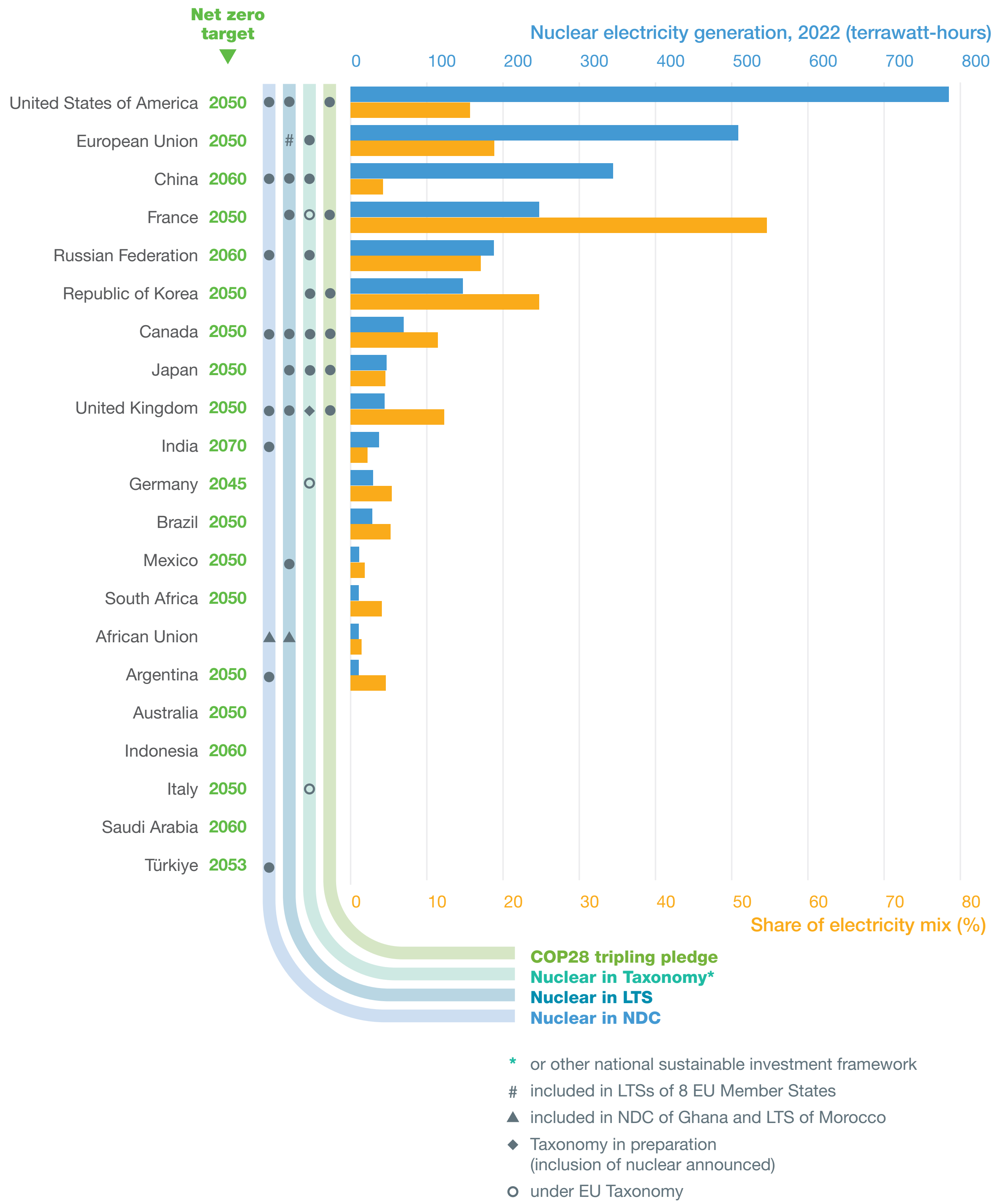


Fig. 8. Nuclear energy, climate change commitments and sustainable investment taxonomies in the G20, ranked by nuclear power generation in 2022 [9, 16–20].

Note: NDC — latest nationally determined contribution submitted under the Paris Agreement; LTS — long term strategy submitted under the Paris Agreement.

By 2030, more than

US $100 billion annual investment

in nuclear energy is needed to reach net zero [1].

NUCLEAR ENERGY SUMMIT

On 21 March 2024 world leaders from more than 30 countries and the European Union met at the **inaugural Nuclear Energy Summit** in Brussels, Belgium. The summit continued to build global momentum for nuclear power in the clean energy transition, coming on the heels of nuclear's historic prominence at COP28 with the inclusion of nuclear energy in the first Global Stocktake.

At the summit, high level representatives from dozens of countries emphasized the importance of using nuclear power to achieve energy security, climate goals and drive sustainable development. Increased financing, workforce development and more proactive support to nuclear newcomer countries were identified as key to long term success.

IAEA

“The Nuclear Energy Summit must be a turning point for nuclear energy, calling for global investment across all economies.”

IAEA Director General,
Rafael Mariano Grossi

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