German Environment Agency

30. November 2023

What is the role of nuclear energy in achieving climate targets in global scenarios?

1 Summary

This factsheet analyses the role of nuclear energy in global climate scenarios. It shows, that a global tripling of nuclear capacity until 2050 is neither realistic nor is it needed to achieve climate targets according to the Paris agreement.

Key messages are:

- Global climate scenarios show very different results for the future role of nuclear energy.
- Global climate scenarios show that nuclear energy is not needed to achieve climate targets according to the Paris agreement.
- Even with a high nuclear energy production, scenarios with low shares of renewable energy miss the climate targets. Thus, the build-up of renewable energy is the crucial and primary driver to achieve climate targets.
- An assessment of government policies of different countries around the world with respect to nuclear energy shows, that a considerable increase in nuclear energy until 2050 is not to be expected.

2 Global climate scenarios: same target, different stories

Global climate scenarios play a helpful role in addressing climate change: By exploring possible futures with different outcomes, model-based scenarios help to navigate climate policy options at a global as well as national level. Scenarios are not forecasts, but 'if-then' statements that help to understand the consequences of certain policy measures or assumptions. Thus, there is a variety of storylines - even for scenarios that share the same climate objectives.

We present an analysis of ten global climate scenarios that achieve climate targets according to the Paris agreement[1] as well as a non-target scenario with an emphasis on the role of nuclear energy.

In September 2022 the "Network for Greening the Financial System (NGFS)" published various scenarios, which were developed for central banks and financial supervisory institutions in a modelling alliance between Potsdam Institute for Climate Impact Research (PIK), the International Institute for Applied Systems Analysis (IIASA), the University of Maryland, Climate Analytics and the National Institute of Economic and Social Research (NIESR) (NGFS 2022).

These scenarios represent a suitable selection for this task. Three different models are used in these scenarios, and nuclear energy is used to very different extents by these three models. Out of the six storylines in this project, which were each modelled with the three different models involved, we focus on the "Net zero" and the "Divergent Net Zero" storylines, all achieving the climate targets.

We also include two scenarios with a phase-out of nuclear energy by 2050 (Teske 2019), which achieve the 1.5°C and 2°C target respectively. As an important international reference, we include three scenarios from the IEA's World Energy Outlook (International Energy Agency (IEA) 2022): one that achieves the target of the Paris agreement ("Net Zero by 2050") by reaching the 1.5°C target, one that would result in a projected global median temperature rise of about 1.7°C ("Announced Pledges") as well as the "Stated Policies" scenario that falls short of the climate targets (by resulting in about 2.5°C increase of global median temperature). The latter is representative of the scenarios found in the literature that have a relevant or high share of nuclear energy but do not achieve the climate targets, like the three scenarios in (World Energy Council 2019) or the developments presented in (Energy Information Administration 2021).

Figure 1 shows the different developments of nuclear energy in the scenarios described above. The contribution of nuclear energy to the total primary energy supply in 2050 ranges from 0 EJ (in both Teske scenarios) to more than 45 EJ (in the scenarios using the MESSAGEix-GLOBIOM model). The latter would mean an increase in nuclear energy by a factor of 4.5 compared to today and to the average electricity production of the last decades.

Such an increase in nuclear energy is not necessary to achieve the climate targets: Except for IEA's "Stated Policies" all other scenarios shown in Figure 1 achieve the Paris agreement targets with less or even without the usage of nuclear energy in 2050.

In order to achieve the climate targets, nuclear energy is in fact only a small part of the story: Even in the MESSAGEix-GLOBIOM modelling, nuclear energy represents (only) 9% of primary energy supply in 2050 and 16% of the world's total electricity generation, while non biomass renewable energy sources provide about 81% of the electricity generation, as can be seen in Figure 2. The contribution of non-biomass renewable energy to the total electricity generation in

[1] As the Paris agreement states to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels" we refer to climate targets (plural) instead of a single climate target. The scenarios analysed here achieve different temperature targets that are compatible with the specified scope of the Paris agreement. The (NGFS 2022) scenarios reach the 1.5°C target with a certain probability.

the scenarios achieving climate targets ranges from 81% in the MESSAGEix-GLOBIOM scenario to 90% in the REMIND-MAgPIE and Teske scenarios.

In the non-target scenario ("Stated Policies") of the IEA's World Energy Outlook, the expansion of renewable energies falls short with only 61% of global electricity generation. **The comparison with the target scenarios implies: It is not the role of nuclear energy that determines compliance with the climate targets, but the sufficient expansion of renewable energies.**

The world electricity generation in 2050 varies between scenarios due to different results for the degree of electrification and overall energy demand. This is visible in Figure 3. It also becomes clear, that nuclear electricity generation plays a minor role in all scenarios compared to (non-bio) renewable generation, as is also evident from Figure 2. The MESSAGEix-GLOBIOM scenarios are not only the ones with the highest nuclear energy generation but also the ones with the highest total electricity generation and the highest renewable electricity generation in absolute terms.

The development of the installed capacity of nuclear reactors worldwide is shown in Figure 4. It shows a wide range of installed nuclear capacity from 0 GW (Teske et al.) to almost 1800 GW (MESSAGEix-GLOBIOM) in 2050 and installed capacities between 540 GW and around 1140 GW for the other scenarios as compared to roughly 370 GW[2] today.

3 Bottom-up analysis of government plans for nuclear energy

In order to assess how realistic these top-down scenarios are, we compare these figures with the plans and programmes of governments for the expansion (or phase out) of nuclear power.

As of November 2023, 31 countries[3] operate a total of 412 nuclear reactors. By far the most nuclear reactors are located in the USA, followed by France, China, Russia and South Korea, as is shown in Figure 5. Only nine countries operate more than 10 nuclear reactors.

The age structure of the existing fleet is a major factor for the future development of the installed nuclear capacity. According to (Mycle Schneider 2023) the mean age of all nuclear reactors in operation as of October 2023 is 31.7 years. The average age of nuclear reactors that have been shut down until July 1st 2022 was 27.7 years according to (Schneider und Froggatt 2022).

As a first step, we take a look at the existing global nuclear capacities (installed and under construction). By varying the lifetime of all nuclear reactors with the same value (40 years, 50 years, 60 years) we get a first, if simplified, impression of the magnitude of global nuclear capacities in the future, that would result from today's fleet taking into account only new nuclear reactors already under construction. Due to the age structure of the existing fleet, an assumed lifetime of 40 years would result in a strong decline of installed nuclear capacity already by 2030, while a lifetime of 60 years on the other hand would postpone this decline until 2040-2050, as is presented in Figure 6.

[2] According to the IAEA's PRIS database (International Atomic Energy Agency (IAEA) 2023) 370.99 GW of net electrical capacity was installed worldwide at the end of 2022. Numbers of installed capacity may include reactors in long-term outage, that are formally declared operational but have not produced electricity for an extended period of time.

[3] In the IAEA PRIS data Taiwan is included in the numbers for China.

In a second step we analyse official programmes of all 31 countries that operate nuclear power plants today as well as of five[4] potential newcomer states, regarding their future plans for nuclear energy. Depending on the local situation in these countries and taking into account their official targets as well as other factors, we have estimated two hypothetical development paths for each country: a “baseline” and an “ambitious scenario”. Experience with nuclear construction projects shows that there is a high level of uncertainty with regard to costs and timelines. The baseline and ambitious scenarios are therefore an expert estimate to provide a range of possible developments. It should be said, however, that the baseline scenario can easily be undercut in reality due to the uncertainties mentioned, while it seems unlikely that the ambitious scenario will be exceeded.

Figure 7 shows the results of this analysis. In the baseline scenario, the installed capacity of nuclear energy would remain roughly at the same level as today (around 370 GW), while in the ambitious scenario the capacity would peak around 2045 at around 500 GW.

4 Comparison of bottom-up analysis with climate scenarios

We compare our bottom-up analysis with the global energy scenarios: Figure 8 shows all scenarios analysed plotted together with the bottom-up analysis of existing capacities and government programmes. **Even the ambitious scenario of our government programmes analysis is lower than the global scenarios except the nuclear phase out scenarios by Teske et al.** It seems similar however to the nuclear capacities assumed in the IEA’s “Stated Policies” scenario.

Figure 11 puts the results of the bottom-up analysis in the context of claims to triple the nuclear capacity by 2050.[5] Even though the maximum global energy scenario in Figure 8 is even higher than the tripling nuclear scenario, it is still evident that such a scenario is not backed by any reasonable political planning up to now.

Figure 9 shows the historic annual grid connections of nuclear reactors worldwide. For the past ten years, between 3.4 and 10.3 GW net electrical capacity came online each year. Before that, 1990 was the last year that more than 10 GW net electrical capacity come online in a single year. The overall historic maximum was in the year 1985 with 31.3 GW net electrical capacity connected to the grid.

A tripling of today’s nuclear capacity of 370 GW would require 1.110 GW net electrical capacity to be operational in 2050.

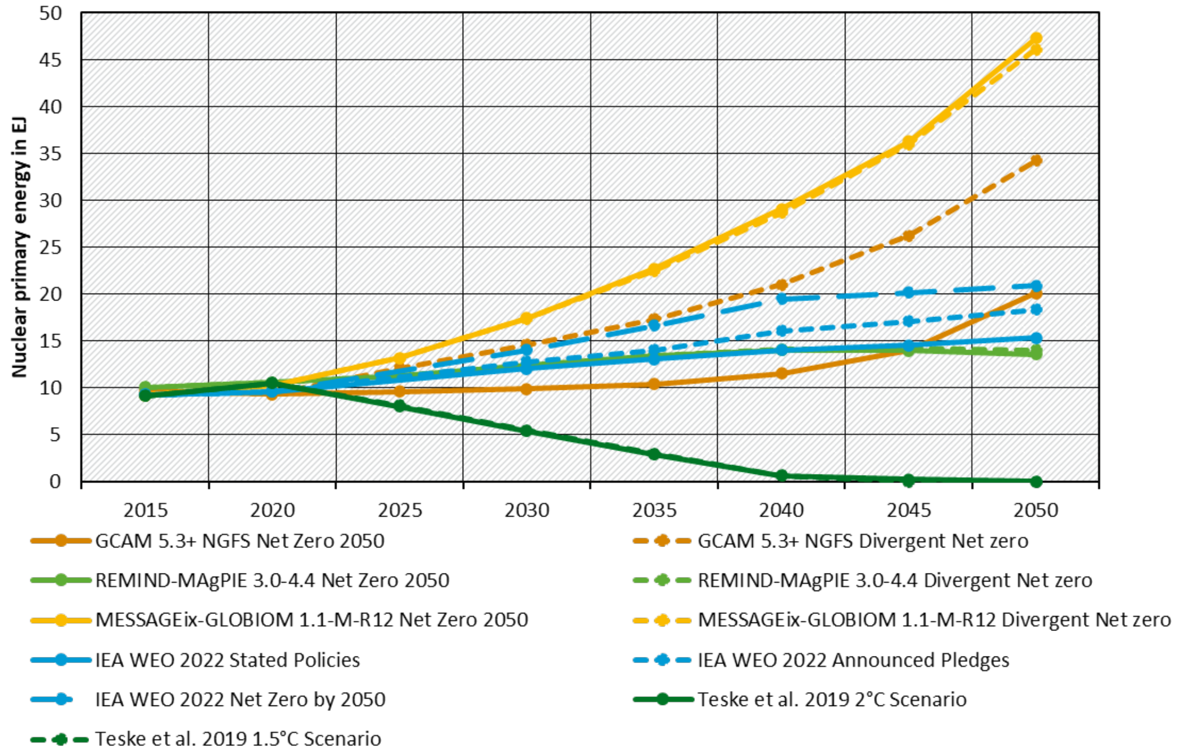
If we assume a very high sixty year lifetime for all nuclear reactors in operation and under construction today, roughly 210 GW of the current nuclear fleet would still be online in 2050. Thus, a total of nearly 900 GW would have to be constructed additionally between 2024 and 2050. Assuming a linear increase in the rate of new construction up to 2050, starting with the amount of new nuclear connected to the grid in 2023, in 2050 more than 60 GW would need to be connected to the grid to meet the tripling nuclear target, compare Figure 10. This would be approximatly twice the maximum historic capacity connected to the grid in a single year. On average, more new capacity would have to be added every year over 25 years as was the case at the historical maximum in 1985.

From these numbers, it is evident, that a tripling of nuclear capacity until 2050 is neither realistic nor is it needed to achieve climate targets according to the Paris agreement.

[4] The five states included are Bangladesh, Egypt, Turkey, Saudi Arabia and Poland. While the number of potential newcomer states may be larger, the impact of such states on the total installed nuclear capacity in the year 2050 will be very limited, as it takes several decades between the start of a nuclear power programme and the first nuclear reactor to become operational.

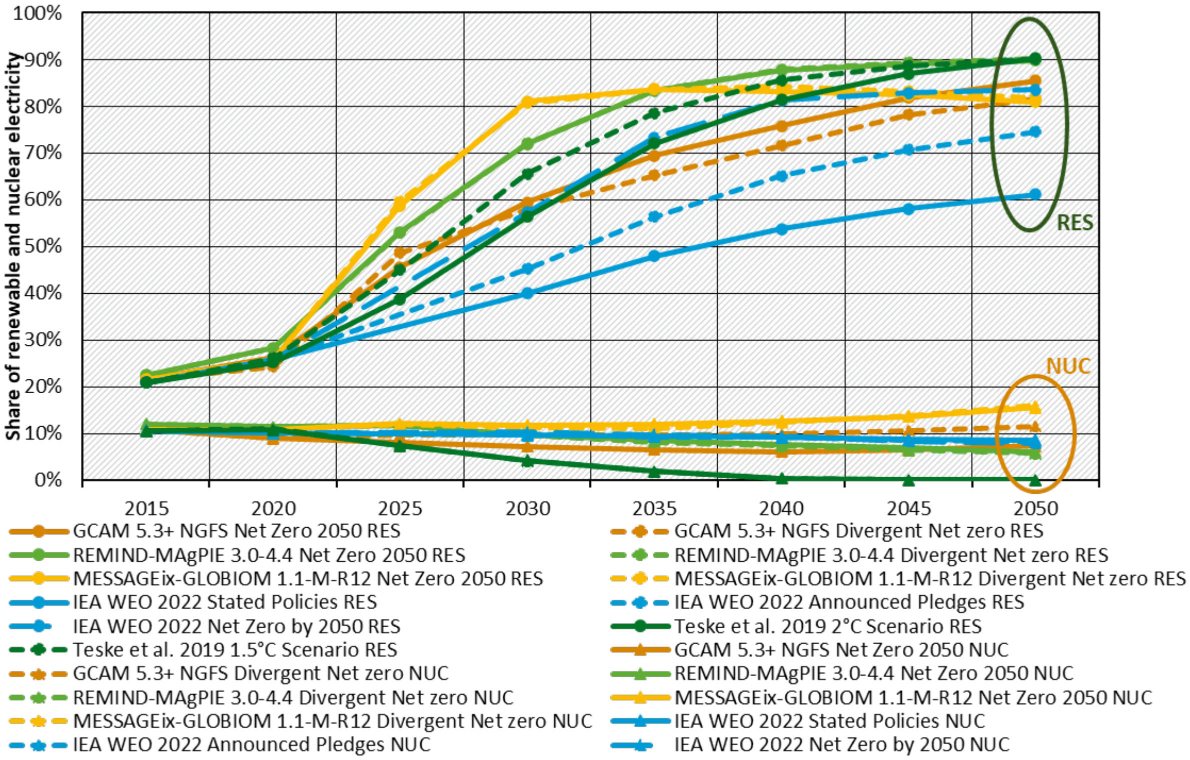
[5] For example https://netzeronuclear.org/.

Figure 1: Nuclear primary energy (world) in the scenarios analysed



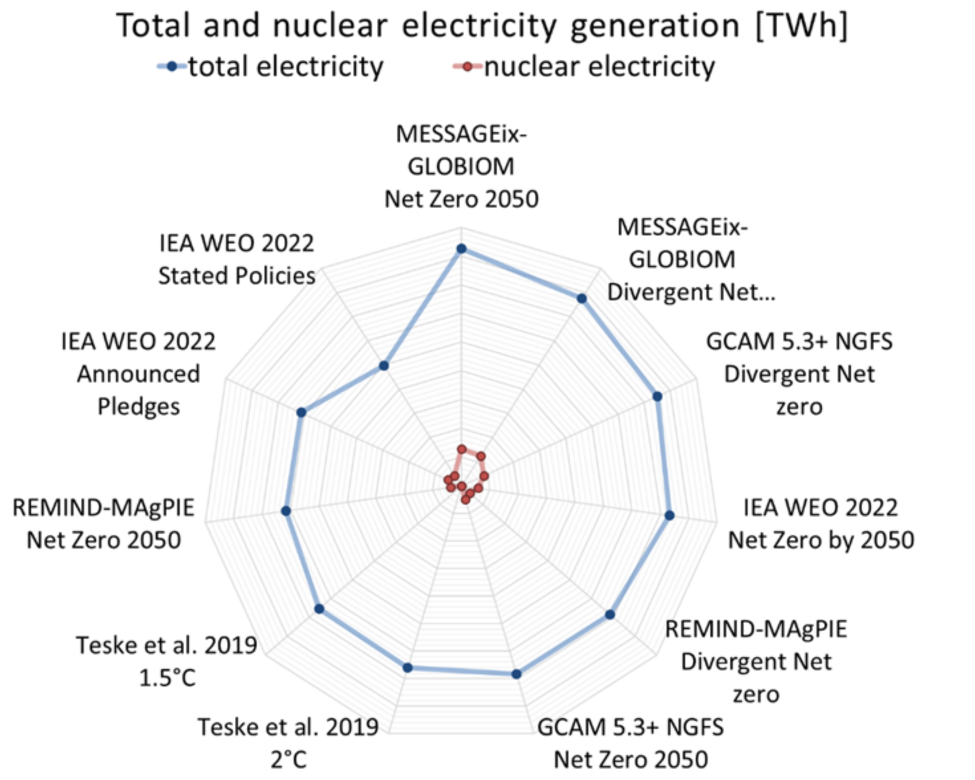
The scenario Teske et al. 2019 1.5°C runs parallel to Teske et al. 2019 2°C and is thus barely visible.
Source: data: (NGFS 2022), (Teske 2019), (International Energy Agency (IEA) 2022); own illustration, Öko-Institut e.V.

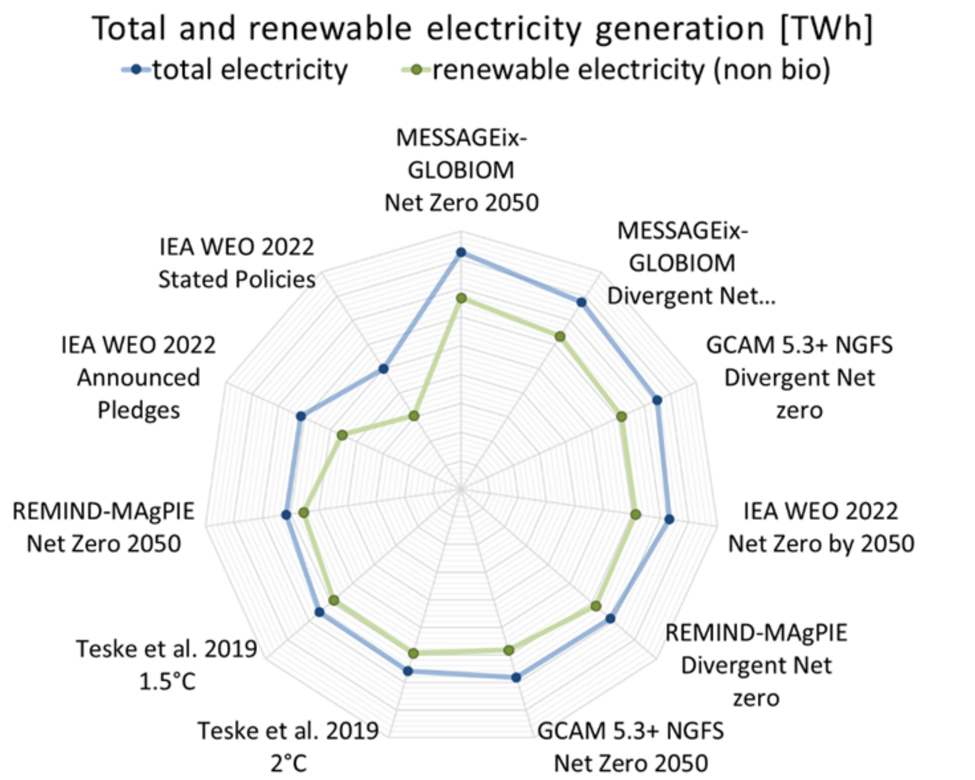
Figure 2: Share of non-biomass renewable (RES) and nuclear (NUC) electricity generation (world) in the scenarios analysed



Source: data: (NGFS 2022), (Teske 2019), (International Energy Agency (IEA) 2022), own calculation; own illustration, Öko-Institut e.V.

Figure 3: World nuclear electricity (top) and renewable electricity (bottom) in 2050 in comparison with total electricity in the scenarios analysed

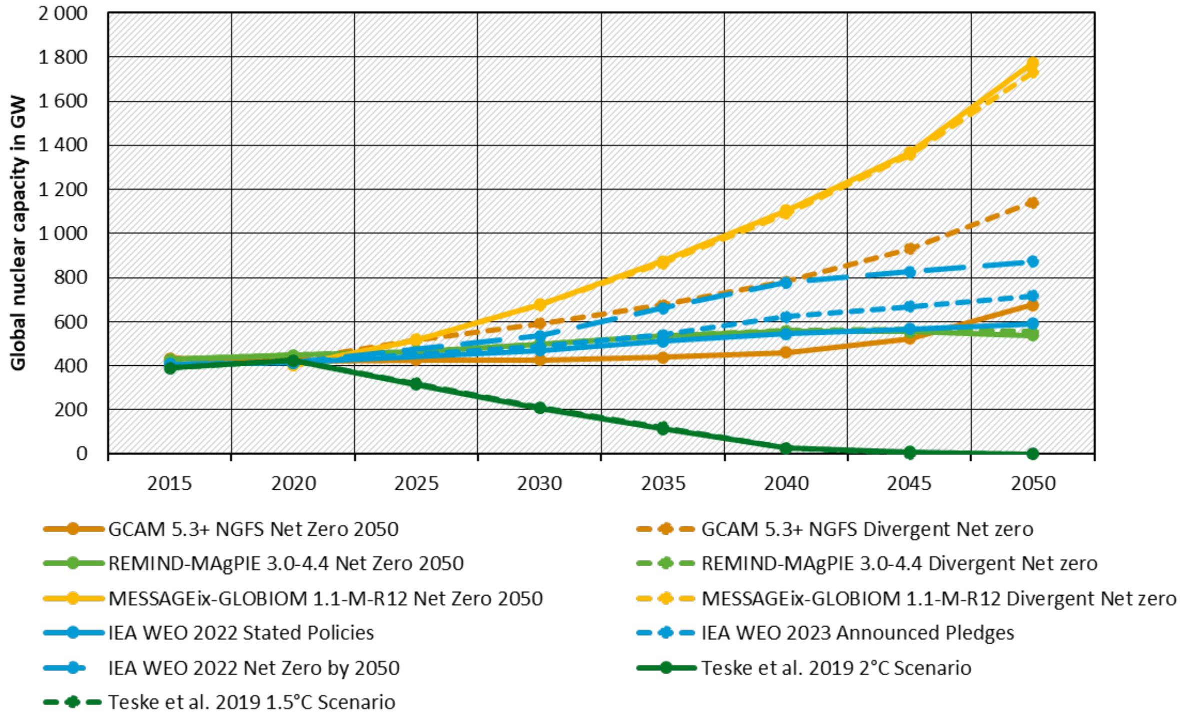




Scale from 0 to 900.000 TWh in units of 100.000

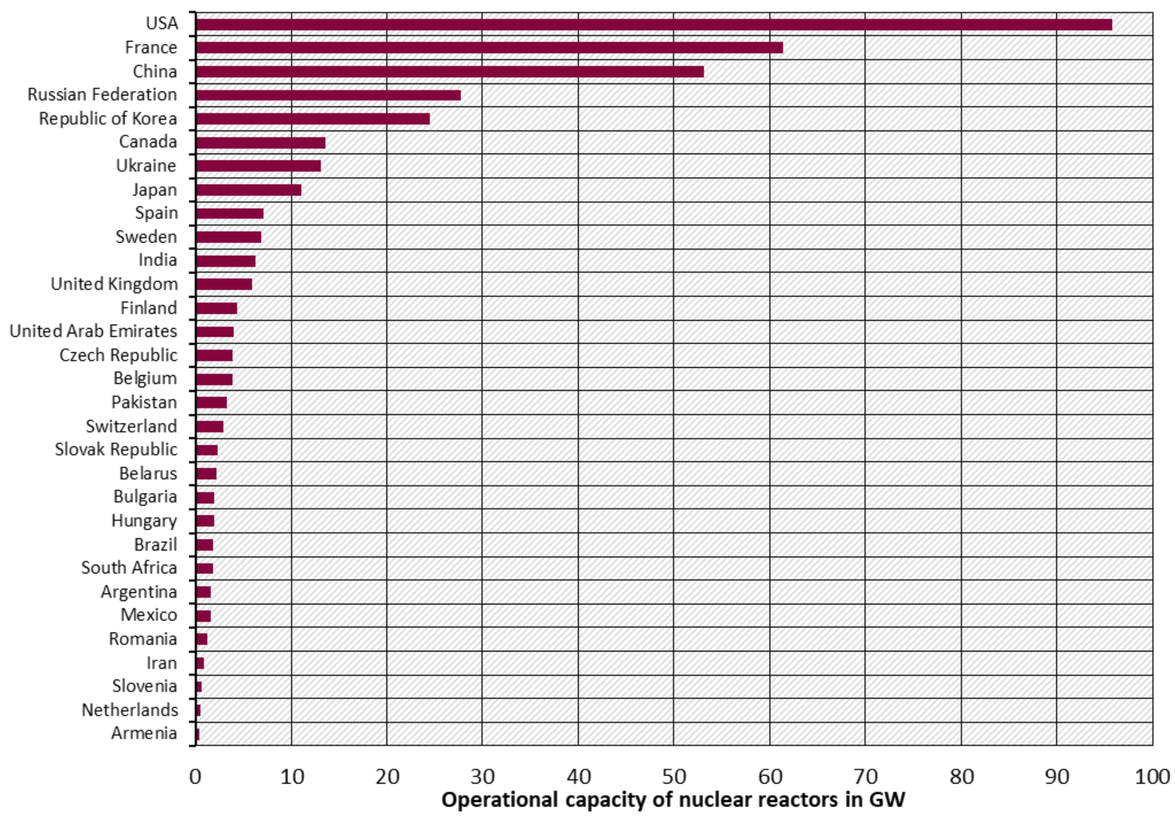
Source: data: (NGFS 2022), (Teske 2019), (International Energy Agency (IEA) 2022); own illustration, Öko-Institut e.V.

Figure 4: Installed capacity of nuclear reactors (world) in the scenarios analysed



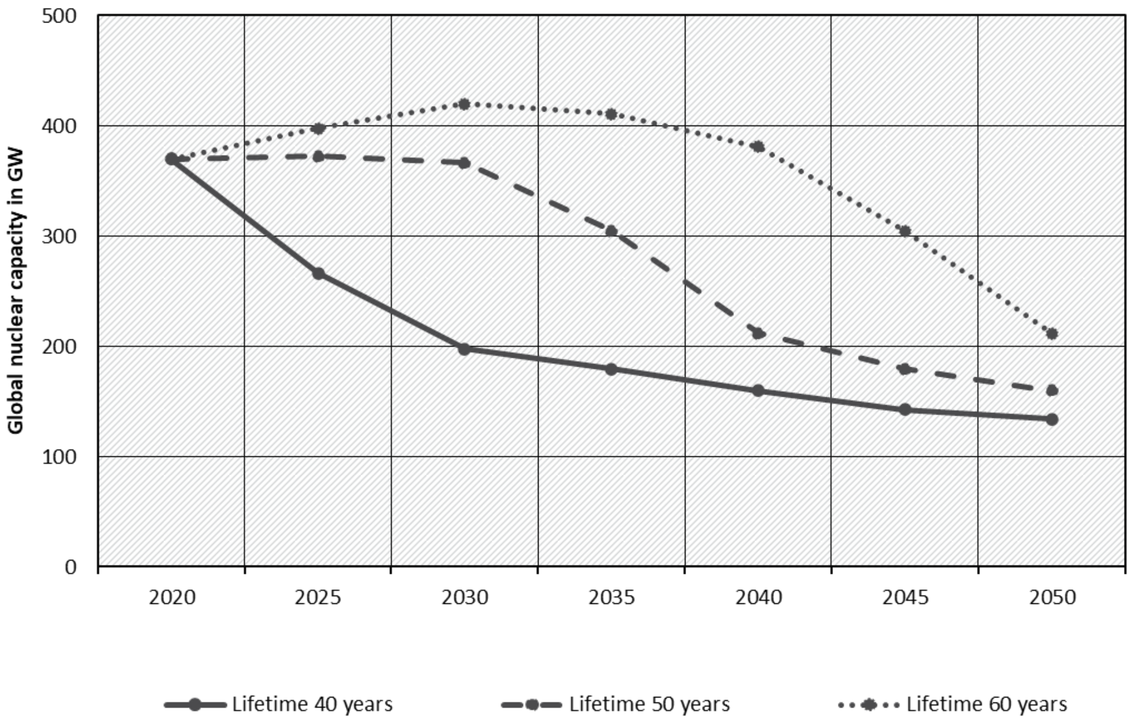
Source: data: (NGFS 2022), (Teske 2019), (International Energy Agency (IEA) 2022); own illustration, Öko-Institut e.V.

Figure 5: Operational capacity of nuclear reactors as of 20 November 2023 worldwide by country



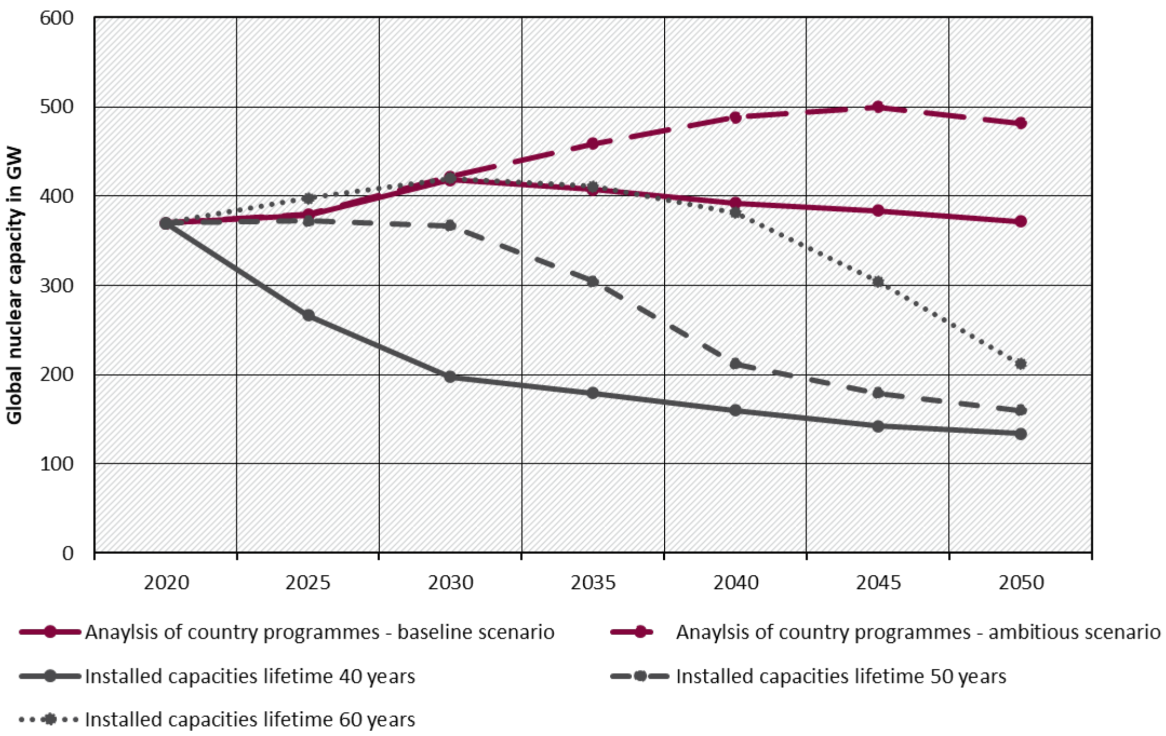
Source: data: (International Atomic Energy Agency (IAEA) 2023); own illustration, Öko-Institut e.V.

Figure 6: **Development of global nuclear capacity (installed and under construction) depending on different lifetime assumptions**



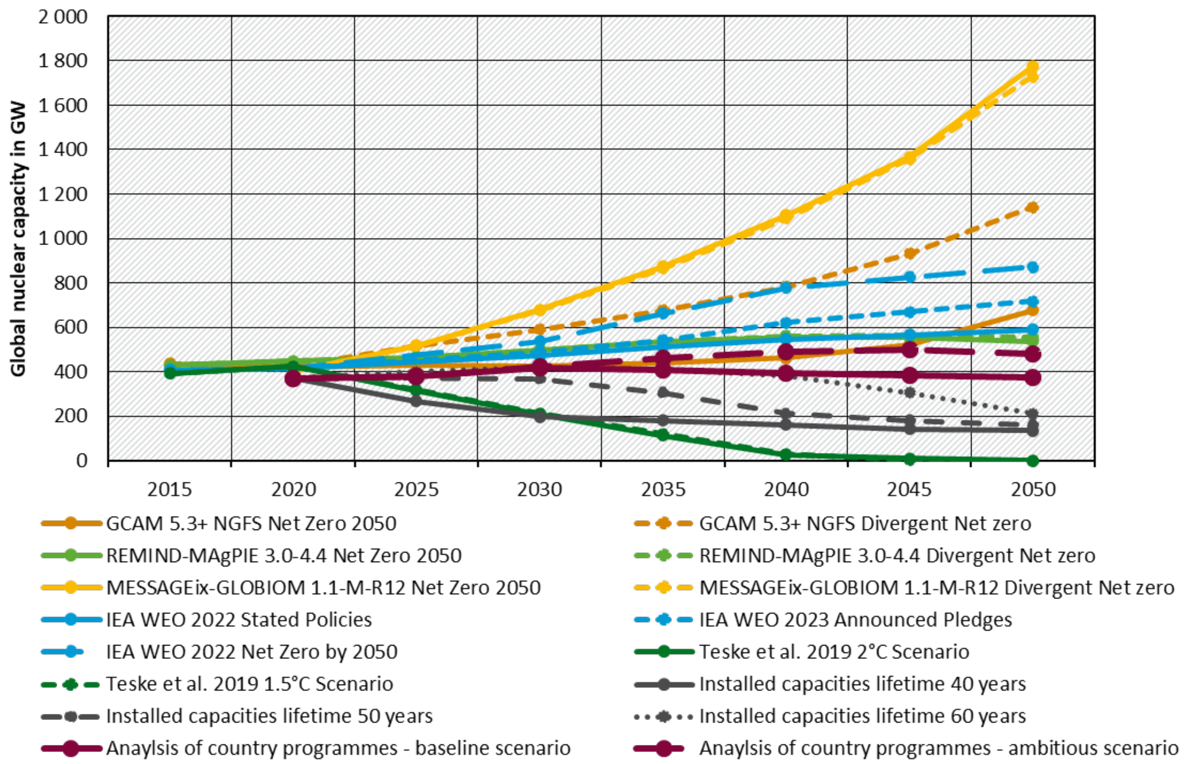
Source: data: (International Atomic Energy Agency (IAEA) 2023), own calculation; own illustration, Öko-Institut e.V.

Figure 7: **Development of global nuclear capacity according to an analysis of government programmes worldwide in comparison with the development of current capacity (including those under construction today)**



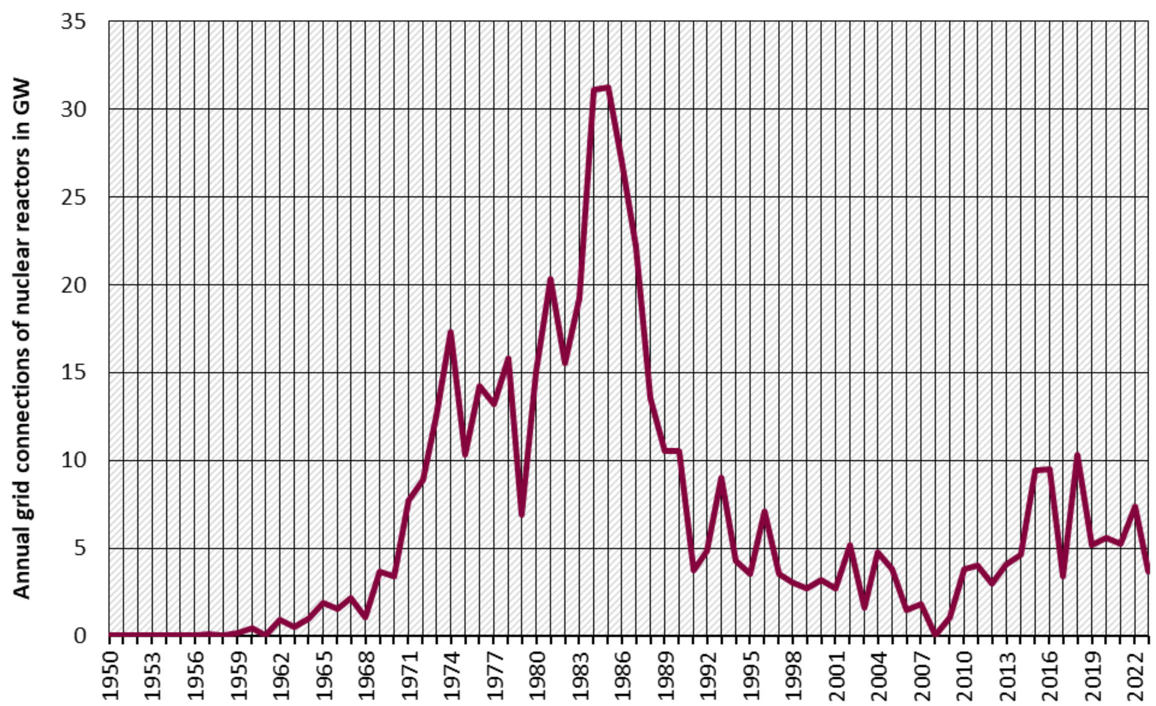
Source: data: (International Atomic Energy Agency (IAEA) 2023), own calculation; own illustration, Öko-Institut e.V.

Figure 8: Development of global nuclear capacities according to an analysis of government programmes worldwide and current capacities (including those under construction today) in comparison with climate scenarios



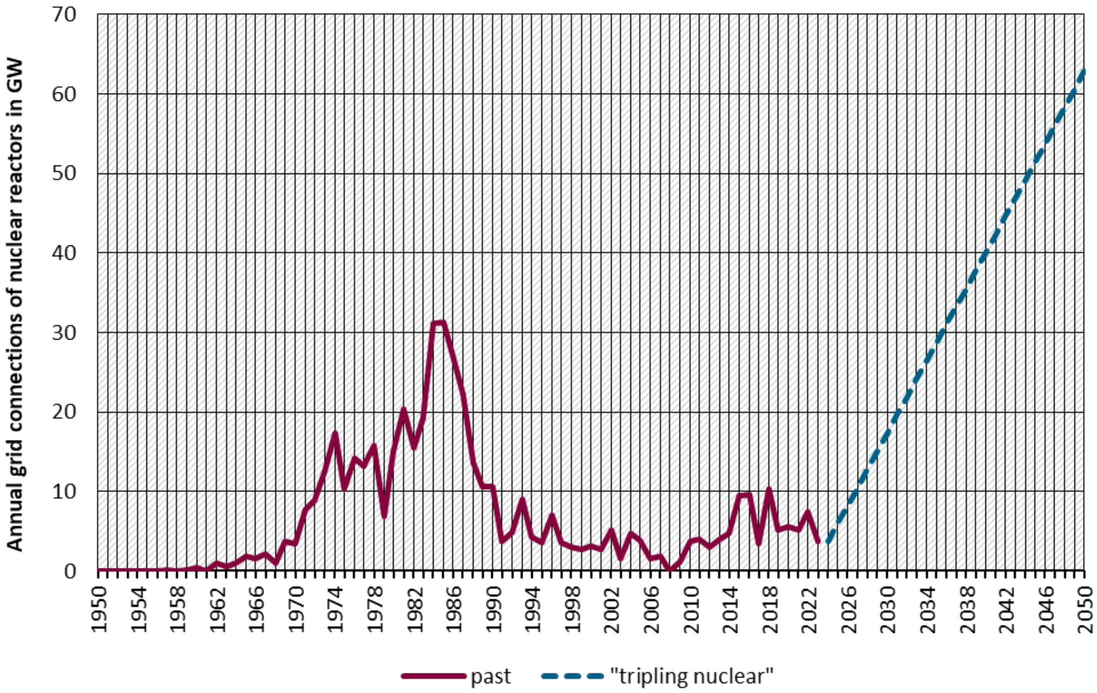
Source: data: (NGFS 2022), (Teske 2019), (International Energy Agency (IEA) 2022), (International Atomic Energy Agency (IAEA) 2023), own calculation; own illustration, Öko-Institut e.V.

Figure 9: Annual grid connections of nuclear reactors worldwide 1950 - 2022



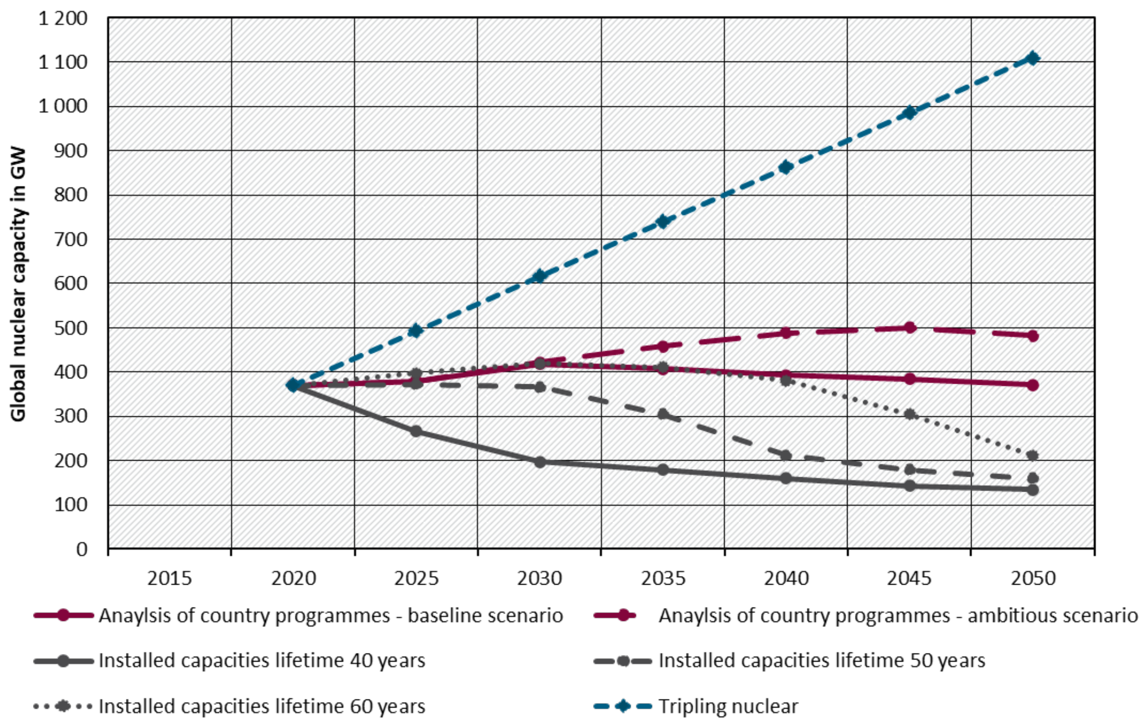
Source: data: (International Atomic Energy Agency (IAEA) 2023); own illustration, Öko-Institut e.V.

Figure 10: Future annual grid connections of nuclear reactors worldwide necessary for "tripling nuclear" in comparison with past annual additions



Source: data: (International Atomic Energy Agency (IAEA) 2023), own calculation; own illustration, Öko-Institut e.V.

Figure 11: "Tripling nuclear" compared to the development of global nuclear capacities according to an analysis of government programmes worldwide and current capacities (including those under construction today)



Source: data: (International Atomic Energy Agency (IAEA) 2023), own calculation; own illustration, Öko-Institut e.V.

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Imprint

Publisher

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Completion: November/2023

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As part of the research project „Klimawirkung von Atomkraft auf Basis einer (empirischen) Analyse der THG Emissionen entlang der gesamten Wertschöpfungskette “ (FKZ 3722 41 5080).

Edited

Section V 1.2 Climate and Energy Strategies and Scenarios

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The responsibility for the content of this publication lies with the author(s).