Nuclear Technology Development and Economics
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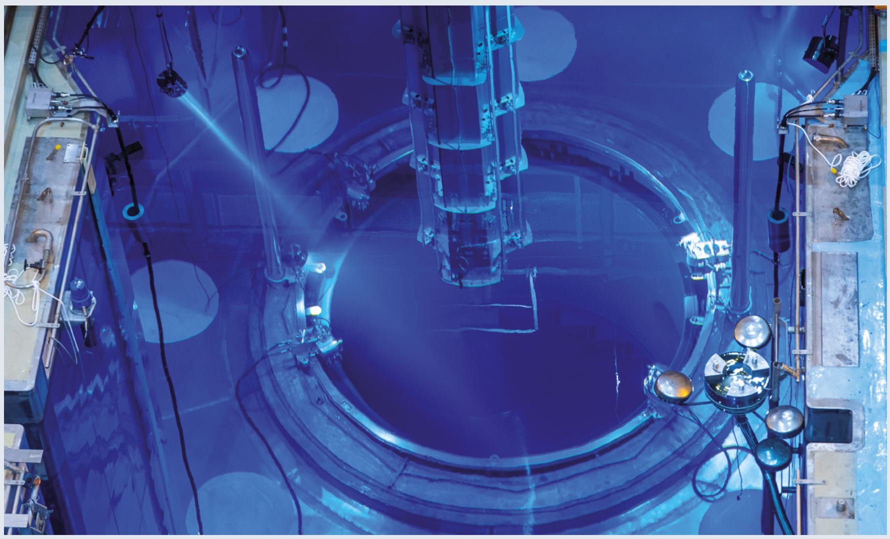

SMRs for Replacing Coal

Opportunities and Challenges for Small Modular Reactors

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Nuclear Technology Development and Economics

SMRs for Replacing Coal: Opportunities and Challenges for Small Modular Reactors

NEA No. 7732

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- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

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Foreword

The global transition away from coal presents a unique opportunity to replace ageing, high-emission infrastructure with clean, reliable, and resilient energy systems. Many countries are considering using nuclear energy – especially small modular reactors (SMRs) – to repower or repurpose former coal plant sites.

This report explores the technical, economic and policy pathways for coal-to-nuclear transitions, combining geospatial analysis with real-world industry insights. It identifies a substantial global addressable market and outlines the conditions needed to realise these opportunities.

By reusing existing assets and supporting communities through this transition, coal-to-nuclear replacement can deliver climate benefits, energy security, social and economic value. This report aims to inform and guide stakeholders on this opportunity.

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Executive summary

A note on the analysis: The data presented in this report was compiled in 2023 and analysed in 2024 and 2025. Since 2023, some energy policies in member countries have changed. These changes are not reflected in the data analysis.

Assuring affordable, clean, reliable, resilient and secure energy supplies and electricity infrastructure remains a top priority for all countries. This is particularly true as countries undergo a massive transition in energy and electricity infrastructure to increase the sustainability and security of their domestic energy supply. A major result of this transition is the shift from coal-fired electricity generation to other technologies in many countries.

Coal has long been the dominant form of electricity generation due to several advantages: its high energy density, abundant supply and low technical requirements. Throughout the 20th century it was one of the most affordable, most reliable and most transportable sources of energy apart from oil and served as the backbone of energy production for many economies. Coal was an accessible source of energy for countries seeking to industrialise, or for industrialised countries seeking to expand their energy capacity. As baseload, coal plants operate most efficiently when they can operate constantly over long periods of time.

However, since the early 2000s, coal has seen its advantages diminish and has begun to lose its dominant position as an energy source. While still the global leader in terawatt hours (TWh) of electricity generation, coal usage has declined. This is due to several factors: i) coal is no longer the cheapest form of energy production in many parts of the world; ii) coal use has been reduced by environmental regulation in many countries; and iii) most coal infrastructure is ageing, with the average global coal plant age being 22 years. With ageing infrastructure, utilities and governments have opportunities to invest in newer, more efficient, less expensive and cleaner technologies. These technologies include natural gas, advanced geothermal, novel hydro, renewables, and nuclear energy.

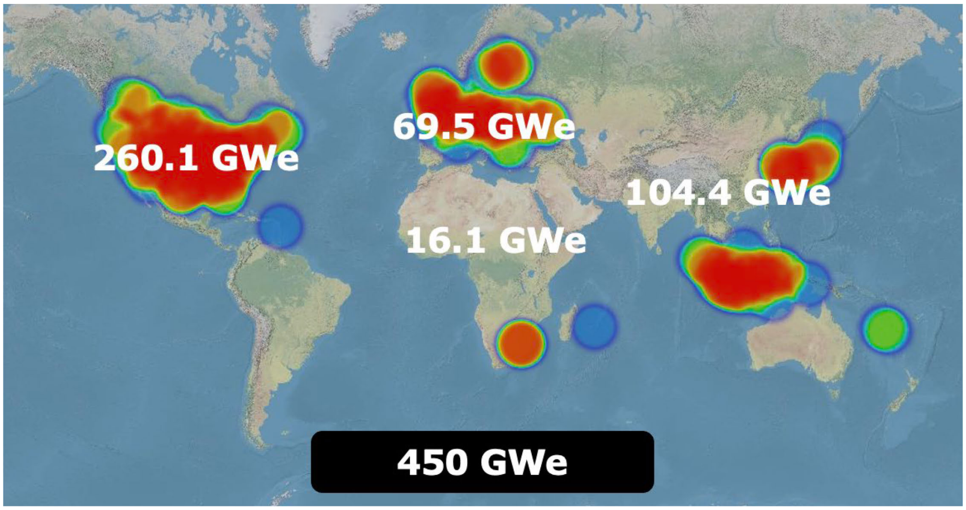
The decline in coal electricity production comes with several challenges. First is a loss of baseload energy. While systems with high levels of dispatchable and variable energy resources require less baseload, a large body of research has identified baseload as a key component in reliable and resilient energy systems. In the case of extreme weather events or stressed energy systems, baseload sources such as coal, nuclear energy and hydropower are often the last to fail and the first energy sources to restart after the loss of power from the grid (what is technically known as “black start capabilities”). In addition to their resilience and reliability benefits, coal plants are sources of stable, well-paying jobs for the communities in which they are located. The micro-economies of such communities are often built around the central coal plant, which provides jobs, tax revenue and certain social benefits to the community (though smog and pollution can also have negative social consequences). Finally, while coal plants themselves are ageing, many of the infrastructures and legal frameworks supporting these coal plants are still valuable. Water cooling systems, grid interconnections, and site environmental and land-use licenses often still have decades of usable life that would be wasted were the coal plant to shut down and not be replaced with other energy generation technologies.

One way to address the gaps left by coal plant shutdowns is to replace coal generation with nuclear generation. Replacing coal plants with nuclear power plants, while reusing as much infrastructure and site licensing as possible, provides benefits such as retaining baseload power generation sources, providing jobs and revenue to the local community, and reducing emissions and smog. The amount of infrastructure and cost savings from a coal-to-nuclear replacement will be site-specific but generally the cost of new nuclear power installation will be reduced.

To help countries and utilities understand the potential for coal-to-nuclear replacement, the Nuclear Energy Agency (NEA) conducted analysis to estimate the addressable market opportunities. This analysis consisted of two parts. First, a geospatial analysis was conducted: Using the Global Energy Monitor from 2023 (GEM, 2023a), the total number of coal installations was estimated. Then, a series of filters were utilised to down select from total global coal capacity to coal capacity that could realistically be transitioned to nuclear energy by 2035, 2040 and 2050. This analysis produced an estimate of coal capacity that could be transitioned to nuclear energy, as well as of which countries have the highest likelihood of transitioning rapidly from coal to nuclear power. Second, an international group of subject matter experts and end users of energy generation technologies was assembled. These experts were surveyed and interviewed to better understand the technical and non-technical requirements of transitioning coal installations to nuclear installations. In this report the potential for coal-to-nuclear transitions will focus on small modular reactor (SMR) technologies; however, large-scale nuclear energy also has a potential role to play in this transition.

From the geospatial analysis it was estimated that there are 2.2 TWe of coal power globally. Of this, 450 GWe of coal capacity was estimated to be of high priority to transition from coal to nuclear technologies by 2050. The primary regions where this technology transition could occur are Asia, Europe and North America. This was calculated using several filters that were representative of the countries' or utilities' policies, experience with nuclear energy, and coal plant age.

Figure ES1: **Country breakdown of the total potential market estimate**



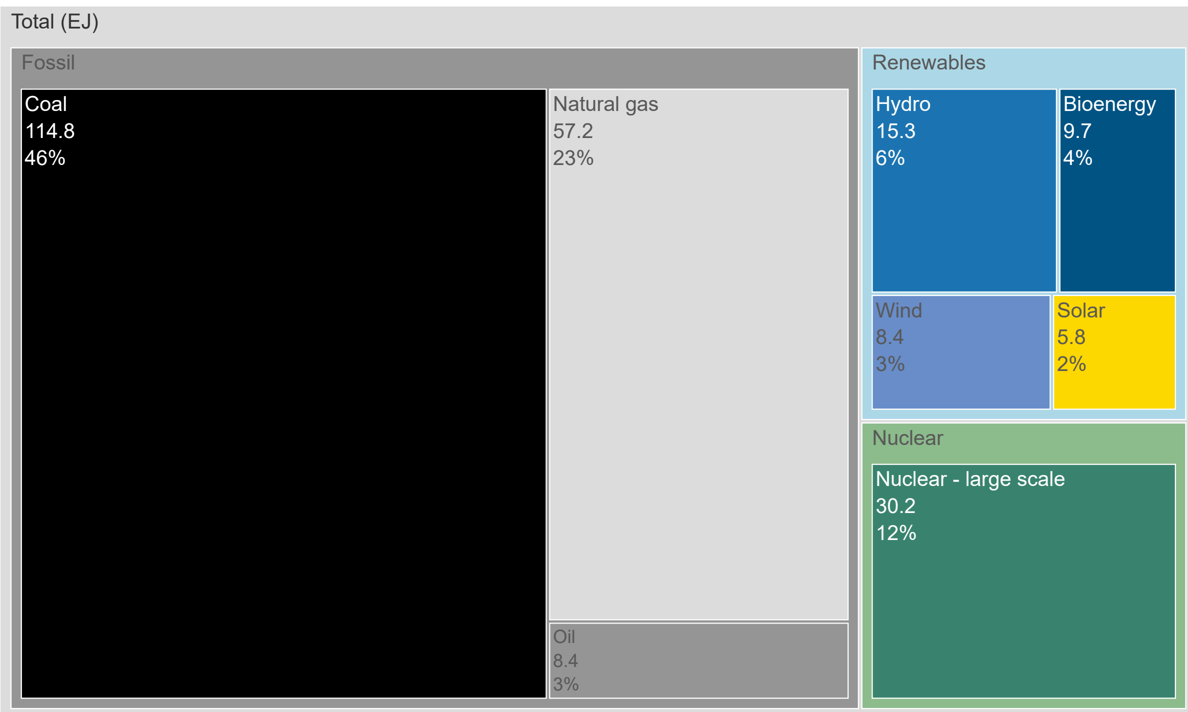
Along with the capacities estimated by the geospatial analysis, subject matter expert surveys and interviews were conducted. These interactions were focused on regions with a high priority for coal-to-nuclear replacement opportunities and were designed to discover the technical and non-technical barriers to this replacement. From the surveys and interviews it was clear that while many organisations were interested in coal-to-nuclear replacement, they did not want to be "first movers" in this space. Being a first mover here was regarded negatively due to the risks associated with first-of-a-kind construction, and the opportunity to adopt the technology after others had proven it was desirable. This led to consensus among those surveyed that there was an important role for government in reducing risk and speeding or demonstrating coal-to-nuclear replacements.

As coal continues to be phased out in favour of other more cost-effective and sustainable resources, nuclear energy is a viable technology for replacing coal power plants while utilising some of the same infrastructure and site permits and licensing. As many countries implement their domestic policies to decarbonise, coal-to-nuclear replacements present a unique opportunity to maintain the existing baseload, grid infrastructure and workforces to provide affordable, clean, reliable, resilient and secure energy for decades to come. Adding to the existing body of work on this topic, this report uses geospatial and expert analysis to identify global opportunities, barriers and potential roles for industry and government to facilitate this transition.

Chapter 1. **Introduction**

Coal is the largest source of electricity production globally. Figure 1.1 shows the energy (in exajoule [EJ]) produced annually by unabated coal plants in 2024 globally. With tightened regulation in many countries, and many plants approaching the end of their operations due to age, the global coal fleet is being replaced by other energy sources. In response, nuclear energy has emerged as a viable alternative to coal due to its ability to produce large amounts of electricity. This report explores the technical requirements, addressable market and end-user perspectives of replacing coal with nuclear energy, examining the economic, environmental and technological factors driving this transition. This report also highlights the remaining challenges and opportunities for coal-to-nuclear replacement.

Figure 1.1: **Global power sector inputs EJ**



Source: NEA figure based on IEA World Energy Outlook (IEA, 2024).

Coal power retirements

Coal power plant retirements are being driven by three main factors: age, national policies and competitiveness.

- **Age**: Ageing coal assets are more likely to be replaced as they are largely amortised and potentially close to the end of their useful operational period.

- **National regulation and policies**: Replacing coal with low-carbon electricity is a priority in countries with net zero commitments.
- **Competitiveness**: Depending on the market, coal assets are becoming less economical compared to gas-fired power plants and other technologies. This is driven primarily by more stringent environmental standards requiring retrofits, carbon pricing and cheaper alternatives.

The potential of nuclear energy to replace coal

Nuclear energy comes in several types but is generally divided by the size of the reactor capacity in megawatts (MW) or gigawatts (GW) and often denoted by thermal or electrical end use: Megawatts thermal (MWth), megawatts electric (MWe), gigawatts thermal (GWth), or gigawatts electric (GWe). Generally, “large scale” reactors are gigawatt scale reactors, while small reactors or microreactors are generally less than 300 MWe. Small modular reactors (SMRs) represent a promising class of nuclear reactor that are designed to be small and manufactured modularly, often in a factory, to reduce system costs.

Nuclear energy offers some attractive features for coal replacement. These reasons, briefly summarised here, have been written about in numerous publications (DOE, 2024; GAIN, 2024; Jenson, 2023; Hansen, 2022). Reasons for considering nuclear energy as a coal plant replacement include:

- **Immediate emissions reduction**: Countries can achieve immediate and long-term emissions reductions due to power generation by replacing coal plants with nuclear energy plants.
- **Workforce transition**: For many communities, coal plants and large power assets represent a source of steady jobs and sustainable tax revenue. Part of the reason for replacing coal plants rather than starting with greenfield builds is to preserve the communities, workforce, and way of life surrounding such facilities. Nuclear energy offers a similar level or more significant opportunity for workforce retraining while maintaining a high standard of living for those workforces serving the facilities.
- **Baseload or dispatchable load replacement**: Large nuclear power plants often operate in a baseload operating regime. SMRs are known and valued for their flexible operations. In either case, the nuclear replacement for a coal asset can operate as the coal plant did as baseload, or as a dispatchable resource to provide grid reliability and reduce overall energy prices.
- **Grid compatibility**: While not true in all cases, often assets such as grid interconnections and site permits can be reused for nuclear infrastructure when replacing coal assets. This compatibility between existing grid infrastructure and new nuclear assets can provide valuable opportunities for coal replacement. While it is not always the case that grid assets can be reused, it is possible some of the time (Hansen, 2022).
- **Reliable power**: Nuclear energy operates on an 18-to 24-month refuelling cycle and, during its uptime, produces reliable energy that can be valuable for baseload or dispatchable operations. While no energy source is completely immune from all exogenous events (e.g. natural disasters), nuclear energy and its high safety factors mean the nuclear power plant can often supply energy even during crises.
- **Long-term cost savings**: Although nuclear energy has a high upfront capital cost, when that cost is distributed over 40, 60 or 80 years, the cost of energy produced can be quite low and competitive with other energy resources, especially when considering the national security, reliability and resilience benefits provided by nuclear energy.
- **Public health benefits**: Most discourse around coal replacement has focused on the impacts on global CO_2 emissions. However, many coal plants also produce harmful aerosols such as nitric oxide (NOx) and sulfur dioxide (SO_2) that can harm local

populations. Nuclear energy emits no such aerosols and can, therefore, be a positive replacement for coal assets, especially in areas where air pollution is a problem.

- **Stable fuel supply and national security**: As has been evidenced by contemporary geopolitical challenges, fossil supply chains can also be subject to volatility in prices and supply depending on their source and geopolitical tensions. Because of the long refuelling cycle and multiple sources, uranium fuel can often have a steadier price and provide energy and national security. Uranium fuel for nuclear energy can also be stockpiled in reasonable amounts when desirable to the country, providing national energy security.
- **Support for renewable energy integration**: As renewable energy increases in its deployment globally; nuclear energy has a valuable role to play in providing a backstop or dispatchable energy to support variable renewable energy sources such as wind and solar photovoltaics (solar PV). By having alternative dispatchable energy resources, daily or seasonal variations in production can be complemented with nuclear energy, reducing the need for costly energy storage solutions.

Based on shared characteristics and the need to replace existing coal assets, nuclear energy could have an important role to play in coal plant replacement.

Objectives of this report

This study aims to inform decision makers about the main drivers, timelines, addressable markets, and end-user perspectives for coal replacement with nuclear energy and focuses on the following areas:

- **Consolidating technical and non-technical requirements**: To achieve a successful transition from coal to nuclear technologies, there are many technical and non-technical requirements that must be met. This publication gathers some of the high-level technical and non-technical requirements for a coal-to-nuclear transition through a literature review conducted in Chapter 2. Technical requirements involve adapting existing infrastructure to support nuclear technology, providing adequate safety systems for nuclear technology, and ensuring environmental compliance. These technical requirements can be met through site assessments, workforce training, integration of cooling systems and addressing potential environmental impact. Non-technical considerations include a focus on regulatory approvals, securing funding and public acceptance. These can be addressed through appropriate studies, effective stakeholder communication, and addressing concerns around safety, waste management and long-term sustainability.
- **Global potential addressable market analysis**: Chapter 3 of this study aims to provide a global estimate of the total market for coal replacement with nuclear energy, assessing the potential market and how it could change under different assumptions and policy considerations. To do this, the global energy monitor was used alongside a set of filters identifying countries with favourable conditions (i.e. adherence to international non-proliferation rules, existing nuclear fleets, climate policies) to identify the realistic potential addressable market available to nuclear energy. This addressable market is present along several time frames to help guide investment into countries with the largest opportunities for coal-to-nuclear replacement.
- **Exploring end-user perspectives**: Understanding the drivers and concerns of end users that have the potential to adopt nuclear energy for coal replacement is key. To this end, a survey was conducted of end users to include considerations from the final customers of coal and potentially nuclear energy to better understand their requirements and main drivers in the decision-making process leading to the final investment decision. The survey explored end-user opinions of nuclear technologies, perceived risks, understanding of economic benefits, and environmental considerations. The results of the survey are presented in Chapter 4.

- **Policy opportunities**: Governments play a crucial role in the adoption of coal-to-nuclear technologies by implementing policies that incentivise nuclear adoption. Domestic and international agreements can facilitate the sharing of nuclear technology, safety standards, and regulatory practices. Exploring policy frameworks that encourage investment in nuclear infrastructure, streamline regulatory processes and ensure environmental protection is essential to overcoming the barriers to the transition. The report summarises the analysis and relevant findings into policy recommendations for decision makers seeking to deploy nuclear energy as a coal replacement.

Chapter 2 of this report focuses on a literature review of coal and of the technical and non-technical requirements of coal-to-nuclear replacement. Chapter 2 includes data on the ageing, climate impacts, and cost-competitiveness of coal plants, a primer on system costs and a brief discussion of baseload and human implications of losing coal energy. This chapter is meant as an introduction and can be skipped by those deeply familiar with coal-to-nuclear background information.

Chapters 3 and 4 provide the new analysis conducted for this report. Chapter 3 focuses on the analysis of down selecting coal plants using market screening criteria to identify the real-world addressable market potential of coal-to-nuclear replacements. The work presented in Chapter 3 is summarised in a series of maps and tables that estimate the GW capacity of coal that could realistically be transitioned to nuclear based on filters that include adherence to the Treaty on the Non-Proliferation of Nuclear Weapons verified by the IAEA, nuclear phase-out plans, existing nuclear capacity, net zero commitments, coal phase-out policies, coal fleet age and utility experience with nuclear energy. By applying these filters, the addressable market can be divided into time frames by 2035, 2040 and beyond 2040. Special attention is given to regions with large existing coal fleets not identified by this analysis to provide the reader with some insight as to why these markets are not now addressable, and when in the future they will become addressable for nuclear replacement.

Chapter 4 details the results of a survey and tailored interviews that were conducted of end users on whether and why they are considering nuclear energy as a replacement for operating coal facilities. As identified by end users, there remain several challenges for coal-to-nuclear replacement. These include timeline mismatch, availability of nuclear expertise, and a desire to be a follower rather than a first mover with such a replacement. Along with challenges, opportunities were also identified by the end users, including synergies between the coal and nuclear sectors and the role of governments in incentivising coal-to-nuclear replacement. These incentives can be economic (i.e. tax incentives or subsidies) or non-economic (i.e. streamlining regulatory frameworks). In either case they can work to move capital and resources into coal-to-nuclear transitions.

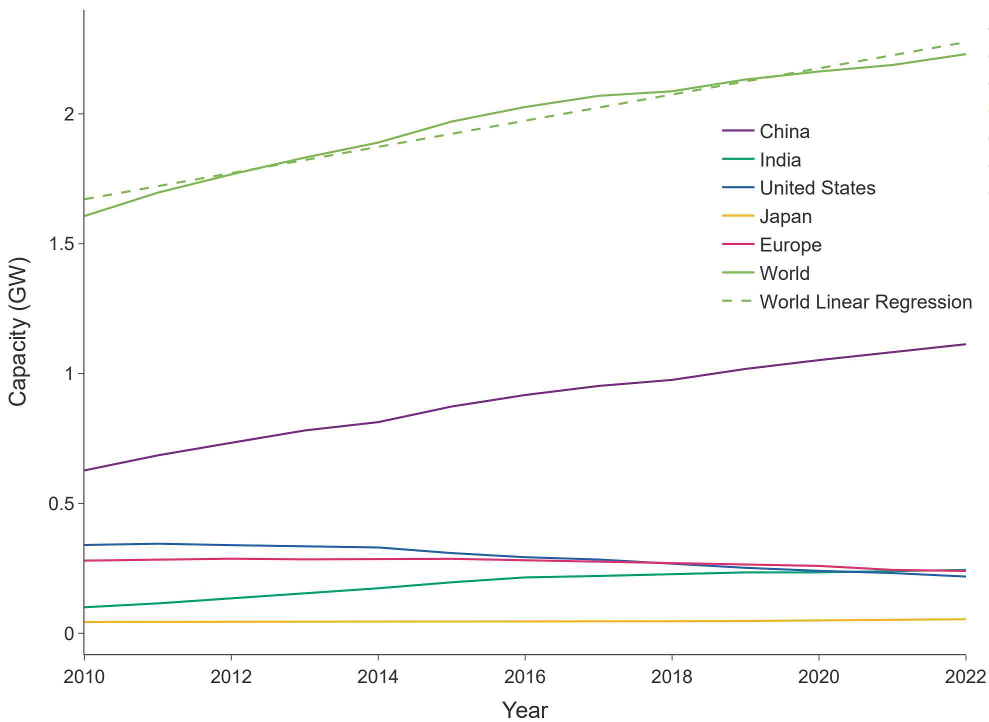
Chapter 5 lays out the conclusions and final thoughts of this report as supported by the analysis conducted. Headline conclusions from Chapter 5 include the importance of public-private partnerships in developing and promoting coal-to-nuclear transitions for all the benefits laid out in the report. Ultimately this work seeks to pave the way for a more sustainable energy future by providing new information for those seeking to better understand the opportunities and challenges associated with the coal-to-nuclear transition.

Chapter 2. Coal power today, nuclear replacements primer, and technical requirements of coal replacement

Coal remains the largest source of electricity generation globally (IEA, 2023). As of 2023, coal electricity generation amounted to around 10 000 TWh, which represents 35% of the total electricity generated worldwide. The installed operating capacity (see Figure 2.1) is primarily concentrated in four countries: The People's Republic of China (960 GW), India (210 GW), the United States (194 GW), and Japan (52 GW) (Energy Institute, 2024). These countries together account for approximately 75% of the total installed capacity, with China alone concentrating over 50% of the operating coal assets (Ember, 2023). The last decade has shown an increasing trend in terms of installed capacity – albeit expanding at a slower rate than in previous decades. This is due to two trends: First, coal growth has been driven by construction of new coal plants in China and India. In China, coal has grown by 65% and in India coal has grown by over 100% since 2010. Second, coal has been steadily retired in Europe and the United States.

The power sector is the largest consumer of coal globally, accounting for around 70% of total coal demand. Coal is also used in other sectors such as the steel and concrete industries, which represent 15% of coal demand. The remaining coal demand is from building heating and other industries (IEA, 2022a).

Figure 2.1: **Evolution of coal generation**



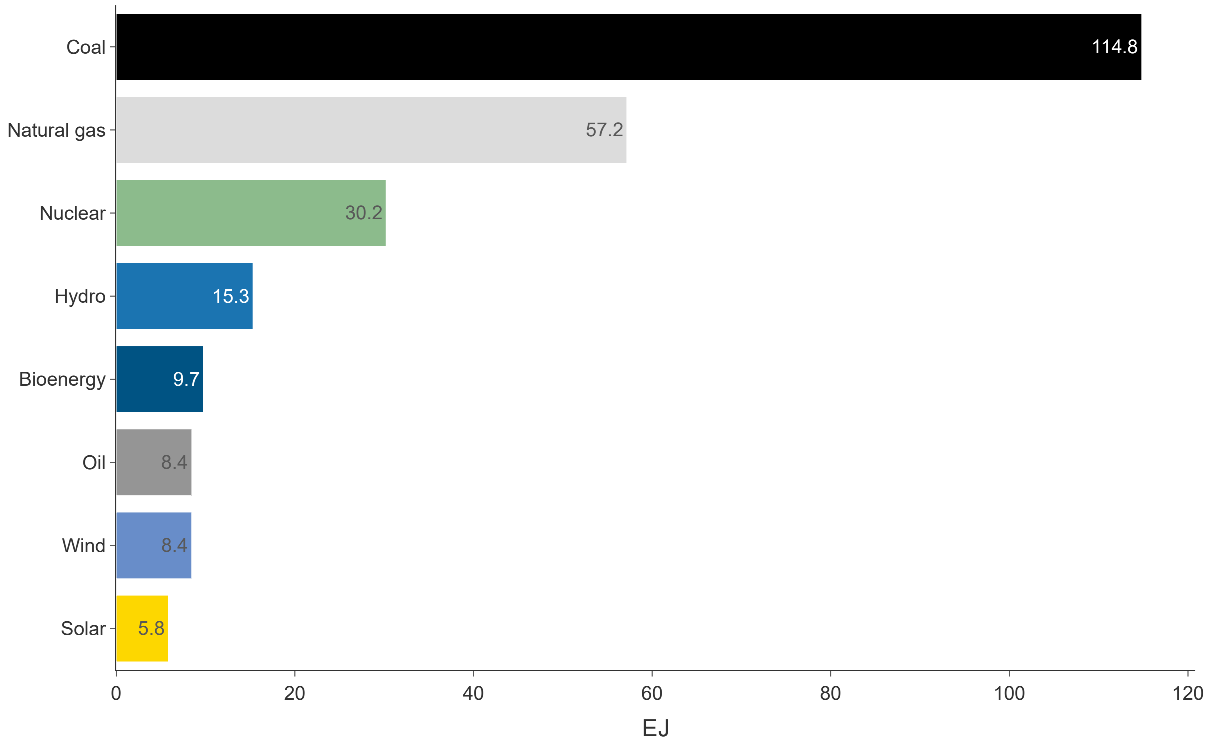
Source: NEA analysis based on Global Energy Monitor (Global Energy Monitor, 2023).

Note: Europe region includes EU 27 countries and Iceland, Norway, Switzerland and the United Kingdom.

Coal remains the single largest source of carbon emissions, estimated to be approximately 15 $GtCO_2$ annually (IEA, 2022b). Due to carbon reduction policies in many countries, an ageing fleet, and the availability of alternative technologies, OECD countries are leading on coal powered retirements. Figure 2.3 shows the change in coal generation by country and Figure 2.4 shows the average coal plant age by country.

As was mentioned in Chapter 1 of this report, coal is being replaced for three primary reasons: age, national regulations and competitiveness. Where it is being replaced it is often replaced with a combination of variable renewable energy and natural gas capacity. This makes sense from a least cost economic perspective as these are the lowest cost resources on a levelised cost of energy basis, but it leaves out several key considerations: system costs, land efficiency, baseload power needs, and human capital in a just transition.

Figure 2.2: **Coal share in global electricity generation**



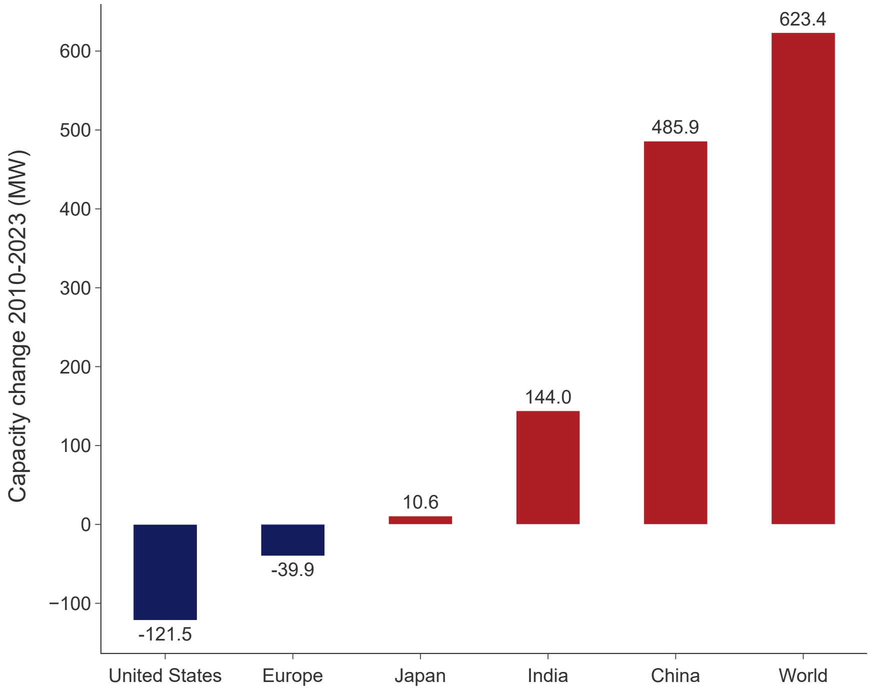
Source: NEA figure based on IEA World Energy Outlook (IEA, 2024).

Ageing

As of 2023, global coal power infrastructure has an average age of 22 years when calculated using the Global Energy Monitor (Global Energy Monitor, 2023). China and India, which together represent more than 60% of global coal power capacity, have operational assets with average ages of 14 and 17 years, respectively. This contrasts with the situation in Europe and the United States, where the average age exceeds 40 years (Global Energy Monitor, 2023).

Currently, approximately 250 GW of coal assets are older than 40 years, constituting about 15% of the total global coal power capacity. North America possesses more than 50% of this capacity, followed by Europe (30%) and Asia (7%). In terms of the top five countries with ageing coal assets, the United States is the leader with 136 GW. The remaining ageing coal capacity is primarily located in countries like Poland, Russia, South Africa and Ukraine.

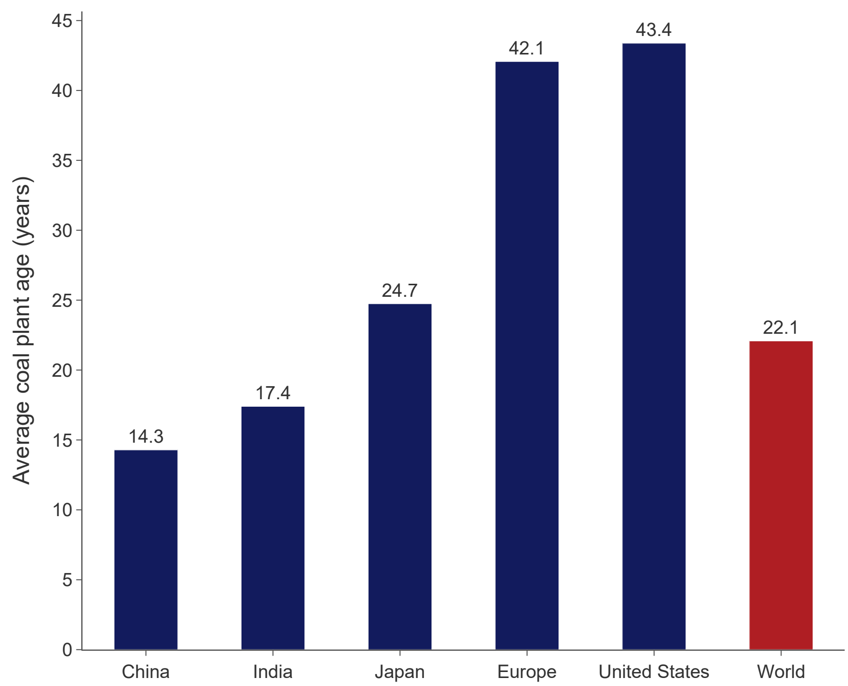
Figure 2.3: **Global coal power generation change by country from 2010 to 2022**



Source: NEA analysis based on Global Energy Monitor (Global Energy Monitor, 2023).

Note: Europe region includes EU 27 countries and Iceland, Norway, Switzerland and the United Kingdom.

Figure 2.4: **Global coal power generation average age by country (for top five countries)**



Source: NEA analysis based on Global Energy Monitor (Global Energy Monitor, 2023).

Note: Europe region includes EU 27 countries and Iceland, Norway, Switzerland and the United Kingdom.

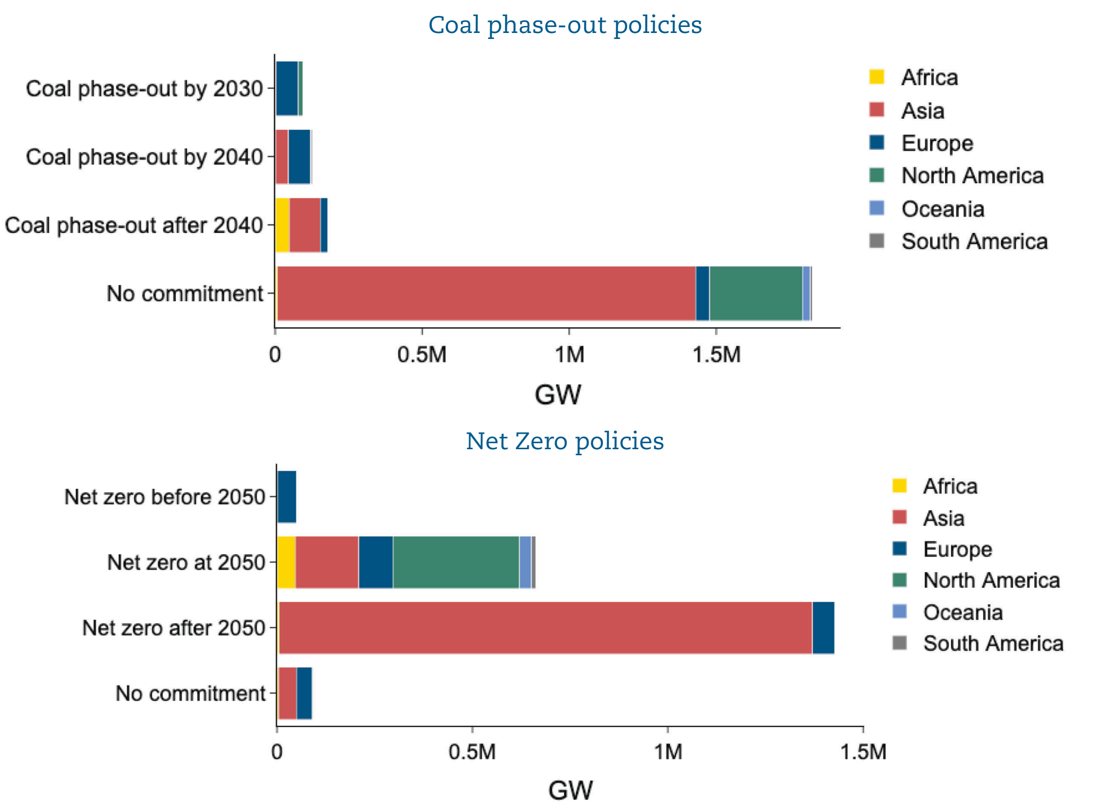
National regulation and policies

For countries with policies and regulations to reduce carbon emissions, retiring coals plants is one of the main strategies being implemented. According to the IEA Net Zero Energy scenario, all unabated coal-fired plants would be phased out by 2040 unless retrofitted (IEA, 2021). Less efficient models like subcritical coal plants would be retired as early as 2030, followed by the retirement of more efficient technologies such as supercritical, ultra-supercritical, integrated gasification combined cycle (IGCC) and combined heat and power (CHP) units. Retiring subcritical plants by 2030 would mean shutting down between 870 and 940 GW within this decade, equivalent to 125-135 GW every year. This is around four to six times the capacity retired in 2022 (Global Energy Monitor, 2023).

Here government policies have a major role to play. Figure 2.5 shows coal capacity by region that is either under a coal phase-out policy or a net zero policy. The majority of coal capacity is under some type of net zero policy but not under a coal phase-out policy.

Figure 2.5 illustrates that most of installed coal capacity today is found in countries that have no commitment to phase out coal. The majority of this installed coal is found in Asia. Figure 2.5 also illustrates that the majority of installed coal capacity is found in countries with commitments to reach net zero either after 2050 or with no commitments to reach net zero. This creates both a challenge and a potential opportunity: it is a challenge for reaching net zero insofar as no commitment to phase out coal suggests that coal will remain in the energy mix. It is, however, also a potential opportunity, as a policy change in a small number of key countries would make a sizeable difference, creating opportunities for nuclear energy to replace large amounts of coal.

Figure 2.5: **Installed coal capacity in regions with coal phase-out or net zero policies**



Source: NEA analysis based on Global Energy Monitor (Global Energy Monitor, 2023).

Alternative technologies

The viability of coal assets differs regionally and is influenced by policy decisions and the availability of domestic resources. The Carbon Tracker Initiative (CTI, 2018) found that nearly 40% of coal assets were unprofitable, with Europe and the United States being especially impacted.

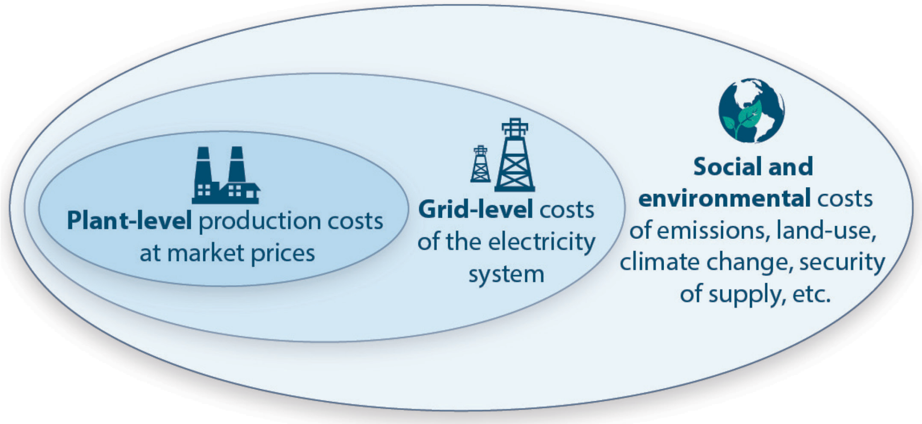
VRE and gas technologies often outcompete coal power in many regions (IEA/NEA, 2020). As VRE becomes more prevalent in energy systems, it both limits coal plant availability and depresses electricity prices, further undermining coal power profitability. In the United States, low natural gas prices exert significant financial strain on coal assets, especially with the potential for coal prices to increase in some regions (EIA, 2022). Meanwhile, coal plants in countries like China, India and Japan hover around the break-even point, being slightly unprofitable in some cases. The United States is also in a spiral of coal retirement, as evidenced by a 55% reduction in coal power generation since 2010. In 2022, the United States led global coal plant retirements with 13.5 GW. The country has been consistently retiring between 7 and 15.3 GW of coal capacity annually between 2018-2022 (based on NEA analysis and the Global Energy Monitor), and forecasts suggest this trend will persist. By 2040, around 70% of the global coal fleet may operate at a loss (CTI, 2018).

Nuclear energy is being pursued by many countries as a coal replacement. Reduced fuel costs, energy security, and resilience benefits make nuclear energy an attractive alternative for countries seeking to phase out coal in support of national energy policies and roadmaps for net zero emissions.

System costs

In evaluating the costs of an electricity system, it is important to consider not just each power plant's costs and levelised costs, but also the costs needed to support each power plant and deliver electricity to end users. These "system costs" include things such as fuel, transmission and distribution infrastructure, and balancing costs. Both coal and nuclear assets are high capital investments. Despite their high capital costs, both coal and nuclear assets help to reduce overall system costs in four key categories (Hirth, 2015; IRENA, 2015; NEA, 2012 and 2019).

Figure 2.6: **Graph of costs in an electricity producing system**



Source: Adapted from NEA (2012).

These four categories of system costs are: profile, balancing, grid and connection costs. Although sometimes connection costs are considered separately, each is important to evaluating the total cost of adopting different energy generation technologies. Each type of system costs are explained below borrowing from *The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables* (NEA, 2019).

- **Profile costs** refer to the increase in the cost at the level of the overall system to satisfy a given demand profile due to the variability of power plant output. Profile costs are not the costs associated with the uncertainty of operating a power plant (such as when unforeseen plant outages occur or when VRE changes due to unpredicted weather) but are the costs associated with operating a system when power plants are unavailable. Profile costs include the costs of providing backup power when the wind is not blowing, the sun is not shining in systems with high levels of VRE, or to an order of magnitude less when a nuclear plant is offline for refuelling, or a fossil fuel power plant is offline for scheduled maintenance. The backup capacity needed to provide power during these times has the same fixed costs as in traditional systems but is now running a lower number of hours. Profile costs also include ramping costs resulting from additional ramping to meet variable demand and the wear and tear on the system caused by this additional ramping. This increases both total outlays in capital costs as well as average costs of dispatchable generators, which shows up in terms of increased overall costs to meet a given demand pattern. Profile costs are therefore at the heart of the notion of system costs. While it is possible to minimise profile costs, such as by planning nuclear refuelling during seasons of low electricity demand, they cannot be eliminated.

- **Balancing costs** are related to increased requirements for ensuring system stability with the help of operating reserves due to short-term uncertainty in power generation, in particular when VRE output is lower than expected. Forecasting the output of weather-based power sources has significantly improved, but there remains an intrinsic risk of sudden generation shortfalls in all weather-based generation technologies. Balancing costs takes the form of cycling costs, which means a dispatchable plant operates at less than full capacity so that it can ramp up quickly in case of need. Such cycling is costly because plants are operated at less than the economically optimal capacity. In the case of dispatchable plants, the amount and cost of operating reserves are generally indicated in terms of the capacity of the largest individual unit (the N-1 rule) connected to the grid. In the case of VRE, their balancing costs are related to the uncertainty of their combined output due to forecasting errors.

- **Grid costs** are the additional costs required to accommodate the particularities of different power generation operations on the transmission and distribution grid due to its size or location. All generation plant technologies have certain siting constraints. For example, large-scale nuclear plants are located near sources of cooling water and wind farms require regions with high wind potential. However, in addition to needing regions with high energy potential, VRE in particular, due to its large land use, entails high grid costs due to the low utilisation of grid infrastructure and large geographic regions. These costs vary greatly by country and technology category and are part of all energy sources. For example, residential vs. utility solar PV differ in terms of the impacts on transmission and distribution grids. Grid costs include the costs of both new (grid extension) and upgraded (grid reinforcement) costs. Transmission losses also increase when electricity must be moved across sizable distances. Quantitative estimates of grid costs are often characterised by large variations, depending on the characteristics of individual systems, the different deployment levels of each technology, particularly VRE, and the inclusion of distribution costs as well as specific methodological assumptions.

- **Connection costs** represent the cost of linking a power plant to the nearest connection point of the power grid. These real costs are at the level of the electricity system and can be considerable. However, the allocation of these costs can vary from country to country. For example, in some cases connection costs are borne by the project developer and should hence be included in the capital costs that form part of the LCOE calculations. In other cases, these costs are socialised due to policy and are then borne by consumers through higher network tariffs. In the latter case, system costs do not change. Determining connection costs also remains an area where further research is necessary to take the specificities of different countries and technologies into account.

Because of its ability to be a large source of stable power generation, nuclear energy is well suited to replace coal plants by providing grid forming and grid stabilising functions while reducing system costs in a way that coal has historically done. Of course, the optimal grid has significant amounts of VRE due to its low LCOE costs, but the right balance of VRE and non-VRE low-carbon capacity depends on the system and system costs analysis, which can estimate an optimal balance of the two resources to minimise system costs while providing a reliable electricity supply.

Baseload

The need for baseload power generation is a hotly debated topic in the field of energy systems. Many jurisdictions globally have been operating in baseload and peaking regimes for decades while new, mainly variable renewable driven systems have been operating for a decade or more on a combination of dispatchable and variable resources with no baseload required. On the one hand, the successful daily management of phenomena such as the well-known “duck curve” show that a combination of dispatchable and variable renewable resources can provide reliable energy daily (Cal ISO, 2016). On the other hand, California and Texas are some of the world’s largest renewable energy producers in the world and have experienced record power outages in recent years (IER, 2024). It would be an oversimplification to suggest that these record power outages are entirely due to high renewable energy deployments, as extreme weather and an ageing grid have played a role in these power outages. However, in the face of these record power outages, energy planners globally are rethinking the value and importance of baseload power in reliable and resilient energy systems. Here, nuclear energy has a potentially very important role to play in providing reliable and resilient power.

Human capital

Many countries argued for both a “just” transition as well as a clean transition. This implies that governments should consider the transition’s impact on citizen wellbeing and, when possible and needed, alleviate any suffering through economic or social policy. With coal plants retiring, especially in the United States, many once stable and well-paying jobs are being lost and communities, especially due to lack of tax revenue, are being impacted. This is a non-trivial problem.

Unfortunately, merely replacing coal plants with natural gas and renewables results in fewer and lower paying jobs (Pollin, 2021). Due to the energy density of renewables, there is often lower tax revenue generated in a city or county for renewable projects (Raimi, 2024). Additionally, because coal plants are being replaced by renewables and natural gas, the overall capacity of natural gas replacements is lower than that of the coal plant, resulting in fewer overall jobs. To replace the jobs lost from coal plant closures, local renewable energy projects can provide similar numbers of jobs but come at an increased cost per job (Vanatta, 2022). Here is a potential role for nuclear energy to provide a just clean energy transition by providing local, concentrated jobs to coal communities transitioning to nuclear power.

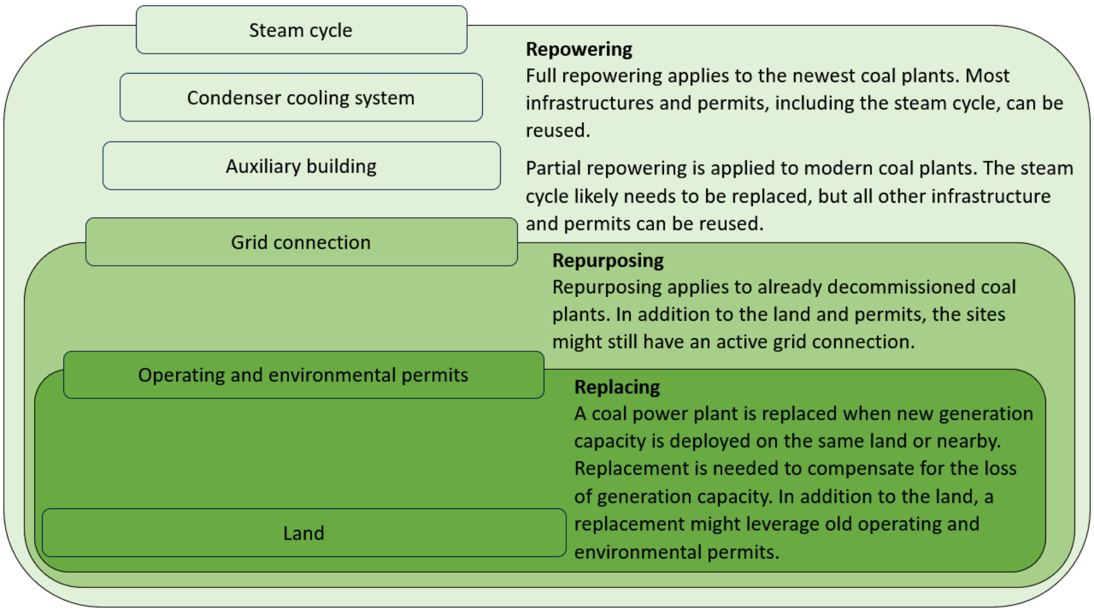
Replacing, repurposing and repowering

This report uses “replacement” as a blanket term throughout to include all categories of coal-to-nuclear transitions. The broader literature sometimes addresses replacement with categories including “refurbishment”, “repowering”, “repurposing” and “replacing”, depending on the level of equipment, permitting and infrastructure re-used.

For the remainder of this report, coal-to-nuclear transitions will be referred to as "replacement". However, the following in-depth definitions are also in frequent use.

- **Replacement**: Reuses only land and permits such as operational and environmental permits.
- **Repurposing**: Involves not only reusing the land and associated permits, but also the grid connection. Repurposing can also involve changing from energy generating to energy consuming facilities such as data centres or industrial complexes if the grid connection is still reused.
- **Repowering**: The most technically challenging but also yields the most economic benefit by maximising the infrastructure that is reused. In this case, as well as utilising the existing grid connection, land and permits, auxiliary buildings, cooling systems and the steam cycle are reused or retrofitted to accommodate a new generation technology such as gas or biomass.

Figure 2.7: **Repowering, repurposing and replacing coal assets vocabulary explained**



Nuclear energy and small modular reactors (SMRs) for coal replacement

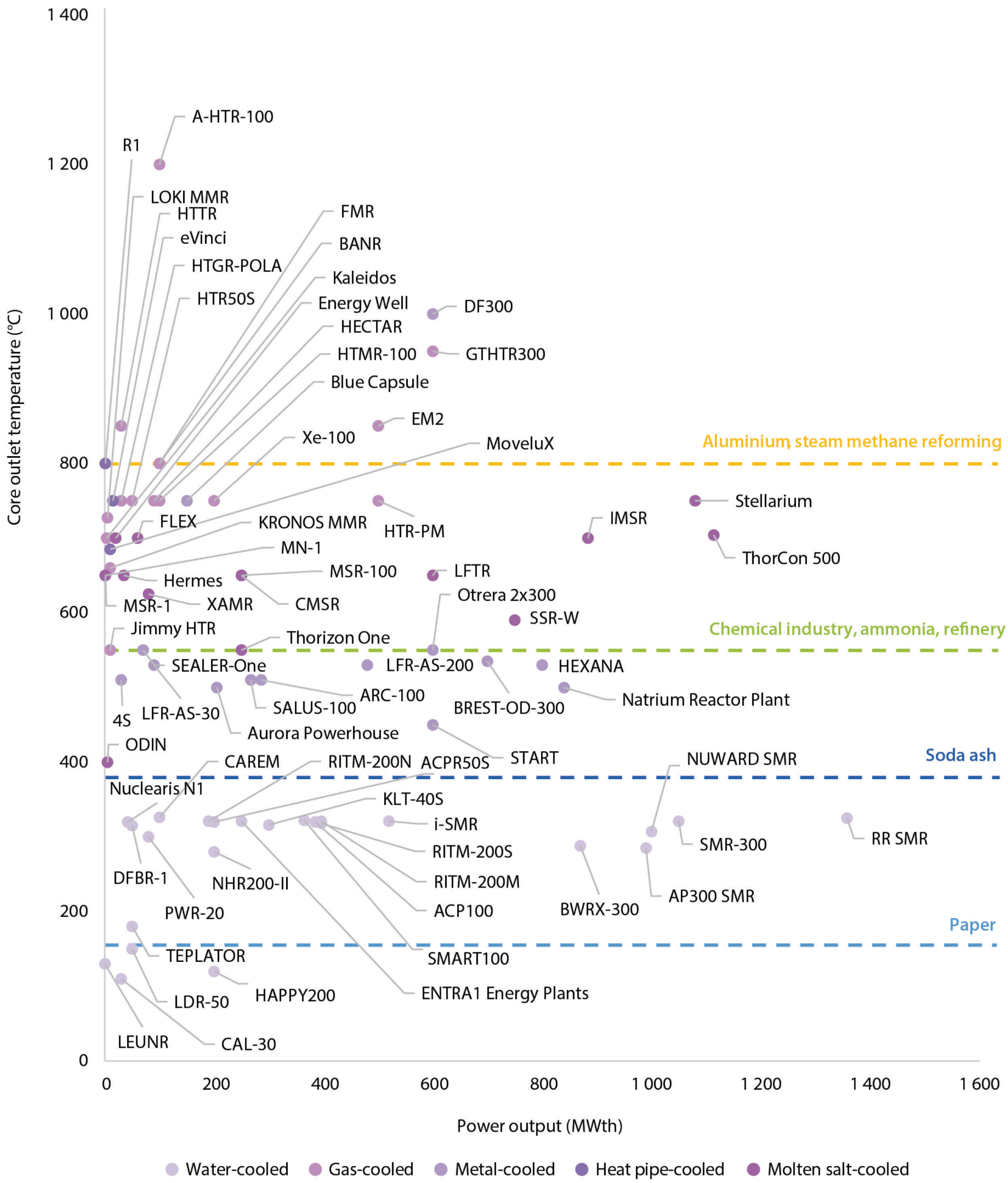
Nuclear energy presents a valuable opportunity for coal replacement as it is very energy dense, generates a large quantity of energy on a small land footprint, often uses steam generators and turbines to produce electricity (similar to coal plants) and is a low-emissions technology over its lifecycle. SMRs are a subset of nuclear reactor designs with a reduced power output and physical footprint compared to traditional nuclear reactors. Designed for modularity, SMRs are often characterised by the ability to be constructed using factories instead of building the nuclear reactor on-site. The electrical output of SMR designs can vary, with some providing up to 300 megawatts of electricity (MWe) or more for grid-connected reactors and others as low as 3 MWe or less for micro-SMRs. Some SMRs may offer additional features in terms of safety, operational simplicity, temperature of usable heat and innovation in fuel.

Micro-SMRs refers to a broad classification of technologies but are expected to feature enhanced transportability, extended refuelling timelines, and be specifically designed for micro-grids or isolated industrial applications that demand a dedicated and reliable supply of heat or electricity.

There is significant activity globally to advance the commercialisation of SMR technologies for a range of applications. Through its *NEA Small Modular Reactor Dashboard* initiative, the progress of over 70 SMRs for applications that extend beyond electricity production with technologies varying in both size and temperature, as illustrated in Figure 2.8 (NEA, 2025), is being tracked.

It is important to note that not all those considering coal-to-nuclear replacements are considering SMRs. Some are considering larger legacy or advanced technologies. In this report, the term "nuclear energy" shall be used to denote both large and modular nuclear designs. Further analysis to identify the nuclear technology that would be best suited to an individual country's needs will be necessary.

Figure 2.8: **Range of sizes and temperatures for heat applications**



Source: NEA, 2025.

Technical requirements of coal replacement

This report does not represent an exhaustive list of the technical requirements of replacing coal plants with nuclear energy. They will depend upon the site and must be analysed by engineers performing the replacement. However, a list of the basic technical requirements that must be considered when replacing coal with nuclear technologies follow below. These requirements are likely to vary by country.

- **Site licensing**: Nuclear plants require more stringent site conditions than coal plants. Specifically, nuclear plants require more geologically stable sites away from seismic fault lines or flood-prone areas. This licensing process is country dependent.
- **Grid integration**: Often the existing grid interconnection can be reused for a nuclear plant when transitioning from a coal plant (Hansen, 2022). However, if capacity is added, if the existing interconnection is aged beyond its useful life, or if the nuclear plant is expected to produce more consistent power than the previous coal plant, grid infrastructure may need to be upgraded for a coal-to-nuclear transition.
- **Cooling systems**: Depending on the size of the coal plant and the size of the proposed nuclear plant, cooling infrastructure may need to be augmented or upgraded. While many coal plants use cooling water, some use air cooling and this needs to be considered in the coal-to-nuclear transition. The availability of sufficient cooling for waste heat rejection is needed.
- **Containment structures**: Unlike coal plants, nuclear plants need containment buildings to house the nuclear reactors and protect against radiation leaks in an accident scenario. These structures must be sited to protect against natural disasters such as earthquakes or tornadoes for which the existing coal site may not be compliant.
- **Security infrastructure**: Unlike coal plants, nuclear plants are high-security facilities and require both personnel and security infrastructure such as physical barriers and surveillance systems to protect against potential threats.
- **Nuclear waste management**: In addition to the nuclear plant operation, it is important to have onsite nuclear waste storage. Facilities to store radioactive waste are essential and may involve on-site dry case storage or transport to a centralised repository.
- **Decommissioning coal infrastructure**: Coal plants and related infrastructure like ash ponds may need to be dismantled and remediated before nuclear plants can be installed. This involves addressing environmental concerns such as removing coal ash and cleaning up contaminated soil.

Non-technical requirements of coal replacement

Along with the technical requirements listed above, there are also non-technical requirements to consider. These include the following.

- **Community engagement**: Nuclear energy projects can be met with public opposition. Community engagement is important to assess the interest and need of the local community in hosting a nuclear energy project.
- **Employment opportunities and labour retention**: Nuclear power plants require different expertise than coal plants, making it important to retrain or recruit a skilled workforce to operate the nuclear reactor.
- **Investment and funding**: Nuclear energy plants usually require substantial upfront capital investment. Securing financing for the transition from coal to nuclear through grants, private investments or public-private partnerships is necessary for project sustainability.

Chapter 3. Global addressable market for coal replacement

To help organise the potential capital and research required for coal plant replacement, it is important to understand the addressable market – a major objective of this report. To meet this objective analysis was conducted to better understand the potential addressable market for coal replacement detailed in this section. This chapter endeavours to estimate the potential global market of nuclear-to-coal replacement applications. To do so, the analysis applies a series of market screening criteria to assess the potential market share of existing coal power plants worldwide that could be replaced by small modular reactors (SMRs).

From an overall market to a realistic potential market

The total market for coal replacement is equal to the global coal plant capacity which, based on the global energy monitor (Global Energy Monitor, 2023), is 2.2 TWe, which includes operating, planned or recently decommissioned (since 2012) plants[1]. However, SMRs and other nuclear energy technologies are not expected to replace all the existing coal capacity in the world. Not all coal plants are suitable for replacement. Examples include countries with bans or planned moratoriums on nuclear energy, countries with little access to nuclear energy, countries with high internal civilian unrest and countries with large alternative untapped resources such as hydropower.

The addressable market for nuclear SMR replacement will be much smaller than the 2.2 TWe, but there has not been an estimate of this addressable market, which is a gap this report seeks to fill. To produce an estimate of the addressable market, the report's analysis uses seven "filters", or market screening criteria, on the global coal power plant database to estimate the total GWe addressable for replacement by SMRs:

- **Filter 1. IAEA protocols**: Countries can be divided into two groups depending on whether they adhere to the IAEA protocols for developing nuclear technologies, particularly the Non-Proliferation of Nuclear Weapons Treaty, which gives countries access to larger international markets of nuclear technology for development. This filter assumes that not adhering to the IAEA protocols could be a hurdle for the country's domestic nuclear energy market. Criteria values that could be adopted for the estimates are:
  - Countries adhering to IAEA protocols
  - Countries that do not adhere to IAEA protocols
- **Filter 2. No nuclear energy phase-out**: This filter assumes that nuclear will not be built in countries phasing out nuclear energy. Criteria values that are adopted for the estimates are:
  - Countries with nuclear energy phase out plans
  - Countries with no nuclear energy phase out plants

1. Coal plants that have recently been decommissioned were included in this analysis because some of the permits, licensing, and infrastructure may be available for coal-to-nuclear transition and reuse. This is why some plants without any currently operating coal plants appear in the analysis as potential coal-to-nuclear adopters.

- **Filter 3. Nuclear energy in energy mix**: This filter assumes that nuclear reactors are more likely to be built in countries that already have nuclear energy in their energy mix. This assumption suggests that countries with a track record of nuclear energy development have a mature nuclear supply chain and human capital to develop new nuclear technologies. This filter is defined as:
  - Countries with existing nuclear plants (i.e. experience in operating nuclear plants)
  - Countries with no existing nuclear plants but national policy that supports nuclear energy development
- **Filter 4. Net zero commitments (NZC)**: Net zero policies should accelerate the phase-out of coal units that could be potentially replaced by nuclear energy. Criteria values that could be adopted for the estimates are implementation of net zero commitments:
  - By 2050
  - After 2050
- **Filter 5. Coal phase-out policy**: Coal phase-out policies are a clear commitment to retirement of coal units, opening opportunities for replacement with nuclear energy. Criteria values that could be adopted for the estimates are implementation of coal phase out:
  - By 2040
  - After 2040 or undefined timeline
- **Filter 6. Ageing coal fleets**: The older a coal unit is the more likely that the unit will be retired. The economic lifetime of a coal plant is around 40 years (IEA/NEA, 2020), which corresponds to the value assumed in the present estimates. In practice, the final decision of retirement includes other factors beyond age such as policy and economic performance.
- **Filter 7. Experienced nuclear operators**: Some utilities own both nuclear and coal assets. Based on inputs gathered through the NEA SMR Advisors for Industrial Applications (SMIA), this could facilitate the replacement of coal units with nuclear energy. Criteria values that could be adopted for the estimates are:
  - Utilities with experience in operating nuclear energy assets
  - Utilities without experience in operating nuclear energy assets

Although not included in the estimates, the report also considers two key additional factors that could impact the market potential for coal replacement:

- **Site constraints and technical feasibility considerations**: A nuclear power plant cannot be built in an existing coal site if several technical criteria are not meet. These criteria include cooling capabilities, seismic conditions and population density.
- **Competitive landscape**: In some jurisdictions competition against low gas prices, renewables, and/or policies such as carbon pricing can accelerate the retirement of coal units (see Chapter 3).

Effects of the filters on the overall market

To produce estimated markets that are useful for moving investment, NEA analysts organised the potential market for coal-to-nuclear replacement into time frames in the section below. However, before organising the data into time frames, it is important to see the effect of each filter on the overall market.

First, each filter was taken individually to see what impact it had on the 2.2 TWe of potential coal capacity identified. The output capacity of each filter can be seen in the maps shown in Figure 3.2.

Figure 3.1: **Impact of filters applied individually (not cumulative)**

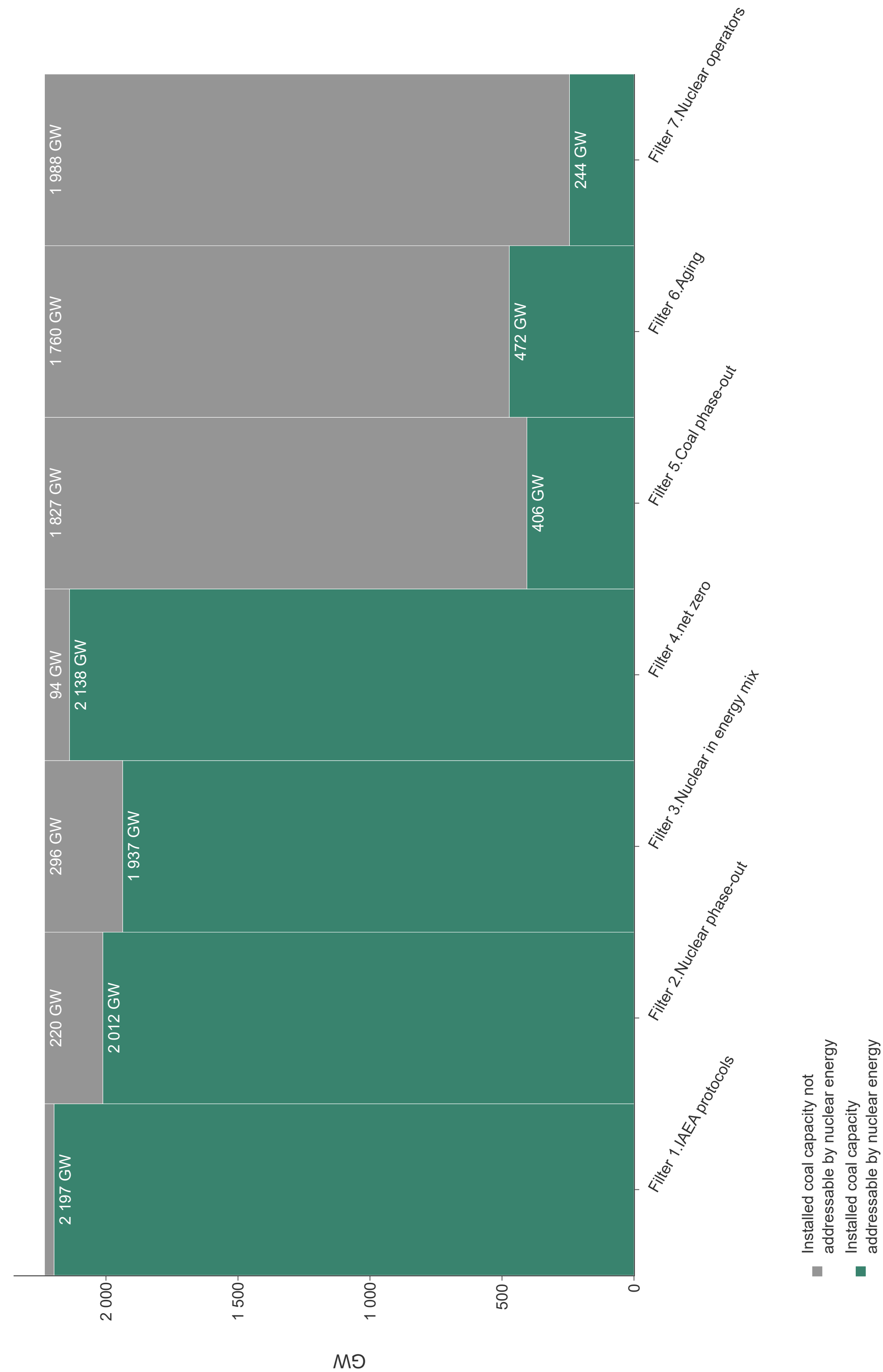
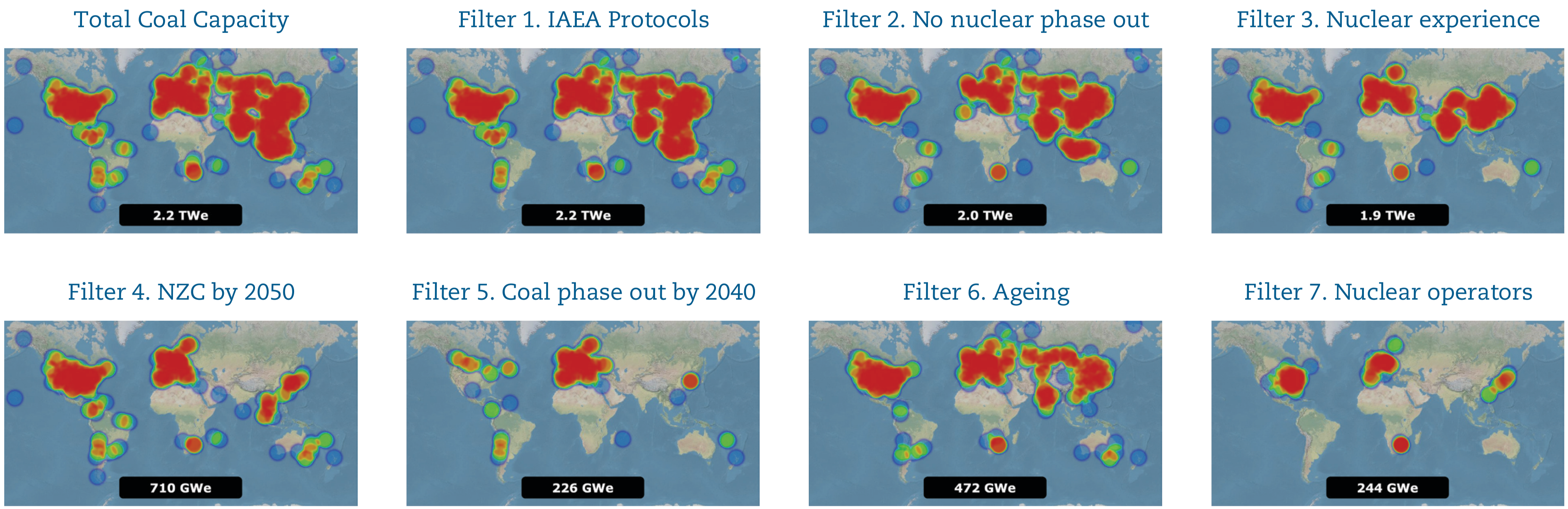


Figure 3.2: **Map of impact of filters applied individually (cumulative)**

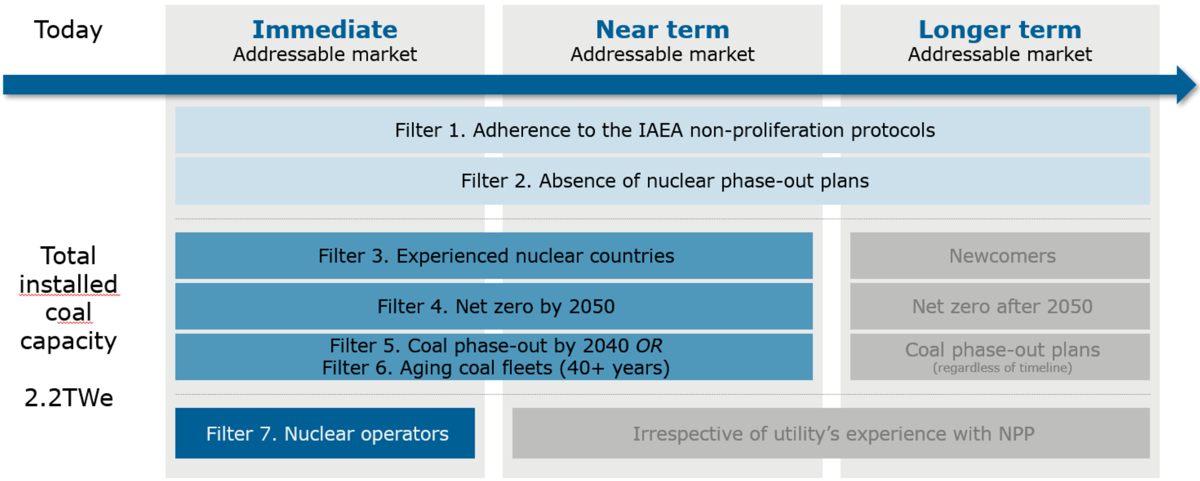


Organising the potential market for SMRs into time frames

The screening criteria described above can be combined to define three market time frames.

- Immediate: Potential market by 2035
- Near term: Potential market by 2040
- Longer term: Potential market beyond 2040

Figure 3.3: **Time frames and criteria values for estimating potential market of SMRs for coal replacement**



Source: NEA.

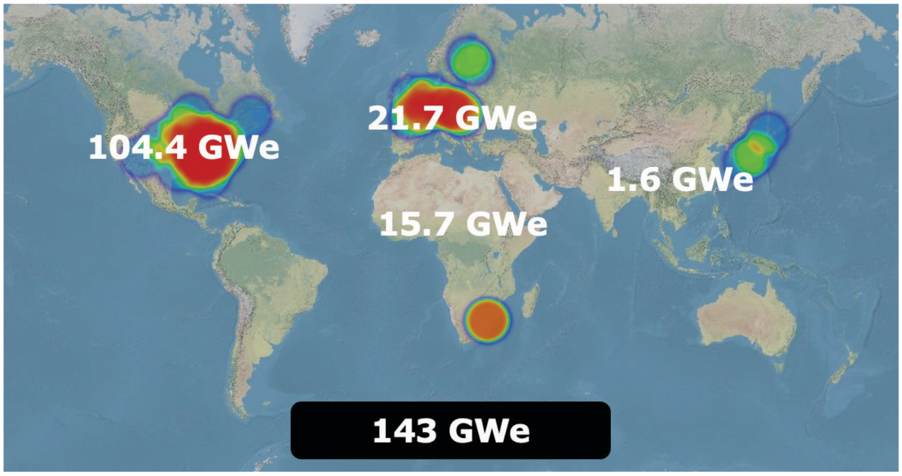
Immediate: Potential market by 2035

The potential market for coal replacement with SMRs by 2035 (near term) is estimated using the following criteria:

- Filter 1. IAEA protocols
- Filter 2. No nuclear energy phase-out
- Filter 3. Nuclear power in energy mix
- Filter 4. Net zero Commitments (before 2050)
- Filter 5. Coal phase-out policy (before 2040)
- Filter 6. Ageing coal fleets (40+ years)
- Filter 7. Experienced Nuclear operators

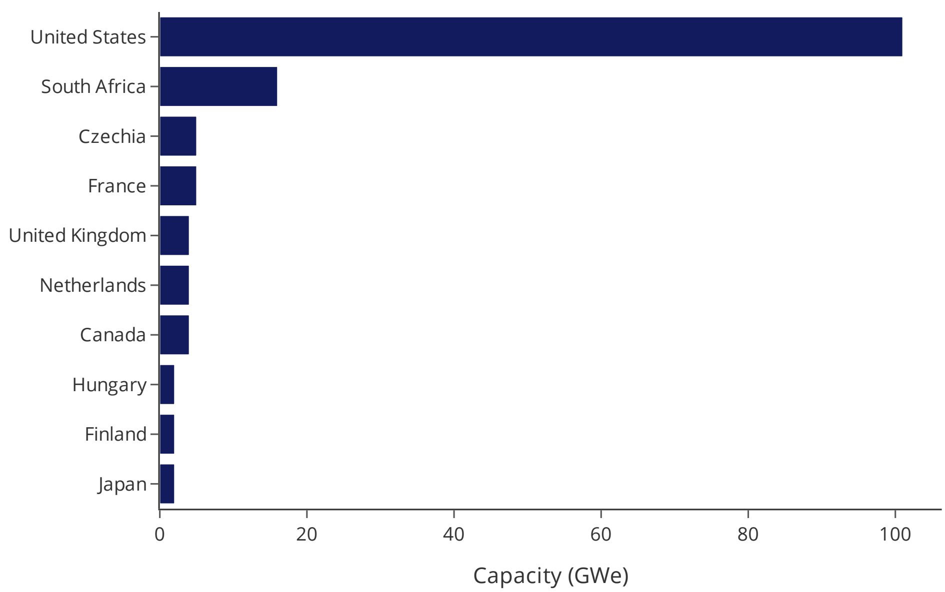
The potential market for coal replacement with SMRs by 2035 is estimated at 143 GW. North America, and particularly the United States, has the largest potential with an ageing nuclear fleet and utilities with both experience in running coal and nuclear energy assets. The United States alone represents 101 GW, the equivalent of 70% of this total potential market by 2035. The remaining 30% is distributed across countries in Africa, Asia and Europe. In Europe the total potential market by 2035 is of 22 GW, with values at the country-level not exceeding 5 GW. In Africa, the main potential market is South Africa, with 16 GW. This country captures the whole potential in the continent, becoming the second largest single country in terms of market potential after the United States. In Asia, the short-term market is relatively small, with 1.6 GW in Japan. The results are summarised in Figure 3.4 and 3.5.

Figure 3.4: **Potential market by 2035**



Source: NEA based on Global Energy Monitor (2023)

Figure 3.5: **Breakdown by country (Top 10) in GWe**[1]



Source: NEA based on Global Energy Monitor (2023).

Please note that this information includes coal plants that have been retired since 2012. Therefore, some countries that have phased out coal still show here as having potential capacity for coal-to-nuclear.

Box 1. **The United Kingdom's journey to a coal power phase-out**

By Paul Nevitt, United Kingdom National Nuclear Laboratory

The United Kingdom's final coal-fired power plant, Ratcliffe-on-Soar in Nottinghamshire, ceased operations on 30 September 2024. This represents a genuine historical milestone, given coal's historical prominence in UK power generation.

Coal has played a key role in the United Kingdom's historical power mix, providing around 95% of all electricity in the 1940s. Even as recently as 2012, coal use represented around 40% of electricity production. Within 12 years, this was less than 1% and now it is 0%. In fact, this final power plant was closed a year earlier than the original 2025 target set by government to phase out coal power in the United Kingdom. The pace of this coal power phase-out has been recognised internationally.

Alongside phasing out coal power, the United Kingdom has also taken steps to encourage rapid growth in renewable generation. Since 2010, renewables have increased from just 7% of electricity supply to over 50% in early 2024. Ninety-nine per cent of the United Kingdom's solar capacity has been installed since 2010 – enough to power the equivalent of over 4.5 million homes – and has reached 16.7 GW of installed solar. This represents a successful, rapid transition from coal to clean energy.

Some of the key steps the United Kingdom took to enable this include:

- The introduction in 2013 of a Carbon Price Floor (CPF), imposing a tax on energy generators using fossil fuels to generate capacity. It consists of two components: (i) the EU Emissions Trading System (ETS) price, and (ii) the Carbon Price Support mechanism (CPS), which tops up the EU ETS allowance price as projected by the UK government to the CPF target. The CPF was frozen at a maximum of GBP 18/tCO_2 from 2016 to 2020 to limit the competitive disadvantage faced by business and to reduce energy bills for consumers.
- The introduction of UK Contracts for Difference (CfDs) in 2014 to boost investment in renewable energy by providing the developers of projects that have high upfront costs and long lifetimes with direct protection from volatile wholesale electricity prices. CfDs also protect consumers by paying back when electricity prices are high.

These measures resulted in rapid market-driven accelerated retirement of coal plants, as the plant owners responded to the poor economics of coal power by shutting down their coal assets and investing in clean energy.

To continue to deliver an accelerated energy transition, the United Kingdom is committed to delivering a fully decarbonised power sector by 2030 – this builds on committing the United Kingdom to bringing all greenhouse gas emissions to net zero by 2050. This will involve speeding up deployment of all clean and renewable technologies, including hydrogen, solar, carbon capture and storage, wind and nuclear.

Near term: Potential market by 2040

The potential market for coal replacement with SMRs by 2040 (near term) is estimated using the following criteria:

- Filter 1. IAEA protocols
- Filter 2. No nuclear energy phase-out
- Filter 3. Nuclear power in energy mix
- Filter 4. Net zero commitments (before 2050)
- Filter 5. Coal phase-out policy (before 2040)
- Filter 6. Ageing coal fleets (40+ years)

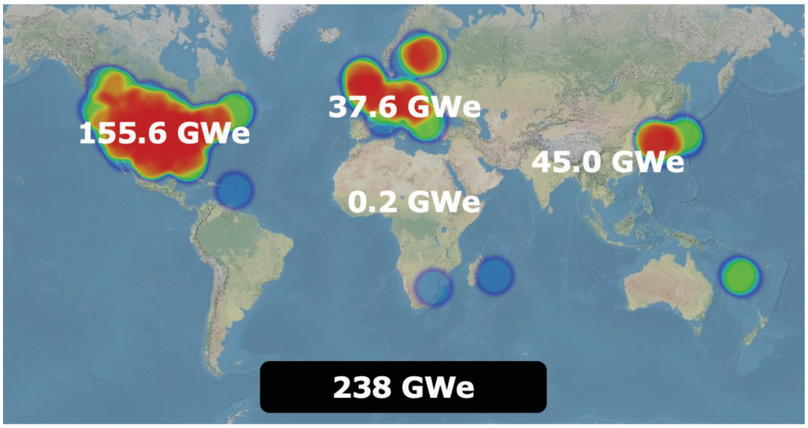
Removed from immediate time frame estimate:

- Filter 7. Experienced nuclear operators

Compared to the near term, only the criterion of nuclear operators has been modified. Instead of considering utilities that have experience in operating both nuclear and coal assets, Time frame 2 includes those utilities that own coal assets but do not have experience in operating nuclear energy assets. A plausible assumption is that these utilities will need more time to develop the necessary competence to license and operate nuclear assets, resulting in a potential market that may emerge by 2040.

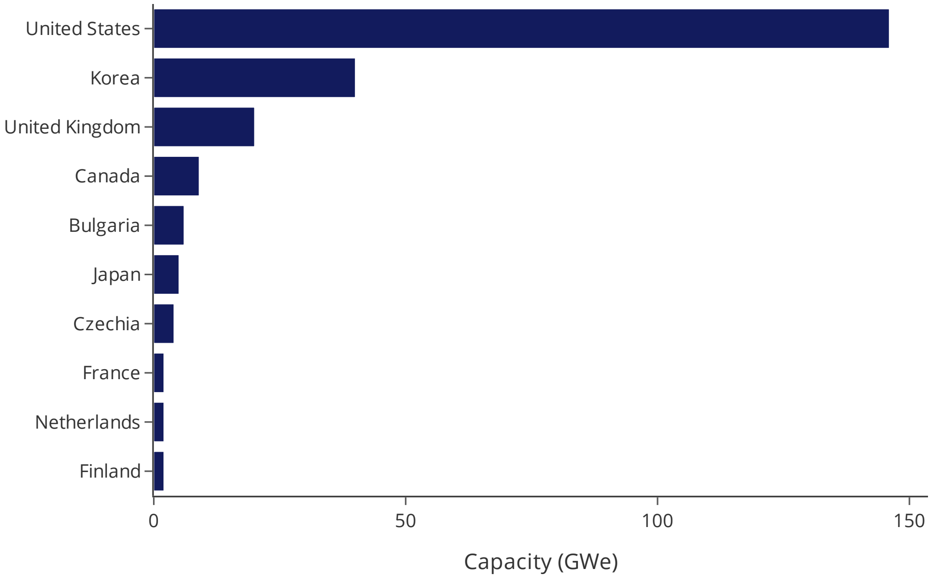
The additional potential of coal replacement with SMRs by 2040 is estimated at 238 GW. The United States remains the largest market, accounting alone for 146 GW, or approximately 60% of the total potential additional market. The remainder 40% is distributed across Asia and Europe essentially. Developments in Asia are led by Korea, with an additional potential market of 40 GW, followed by Japan with 5 GW. Korea is therefore the country with the second largest potential after the United States. In Europe, the total additional market by 2040 is of 38 GW, led by the United Kingdom, which represents 20 GW, or around 50% of the additional potential. The results are summarised in Figure 3.6 and Figure 3.7.

Figure 3.6: **Potential market by 2040**



Source: NEA based on Global Energy Monitor (2023).

Figure 3.7: **Breakdown by country (top 10) in GWe**[1]



Source: NEA based on Global Energy Monitor (2023).

1. This information includes coal plants that have been retired since 2012, which explains why some countries that have phased out coal still show here as having potential capacity for coal-to-nuclear.

Box 2. **How France achieved its decarbonised electricity grid by phasing out coal and deploying nuclear energy**

By Antoine Herzog, EDF

With no oil production and limited coal production in the country, French industry has long relied on charcoal from French forests and hydroelectricity from rivers. In the 1950s and 1960s, major hydroelectric programmes produced around half of the country's electricity, but this share has declined due to the scarcity of new sites.

Coal-fired power stations began to be deployed on a large scale in the 1960s. The share of coal and oil-fired power stations in the electricity generation reached around 60% in the mid-1970s, with a dependence on coal imports mainly from countries such as Germany, South Africa and Poland. With the deployment of nuclear capacity in the 1980s, this share was sharply reduced to less than 10% by the mid-1990s. Today, there are only three coal-fired units left in the country, representing less than 0.2% of France's electricity generation and coal production is due to be definitively phased out in the next two years.

Throughout this period, France developed its nuclear fleet. After the first-generation reactors built in the 1950s and 1960s, France chose the pressurised water technology for its programme. Six 900 MW pressurised water reactors were built at Fessenheim and Bugey in the 1970s.

In response to the quadrupling of oil prices resulting from the 1974 oil crisis, the French government drew up an energy plan, based on energy-saving measures and the acceleration of the development of nuclear power. In 1974, the government decided to launch the construction of 13 large nuclear reactors, marking the start of a major programme. In addition to the first six reactors, 52 reactors, in three power series of 900 MW, 1 300 MW and 1 450 MW, were commissioned between 1980 and 2002, 75% of them in less than ten years. At the end of the programme, the capacity of the French nuclear fleet reached 63 GW.

In parallel with the construction of France's nuclear power plants, the fuel cycle industry has developed: mining, uranium extraction and enrichment, fuel assembly manufacturing, reprocessing of spent fuel and radioactive waste management.

The deployment of nuclear power, combined with a reduction in the use of fossil fuels, led to a world record in planned decarbonisation, with emissions falling by 4.5% a year over the 5-year period from 1980 to 1985 (Hallegatte, 2015).

Thanks to the development of nuclear power (currently 65% of the electricity generation) and renewable energy (29%), the carbon intensity of French electricity production is now only 32 gCO_2eq per kilowatt-hour produced (Réseau de Transport d'Électricité, 2023), or around 15% of the average carbon intensity of electricity in the European Union. The competitiveness of French electricity favours electricity exports: their net volume is around 10% of the electricity produced in France (Réseau de Transport d'Électricité, 2023), which also contributes to the decarbonisation of the electricity sector at the European level.

Several key factors have led to the success of the French nuclear programme, including a stable political will over the long term, industrial experience acquired over more than 15 years, systematic standardisation, and the use of proven technologies.

The international experience of the last 70 years shows that once a reactor design has passed the "first-of-a-kind" stage, nuclear programmes can be completed on schedule and at competitive full cost. The conditions for success are available to countries that have both the appropriate governance institutions and scientific base: a long-term political vision, a competent safety authority, a standardised reactor design, an experienced industrial base, high-quality worksite organisation and project management, series construction enabling economies of scale and the optimisation of experience feedback and, finally, the rules of the game on the electricity markets enabling long-term investment commitments.

Box 3. How coal phase-out helped clear the air in Ontario

By Colin Hoult, Jeremy McEachern, Chris Grills, OPG

Background

More than a decade ago, Ontario Power Generation (OPG) carried out one of its most impactful actions to fight climate change and one of the largest climate actions in North American history. In April 2014 (OPG, 2025), the company burned its last piece of coal to generate power, making Ontario the first jurisdiction in North America to remove coal entirely from its electricity system. This culminated a multi-year effort to phase out coal-fired electricity in the province, a process that began in 2003, when coal-powered generation represented about 25% of Ontario's electricity supply.

Replacing coal in Ontario would not have been possible without nuclear and hydroelectric power – the province's clean and reliable energy workhorses, which will continue to play an important role in decarbonising the broader economy through electrification.

Now, Ontario's Independent Electricity System Operator (IESO) forecasts the province's demand for electricity will increase by 75% by 2050, the equivalent of adding four and a half cities the size of Toronto to the grid. This increase is largely due to Ontario's rapid growth in population, new manufacturing facilities, advanced technologies like artificial intelligence (AI) data centres, the electrification of industry, and the charging energy required for electric vehicles.

Minister of Energy and Electrification policy announcements

In November 2024, Ontario's Energy and Electrification Minister, Stephen Lecce, announced plans to address the province's rising electricity demand to ensure a reliable and affordable supply of electricity for future generations. The Minister's announcement asked for engagement with local municipalities and First Nation communities on new electricity generation, which could include new nuclear generation, in regions that contain the OPG-owned Wesleyville, Nanticoke and Lambton sites.

In January 2025, building off the announcement in November, the Ontario government also asked OPG to explore opportunities for new nuclear energy generation at the Wesleyville site specifically. This followed expressions of interest from the Municipality of Port Hope and the Williams Treaties First Nations (WTFNs). OPG will seek to work with local communities to determine support as the province seeks to expand Ontario's generation capacity to meet the rising demand for electricity.

Previous coal (and oil-fired) generation sites

In the early 2000s, Ontario's coal-fuelled generating stations produced about 25% of Ontario's energy needs. Over their 60 plus years of operation, OPG's thermal plants generated more than 1 250 TWh of electricity for Ontario.

While OPG maintains many desirable sites appropriate for new generation, the three sites mentioned in the announcement are potential strategic sites for OPG and the province:

- **Nanticoke –** For almost 42 years, Nanticoke employees maintained an outstanding reputation – serving their local community and providing power to Ontario. Nanticoke GS produced up to 4 000 MW of coal-fuelled generation for the province of Ontario. OPG first decommissioned the site, then, in 2018, demolished the plant.
- **Lambton –** The Lambton Generating Station was a coal-fuelled power plant located near Corunna, Ontario, delivering up to 1 976 MW, prior to shutdown of units 1 and 2 in 2010 and units 3 and 4 in 2013. The majority of the plant was demolished by 2022.
- **Wesleyville –** OPG has a nearly 60-year history at the Wesleyville site in Port Hope Ontario. OPG's predecessor company began construction of a four-unit oil-fired power plant but construction was later paused. The plant never became operational due to the OPEC oil embargo in the early 1970s. The plant still sits on the east side of the site.

OPG has retained ownership of Nanticoke and Lambton site post decommissioning and demolition and continues to use the Wesleyville site for various operational support activities. All these sites are valuable to Ontario for future electricity generation development to meet electrification and climate change goals.

Site screening for nuclear deployment

OPG follows a systematic process, consistent with industry best practice (e.g. IAEA SSG-35, "Site Survey and Site Selection for Nuclear Installations" [IAEA, 2015]) to identify sites which may be suitable for deployment of new nuclear technology.

The process is intended to select a suitable location such that the characteristics of the site meet regulatory requirements, engage and provide meaningful benefit to local municipalities and First Nation communities, and provide economic benefits and opportunities for a reasonable investment to the people of Ontario.

Attributes of a desired nuclear site

A site must first be suitable for deployment of a nuclear power plant from the perspective of the conditions and any natural external events. This includes ensuring the site's geotechnical (and seismic) conditions, meteorological hazards (rainfall, tornado) and climate change are acceptable. These criteria are established based on the guidance communicated in CNSC REGDOC-1.1.1 (CNSC, 2018) and IAEA SSG-35 (IAEA, 2015) regarding the identification and characterisation of hazards.

For a site to be economical it must also be able to provide electricity where it is needed with cost effective access to the provincial electricity grid. Examining the transmitter system maps can be used to identify the proximity of proponent sites to the existing Ontario high-voltage electricity grid. Similarly, a site must have availability and access to a source of water for condenser cooling. Both once-through cooling systems and cooling towers (for makeup) will require a source of water.

Prospective sites should also have characteristics that are compatible with Emergency Planning and Site Security. Assessing the feasibility of an onsite exclusion zone and establishing nuclear emergency plans to ensure public safety in the event of a nuclear emergency is paramount. There is also a requirement to establish physical protection measures on the site. In general, sites which have inherent characteristics which optimise the ability to detect, delay and deter a nuclear security event and do not impact the ability to implement adequate physical protection, are considered preferable.

Why previous coal (and oil-fired) sites may be ideal for nuclear

Converting previous coal sites to nuclear power could save significant construction costs, providing benefit to the Ontario rate payer. A US Department of Energy report (DOE, 2024) found that deploying new nuclear power plants at previous fossil fuel station sites could save up to 35% on construction costs, depending on how much of the existing site assets could be repurposed.

In the case of OPG's sites, savings of this magnitude would not be expected if converted for nuclear power, but there would be notable efficiencies. Critical assets include the existing land, the coal plant's electrical equipment, especially the transmission connection and switchyard, the water intake and any other civil infrastructure, such as roads and buildings. In the case of OPG's sites, repurposing of portions of the actual coal plant is not possible as they have mostly been demolished.

Converting previous coal plants to nuclear can also create new jobs and preserve existing ones in areas where needed. The transition can lead to increased economic activity and higher tax revenues for local communities.

About OPG

As Ontario's largest and one of North America's most diverse generators, OPG invests in local economies and employs thousands of people across Ontario and the United States. Together with its family of companies, it is leading the development of new clean technologies, advancing electrification initiatives, and refurbishing existing assets to power growing electricity demands.

Longer term: Potential market after 2040

The additional potential market for coal replacement with SMRs beyond 2040 (long term) is estimated using the following criteria:

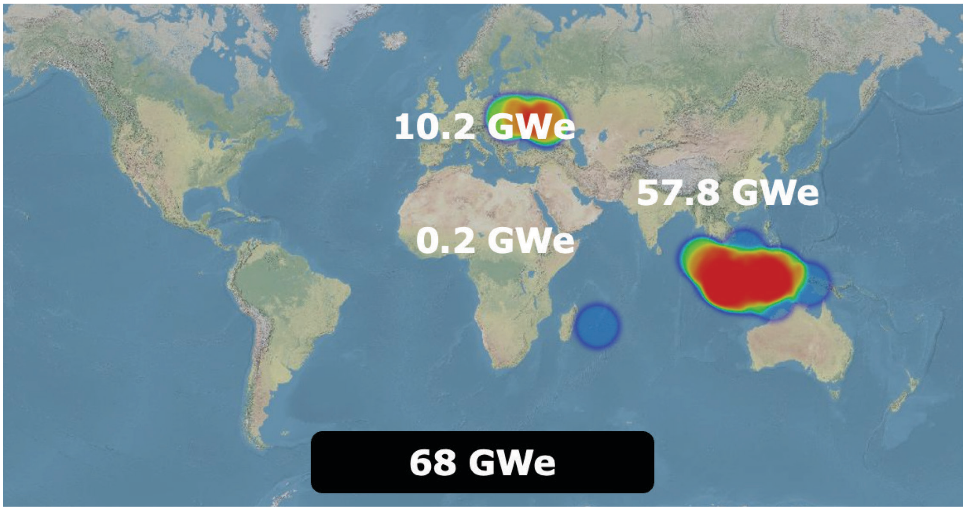
- Filter 1. IAEA protocols
- Filter 2. No nuclear energy phase-out
- Filter 4. Net zero commitments (after 2050)
- Filter 5. Coal phase-out policy (after 2040)

Compared to Time frames 1 and 2, Time frame 3 modifications include:

- Filter 4. The implementation of net zero commitments after 2050
- Filter 5. The implementation of coal phase-out policies after 2040
- Filter 6. Any coal plant regardless of age
- Filter 7. All coal utilities are considered irrespective of their experience operating nuclear assets.

In the long term, the potential market for coal replacement with SMRs grows by 68 GW, driven by developments in Southeast Asia and Eastern Europe. Indonesia captures the largest portion of market growth beyond 2040, followed by Poland, the Philippines and Ukraine. These four countries represent almost 90% of long-term growth. The results are summarised in Figure 3.8.

Figure 3.8: **Potential market after 2040**



Source: NEA based on Global Energy Monitor (2023).

Box 4. Coal-to-nuclear transition in Korea

By Joo Hyung Moon, Kyungsoo Yoon, Jai Oan Cho, Youngwoo Lee, Young Joon Lee, KAERI

1. Coal-to-nuclear transition policy

This section examines the policy of Korea concerning the transition from coal-fired power plants to nuclear power plants. To date, the government has not officially announced plans to transition coal-fired power plants to nuclear power plants. Instead, it prioritises the conversion of coal-fired power plants to liquefied natural gas (LNG) and intends to transition to carbon-free energy sources in the future. Examples of these carbon-free energy sources include pumped storage and hydrogen-ammonia co-firing, but there is no mention of nuclear energy, specifically small modular reactors (SMRs).

1-1. Policy direction for coal-fired power plants phase-out or reduction

The Ministry of Trade, Industry and Energy announced the "Policy Direction for Coal-Fired Power Plant Phase-out or Reduction" in December 2021 to accelerate the transition of coal-fired power plants to clean energy while ensuring a stable electricity supply. The plan involves replacing coal-fired power plants with LNG or carbon-free energy sources like hydrogen-ammonia co-firing under the assumption that those technology developments and demonstrations are well achieved.

1-2. National Framework Plan for Carbon Neutrality and Green Growth

The government established the "National Framework Plan for Carbon Neutrality and Green Growth" in April 2023 to achieve a carbon-neutral society by 2050 and promote harmonious development of the environment and economy. According to the plan, coal-fired power plants that have been in operation for 30 years or more will be phased out (28 units by 2036), and hydrogen-ammonia co-firing power plants will be promoted subject to the development of environmentally friendly technology.

1-3. Formation of the Coal-Fired Power Plant Transition Council

In December 2024, the government formed the "Coal-Fired Power Plant Transition Council" to minimise the adverse impact of domestic coal-fired power plant shutdowns on regional economies and employment and to reuse existing infrastructure such as power generation facilities, transmission lines, and sites after shutdown. The plan developed through this council will be promoted smoothly through the concerted efforts of multiple government departments, including the Presidential Commission on Carbon Neutrality and Green Growth, the Ministry of Employment and Labor, the Ministry of Trade, Industry and Energy, and the Ministry of Economy and Finance. The "Coal-Fired Power Plant Transition Roadmap" is expected to be published in the first half of 2025.

1-4. Basic Plan on Electricity Supply and Demand

The government has been establishing the "Basic Plan on Electricity Supply and Demand" every two or three years to foresee mid-to-long term electricity demand and secure necessary power facilities for a stable electricity supply. A total of 11 plans have been established since the first plan in 2002. The 8th plan (2017) was the first one to include the plan to convert coal-fired power plants to LNG power plants. According to the plan, 6 units will be converted to LNG by 2030. The 9th plan (2020) increased this to 24 units, and the 10th plan (2023) further expanded it to 28 units. The 11th plan (2025) added 12 more units, but instead of converting them to LNG, they will be converted to carbon-free energy sources such as pumped storage or hydrogen-ammonia co-firing to avoid increased dependence on LNG. Table 1 summarises these transition plans.

Table 1: **Coal-fired power plants transition plans**

Plans	Date	Coal-fired power plants to be replaced	Alternatives
The 8th	Dec. 2017	6	LNG
The 9th	Dec. 2020	24	LNG
The 10th	Jan. 2023	28	LNG
The 11th	Feb. 2025	28	LNG
		12	Carbon-free

A notable aspect of the 11th plan is that it included SMR power generation plans for the first time, with a planned capacity of 700 MW, although a specific domestic site has not been determined. It is also noteworthy that the 11th plan included carbon-free energy sources as alternatives to coal-fired power plants, whereas previous plans were limited to LNG only.

2. Coal-to-nuclear transition research

Research on the just transition of the coal-fired power generation sector in Korea is being actively pursued. A study by Lee et al. (Lee et al., 2022) compared and analysed the just transition policies of major countries and proposed that for Korea, a long-term roadmap for decarbonisation should be established, a dedicated organisation should be set up, and comprehensive worker support measures should be prepared.

Additionally, the feasibility of implementing international strategies to support the closure of domestic coal-fired power plants was explored (Kim, 2023) and financing measures for decarbonisation of power generation industry were reported (Kim, 2022).

Kwon (Kwon, 2023) analysed the changes in employment resulting from the closure of coal-fired power plants and identified key challenges to be addressed for a just transition, including expanding the scope of stakeholder participation, establishing a just transition fund, and conducting comprehensive surveys and analyses to develop job transition strategies.

Research on converting domestic coal-fired power plants to carbon-free energy sources as well as SMRs are also underway. Kim and Cho (Kim, 2024) conducted a study on the impact of carbon-free energy sources, such as hydrogen-ammonia co-firing power plants that can be introduced to replace domestic coal-fired power plants, on the domestic electricity market.

In the report "A Study on the Implementation of Carbon Neutrality Policy in Power Generation Sector" (Industry-Academy Collaboration Centre, 2023 – not publicly available), SMRs were proposed as an alternative to coal-fired power generation. Since SMRs share similarities in terms of generation principles, facilities and infrastructure, construction costs can be saved by up to 33% compared to new constructions, and employment can be doubled, which are cited as advantages.

The study by Hwang (Hwang, 2024) analysed the current status of domestic and foreign coal-fired power plants to establish a Korean coal-to-nuclear policy and assessed the required capacity of nuclear power or SMRs to replace coal-fired power plants. According to the assessment, the United States would need 1 967 units of 100 MW SMRs, while Korea would need 423 units.

Kim et al. (Kim et al., 2022a) proposed a hybrid system combining SMRs and solar power as an alternative to coal-fired power plants and evaluated its economic feasibility. They found that combining the two power sources is more economical than building them separately.

Shin and Kim (Shin and Kim, 2023) investigated the potential for replacing ageing coal-fired power plants and decommissioned nuclear power plant sites with i-SMRs, currently under development for overseas export. The study estimated the optimal number of units of i-SMRs deployable in each country under their power generation plans, targeting Indonesia, Poland and Saudi Arabia. According to the results, 85 units can be deployed in Indonesia, 11 units in Poland, but no demand is expected in Saudi Arabia. Although this study has the limitation that it was not conducted specifically on Korea's coal-fired power plants, its results are expected to provide basic data for Korea's future coal-to-nuclear policy.

The Korean Nuclear Society released the results of a feasibility study on using Korean SMRs to replace a coal-fired power plant in the Philippines (Cruz, 2023). The study evaluated whether SMR models currently being developed in Korea can be used to replace coal-fired power plants in the Philippines. According to the findings, it was considered appropriate to replace 28 coal-fired power plants in the Philippines with Korea's PGSFR (Prototype Gen-IV Sodium-cooled Fast Reactor).

At the 170th Forum hosted by KISTEP (Korea Institute of Science and Technology Evaluation and Planning), it was proposed that SMRs could be installed on smaller sites compared to coal-fired power plants, making it possible to reuse existing coal-fired power plant sites (Kim, 2024). This would be a good option for reducing coal power generation and achieving carbon neutrality.

A newspaper column (Yoo, 2023) was published suggesting the replacement of domestic ageing coal-fired power plants with SMRs. The column proposed promoting coal-to-nuclear policy at existing coal-fired power plant sites while obtaining the understanding of local residents. The advantages of coal-to-nuclear policy were presented as follows: (1) the reuse of existing sites and facilities can reduce SMR construction costs; (2) existing employment can be maintained or even increased; (3) increased regional support funds can contribute to regional economic revitalisation; (4) energy security will be enhanced; and (5) the track record of SMRs in Korea can be utilised to promote SMR exports.

3. Outlook

In Korea, efforts are already underway to convert ageing coal-fired power plants to LNG power plants, and concrete plans for the transition to carbon-free energy sources were also announced in February 2025. However, no specific plans for transitioning to nuclear energy have been established yet, and the focus thus far has been on feasibility studies at the basic research level.

However, SMRs are now included in the national plans and discussions on converting Korea's ageing coal-fired power plants to nuclear power, particularly SMRs, are expected to gain momentum. According to the results of a recent study the stranded assets of the 28 ageing coal-fired power plants scheduled to be phased out by 2036 are estimated to be around USD 3 billion (Industry-Academy Collaboration Centre, 2023 – not publicly available). To minimise losses and maximise efficiency, coal-to-nuclear policy is likely to gain significant attention.

Moreover, it is essential to gather policy implementation cases from other countries regarding coal-to-nuclear policy. This will provide valuable insights and support for Korea's decision-making processes in coal-to-nuclear policy in the future.

Box 5. **Czechia's coal-to-nuclear transition**

By Jan Prášil, CZ MIT

In 2023, Czechia's gross electricity generation came mainly from nuclear energy (40%), coal (38%), and renewable (14%) sources. Around 55% of heat production comes from coal, with 1.7 million households (about 4 million people) being served by district heating, where coal remains the dominant fuel. The Czech TSO's decarbonisation scenario (MAF, 2022) predicts that even with the construction of four new large reactors with a unit capacity of 1.2 GWe, the use of the maximum allowed electricity imports (i.e. at 90% self-sufficiency), and the deployment of gas-fired power plants, the electricity system will face a severe resource inadequacy in 2050, requiring timely measures and investment incentives (CEPS, 2022). The capacity deficit in this scenario is estimated at about 2.8 GWe – which could be covered by SMRs. The 2023 update of the Assessment of Decarbonisation of District Heating in Czechia put a conservative estimate of SMRs' heat supply potential in 2050 at about 7 PJ (Ministry of Industry and Trade, 2024).

SMRs in the State Energy Policy

In comparison to the 2019 National Climate and Energy Plan (NECP) (Czech Government, 2019) in which coal would account for 38% of electricity generated in 2030, the 2024 NECP update envisages only 9%. The 2024 update confirms the increased share of renewables to over 30% and a coal phase out by 2033. Energy utilities predict an even earlier transition date due to the rising costs of emission allowances. The natural gas-fired production cannot adequately replace this decrease of generation capacity, with the price volatility of gas presenting an added risk. Nuclear power will gradually take over the role of coal power in the Czech electricity mix, especially after 2035. In 2021, Czechia adopted the Act on Measures for the Transition of Czechia to a Low-carbon Energy Sector (Czech Government, 2025), which sets out the framework for state aid for new nuclear projects, including SMRs.

In the Czech SMR Working Group, set up in 2022, the Ministry of Industry and Trade and the State Office for Nuclear Safety regularly update potential investors and other interested stakeholders about licensing and permitting requirements. The Act 263/2016 Coll., the Atomic Act, rules in its Section 47 the site assessment (Act 2016). The Decree 378/2016 addresses regulations regarding the siting of a nuclear installation, including the documentation required for the licensing process. The Czech Geological Survey as the state geological service advises potential investors. Several research projects administered by the Technology Agency of the Czech Republic (TACR) deal with the preconditions for new nuclear sites, such as the mapping of seismic amplification or the interactive map of seismic hazards (seismickamapa.cz). Experience has highlighted the limited capacity of experts in the field of geotechnical hazards (Seismickamapa, 2025).

In 2023, the Czech government acknowledged the SMR Roadmap (Czech Government, 2023) in its resolution No. 808 and tasked the Minister of Industry and Trade with using the Roadmap as an input for the State Energy Policy and the Minister of Industry and Trade and the Chairperson of the State Office for Nuclear Safety with proposing the streamlining of licensing and permitting processes for SMRs in the forthcoming amendments to the legislation on the preparation of nuclear new build. The Roadmap provides an overview of possible sites where SMRs can replace coal-fired units for heat and electricity production.

SMRs in strategic plans

Potential investors focus on SMR designs deployable in the 2030s. These designs have a capacity of 300 MWe/800 MWt or more, which limits their applicability in providing district heating to larger agglomerations only, e.g. Prague, Central and East Bohemia, the Moravian-Silesian region, Ústí nad Labem and the Karlovy Vary regions.

Three potential investors are currently assessing their sites for SMR construction. In its investor presentation on 29 November 2024, the CEZ Group announced preparations for potential SMR construction with total capacity of 3 GWe and its aim to commission the first SMR before the completion of a new large-scale reactor. SMRs could substitute coal-fired power plants and produce heat for surrounding towns. CEZ will determine the actual number of SMR units based on electricity demand and the pace of development of renewables. In 2024, CEZ became a strategic shareholder in Rolls-Royce SMR Ltd in order to secure the timely delivery of SMRs as well as the involvement of CEZ's supply chain (subsidiaries) or local chain and additional economic benefits (share of profit) from SMR deliveries worldwide. In 2023 and 2024, SUAS Group assessed its sites within the framework of the US-backed Project Phoenix and worked on a feasibility study. Also in 2024, OSGE established and registered BWRX CZ, a special purpose vehicle dedicated to the development of SMRs in Czechia.

Repurposing former coal sites

Replacing coal with nuclear energy does not necessarily mean utilising current coal power plant sites. It is rather about compensating the phased-out capacity and, if possible, making use of existing infrastructure (i.e. roads, lines, water supply). The main obstacle to siting nuclear power plants are the strict geological requirements. Coal-fired power plant sites can interfere with this requirement as they tend to be located close to coal mines and on unstable bedrock. Increased investment costs may be necessary to technically adapt such locations to meet nuclear siting requirements. Capable faults located in the coal-fired power plant site area and complex subsurface conditions such as previous mining activities have been identified as the main challenges for site assessment. If a site does not comply with regulatory requirements, specific technical measures may be considered to eliminate non-compliant characteristics.

Box 6. Potential of coal-fired power plant conversion to nuclear energy in ASEAN

By Bayu Jamalullael, Rully Hidayatullah, Suwanto,
Beni Suryadi, Association of Southeast Asian Nations (ASEAN) Centre for Energy

Total electricity generation in the ASEAN Member States has been consistently increasing, reaching a production record of 1 263 TWh in 2022, and is predicted to have tripled in 2050. While fossil fuels remain the dominant energy source, their overall share has steadily decreased from 85.8% in 2005 to 71.2% in 2022. Renewable energy, mainly hydro and solar, has emerged strongly, driving a notable diversification in energy generation. Specifically, coal's contribution decreased from 45% in 2020 to 42.1% in 2022. This gradual yet significant shift towards a diversified energy portfolio signals the region's growing awareness of sustainability issues and the importance of reducing dependency on fossil fuels. Furthermore, nuclear power is also considered by some ASEAN Member States to secure future electricity supply and address environmental concerns (ACE, 2024a).

However, ACE's report on coal finds that despite its declining share, coal continues to be a vital and cost-effective energy resource in ASEAN, particularly in Indonesia, Malaysia, the Philippines, Thailand and Viet Nam. The report suggests that coal remains economically crucial for ASEAN countries, contributing significantly to national economies beyond just electricity generation (ACE, 2024b). Approximately 70% of coal-fired power plants (CFPPs) in ASEAN are low-capacity (less than 300 MW) captive facilities (built by a company to perform a specific service), with the majority serving as captive power plants for energy-intensive industries such as mineral smelting, pulp and paper production, and others, particularly in Indonesia. The remaining 30% of CFPPs consist of medium- and large-capacity plants (300-1 000 MW), utilised for on-grid and captive purposes. Around 91% of these CFPPs have operational lifespans exceeding 30 years, suggesting continued coal reliance; however, 48% of existing facilities will retire by or before 2040, including ageing and less economically viable plants. Utilising infrastructure at retiring plants presents cost-effective opportunities for targeted, gradual transitions toward lower-carbon solutions, particularly within industrial sectors. Strategic prioritisation of plant conversions could effectively support ASEAN's regional energy security, decarbonisation ambitions, and balanced energy development objectives.

ASEAN nations are increasingly vulnerable to extreme weather events and climate-related disruptions, emphasising the need for flexible and resilient energy systems. Modern CFPPs equipped with advanced technologies offer rapid output adjustment capabilities, grid stabilisation services, and other vital functionalities. Yet, investment considerations are complex, with CFPPs typically having a 35-year economic lifespan; premature closures could cause financial losses for stakeholders reliant on projected returns. Conversely, operating plants exceeding 25 years often experience declining profitability and rising maintenance expenses, highlighting critical policy considerations. Addressing these economic and operational challenges is essential for ensuring ASEAN's long-term energy security.

AMS interest in nuclear energy

The ASEAN Energy Outlook 8 predicts that nuclear energy will be introduced in the region after 2030, starting with an initial capacity of around 3 GW, and potentially increasing to around 10 GW by 2050 (ACE, 2024a). Although there are currently no operational nuclear power plants in ASEAN, nuclear energy remains an attractive option for many countries in the region as they plan to achieve carbon neutrality or net zero emissions targets. However, recent national plans show that the region might consider higher levels of nuclear power, in light of more ambitious nuclear energy targets in recently updated national policies, as well as potentially hydrogen production in the future.

Indonesia

Indonesia is considering including nuclear energy in its energy mix as part of its Net Zero Emissions (NZE) 2060 target. In the recent Indonesia Power Development Plan (RUKN), nuclear energy is expected to contribute to national electricity started in 2030s and will increase in capacity until 2060. According to the document, Indonesia plans to install 35 GW of capacity, supplying nearly 14% of the national electricity production in 2060. In addition to electricity, the document mentions nuclear energy for hydrogen production, in which nuclear capacity could be increased to 49 GW. To support the planning, 29 sites have already been identified by the national Energy Council to host the future nuclear power plants (ACE, 2025a; ACE, 2025b). Indonesia has also investigated the potential for SMRs, initiating co-operation with the United States and Korea to conduct a feasibility study on SMR deployment (Antara, 2023; World Nuclear News, 2023a). Furthermore, Indonesia has built a partnership with a Danish nuclear energy company to conduct a feasibility study on using SMR technology for ammonia production (World Nuclear News, 2023b). On the coal to nuclear initiative, the PLN Nusantara Power (the national utility company) and BRIN (national research and innovation institute) have conducted a joint project to develop a coal-to-nuclear simulator (Petromindo, 2024).

Philippines

The Philippines plans to commission its first nuclear power plant by 2032, with an initial capacity of 1.2 GW, and aims to gradually increase this to 4 800 MW by 2050, alongside renewable energy sources, to diversify its clean energy portfolio. To enhance national co-ordination, the Nuclear Energy Programme Inter-Agency Committee (NEP-IAC) was established as NEPIO, with a total of 24 agencies involved, gathering the stakeholders focusing on energy, finance, and environmental and foreign affairs, among others (ACE, 2024a). During the IAEA General Conference 2024, the country unveiled a national nuclear roadmap and priority activities until 2032. Among the priorities are the establishment of an independent nuclear regulatory authority and the development of a solid nuclear legal and regulatory framework to ensure safety, security and non-proliferation for the deployment and operation of a national nuclear power plant (Department of Energy of Philippines, 2024).

Viet Nam

After halting its nuclear power programme in 2016, Viet Nam appears to be reconsidering nuclear energy as part of its strategy to achieve a 2050 net zero emissions target. In November 2024, the Vietnamese lawmakers approved plans to resume the Ninh Tuan nuclear power plant project, with proposed generating capacity of 4 GW. Aside from hydrogen, nuclear energy has become one of the main priorities of Viet Nam's journey to ensure energy security, following the release of the Prime Minister's Decision No. 72/QD-TTg, which set up the steering committee for the construction of Viet Nam's first nuclear power plant project with the target to commission it by 2030 (ACE, 2025a). Nuclear power will not only diversify energy sources and ensure energy security but also support environmental protection in Viet Nam. Currently, the national power system has a total capacity of about 80 GW, and an additional 70 GW will be required by 2030. To supply the projected demand in 2050, capacity needs could increase to between 400 and 500 GW (Vietnam News, 2024).

Coal-to-nuclear replacement potential in ASEAN

Studies on coal-to-nuclear replacement have been carried out in countries such as China, Poland, South Korea, and the United States to identify the technical, socio-economic and environmental challenges as well as the advantages to the coal power plant communities and to the public in general. In addition to supplying reliable base-load electricity, the coal-to-nuclear initiatives may offer substantial benefits to the community. From the environmental perspective, replacing unabated coal combustion with nuclear power plants would potentially reduce high amounts of greenhouse gas emissions as well as particulate matter and other emissions that would lead to directly improving the air quality in the region. The initiative may also provide economic and social advantages because existing infrastructure and a skilled workforce can be repurposed, preserving employment across functions such as power plant operation, maintenance and supply chains. Indirectly related jobs and more tax revenue could also potentially be created. Further analysis on the location of suitable retired coal facilities and what factors make a site feasible for transition; what is required to attract investment; the needed policy and regulatory adjustments and how repurposing will impact local communities could further impact the decision-making process (Luo, 2024; Hansen, 2022; Joo, 2024; Ochmann, 2024).

Lastly, public engagement is essential in the coal-to-nuclear replacement initiative, serving as a critical enabler for successful transitions. Engaging local communities and effectively addressing concerns surrounding nuclear energy fosters transparency and builds trust. As coal plants retire, communities face significant economic challenges, making it vital to involve them in planning and decision-making processes. By facilitating open dialogue, government and project developers can align their goals with community interests, thereby enhancing the likelihood of successful implementation. Moreover, public engagement plays a crucial role in correcting misinformation about nuclear energy and mitigating resistance from stakeholders. Ultimately, a collaborative approach empowers communities to embrace clean energy transitions while revitalising local economies and ensuring a sustainable future.

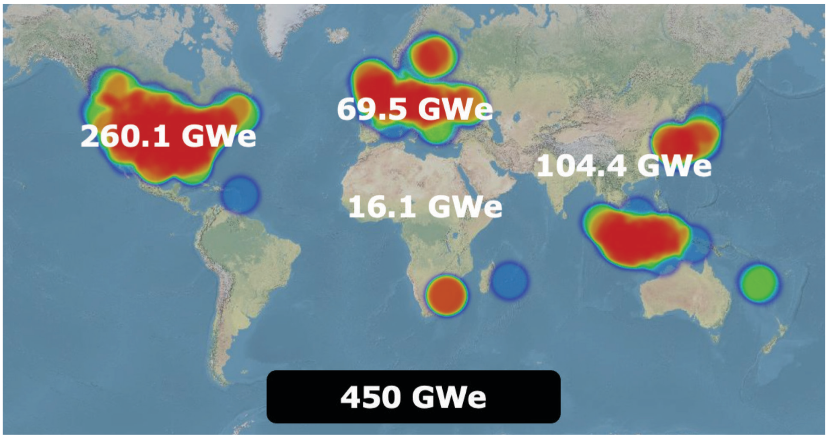
Estimate of the total potential market for coal replacement with nuclear energy

Summing up the figures for the three time frames outlined above, the NEA estimates the total potential market for coal replacement at 450 GW. This represents more than the current global nuclear installed capacity.

The potential market remains heavily concentrated in North America, particularly the United States, with 250 GW, or 50% of the total market. The remainder of the potential market is split between Asia and Europe, representing roughly 25% each. Asian countries with strong potential include Indonesia, Japan, Korea and the Philippines. In Europe, Poland, the United Kingdom, Czechia and France comprise most of the market. Lastly, South Africa holds most of the market potential in the African continent. The detailed breakdown is summarised in Figure 3.9 and Figure 3.10 below.

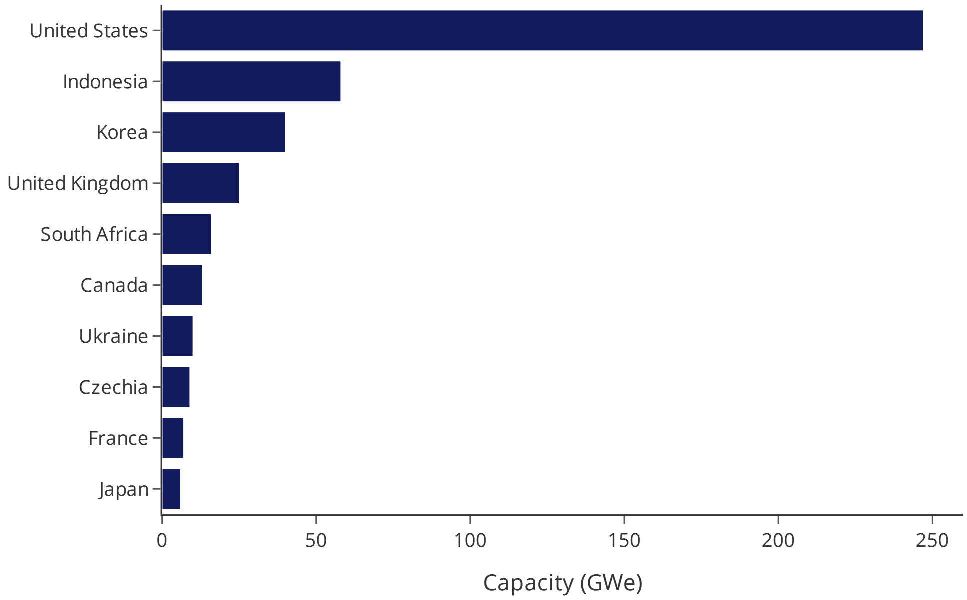
When considering timelines, around 381 GW, or 75% of the market, could be realised before 2040. The regions that have a significant market potential before 2040 are North America, representing 65% of the market potential before 2040, followed by Europe (16%) and Asia (12%). Beyond 2040, market growth will be driven by Asia (63%) and Europe (34%) as new countries adopt nuclear power.

Figure 3.9: **Country breakdown of the total potential market estimate**



Source: NEA based on Global Energy Monitor (2023).

Figure 3.10: **Breakdown by country (top 10) in GWe**



Source: NEA based on Global Energy Monitor (2023).

Box 7. **India is converting coal power plants into nuclear power locations – A distinct possibility…with caveats**

By Rahul Tongia, PhD, FNAE India

India fulfils a number of theoretical criteria for converting coal power plants into nuclear power plants: (1) It has a large coal power fleet with a commitment to move to net zero carbon emissions over several decades, a process that will require steps to be undertaken well before the deadline of 2070; (2) it has a long history of capabilities and know-how in nuclear power, having established Asia's first nuclear reactor in the mid-1950s, and its first nuclear power plant in the late 1960s; (3) it is a country with massive growth in demand for electricity – with per capita consumption of 1 395 kWh/capita as of FY2023-24, (Government of India, 2025), measurably less than half the 2023 world average estimated at over 3 400 kWh, based on IEA data (IEA, 2024) – and a large population that puts pressure on land use.

Is this sufficient? There are a range of nuances to India, in terms of energy policy, nuclear fuel cycles, and legacy issues that can either support or hamper the ambition to convert coal power plant locations into nuclear power facilities. This is in addition to the global challenge that nuclear power faces in terms of economic competitiveness.

Approximately three-quarters of India's electricity today comes from coal, but policies as well as recent market forces have slowed down its growth. From March 2017 to 2024, 77% of capacity growth has come from renewable energy (RE) (CEA, 2024), especially for solar power, whose prices have fallen dramatically. However, almost all this capacity has been for variable RE (VRE), without storage, which leaves the challenge of intermittency.

Two significant questions remain when considering the competitiveness of converting coal plant facilities into nuclear power plants. First, what is the overall competitiveness of nuclear power compared to renewable energy firmed up with storage, whose costs are falling? Second, how much cost reduction is possible through the synergies from existing coal power plants if converted into nuclear power facilities?

There are several lenses that can be applied, and these tie into technical nuances.

First: Are the techno-economics favourable? Part of this relates to issues of size and design, and even nuclear fuel cycle, which determines how much of any existing plant could be reused. In theory, one could aim for using much of the secondary side (steam side) plant, including cooling towers. But this depends on the sizes and separation distances required between plant components. While there is land available at coal power plants, and a grid interconnection by definition (and, often, a railway link that has been used to carry coal to the plant), land and grid connectivity can be of value even to a solar power development on coal plants. A Lawrence Berkeley National Laboratory study (Paliwal et al., n.d.) has attempted to quantify this exact question, and this undercuts the value for moving to nuclear power. This analysis uses GIS to quantify buildable land for solar and uses variable cost data per plant to come up with a national aggregate figure of viability for solar instead of coal of 30%.

The second lens is the availability of appropriate sites. While India's coal fleet is relatively young, with almost half having been built between 2011 and 2016, there are still a sizeable number of older power plants that are ostensibly at or near "end-of-life". However, there are three challenges with repurposing such facilities. First, India is behind schedule in adding RE power and thus falls back to its coal power as a backstop. In fact, the government recently announced a freeze on plans to retire older coal plants, despite them often being the least efficient and most polluting ("Phasing out of Coal-Based Thermal Power Plants and Adoption of Super-Critical Technologies in Thermal Power Plants", 2023). Second, many of the older coal plants are the smallest, under 200 MWe in some cases, and it remains to be seen if the thermal sizes (MWt) align with planned new nuclear builds. Most domestic builds as of now aim for economies of scale, and India is yet to build next-generation SMRs. Third, in many locations, most coal plants have been built in tranches, e.g. with units 1-2 built first and units 3-4 built years later. Thus, even if units 1-2 are closed, the facility is still active overall, which may hamper the practical conversion to nuclear power units (both during construction and operation).

Thus, a key area of analysis would be how many plants are amenable to a nuclear switchover based on the entire facility being available. A subtle challenge is the readiness of such facilities for not only nuclear plant construction but restrictions on access that are inevitable under nuclear power facilities. One issue is the extensive amount of coal ash on most coal plant lands, often in ash ponds. These are meant to not just be cleaned up but also utilised for ash brick production.

The third lens is one of legality and regulatory frameworks. This is one that has recently been updated and can align with a conversion of coal to nuclear energy. Historically, all nuclear power was built by the 100% government-owned public sector enterprise (PSE) Nuclear Power Corporation of India Limited (NPCIL). The government of India recently amended the rules to allow joint ventures, and in 2024, NTPC, India's largest coal power plant operator (also a PSE) set up a joint venture with NPCIL called ASHVINI to build new nuclear power plants (NTPC, 2024). Such an entity seeks financial, technical and operational synergies, and this could more easily enable the conversion of coal facilities to nuclear power facilities. Of course, all such efforts will need clearance from India's Atomic Energy Regulatory Board (AERB).

Nuclear energy remains an important option to consider for a country like India as it balances economic development with decarbonisation. The good news is there is limited public resistance to nuclear power, unlike what the United States experienced post Three Mile Island, or other countries post-Fukushima Daiichi. Most resistance is about land acquisition rather than nuclear energy per se. As India continues its nuclear power journey, most current plans call for an acceleration of existing technologies at "nuclear only" facilities. Coal-to-nuclear, or at least its investigation, should join the planning process. India should also figure out how much help it can gather from global R&D for next-generation reactors including SMRs. While India is not a signatory of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), it does have waivers and permissions from the Nuclear Supplier Group to enable nuclear material exchanges for power plants (Ramana, n.d.), and India has a successful track record of non-proliferation and safety.

Ultimately, one cannot overstate the role of government policy and support in making any use of coal facilities for nuclear power in India. However, this only goes so far – it can enable it, or even get it started, but scale will only come when there is economic viability. The next steps for coal-to-nuclear replacement in India would be detailed modelling and analysis, not only for specific sites and possible cost savings, but also for how such systems are likely to integrate into India's high-RE future power grid. While nuclear power is firm, it has typically been "must run", more so for existing pressurised heavy water reactors, or PHWRs, which cannot shut down and restart easily. In contrast, France has pioneered load-following nuclear plant capabilities which will provide flexibility in ramping output up and down in response to RE and grid conditions. This ties back into the chosen fuel cycle and reactor design chosen.

India already has a commitment to triple nuclear power by 2032 (News On Air, 2024), and it has ambitions to grow nuclear power more than 10 times by 2047 as part of its net zero trajectory. For this to happen, India needs to add more options and opportunities for scaling nuclear power safely and cost-effectively, which would not only encompass SMR options but also the possibility of converting retired coal power plant facilities into new nuclear power plants. The next steps need to be analysis and planning – such plants will take many years to come to fruition.

Chapter 4. **End user perspective**

To inform this report, interviews were conducted and a cross-sectional survey undertaken to engage with stakeholders who may be considering nuclear energy among a range of options to replace coal generation. This includes existing operators of coal or nuclear power plants, research organisations, and other relevant groups. The engagement activities aimed to address key questions to inform the opportunity for nuclear energy to replace or repower coal generation, including:

- Why are end users considering nuclear energy?
- What are their motivations and key drivers for choosing this technology over other alternatives?
- What are the main enabling factors that could, according to end users, accelerate the adoption of nuclear energy?
- To what extent is nuclear energy aligned with end users' energy planning decisions?

The responses to these key areas provide a demand-side perspective that can help inform policymakers about the main drivers, detailed characteristics and timelines for nuclear energy to replace coal generation assets.

Fifteen individual experts participated in structured interviews and a distributed survey to share quantitative data from their operations, as well as perspectives regarding the energy transition and the trend towards a reduced reliance on coal generation. End users commented on the specific energy and technical requirements and shared their views on the barriers and enabling conditions for nuclear energy to replace coal generation across a variety of jurisdictions. This chapter includes a non-exhaustive inventory of the end-user requirements that have been identified through these engagement activities.

Combined, these stakeholders represent a diverse set of jurisdictions and sectors. Engagement with stakeholders seeking to replace coal generation was also informed by engagement with an expert group convened to understand the technical, business and operational requirements associated with the adoption of nuclear and other clean energy technologies. The engagement includes utilities, research organisations, international organisations and other relevant stakeholders.

The companies engaged in support of this case study primarily represent markets in North America and Europe. This is aligned with NEA estimates on initial near-term markets for nuclear energy to replace coal, as described in the Chapter 3. Future work should engage markets in Africa, Asia and South America to understand longer-term considerations required to reduce coal generation in support of national targets to achieve net zero emissions around 2050.

Timeline mismatch: Coal-to-gas instead of coal-to-nuclear

Many utilities have committed to achieving net zero by 2050, with many also committing to intermediate emission reduction targets. In conflict with these emissions' reduction targets, the utilities interviewed perceive nuclear energy as a technology that could become commercially viable from 2035 onwards, with the first units expected to be constructed between late 2020 and early 2030s. Therefore, according to utilities, SMRs are unlikely to contribute to short-term emissions reduction targets, but rather to long-term decarbonisation efforts towards net zero.

In the short term, it is likely that some coal plants will be replaced by a mix of solar, wind, batteries and natural gas as these technologies are viewed as more mature and lower-risk options compared to SMRs. In some regions, like the United States, it is also necessary to propose immediately deployable solutions to secure contracts that guarantee the utility capacity on electrical transmission lines, which could be lost if other competing utilities propose new generating capacity in shorter time frames.

Nuclear experience matters

End users noted that experience in owning and operating nuclear energy assets could provide a significant advantage for companies that are exploring transitions from coal to nuclear energy. Nuclear power plants require specific capabilities related to nuclear physics and engineering, safety, public engagement and environmental protection. Operating a nuclear power plant also requires increased interactions with regulators and an established safety culture that is shared across the organisation and with suppliers. Having these capabilities in-house could help identify and mitigate potential risks, save costs in building new capabilities, and leverage cost synergies between an existing coal and nuclear portfolio, thus facilitating the transition from coal to nuclear.

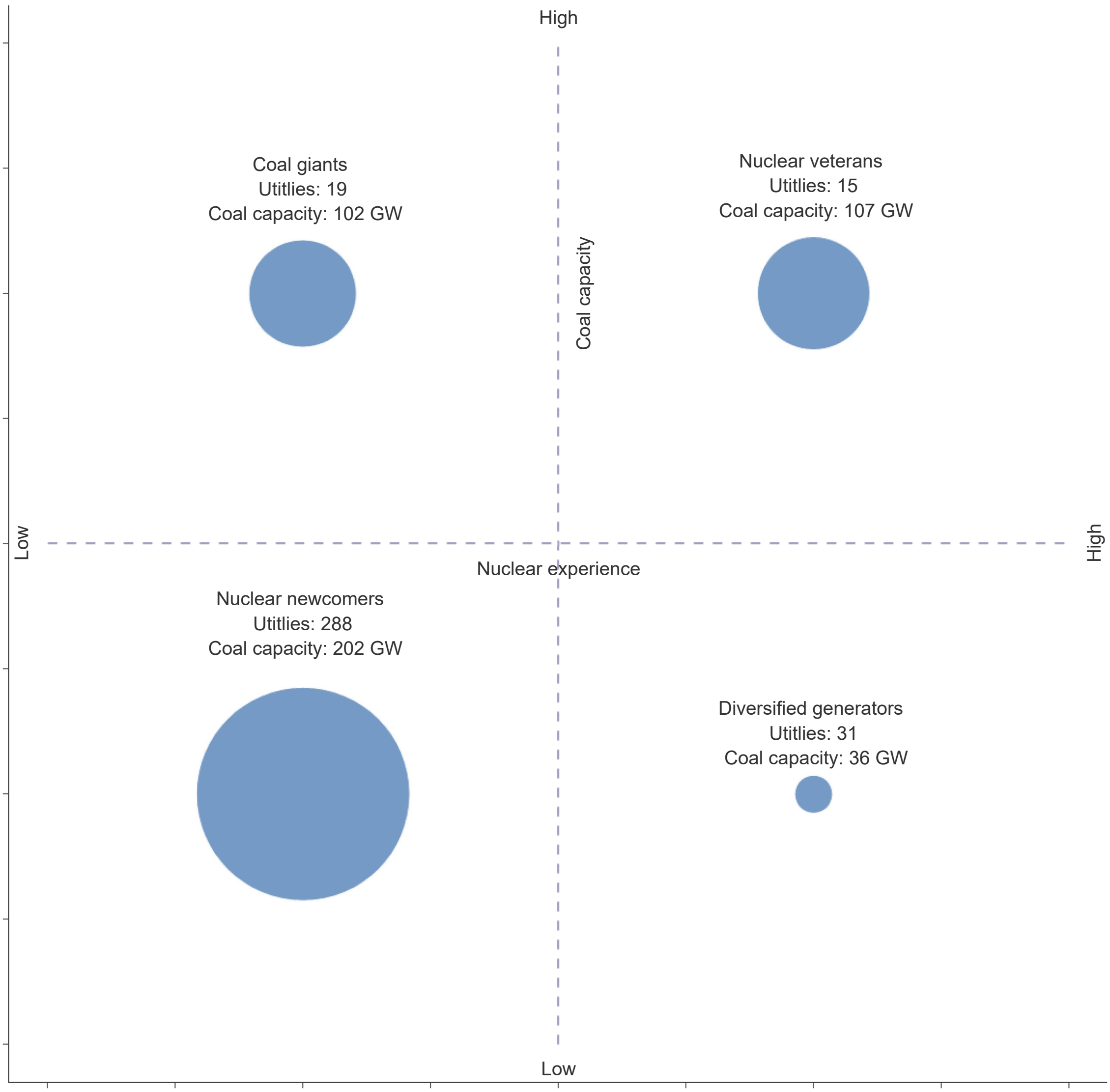
Following the global market assessment for coal replacement identified in Chapter 3, 17% of utilities in time frames 1 and 2, representing the potential addressable market by 2035 and 2040, respectively, own both nuclear and coal assets and would be able to leverage their experience with nuclear power to replace coal assets with SMRs. This 17% of utilities accounts for almost 40% of the total generating capacity of coal today at around 150 GW. To further emphasise this, the coal capacity from all three time frames were arranged by coal capacity and nuclear experience as shown in Figure 4.1. Those with high coal capacity were those with greater than 3 GW of coal and those with high nuclear experience had at least one operating nuclear reactor currently. As can be seen in Figure 4.1, a few utilities have a large coal capacity and are "nuclear veterans" that will likely be first movers in the coal-to-nuclear space. In the bottom left quadrant of Figure 4.1 can be seen that many small utilities have a large fraction of the coal capacity and likely will need policy support to adopt coal-to-nuclear transitions.

Many fast followers, few first movers

Utilities are typically risk-averse organisations with capital-intensive investments. Utilities currently perceive SMRs as a "non-least-cost and risky" option from a plant-level perspective. This perception is influenced by recent industry experience with first-of-a-kind (FOAK) projects and uncertainty around innovative nuclear energy technologies, leading to overall uncertainty about the ultimate plant-level cost of nuclear energy power plants. Critically, the utilities interviewed acknowledge the potential for nuclear energy to enable least-cost generation portfolios despite their plant-level costs. The overall value proposition of SMRs is well understood among end users, and there was a general willingness to invest in SMRs once they become more competitive and commercially proven.

As a result, there are very few end users among those interviewed who are willing to be first movers to replace coal plants with nuclear power plants and many potential fast followers ready to adopt the technologies once the initial learning curve has been financed by others. Accumulating this necessary deployment experience requires new nuclear energy projects, which are unlikely to materialise if potential investors refrain from placing new orders. In the United States, this has created a commercial stalemate among industry stakeholders. As the US Department of Energy notes: "Utilities and other potential customers recognise the need for nuclear power, but perceived risks of uncontrolled cost overrun, and project abandonment have limited committed orders for new reactors" (DOE, 2023a). In such a situation, new policy enablers may be needed to catalyse projects.

Figure 4.1: **Potential market groups as a function of the size of the companies and their experience with nuclear power**



Potential synergies in the coal and nuclear sectors

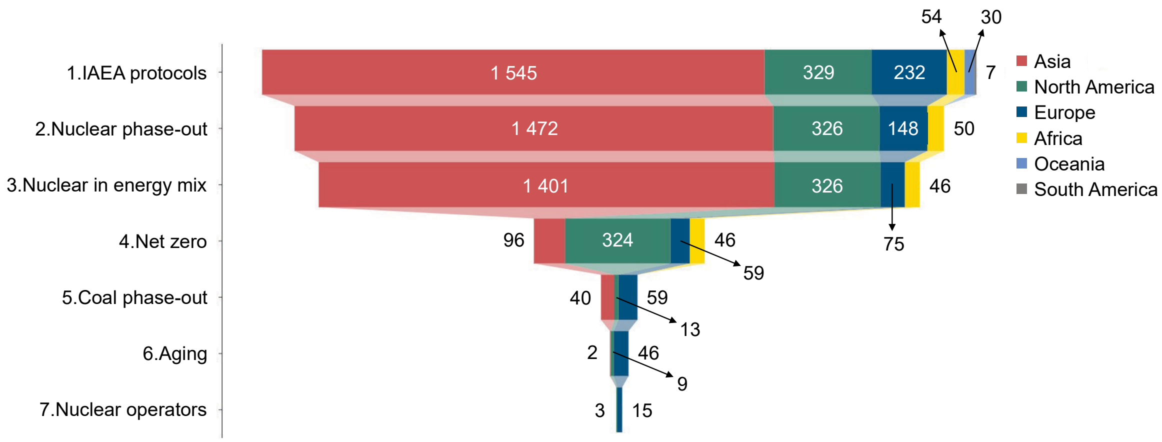
While experience operating a nuclear power plant among utilities offers advantages when considering a coal-to-nuclear transition, end users also noted the similarities that are shared among the two types of thermal generation plants. There may therefore be similarities and synergies for utilities that are familiar with coal generation to adopt nuclear power.

As coal plants are closed the workforce may be displaced, which has potential impacts on local economies and community stability. As an alternative form of baseload thermal power generation, there may be an improved opportunity to retrain and redeploy the coal plant workforce when compared to solar, wind, or other forms of non-emitting electricity. There is expected to be significant commonalities in the operations and maintenance of power conversion components, as well as grid management practices and jobs intended to ensure overall grid suitability.

The role for governments

End users noted the key role of government and policies in accelerating the transition from coal to nuclear energy by addressing many of the risks identified above, including decarbonisation policies, nuclear deployment policies, regulatory frameworks and economic incentives. To demonstrate the area of potentially most impact, the total global coal capacity was subjected to all seven filters. Each step in the filter represents the application of one filter. The largest change in capacity is from step 3 to step 4 where only coal plants under a net zero policy remain. This shows that net zero policies could be high priorities for governments to implement to send a clear market signal that coal-to-nuclear transitions are valuable in the long term.

Figure 4.2: **Cumulative effect of each filter on global coal capacity**



Nuclear deployment policies

Targeted national nuclear development and deployment policies are encouraged and will vary according to local priorities and challenges. Countries may wish to consider a specific roadmap for the deployment of SMRs, highlighting the opportunities that coal sites provide, such as the case of the "Czech SMR Roadmap: Applicability and Contribution to the Economy" (Ministry of Industry and Trade of the Czech Republic, 2023).

Regulatory frameworks

In general, end users perceive the regulatory and permitting aspects of nuclear energy as a source of uncertainty in their energy infrastructure plans. Timelines remain unpredictable, particularly for the licensing of new technologies. End users noted issues in existing processes but also in the capacity of regulators to review applications for new projects, which may increase in the future.

Creating enabling frameworks for regulators to support faster deployment without compromising safety is an area of active work in many countries. The US NRC has submitted a draft 10 CFR Part 53 licensing process which proposes a risk-informed, technology-inclusive regulatory framework, reflecting greater flexibility that could suit a variety of advanced reactor designs (NRC, 2023). The French Senate adopted a plan to merge the regulator ASN with the technical support organisation IRSN to streamline processes and achieve cost synergies (SFEN, 2024).

For coal-to-nuclear transitions, it may be possible to explore higher standardisation in the licensing process. This may include envelope permits that once acquired can be applied to a range of sites and reactor types, reducing site-specific considerations as much as possible. The Southern Ohio Diversification Initiative (SODI) in the United States offers a useful example of an envelope approach that was created to evaluate the potential of building an advanced nuclear reactor in the former Portsmouth Gaseous Diffusion Plant (PORTS). In particular, the Southern Ohio Diversification Initiative (SODI) issued a Plant Parameter Envelope template for use at PORTS and other sites, in collaboration with the US Nuclear Regulatory Committee (NRC), and worked to provide guidance and data to develop an early site permit and plant parameter envelope templates to be use at the PORTS site for advanced reactors.

Economic incentives

End users have emphasised the importance of sharing risks and costs with the government to secure an order book of projects. This is particularly important for first-of-a-kind projects involving novel technologies. Governments can facilitate the realisation of such projects through direct or indirect measures, playing a transitional role in early stages until the technology becomes more competitive and the private sector becomes more engaged (NEA, 2020).

End users noted that governments could be particularly effective in sharing construction risks. This approach has already been applied in recent projects where government support mitigated construction risks through both equity and debt financing from government banks or export credit agencies.

Chapter 5. Conclusions

Hundreds of gigawatts of coal capacity will be decommissioned globally in the coming years. This trend is driven by the age of the existing coal fleet, national decarbonisation goals and competitive alternative technologies. This study explores the opportunities and challenges associated with replacing existing coal fleets by conducting a literature review, carrying out a geospatial analysis to estimate the addressable market of coal-to-nuclear conversion, and by interviewing and surveying end users for their perspectives. From this work, several conclusions can be drawn that are highlighted in this chapter.

Global imperative for a reliable energy transition

Coal power remains a dominant source of global electricity, particularly in countries such as China, India, Japan and the United States which together hold around 75% of the global installed coal capacity. However, coal is also ageing infrastructure that is increasingly economically unviable.

Nuclear energy, with its high reliability and high capacity factors, represents a promising alternative that can replace coal assets in a way that meets both baseload and dispatchable generation requirements. In this way, nuclear energy can contribute to a reliable energy transition by maintaining the baseload generators that have been used in electricity systems for decades. In addition to their reliability, nuclear reactors can be a source of new, high-paying jobs in communities that have reaped economic benefits from coal plants. By providing new employment as countries transition fuel sources through retraining programmes, nuclear energy can be part of a just transition.

Transitioning from coal to nuclear energy involves both technical and non-technical challenges. Technically, existing coal plant sites must meet stringent safety criteria and environmental criteria to host nuclear facilities. The site must be licensed and capacity for grid integration with existing connections must be evaluated. There must be adequate space for containment structures, augmentation to cooling systems, security infrastructure and nuclear waste management. From a non-technical perspective, there must be community engagement, considerations for workforce retraining or recruitment, and sufficient investment and funding.

From the literature review, most of the research being published on coal-to-nuclear transitions is occurring in North America and Europe. This makes sense from the perspective that these regions have some of the oldest coal fleets in the world and are likely to be the first to adopt coal-to-nuclear technologies.

Addressable market and feasibility

The addressable potential market for coal-to-nuclear transitions varies by region, with the largest variable being coal plant age. Other factors include a country's government policies, existing nuclear infrastructure, and coal phase-out plans. North America, particularly the United States, emerged from the analysis as a potential early adopter due to its ageing coal fleet and robust nuclear energy experience. Europe also shows promise and would likely to benefit from coal-to-nuclear replacements.

The total global coal capacity of 2.2 TWe was filtered using market screening criteria. This gave an estimated potential market for coal replacement with SMRs of 143 GWe by 2035, mostly centred in the United States, which could be a prime first mover for coal-to-nuclear demonstration. By 2040, this number expands to 238 GWe with the major change being the availability of Europe and Asia as potential markets for the coal-to-nuclear transition. After 2040, Asia and Europe become the primary targets of a coal-to-nuclear transition. Globally, 505 GWe of coal production were identified as having high potential to transition to nuclear technologies.

End-user perspectives and challenges

Among the stakeholders surveyed and interviewed, those in the energy sectors expressed strong interest in nuclear technologies as a viable option to replace coal. These included utilities and large industrial energy consumers. However, many cited the need for established commercial viability and favourable regulatory environments before committing to nuclear investments. Utilities are generally risk-averse, preferring proven technologies, which places nuclear technologies, especially SMRs, in a position of needing further demonstration projects to alleviate cost and construction risk perceptions. Additionally, potential adopters emphasised the importance of government policy in catalysing initial projects and addressing economic barriers for first-mover deployments. To assist end users, it is important to consider the following.

- **Anticipation is key to reduce risk**: As indicated by others (Almalki, 2019; Belles, 2013, 2014, 2021; Omitaomu, 2024) and by survey and interview respondents, identifying potential sites for coal-to-nuclear replacement prior to plant closure is key to project success. Examples from the literature review and panel of experts include important steps such as assessing and upgrading site infrastructure and procuring land, transmission, and water right permits. These were deemed critical to the process. Governments can assist with these steps by performing a national study of the criteria and sites that fit such criteria for coal-to-nuclear transitions.
- **Supporting locations through technical analysis**: There are many differences in the regulatory requirements for coal and nuclear plants. This means that for each coal-to-nuclear project there is a gap in regulatory adherence that must be met through exhaustive analysis, planning and licensing. It is possible that a coal site will not meet the technical and regulatory requirements to host a nuclear power plant. This should be identified as soon as possible. To aid in this assessment, organisations have established lists of criteria that can be used to qualify or disqualify sites for potential coal-to-nuclear transitions. From both the geospatial and end-user analysis, there is similarly a role for government in making the operating license process of the coal-to-nuclear transition transparent and accessible for existing coal utilities.

Role of government in creating enabling policy frameworks

Effective policy frameworks and strong domestic policies that are favourable to nuclear energy development and deployment are essential for a sustainable coal-to-nuclear transition. Governments can drive nuclear adoption through clear decarbonisation policies, direct financial incentives, and streamlined regulatory processes. Public-private partnerships could support this transition by sharing risks associated with early-stage nuclear projects and providing financial backing to ensure continuity in community-level economic contributions previously supplied by coal plants. Moreover, policies fostering job retraining and local economic support could facilitate a “just transition” for coal-dependent communities. Examples of supportive governments in this space can be found in the literature (NEA, 2020; NRC, 2023).

- **Support coal site evaluations**: Due to the complicated nature of coal-to-nuclear replacement, governments have an important role to play in lending expertise of licensing bodies in the assessment of potential sites for coal-to-nuclear replacements. National studies could be conducted by countries to help identify sites and streamline the site selection process for utilities that want to investigate coal-to-nuclear replacements. National governments have a strong potential role in identifying sites or regions that may benefit from coal-to-nuclear replacements.

- **Increase the regulatory readiness of coal-to-nuclear replacements**: Similar to supporting coal site evaluations, there are many steps governments can take to help create regulatory certainty around coal-to-nuclear replacement projects. This could include identifying and pre-approving existing coal sites for nuclear projects, investing in demonstration projects, offering training for regulators, and helping to re-skill the coal workforce.
- **Incentivise coal-to-nuclear transitions**: Along with site and regulatory certainty, governments can take additional steps to incentivise coal-to-nuclear transitions. These steps include long-term guarantees that make it clear nuclear energy has a crucial role in the future energy mix. This could also include financial incentives. Simple financial incentives include grants, direct subsidies or tax credits. More complicated financial incentives include low-interest loan guarantees, carbon pricing mechanisms, and helping to pool potential customers by creating long-term contracts and power purchase agreements to guarantee customers for the nuclear energy to be produced. Other incentives include public funding for infrastructure upgrades such as grid modernisation and decommissioning support.

One often-discussed potential form of incentive that could be utilised is providing financing opportunities for coal-to-nuclear transitions. This could take the form of simple loan guarantees, publicly provided financing at reduced rates or working with private financing institutions to specialise and build expertise around nuclear financing projects. This topic has been addressed in other publications (NEA, 2022).

Opportunities for future analysis

The analysis presented in this work adds to the body of literature on coal-to-nuclear transitions. It provides novel insights into the potential addressable coal-to-nuclear market globally and from the end-user interactions it suggests some important next steps for public and private organisations to support the coal-to-nuclear transition. However, the work in this area is clearly not finished. There are several opportunities for additional analysis to be conducted, as described below.

- **Addressing literature gaps**: While there is significant literature on coal-to-nuclear transitions, there were several gaps identified that future studies could address. These included topics on brownfield nuclear construction for already retired coal plants, public engagement approaches that explore and identify effective methods to address community concerns on nuclear energy and garner public support, and coal plant remediation activities that may be required for environmentally safe decommissioning and cleanup of coal plant sites.
- **Economic modelling**: While several case studies have been conducted, additional economic modelling could be pursued to better understand the financial viability of different nuclear technologies in replacing coal plants as well as to compare the long-term benefits of coal-to-nuclear transitions in comparison to other technologies such as gas or renewables that could replace the coal plant capacity and utilise existing grid infrastructure.
- **Policy and regulatory research**: Several policy and regulatory approaches have already been mentioned but future work could focus on quantifying the impact of policy and regulatory innovations as well as assessing the impact that international agreements have on the feasibility of deploying nuclear technologies
- **Technical feasibility studies**: Each level of coal plant replacement, whether it be repurposing, repowering or replacing the coal site, will likely require its own country-specific technical feasibility study to understand the engineering challenges of

retrofitting existing coal plant sites to meet nuclear regulatory and safety standards. This work will necessitate close collaboration between research and regulatory institutions to create viable technical pathways for coal-to-nuclear transitions.

Nuclear energy and SMRs present an attractive solution for reducing reliance on coal, strengthening countries' energy security, reducing emissions and encouraging a just transition. This transition will require a combination of market readiness, technical work, regulatory reform and public sector support. Moving forward, policymakers and industry stakeholders would need to collaborate to address these factors to realise the potential of nuclear energy as a cornerstone of a low-carbon energy future.

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SMRs for Replacing Coal: Opportunities and Challenges for Small Modular Reactors

This publication presents a comprehensive analysis of the global potential, technical requirements, and policy opportunities of using small modular reactors (SMRs) for on-grid applications at coal plants. It is part of an NEA series of case studies to assess the opportunities and challenges for SMRs to support the decarbonisation of hard-to-abate industrial sectors while preserving jobs and securing reliable, resilient energy infrastructure. This study was informed by direct engagement with stakeholders in the electricity and coal sectors who identified a range of considerations and barriers to nuclear adoption at coal plant sites. It includes estimates of the coal capacity that could be transitioned to nuclear energy, as well as of which countries have the highest likelihood of transitioning rapidly from coal to nuclear power. Near, intermediate and long-term opportunities for nuclear energy at coal sites are quantified and presented.

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