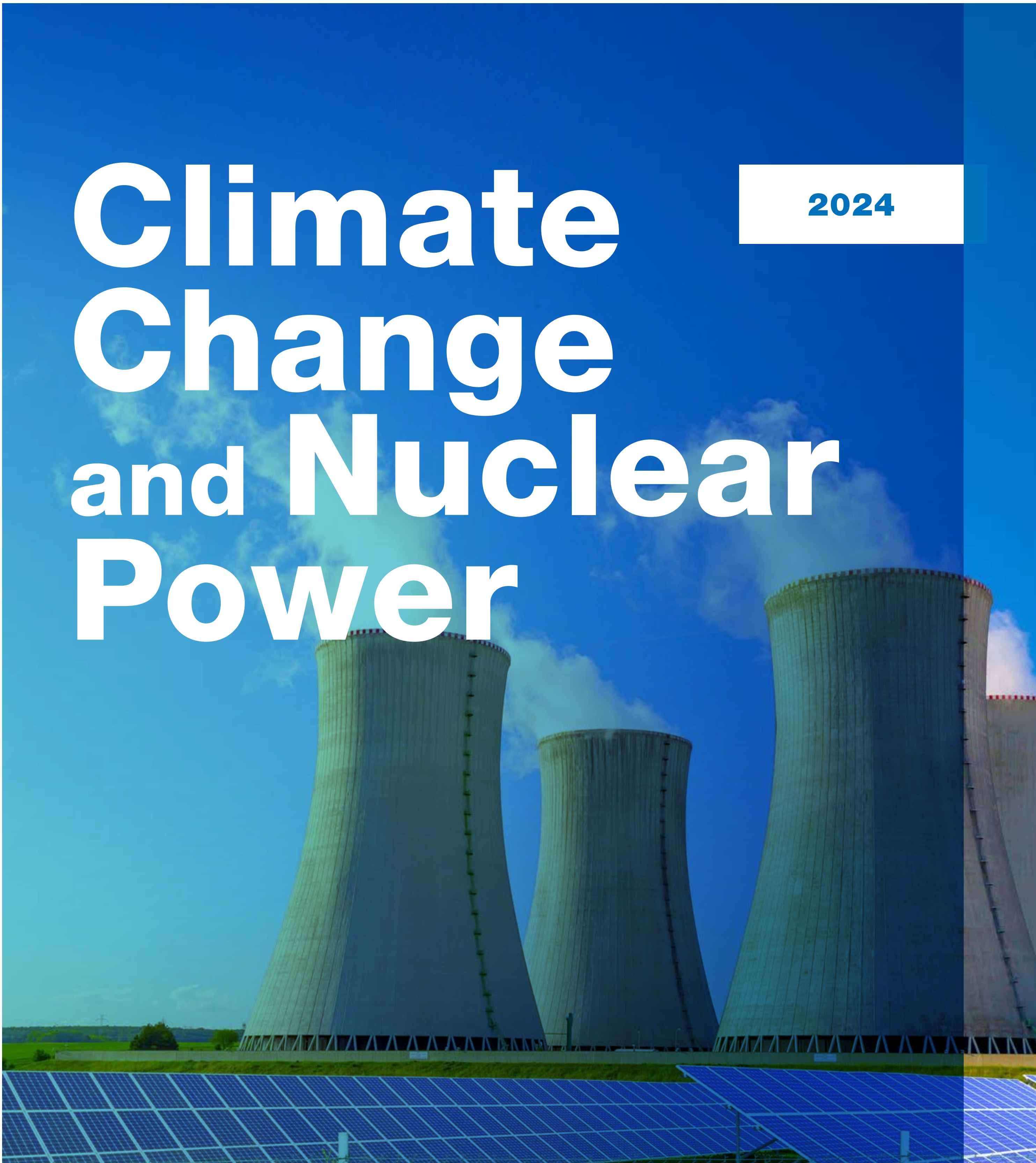
IAEA
International Atomic Energy Agency

Climate Change and Nuclear Power

2024



FINANCING NUCLEAR ENERGY IN LOW CARBON TRANSITIONS

2024

Climate Change and Nuclear Power

FINANCING NUCLEAR ENERGY IN LOW CARBON TRANSITIONS

FOREWORD

RAFAEL MARIANO GROSSI
Director General, International Atomic Energy Agency

Financing Nuclear is Central to the Shift to Net Zero

The inclusion of nuclear in the first Global Stocktake under the Paris Agreement was nothing short of historic. After almost 30 years of United Nations climate conferences, countries – both those using nuclear power and those not – agreed that reaching global climate goals would require further investment in nuclear power. This acknowledgement reflects how much global attitudes to nuclear have shifted in the past few years.

Last December at COP28 in Dubai, more than 20 countries also pledged to work towards tripling nuclear power capacity by 2050. The twin catalysts of the change were the urgency of the climate crisis and the renewed push for energy security. When it comes to nuclear, fact based analysis and science have finally overcome misunderstanding and ideology.

Now the challenge is to turn ambition into the hundreds of additional nuclear reactors we need to reach net zero. Time is of the essence.

In the past year, levels of harmful greenhouse gas emissions and global temperatures reached new record highs. A relentless succession of floods, fires and droughts warn that we are running out of time.

In March 2024, the IAEA shifted action into a higher gear when, together with the Government of Belgium, we hosted the first Nuclear Energy Summit. World leaders from more than 30 countries and the European Union gathered under Brussels's famous Atomium landmark and agreed to urgently put in place conducive financing conditions and to increase investment.

The IAEA's support goes beyond high level summits.

Every day, whether through analysis or assistance in the field, the IAEA is helping Member States reach their goals. There is hardly a more important one than ensuring that we leave coming generations an inhabitable planet.

The scale and versatility of nuclear energy as a tool for achieving that goal are often overlooked. The IAEA's Atoms4NetZero Initiative builds on decades of experience supporting countries in developing capacity in energy planning. It provides analytical tools and expertise to help countries assess the usefulness of nuclear power for them, including in the form of innovative technologies, such as small modular reactors (SMRs). Introducing a nuclear programme for the first time is a multi-step process. Through its Milestones Approach, the IAEA assists countries from Africa to Asia in establishing the infrastructure necessary for a safe, secure and sustainable nuclear power programme.

Across its near century-long lifetime a nuclear power plant is affordable and cost competitive. Financing the upfront costs can be a challenge however, especially in market driven economies and developing countries. The private sector will increasingly need to contribute to financing, but so too will other institutions. The IAEA is engaging multilateral development banks, including the World Bank, to highlight their potential role in making sure that developing countries have more and better financing options when it comes to investing in nuclear energy.

Demand is also coming from digital technology companies. The IAEA is helping to inform their decisions as they look to nuclear to power their growing use of artificial intelligence (AI) and data centres.

Emerging SMR technologies hold immense promise to deliver clean energy. The 90 or so designs under development are a testament to the level of innovation and excitement these technologies are generating. But there is work to do before their potential can be realized. That is why the IAEA, through its Nuclear Harmonization and Standardization Initiative (NHSI), has brought together the nuclear community to develop common regulatory and industrial approaches to facilitate global deployment and financing of SMRs.

Energy-hungry technology, electrification, the shift to low carbon energy and population growth are all contributing to greater demand for nuclear. The IAEA's latest high case projection for nuclear power capacity in 2050 sees a 150% increase from current levels to 950 gigawatts. This reflects decisions around the world supporting the long term operation of existing reactors, new construction of large nuclear power plants, and the development and deployment of SMRs. Realizing an increase of this scale requires annual investment of more than US $100 billion between now and 2050 – a fraction of what the world invests in energy infrastructure overall, but a big change from the level of investment in nuclear over the past 20 years.

This latest edition of **Climate Change and Nuclear Power** continues the IAEA's contribution over more than 20 years to the analysis of the role of nuclear energy in responding to climate change. Our work in this area this year includes supporting the G20 Energy Transitions Working Group, under the Brazilian presidency.

The IAEA will again be at COP this November. At COP29 in Baku, the world will find itself at a critical juncture.

Can we muster the money necessary to turn ambition into reality? Financing is the central question, and that is why it is also the focus of this edition of **Climate Change and Nuclear Power**.

Rafael Mariano Grossi
Director General, International Atomic Energy Agency

Table of Contents

FOREWORD

EXECUTIVE SUMMARY 2

1. Introduction 4

1.1. Investments for Clean Transitions 5
1.2. Nuclear Energy and International Climate Policy 12
1.3. Objectives, Scope and Structure 15

2. Economics and Risk Management for Nuclear Energy Projects 17

2.1. Economics of Nuclear Energy 18
2.2. Mapping Risk 20
2.3. Getting to 'On Time and on Budget' 22

3. Financing Approaches for Nuclear Investment 29

3.1. Financing New Build 30
3.2. Financing Long Term Operations 58

4. Considerations for Small Modular Reactors 62

4.1. Economics of Small Modular Reactors 63
4.2. Opportunities for SMRs to Access New Financing Pathways in the Transition to Low Carbon Energy Systems 65
4.3. SMR Financing Considerations and Challenges 72

5. Considerations for New Nuclear Programmes in Emerging Markets and Developing Economies 73

5.1. Considerations for Nuclear in EMDEs 74
5.2. Funding Infrastructure Development 76
5.3. Access and Cost of Financing 77

6. Recommendations and Conclusions 83

REFERENCES 86

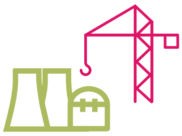
LIST OF ABBREVIATIONS 95

CONTRIBUTORS TO DRAFTING AND REVIEW 96

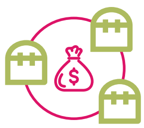
EXECUTIVE SUMMARY

The 2024 edition of Climate Change and Nuclear Power delves into the dynamics of financing nuclear projects to unlock much needed nuclear energy capacity as ambitious climate targets draw nearer. We explore the imperative for robust financial frameworks to propel the adoption of nuclear energy as a cornerstone of global decarbonization efforts.

Nuclear energy investment must increase from around US $50 billion per year during 2017–2023 to **US $125 billion annually to meet the IAEA's high case projection for nuclear capacity in 2050.** Tripling the existing nuclear capacity would require more than $150 billion annually. To mobilize such capital, nuclear projects must prove bankability by mitigating financial risks.



Ensuring construction and cost predictability is pivotal to investor confidence. Nearly two thirds of the total cost per megawatt-hour from a nuclear power plant (NPP) can be attributed to construction and investment costs. With a **construction duration of almost six years for the majority of large reactors**, construction cost remains acutely sensitive to fluctuations in construction schedules and finance costs.



Commitment to multiple reactors transforms first-of-a-kind (FOAK) risks and challenges into investment opportunities to achieve construction time and cost predictability. The first large reactor projects built in countries after one or two decades are reported to have capital costs of around US $8 000–11 000 per kilowatt (excluding financing), or more. In comparison, **countries with uninterrupted experience in nuclear new build projects are reported to have capital costs closer to US $2500–5000/kW.**

Sizewell nuclear power station, United Kingdom.

While government involvement remains crucial for managing certain risks, **private sector financial involvement is becoming increasingly viable for nuclear energy projects.** Financial mechanisms such as green bonds and loans, coupled with guarantees, offer tools for risk mitigation and broader investor participation. Including nuclear power in sustainable taxonomies could further catalyse commercial bank involvement, with multilateral development banks potentially playing a supportive role, particularly in developing countries with nascent financial markets.

Small modular reactor (SMR) developers promise economies of volume to lower initial capital costs and reduced construction risks alongside the potential for diversified revenue streams. While no current SMR project offers a realistic view into the cost of SMRs in serial production, **collaborative efforts among the nuclear industry, policy makers and regulators are needed to clear the path for the significant rollout of SMRs.**

Multifaceted approaches that include policy reforms and international partnerships are imperative to **bridge the financing gap and accelerate the clean energy transition in emerging markets and developing economies** (EMDEs). Robust regulatory frameworks, new delivery models (especially for SMRs), skilled labor development and comprehensive stakeholder engagement strategies could unlock new avenues for sustainable energy investments towards development goals.

This evolving landscape hints at a potential shift towards broader acceptance and support for nuclear energy financing, bolstered by innovative financial mechanisms and a growing recognition of nuclear's crucial role in achieving global climate targets.

1. Introduction

The impacts of climate change are increasingly visible across the globe, highlighting the need to rapidly reconfigure the global energy system to achieve carbon neutrality by mid-century and limit global warming to 1.5°C [1]. At the same time, the world continues to grapple with energy security vulnerabilities and broader sustainability challenges, which remain acute in many emerging markets and developing economies (EMDEs) [2]. The overall demand for clean energy – such as that required with an increased use of AI and electrification of transportation networks – exacerbates this need.

Responding to these challenges necessitates urgent action to scale up, redirect and accelerate investment to deliver clean, sustainable and just energy transitions around the world. In this context, mobilizing financing for investment in nuclear energy will play a critical role in supporting ambitious climate change mitigation and adaptation and in delivering reliable, affordable, clean and modern energy to underpin economic and social development and energy security (see Box 1).

1.1. Investments for Clean Transitions

To achieve the goals of the Paris Agreement, it will be necessary to deploy a combination of low carbon technologies. The electricity sector — responsible for roughly 40% of energy related emissions [3] — will need to shift from unabated fossil fuels to renewables, fossil with carbon capture technology and nuclear generation while delivering substantially more electricity as end use applications in buildings, industry and transportation are electrified to replace the direct use of fossil fuels [4]. In sectors less suited to electrification, a switch to other clean energy carriers will be critical for reaching net zero.

The International Energy Agency (IEA) estimates that reaching net zero carbon dioxide (CO_2) emissions by 2050 will require annual energy sector investment of US_{2022} \$4.7–5 trillion from 2030 to 2050, compared with US \$2.8 trillion in 2023 [4]. The increase between 2023 and 2030 represents around one percentage point of global gross domestic product, indicating the need to channel substantial additional capital to the energy sector [4].

Most of the investment (around US \$4.2 trillion in 2030) needs to be directed towards clean energy, representing roughly a doubling in advanced economies and China, and a fivefold increase in other EMDEs by 2030 (increasing to almost tenfold by 2050). The main investment targets include clean power (over US \$2 trillion per year in generation and grids) and energy efficiency and end use, with a smaller amount for other clean energy supply [4].

Almaraz nuclear power plant, Spain.

BOX 1

Nuclear energy: a key part of secure, reliable, stable and sustainable net zero transitions

Sanmen nuclear power station, China.

Nuclear energy's broad contribution is not always remunerated in energy markets or considered in investment decisions.

Nuclear and Renewables Partner to Achieve Net Zero

All low carbon technologies are needed to achieve net zero targets. Nuclear energy offers substantial mitigation potential and can support the integration of renewables in low carbon energy systems.

Decarbonizing Beyond Electricity

In addition to providing a 24/7 electricity supply, nuclear power is the only low carbon, large-scale heat source able to replace fossil fuels for industrial heat and hydrogen production.

Resilience, Reliability and Security of Energy Supply

Nuclear power can ensure a secure, reliable and resilient energy supply. Operating on demand, irrespective of weather, nuclear power can stabilize the grid in systems with high shares of variable generation while contributing to security of energy supply.

Affordability

Nuclear power can underpin an affordable, low carbon energy system by minimizing the amount of energy generation that exceeds demand and the need for expensive flexibility and storage infrastructure.

Sustainable Development and Just Transitions

Nuclear energy can help developing nations secure electricity access, socioeconomic development and industrialization to meet their Sustainable Development and Climate Goals as part of a just transition.

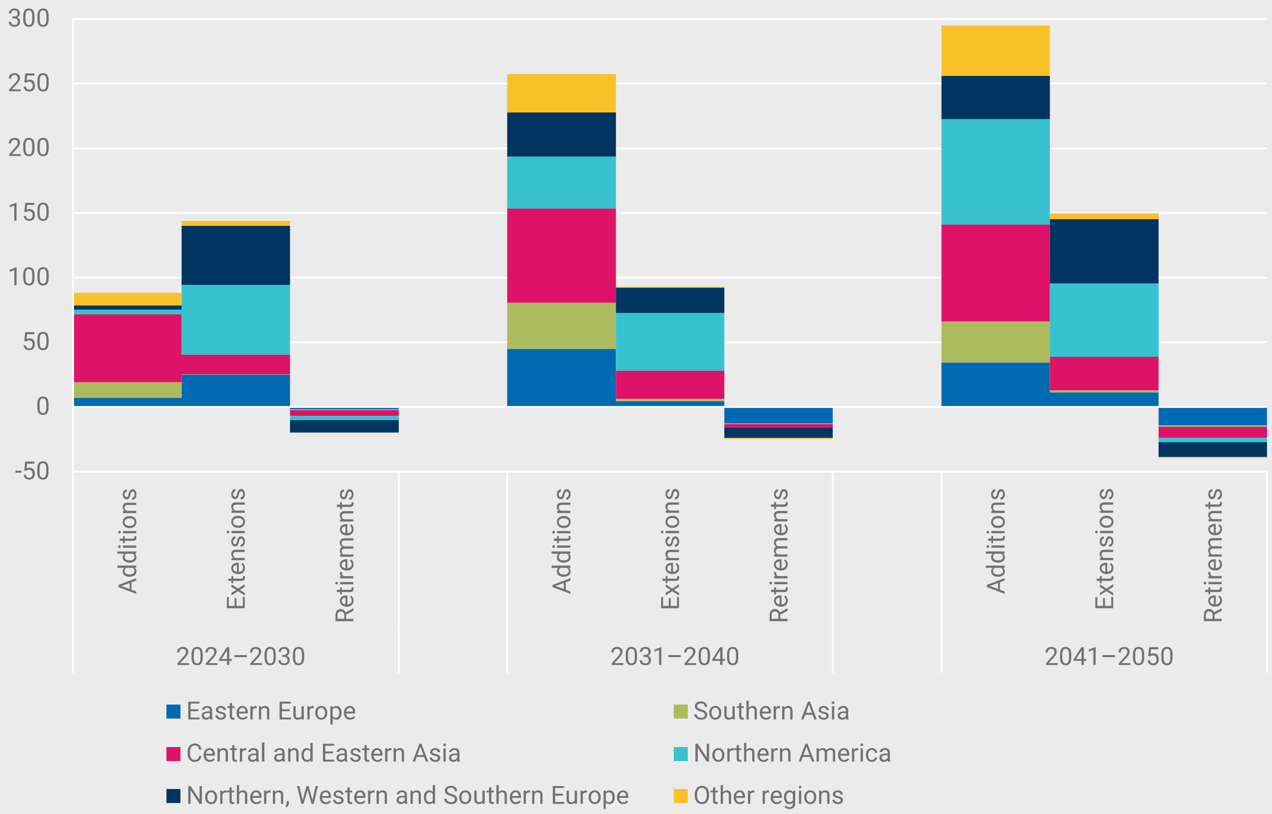
Sources: Refs [5–8]

In the power sector, the IEA estimates that installed capacity of nuclear power will need to more than double by 2050 to reach net zero [9], which is similar to the increase in the IAEA's high case projection (which is not a net zero pathway *per se*) [10].[1] Large reactors are likely to remain the main source of nuclear power over the coming decades, encompassing both existing reactors, many of which are projected to be extended beyond their originally anticipated operational lifetimes, and new construction (as shown for the IAEA high case in Fig. 1).

However, there is also increasing interest in SMRs, which can potentially increase the role of nuclear energy, including in small grids, new markets and applications, both electric and non-electric. Utilizing low carbon steam and heat from nuclear power plants could serve as a crucial strategy for decarbonizing heavy industries, which significantly contribute to global emissions.

FIG. 1.

Nuclear power capacity additions, long term operations and retirements in the IAEA high case projection, 2024–2050 (GW_{net}) [10, 12].



[1] However, other scenarios, including many compiled for the IPCC Sixth Assessment Report, see a much larger potential for nuclear energy to contribute to net zero — for instance, around 30% of low carbon scenarios in the Sixth Assessment Report envisage more than a tripling of nuclear electricity generation by 2050 [11].

The IAEA high case projection for nuclear capacity reaches 950 GW (net) in 2050, a 2.5-fold increase from 2023 installed nuclear capacity, requiring an increase in average annual investment from historical levels. While investment in nuclear power has averaged US_{2022} $50 billion per year during 2017–2023, it is projected to reach US_{2022} $75 billion in 2024 [13]. Realizing the nuclear capacity expansion in the IAEA high case projection is estimated to require over US_{2022} $90 billion from 2024 to 2030 and US $125 billion from 2031 to 2050, for both construction of new nuclear power plants and long term operation of existing plants, not including supply chain and fuel cycle investment (see Table 1) — that is, equivalent to around 2.5% of total annual investment requirements for net zero [4]. In comparison, the IAEA low case projection implies maintaining investment at recent historical levels. In the IAEA high case, the investment requirements are split roughly equally between advanced economies and EMDEs.

Over the period to 2050, average nuclear investment in the IEA Net Zero Emissions by 2050 (NZE) Scenario is similar to the estimate for the IAEA high case (see Fig. 2). Realizing higher levels of nuclear deployment, exemplified by the ambitious declaration launched at the 2023 UN Climate Change Conference (or COP28) by 25 countries, pledging to triple global nuclear capacity by 2050 [14], will require an even larger increase in annual investment from current levels [15, 16]. For example, extrapolating the capacity addition assumptions in the IAEA high case to reach a tripling of capacity shows that more than US $150 billion is estimated to be required annually from 2031 to 2050 (Fig. 2).

BOX 2: CONTRIBUTION BY EQUILIBRION

Nuclear for sustainable aviation fuels

Generally not captured in many projections or scenarios is an expanded role for nuclear energy to provide low carbon fuel and heat, for instance for sustainable aviation fuels. The Eq.Flight system developed by Equilibrion is designed to produce low carbon sustainable aviation fuel using nuclear energy, air and water. The primary energy required for generating hydrocarbons through this process is immense, and as a high density energy source with consistent operation and flexible siting, nuclear is naturally well suited to these demands. The market is large, as well. The global airline industry expects to need 440 billion litres per year by 2050. That would require the equivalent of approximately 1200 GW of electricity, which could be provided by approximately 1200 large nuclear reactors or 4000 SMRs, assuming a 300 MW capacity for SMRs.

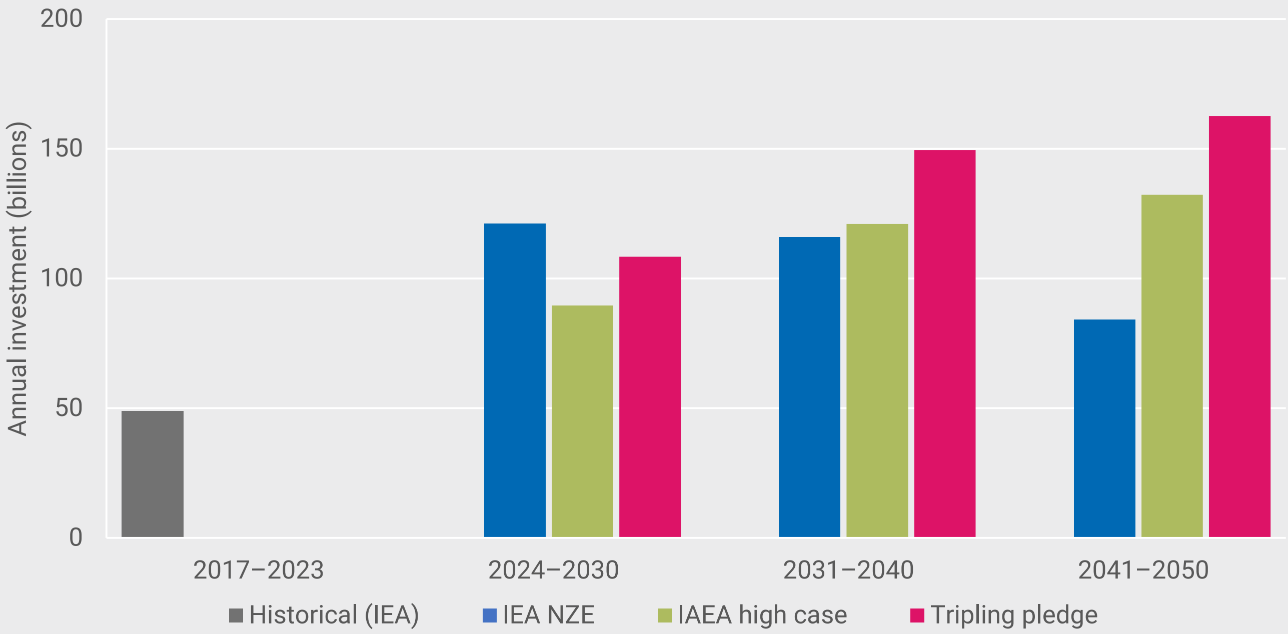
TABLE 1.

Average annual nuclear power investment in the IAEA high and low case projections, 2024–2050 (US_{2022} $ billion) [4, 10, 12, 17]. Note: based on investment cost assumptions in [4] and [17]; columns may not sum to the reported totals due to rounding; 'other regions' comprise Africa, Latin America and the Caribbean, Oceania, Southeast Asia and Western Asia [10].

	LOW CASE			HIGH CASE		
	2024–2030	2031–2040	2041–2050	2024–2030	2031–2040	2041–2050
Central and Eastern Asia	16	17	14	24	24	23
Eastern Europe	9	10	8	15	21	17
Northern America	8	6	6	17	30	45
Northern, Western and Southern Europe	10	10	9	17	21	21
Southern Asia	5	5	4	8	11	10
Other regions	5	5	4	9	14	17
Total	**53**	**53**	**45**	**90**	**121**	**132**
of which:						
New construction	39	48	38	75	114	122
Lifetime extension	14	6	7	14	7	11

FIG. 2.

Comparison of annual nuclear energy investment to 2050 under different projections and scenarios (US_{2022} $ billion) [4, 9, 10, 12, 13, 17, 18].



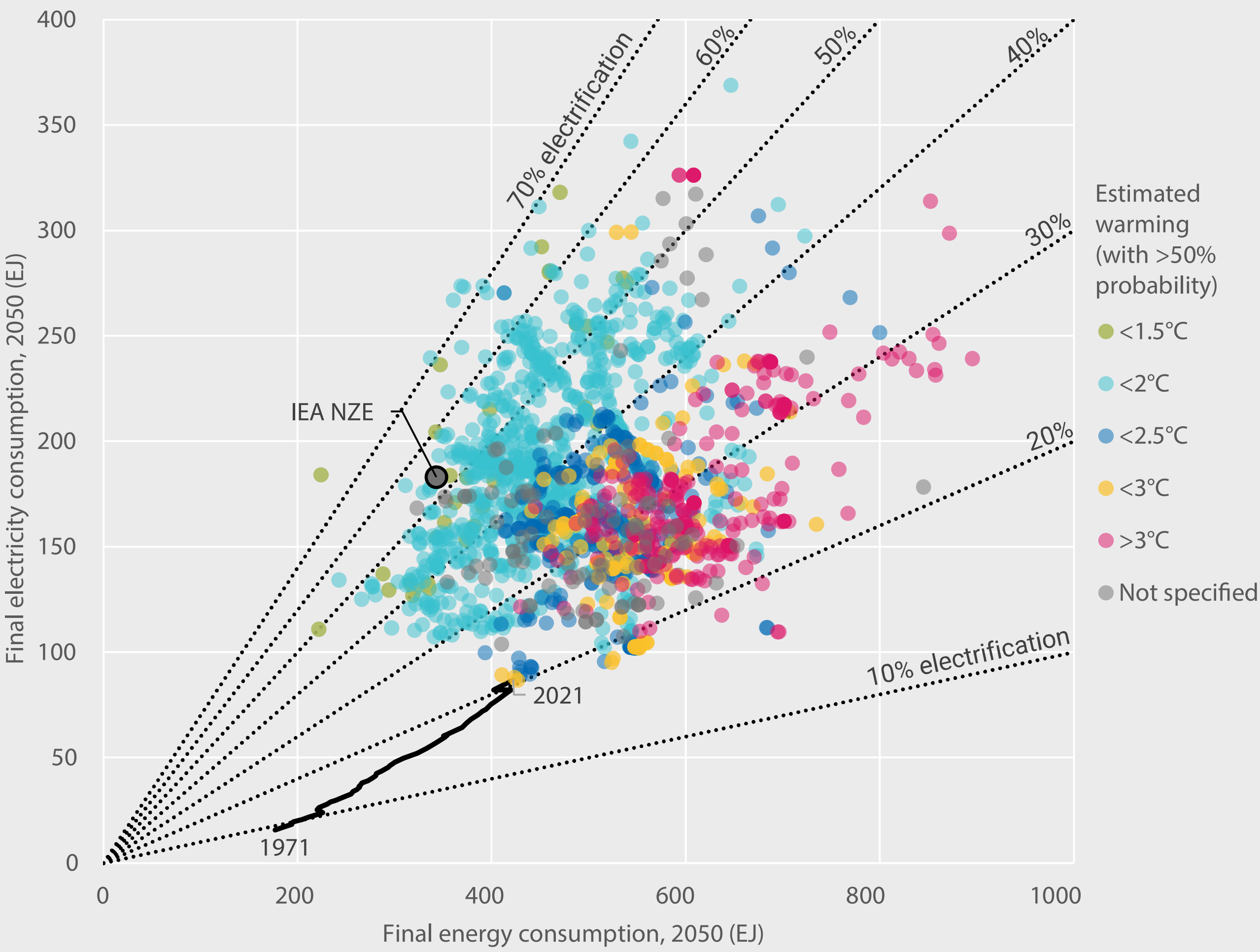
BOX 3

A dynamic energy and finance landscape

The need for substantial investment to realize net zero comes at a time when many energy markets, particularly deregulated electricity markets, are failing to drive sufficient low carbon investments in critical long-lived generation and transmission assets and system flexibility measures [19, 20]. In addition, the broader outlook for the global energy, policy and finance landscape continues to evolve on both the demand and supply sides.

FIG. 3.

Total final electricity and energy consumption in IPCC Sixth Assessment Report and IEA NZE pathways, 2050 [4, 21–24].



On the demand side, the urgency of reaching net zero emissions is projected to drive stronger demand for electricity in the heating and cooling, transportation and industrial sectors (see Fig. 3); at the same time, rapid developments in the technology sector are driving new electricity demands (see Section 3.1.3.2).

On the supply side, renewed interest in energy security in the face of geopolitical tensions is influencing patterns of global energy production and trade. For instance, the IEA expects an almost 50% increase in global liquified natural gas capacity this decade at a time when the outlook for demand remains uncertain [4], potentially changing the economics of gas-fired electricity generation. Natural gas generators, which can provide highly flexible, dispatchable generation (albeit with higher carbon emissions), may compete with investment in new nuclear power projects, particularly given the lower upfront costs and different risk profile of gas generation (see Section 2).

Angra nuclear power plant under construction, Brazil.

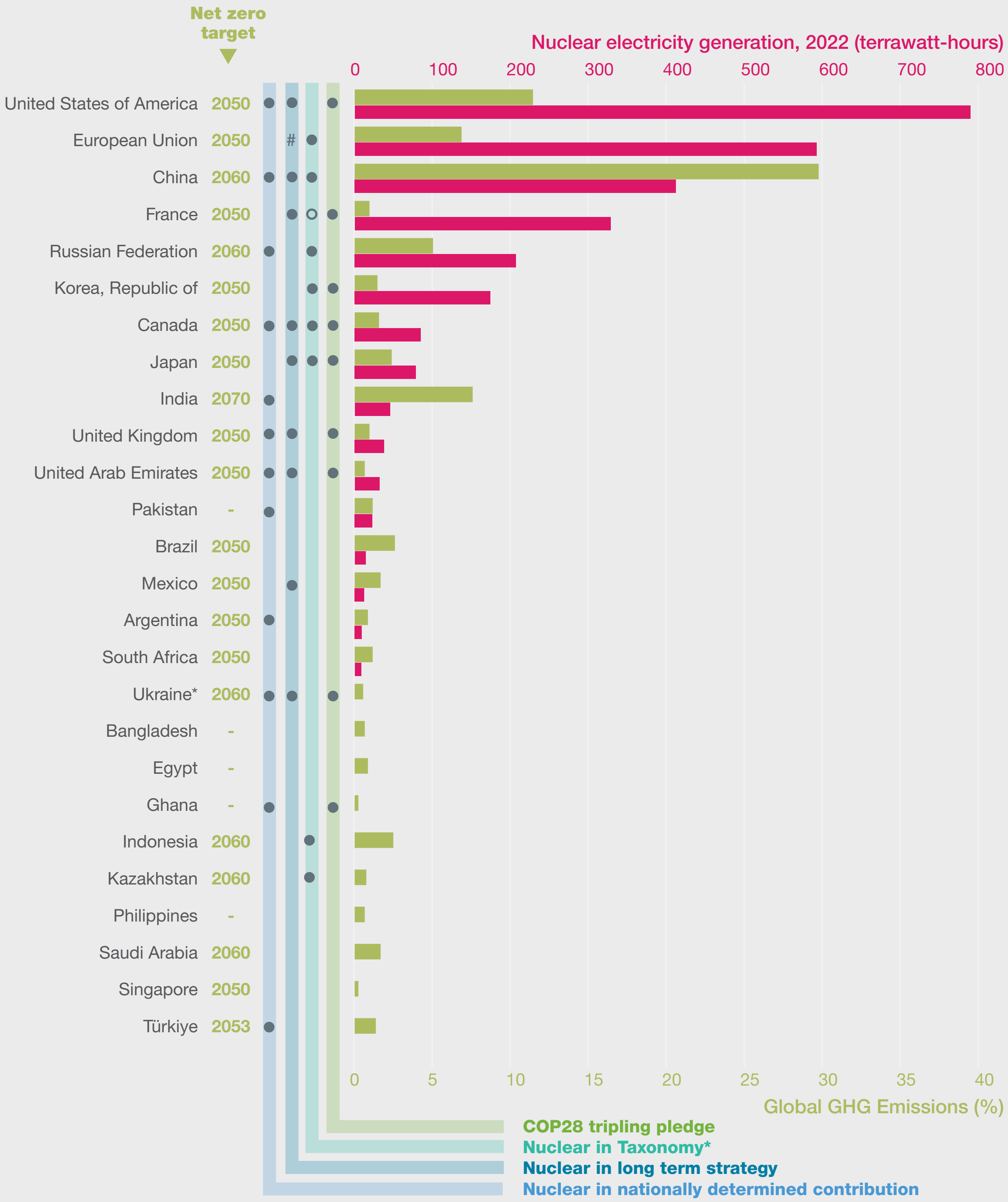
1.2. Nuclear Energy and International Climate Policy

The world has reached an inflection point in recognizing nuclear energy's key role in meeting ambitious climate change targets. This is reflected by the inclusion of nuclear energy in the outcomes of the first Global Stocktake under the Paris Agreement [25] and the declaration issued at COP28 by 25 countries pledging to triple nuclear capacity by 2050 [14]. As of early 2024, 15 countries include nuclear in their latest nationally determined contributions (NDCs) under the Paris Agreement, and more than 20 include nuclear in their long term low emissions development strategies, as summarized in Fig. 4 [26, 27].

Many countries are also including nuclear energy in sustainable investment taxonomies and similar frameworks or providing other forms of direct policy support — for example, in the United States of America under the Inflation Reduction Act and in the European Union under the Net Zero Industry Act (see Section 3.1.4.4) [28, 29]. Together, this expanding group of countries accounts for a substantial share of the global economy and investment flows as well as global emissions [3].

FIG. 4 .

Nuclear energy, climate change commitments and sustainable investment taxonomies in selected countries, ranked by nuclear power generation in 2023, as of August 2024 [5, 10, 13, 30–32].



* or other national sustainable investment framework

\# included in long term strategies of 8 EU Member States

o under EU Taxonomy

* Ukrainian operational data were not available for the year 2023

Despite this interest, current market and policy environments may be unable to mobilize the scale of investment required for net zero — for both nuclear energy and the clean energy transition more broadly. Simon Stiell, Executive Secretary of the United Nations Framework Convention on Climate Change (UNFCCC), reminded decision makers early in 2024: “We need torrents — not trickles — of climate finance” [33]. This is especially the case in many EMDEs, which face a significant gap between access to financial assets and investment requirements, as outlined in Section 1.1.

Accelerating and scaling up investment is one of the pressing priorities for the international climate change community, with key commitments expected at the upcoming 29th UN Climate Conference (COP29) [34, 35]. A new collective quantified goal on climate finance (NCQG), with an emphasis on the “needs and priorities of developing countries” [36], is expected to be set at COP29. Key decisions and negotiations during 2024 are addressing “the scale and elements of the NCQG” and “the need for enhanced provision and mobilization of climate finance from a wide variety of sources and instruments and channels” among others [37].

Deliberations are also expected to build on the outcomes of the first Global Stocktake, and it is notable that the COP29 host government has highlighted nuclear energy’s inclusion in the Stocktake and affirmed Azerbaijan’s intention to prioritize mobilization of “resources for the peaceful utilization of nuclear technology in combating climate change” (along with nuclear safety) during its COP29 presidency [38].

“We need torrents — not trickles — of climate finance”

SIMON STIELL

Executive Secretary, United Nations Framework Convention on Climate Change (UNFCCC)

1.3. Objectives, Scope and Structure

Against this backdrop, this publication seeks to inform the climate change community — negotiators, government officials, energy and climate policy makers, experts, non-governmental organizations and media representatives — about the potential of nuclear energy in mitigation and to highlight challenges and best practices in financing nuclear projects. This includes financing the construction of both large reactors and SMRs as well as investment in long term operations and enhanced climate resilience of existing plants. The booklet also considers potential policy and market reforms to support the construction and planning stages of nuclear power programmes as well as the suitability of various financing models under different market and policy regimes. The role of government in unlocking the potential of nuclear energy, in cooperation with the private sector, and the emergence of new financing frameworks and partners are also explored.

The next section introduces the economics and financing of nuclear energy projects, including fundamental concepts related to nuclear project capital cost and cost of capital. Unique considerations and risks for investors in nuclear projects are also introduced, including risks linked to construction, revenue and public acceptance, among others, along with critical elements in de-risking projects by ensuring construction and cost predictability.

Section 3 presents a comprehensive analysis of financing options for nuclear energy projects, illustrated with case studies and lessons from financing approaches in recent new build projects around the world — covering both deregulated and regulated electricity markets. The section covers a wide range of financing approaches, from traditional financing mechanisms through to emerging sustainable finance instruments, such as green bonds and carbon markets. The potential role of new players in nuclear investment, such as multilateral financial institutions and export credit agencies, along with interest from private sector investors is also explored. In addition, the section discusses options for financing the long term operation of existing nuclear power plants and measures to enhance climate resilience.

Section 4 then focuses on specific considerations for financing SMRs, which may be inherently less exposed to construction and financing risks — and have the potential to open up new markets, including by delivering clean heat, electricity and hydrogen.

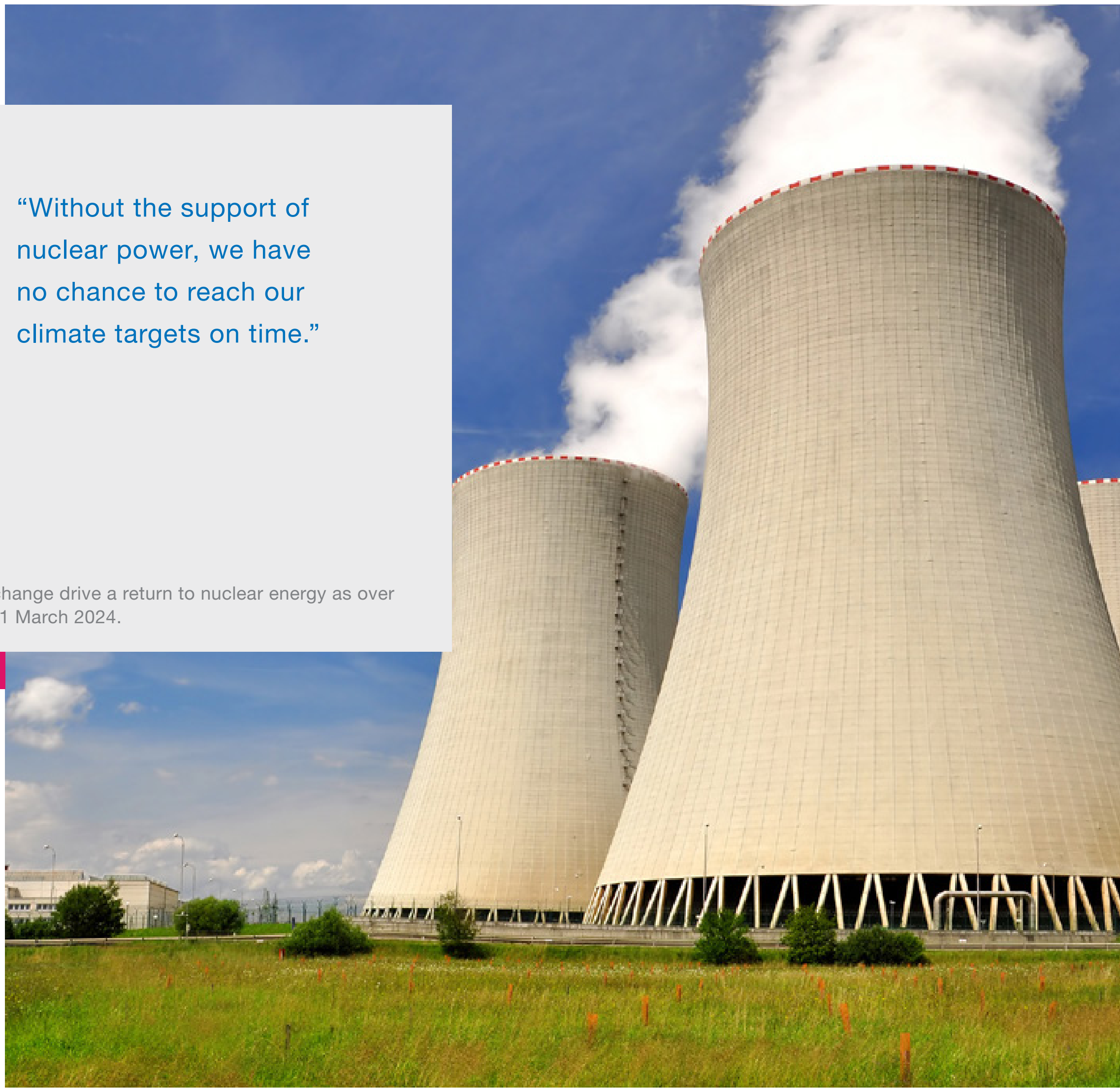
Section 5 seeks to address the particular challenges and opportunities associated with nuclear projects in EMDEs embarking on a nuclear energy programme. Some of the issues explored include technology transfer, localization considerations and securing access to affordable finance. Several case studies are presented to illustrate the range of approaches employed in EMDEs depending on national circumstances and priorities.

Section 6 then synthesizes key recommendations and conclusions for decision makers in governments, the finance sector and the nuclear industry related to policy and regulation, market design, multi-stakeholder cooperation, supply chain development, project management and risk sharing, among others.

FATIH BIROL
Executive Director, International Energy Agency

"Without the support of nuclear power, we have no chance to reach our climate targets on time."

AP NEWS, Security and climate change drive a return to nuclear energy as over 30 nations sign summit pledge, 21 March 2024.



Temelin nuclear power plant, Czech Republic.

2. Economics and Risk Management for Nuclear Energy Projects

Nuclear power projects share economic and financial similarities with other large-scale infrastructure projects, but the project lifetime far exceeds that of most electricity generation projects. The economic cycle of a new nuclear power project, encompassing initial planning and development, construction, commercial operation and decommissioning, can span more than a century. Investing in new nuclear projects requires significant capital, which remains tied up for several years until the plant becomes operational and starts generating revenue. While not detailed in this publication, investments in nuclear programmes can yield considerable macroeconomic benefits that may also impact investment decisions [39, 40].

Two main components drive project feasibility and financial sustainability of a capital-intensive investment such as nuclear: *capital costs* and the *cost of capital*. *Capital costs* encompass all of the expenses associated with constructing nuclear power plants, including labour, plant materials and professional services. The *cost of capital* reflects the required rate of return required by lenders and investors to deploy their capital into the project. It encapsulates factors such as inflation, risk premiums and opportunity costs, shaping the financing landscape and influencing investment decisions in the nuclear energy sector.

2.1. Economics of Nuclear Energy

Construction costs, which are made up of overnight costs and the interest accrued during construction, constitute a large portion of the lifetime generation costs of a new nuclear project (referred to as levelized cost of electricity or LCOE), while the remaining portion is divided almost equally between fuel procurement and management and operation and maintenance costs. For example, assuming a cost of capital of 7%, which is a typical rate for a utility, construction costs would constitute roughly 70% of the total lifetime generation costs, of which 15% can be attributed to interest accruing during construction (see Fig. 5).

A similar cost structure can be observed for SMRs, for which a shorter construction time, and thus less interest during construction, may only partially compensate for higher expected overnight costs per unit of electricity generation (see Section 4). Most low carbon energy technologies are characterized by high overnight and fixed costs compared to fossil fuel generation. These technologies require substantial pre-construction investments in land acquisition and permits, which must be addressed before any construction expenses are incurred. Shifting to a low carbon energy mix will require a considerable upfront investment, irrespective of the chosen blend of technologies.

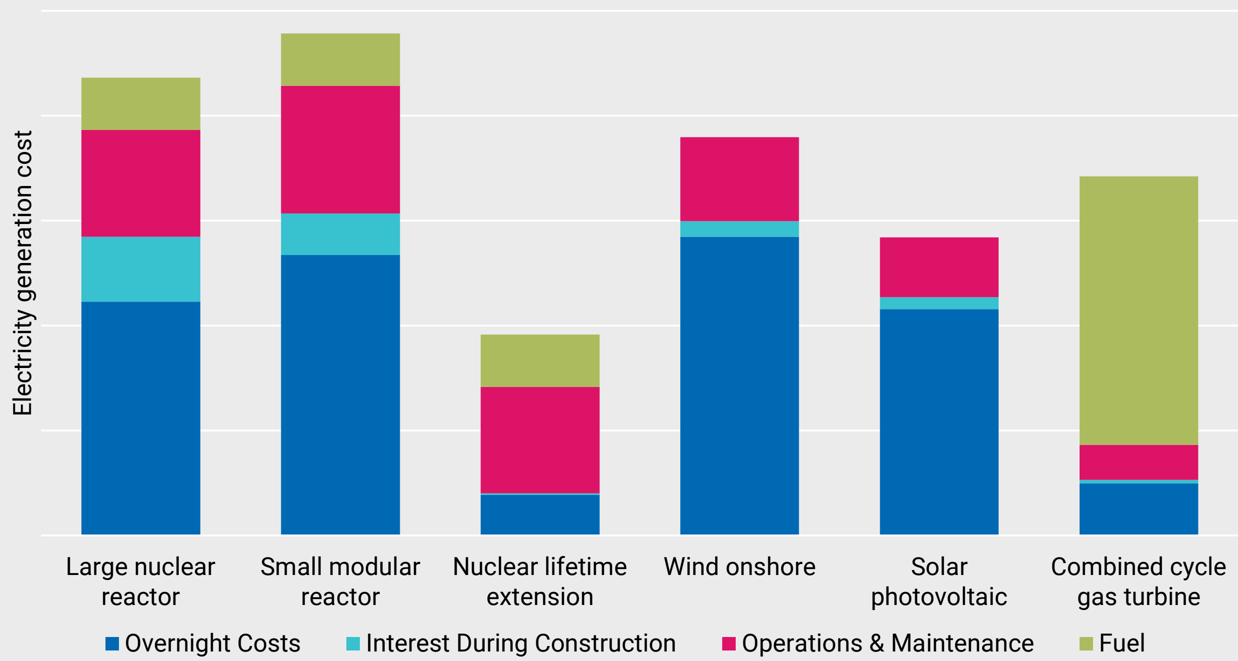
The cost structure is radically different when considering the long term operation of existing plants: lower refurbishment cost significantly reduces the overall share of capital costs, leading to a very competitive electricity generation cost against other energy technologies (see Section 3.2 on financing long term operations).

The substantial capital intensity of a new nuclear build renders the project highly sensitive to fluctuations in the cost of capital, overnight costs and the construction schedule. A 1% variation in the cost of capital for a nuclear project can lead to an approximately 10% increase (or decrease) in electricity generation costs. Similarly, a two-year delay in construction is estimated to result in a 5% increase in electricity generation costs.[2] Consequently, the investment community places greater emphasis on the predictability of costs and schedules rather than the actual expenditure.

[2] This increase reflects only the higher interest that accrues during construction and does not include higher overnight costs as a result of the delay.

FIG. 5.

Representative breakdown of electricity generation costs by technology [4].



For new NPPs, construction costs are highly project specific and vary widely across countries, reflecting not only differences in technologies, labour costs, project scope and financing mechanisms but also different recent experiences in plant construction. For instance, the deployment of FOAK large reactors and the need to re-establish specialized new build nuclear energy supply chains and workforce have contributed to delays and cost overruns in some new nuclear projects. Reported capital costs (excluding financing costs) for the first projects after many years in the EU, UK and USA range around US $8 000–11 000/kW or more [17, 41–44].

In comparison, in countries with ongoing experience in NPP construction and mature expanded nuclear energy supply chains, and often lower labour and regulatory costs, construction costs (and construction times) have been comparatively lower. For example, recent new builds in China, the Republic of Korea and the Russian Federation are reported to have capital costs closer to US $2500–5000/kW [45, 46]. The recent experience in these countries, along with lessons from the rapid deployment of nuclear energy historically in much of the world, provides important insights into how to minimize risk and cost by delivering on time and on budget.

By reusing the same design from one project to the next and constructing multiple units simultaneously, along with other approaches described in Section 2.3, the IEA assumes that China and India will be able to deliver nuclear projects for less than US $3000/kW, while in the EU and the USA, new build costs could be reduced to around $4500/kW by 2050 [17].

2.2. Mapping Risk

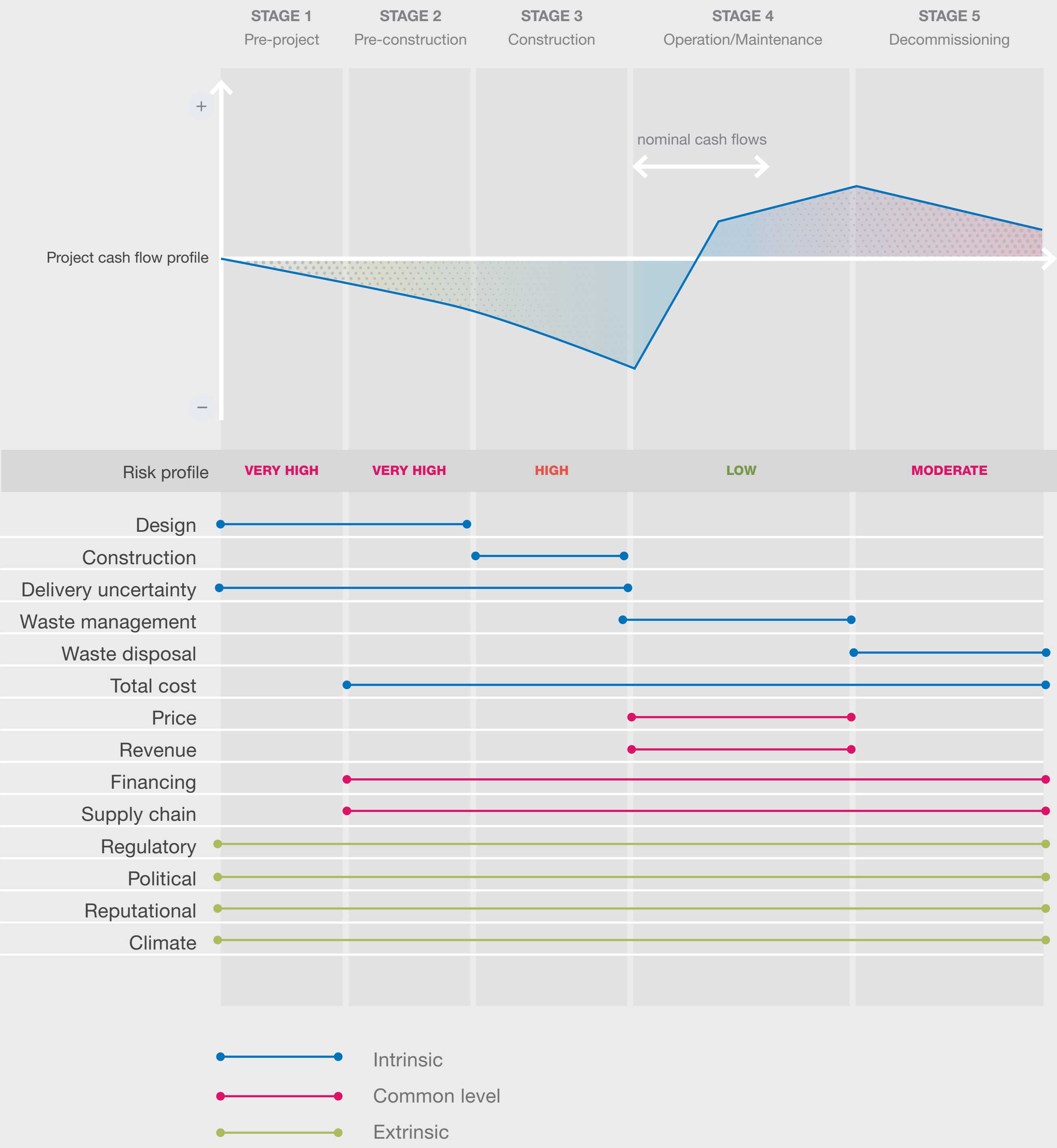
Nuclear energy projects are similar in many ways to other large-scale, high capital cost infrastructure projects. However, nuclear energy investments are also characterized by an additional distinct set of considerations and risks, which influence the cost of capital. The complex project planning period, long construction timelines, regulatory complexities, long payback periods and lengthy debt tenors inherent in nuclear energy projects amplify the risk profile and necessitate meticulous risk management strategies.

Risks over the lifetime of a nuclear energy project fall into three categories: intrinsic, common level and extrinsic risks (Fig. 6). Intrinsic risks are largely within control of the project owner; common level risks are project related uncertainties that reflect the shared allocation of risk mitigation among the project owner and its commercial partners; and extrinsic risks reflect an array of additional factors, which can significantly influence the project's viability but over which the project owner has little to no control. Mitigating intrinsic and common level risks as perceived by financial institutions – which can, to some degree, be controlled or mitigated by parties to the nuclear energy project – could aid in lowering the cost of capital for nuclear energy projects.

The project and financial risk of a nuclear new build change significantly with time. Risks are maximal in the early phases of the project (pre-construction, beginning of construction) and progressively decline as the construction advances. The project risk for nuclear new build drops significantly after commissioning, when the plant begins generating revenue through energy sales and provides a steady cash flow to cover operating costs and debt obligations. This risk profile limits the number of potential investors in the early phases of a nuclear project. However, the investment basis becomes much broader in the advanced phases of construction and after commissioning, making refinancing possible and contributing to a lower cost of capital.

FIG. 6.

Representative nuclear energy project cash flow and risk profile.



2.3. Getting to 'On Time and on Budget'

While renewable projects have seen significant growth in new markets driven by project developers, the nuclear industry faces a shortage of developers who can effectively connect policy goals with actual project implementation. For renewable energy projects, developers typically bring technical expertise along with a willingness to navigate innovative financing mechanisms, complex regulatory processes, risk management and community engagement. In the nuclear energy sector, time and cost unpredictability of projects heightens the perceived financial risk, which could be a limiting factor to deploying sufficient nuclear energy capacity to achieve net zero targets.

The skillful management of the construction schedule is fundamental to minimizing cost and attracting private sector investment. A proven track record of timely project delivery can foster investor confidence and thereby secure financing on more favourable terms. In addition, adherence to the stipulated construction timeline ensures on-schedule completion and adherence to budgetary constraints and enables the project to generate revenues as planned. Nuclear energy construction sites typically entail extensive operations, engaging a peak workforce of up to 10 000 individuals over prolonged durations [47]. Consequently, even a one-month delay during the peak construction phase can incur costs of tens of millions of dollars before accounting for additional interest costs [48].

URSULA VON DER LEYEN
President, European Commission

"Key tasks lie ahead if nuclear is to make a substantial contribution to climate neutrality objectives. The main one is to secure new investments. Support is needed from governments to ensure that financing is available and that nuclear's contribution to electricity security is properly valued and remunerated."

EUROPEAN COMMISSION, Speech by President von der Leyen at the Nuclear Energy Summit, 21 March 2024.

Nuclear energy programmes that have historically achieved construction and cost predictability — which covers most of the large reactors ever built, with a majority constructed in less than six years (see Fig. 7) — tend to share several key features:

Standardization of reactor technology

Finalizing the reactor design prior to the start of construction has historically minimized costs overruns. Standardized designs paired with commitment to volume streamline supply chains and facilitate the training of personnel, leading to smoother project execution. Decoupling the nuclear island from other civil elements of the project can help to facilitate the predictability of the cost and schedule.

Commitment to volume

Building an order book for multiple reactors can help to socialize FOAK costs across multiple projects and later achieve economies of scale. This commitment to volume can be established through robust energy planning and may be spread among countries via inter-country agreements to allow for a sharing of initial costs and reduced financial risk for individual projects.

Effective interactions with regulators and harmonization of regulatory requirements

Establishing regular consultations and clear lines of communication between stakeholders and regulatory bodies can help ensure understanding and compliance to requirements, targeting their harmonization. Proactive engagement can help to ensure that regulatory requirements translate into practical technical terms, enhancing understanding and adherence to standards.

Shared ownership models

Distributing financial risks among multiple stakeholders and mitigating the risk and cost for any single entity can lead to more efficient utilization of capital and expertise. Shared ownership models encourage long term investment and commitment for nuclear energy projects, contributing to the sustainability of nuclear energy projects over their lifespan.

Building or rebuilding supply chain and workforce

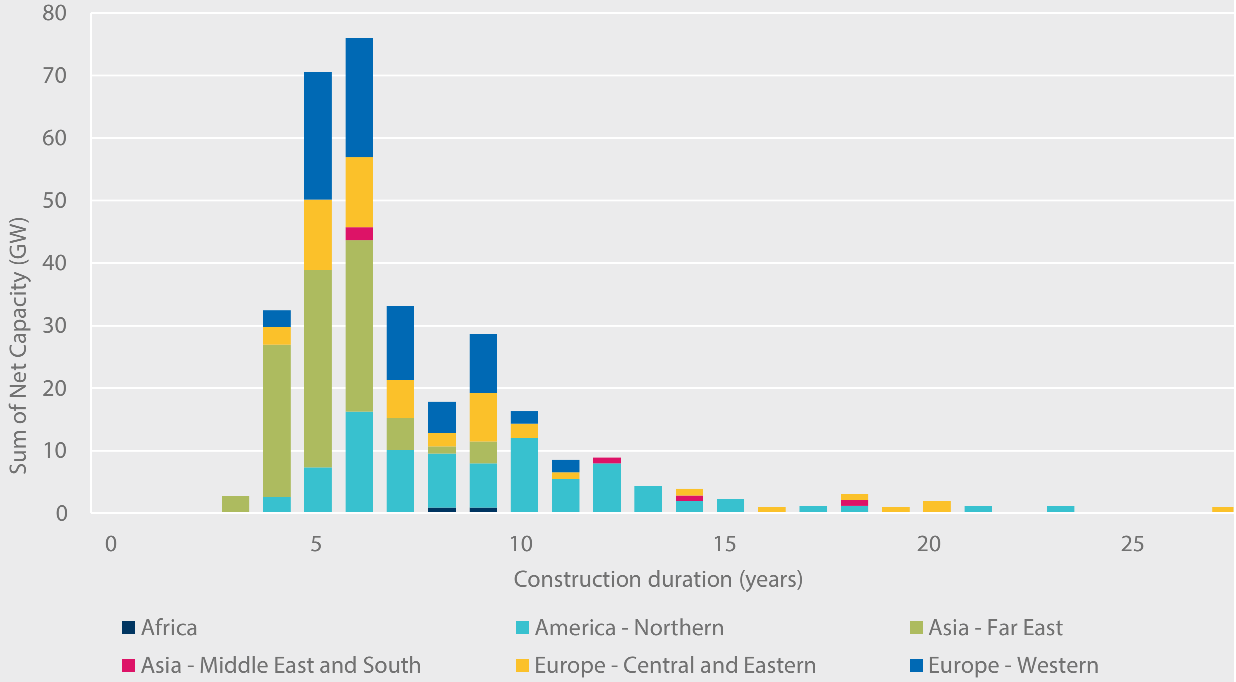
A strong domestic industrial base can support the construction of nuclear facilities and contributes to broader economic development. Historically, the endeavor to strengthen a nuclear energy supply chain was shaped by a strong political will to build a series of reactors that could benefit from the learning curve and standardization effect. Building confidence in a pipeline of projects can also serve to build both a robust supply chain and a skilled workforce.

Willingness to take on learning costs

For countries climbing the nuclear learning curve, construction delays and subsequent cost overruns could occur, especially in cases where the host country would like to localize part of the supply chain. This can be appropriately accounted for in early stages of a new nuclear energy programme. To reach Nth-of-a-kind (NOAK) can require specific adjustments to the financing scheme to accommodate construction risks and delays in revenue generation. Third party assurance can also help to build investor confidence in early projects.

FIG. 7.

Total capacity added by construction duration for all reactors with capacity between 800 and 1200 MW, by region [18].



Nogent nuclear power plant, France.

BOX 4: CONTRIBUTION FROM EDF

Nuclear New Build Programme optimization strategy

EDF organized the renewal of the French nuclear fleet by setting up a programme for the construction of several pairs of identical EPR2s (initially 3 pairs (6 units), with a potential project of extension to 7 pairs (14 units in total).

This programme strategy makes it possible to:

→ develop a bearing to ensure a unique envelope design for the entire series

→ benefit from increased volumes on purchases and maintenance over time

→ create a dynamic of learning and continuous improvement

→ de-risk the construction and operation of series reactors

→ provide the operator with a homogeneous fleet for the benefit of safety, operating quality and control of operating costs.

Except for certain works that are site specific in nature, the EPR2 design is generic and meets envelope requirements, which make it possible to cover the conditions of the different implementation sites envisaged for the EPR2 in France.

The choice of a generic design coupled with a strategy of standardizing equipment and grouping purchases in framework contracts covering the three pairs makes it possible to reduce the volume of engineering studies to be performed (in particular for equipment qualification) and to pool the costs of contracting contracts.

It also allows for reductions of unit prices. The approach makes it possible to benefit from the series effect in terms of equipment production. It also gives visibility to the industrial sector and thus contributes to the development of skills. An analysis carried out on the nuclear fleet in operation highlights an economic benefit associated with the substantial volume effect, depending on the areas and conditions of the purchase (framework contracts, firm commitments, deployment schedule, common shares in the contracts, etc.). The learning effect will reduce construction times and consequently the cost of the civil engineering, assembly and testing phases as well as site engineering hours for both the construction and operations (e.g. team training, performance of industrial partners during unit outages, modification studies linked to periodic reviews).

With this programme strategy, the risks and uncertainties will mainly affect the core studies and the implementation activities carried out on the FOAK unit (first-of-a-kind unit to be built). The subsequent pairs will be built based on a fixed design, except for site-specific design works, and controlled industrial processes and construction sequences.

The planning and cost at completion of the programme therefore benefit from margins and provisions for risks, contingencies and uncertainties decreasing between pairs.

BOX 5: CONTRIBTUTION FROM BNP PARIBAS

Financing nuclear projects: the view of BNP Paribas, the leading bank of the Eurozone

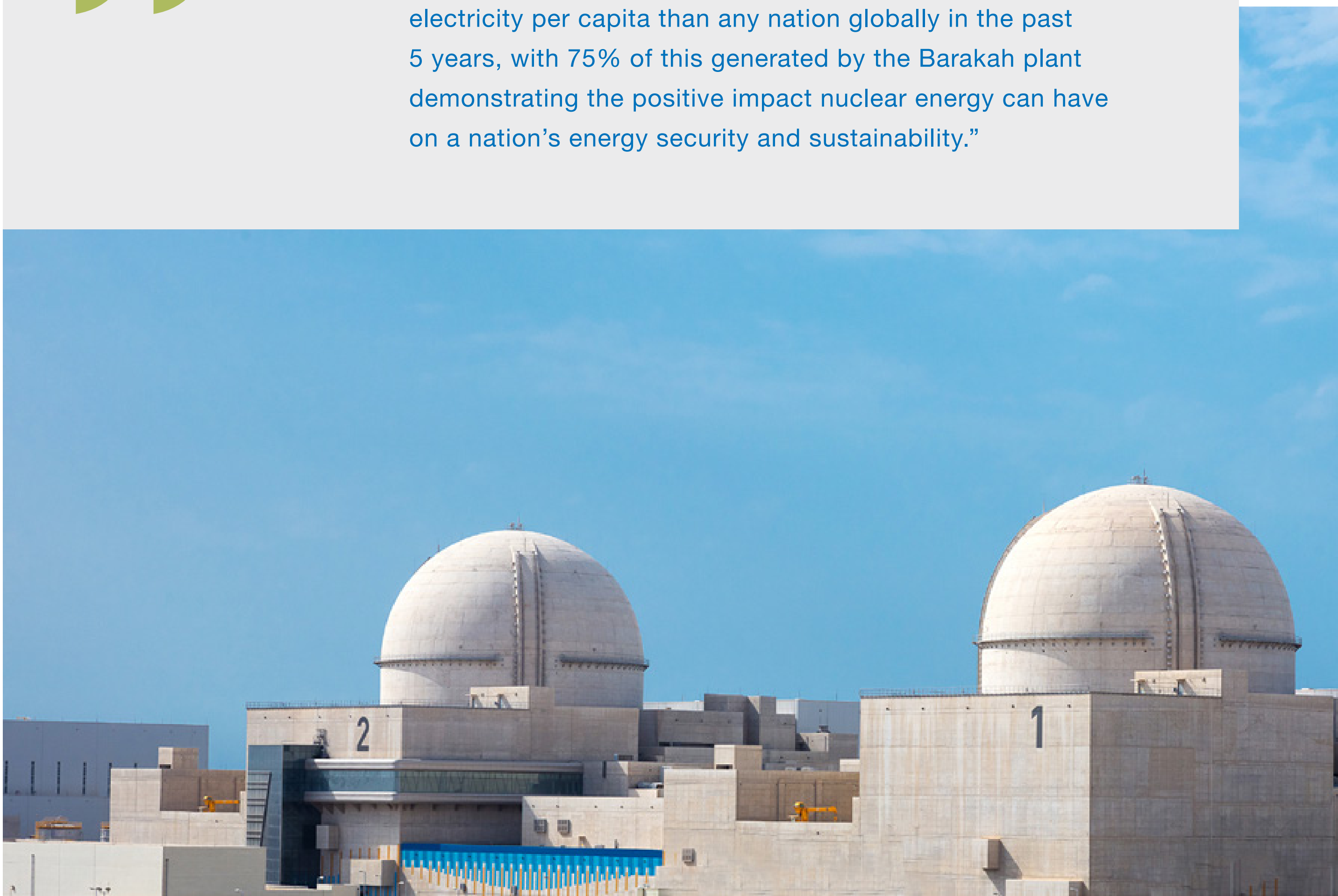
BNP Paribas is a significant player in the energy sector and can provide financial products and services to governmental entities, utilities, developers and the supply chain developing civil nuclear power. BNP's lending policy defines the major requirements for investing in a nuclear project, including limitations on host country, technology and spent fuel management.

In recent decades, there has been a notable deceleration in the development of nuclear power plants, accompanied by waning interest in financing. However, the present geopolitical and energy sector landscape has undergone significant changes, igniting a newfound momentum for the expansion of nuclear capabilities. This momentum is particularly evident given the Intergovernmental Panel on Climate Change's finding that all scenarios that achieve carbon neutrality in 2050 include nuclear power.

As a bank committed to allocate €40 billion in financing to low carbon energies (including nuclear energy) by 2030, we are currently involved in advising on and financing a number of different projects in a variety of countries. The financing structures are always complex, as there is no standalone financing: many stakeholders must be involved, starting with governments that need to support the projects from inception by putting in place the adequate regulation, subsidies, and a long-time power purchase agreement to guarantee an off-take price. Notwithstanding the challenges (time and cost intensive certification, permitting and building process, etc.), we have seen much stronger, while still cautious, interest in the sector from a wide range of debt and equity investors. This interest applies both to conventional large-scale plant and to SMRs, where there is significant interest given the potential for relatively rapid deployment and shorter construction phases.

MOHAMED AL HAMMADI
Managing Director and Chief Executive Officer, Emirates Nuclear Energy Corporation

"The development of the UAE Peaceful Nuclear Energy Program and its flagship Barakah Nuclear Energy Plant have been central components to enabling the UAE's energy transition and becoming an international player in the civil nuclear energy industry. The Barakah plant in just three years has transformed the nation's energy landscape, generating 40 TW·h of clean, baseload electricity while preventing the release of 22.4 million tons of carbon emissions annually. Indeed, the UAE has added more clean electricity per capita than any nation globally in the past 5 years, with 75% of this generated by the Barakah plant demonstrating the positive impact nuclear energy can have on a nation's energy security and sustainability."



Barakah nuclear power plant, United Arab Emirates. Courtesy of Emirates Nuclear Energy Corporation, 2024.

BOX 6: CONTRIBUTION FROM KPMG

The role of cost and deliverability assurance in achieving on-time and on-budget performance

Completion of a project on time and on schedule requires the project to set the appropriate cost and schedule baselines at the outset. The UK's Infrastructure and Projects Authority publishes guidance for the appropriate estimation techniques, which evolve in line with the project's development maturity [49]. At early project maturity, parametric techniques such as reference class forecasting can capture outturn cost and schedule data from previous, similar projects and generate a probability distribution to establish the most likely outcome for the new project. This provides an advantage to clients with an established historic portfolio of projects from which they can obtain data. This means FOAK nuclear technologies may initially be challenged in setting accurate baselines. Such a challenge is not unique to the nuclear sector, however. New technologies (such as carbon capture, utilization and storage) have the same challenges of being able to benchmark based on prior examples.

As a project design matures, bottom-up estimates will be used and eventually replaced with market data as a project is tendered and contracts awarded. Third party assurance supports investor confidence in the appropriateness of the estimating technique used, given the maturity of the project. KPMG designs cost intelligence approaches for clients to invest effort in the early stages of a project to get the baseline costs right, leveraging outturn costs from the portfolio to feed into more intelligent estimates.

Once the cost and schedule baselines have been set, the project's organization and management approach will impact its ability to deliver to those baselines. The UK Government's Green Book methodology for business case compilation includes the Management Case as one of the five key dimensions of the project because the integration of people, processes and technology enables delivery of the project as a whole. FOAK projects may look organizationally like start-ups in the early project stages, having grown organically from a small number of people. However, as they scale for delivery, the organizational structure and governance must also grow to ensure that capacity and capability remains right-sized. A third party view to compare the project to both other sectors and good practice can give the confidence in delivery ability; KPMG frequently completes rapid diagnostics of programmes to provide this insight cross-sector.

3.

Financing Approaches for Nuclear Investment

When it comes to financing long term investments in nuclear power projects, strategic planning and financial foresight play pivotal roles. Financing nuclear power projects requires balancing capital-intensive investments with long term project sustainability. This section will delve into the distinct characteristics and financing strategies for new nuclear projects, compare them to long term operations of nuclear projects and highlight recent notable endeavors.

3.1. Financing New Build

Typically, long term nuclear energy projects are financed through a combination of the following:

- **GOVERNMENT BACKING:** Governments play a crucial role in underpinning and sustaining nuclear power initiatives through energy planning. Through direct investments, loan guarantees, subsidies and export credit agencies (ECAs), governments provide financial stability and incentivize private investors to participate in these ventures.
- **PUBLIC–PRIVATE PARTNERSHIPS:** Collaboration between public entities and private investors is common in financing nuclear energy projects. Public–private partnerships distribute risks and responsibilities among stakeholders while leveraging the strengths of both sectors. This model can ensure a more robust financial framework, mitigating uncertainties and enhancing project feasibility if managed appropriately. Public–private partnerships can create the possibility of a misdistribution of risk among stakeholders; this has led to the bankruptcy of stakeholders during the construction phase of nuclear energy projects.[3]
- **OFFTAKE CONTRACTS:** Securing power purchase agreements or feed-in tariffs with high volume users like utility companies or industrial consumers guarantee revenue streams over extended periods, bolstering investor confidence. Such contracts provide stability amidst fluctuating market conditions, rendering nuclear investments more attractive to financiers. It is uncommon today for energy intensive or industrial consumers to act as counterparties to power purchase agreements or feed-in tariffs for new build reactors.
- **OTHER FINANCING INSTRUMENTS:** Various mechanisms to attract financing can be employed to fund nuclear power projects, including bonds and infrastructure funds. These instruments diversify financing sources and reduce reliance on traditional bank loans, fostering greater resilience and flexibility in project financing.

[3] The strategy of allocating risk to suppliers contributed to the bankruptcy of the EPC contractors of both Olkiluoto unit 3 and Vogtle units 3 and 4. Areva, a French multinational group, faced significant cost overruns and delays in the construction of Olkiluoto 3 in Finland, causing financial strain and contributing to Areva's bankruptcy in 2017. Around the same time, Westinghouse Electric Company faced delays and cost overruns in the construction of Vogtle 3 and 4 and VC Summers 2 and 3, in part due to regulatory hurdles and technical challenges with the AP1000 reactor design. Westinghouse filed for bankruptcy in March 2017 [50].

The highest risk to the economics of a nuclear power project occurs during the construction period. During construction, the project incurs high levels of debt with no guarantee that the power plant will be completed on time and on budget. This delivery risk and cost uncertainty is exacerbated by FOAK design, performance, regulatory and political uncertainties that can all disrupt or extend the time before the project is operational and can begin generating revenue.

These risks have historically been too great for the debt market to accommodate without guarantees. Debt and equity of the project are often intertwined in this period due to a relatively limited number of parties willing or able to take on such significant financial risk; these ownership models are typically in the form of government and corporate financing. This may change as countries or regions mitigate their construction risk with a series approach to deploying nuclear energy projects.

Throughout the nuclear energy project's life, different debt and equity combinations may be pursued to ensure positive project economics. In addition to raising equity, the owner of a nuclear power plant can draw substantial benefit from deploying various complementary debt instruments to minimize the cost of capital. Financing sources can be a combination of loans, export financing, bank financing, bilateral credit, bonds and structured financing, all of which can change throughout the life of the project as the risk profile varies.

3.1.1. Government backing

Most export nuclear energy new build projects have seen significant involvement of governments (vendor country, host country or both) in financing, often with a direct formal agreement. Host government financing may be direct, by providing equity or debt, or indirect, such as loan guarantees to private lenders or mechanisms to share revenue risk such as power purchase agreements or other offtake contracts. Both sovereign loan guarantees and grants provided by the vendor government via an ECA have been used to finance recent nuclear power projects. In several projects, vendors also participate as equity and/or debt provider, but the host government will retain full ownership of the project and bears most of its construction risks.

BOX 7: CONTRIBUTION FROM CHINA NUCLEAR POWER ENGINEERING CO. LTD

Financing new nuclear in China

New build NPPs in China

Nuclear power, a clean and low carbon energy source, is strongly supported by the Government of China. Therefore, NPP projects can proceed sustainably with continuous construction. China's nuclear technology has become increasingly mature in design, construction and operation through serial construction efforts.

Additionally the design, equipment supply and construction of NPP projects in China generally follow a relatively centralized approach. This ensures continuous improvement of professional expertise across teams and drives ongoing optimization, effectively managing overall construction costs and risks.

Financing Methods >>

In China, the total funds for an NPP project mainly come from two sources: equity capital and debt financing, with the proportion of equity capital generally not falling below 20%.

Equity capital is provided to the project company by its shareholders through a capital contribution agreement. In this agreement, shareholders agree to contribute funds based on their respective shareholding ratios and according to the planned investment schedule. Shareholder entities of the NPP project company mainly include power enterprises that are subordinate to nuclear power groups as well as local investment institutions.

Debt financing is mainly sourced through commercial bank loans. Given that NPP projects are strongly supported by the State, and the project companies are all affiliated with large State-owned groups, which inherently have a low risk of defaulting on debts, domestic banking institutions are generally willing to participate in financing these projects. Therefore, the contracted interest rate can be set at a level below the loan prime rate. However, due to the substantial amount of required funds, project loans are often arranged as syndicated loans or joint loans involving multiple large State-owned banks. During the preliminary feasibility study phase of the NPP projects, the interest rate on commercial loans is assumed to be fixed based on the benchmark loan prime rate. During the construction and operational phases of the project, the interest rates on commercial loans can fluctuate with the loan prime rate depending on the fluctuation of the economy. Repayment usually spans 15 years, commencing from the month when the project enters commercial operation. Additionally, debt financing for some NPPs also includes methods such as corporate bonds and export credits. Export credits are primarily utilized within import projects, for instance, when importing large-scale equipment like the French EPR project in China.

Challenges and Strategies >>

PROJECT SCHEDULE OVERRUNS

Nuclear power plant investments are considerable, and any extension of the construction period not only adds to the financial costs, escalating the total project completion expense, but also postpones revenue streams, thereby complicating repayment obligations. China possesses strong capabilities and rich experience in ensuring that NPPs are completed on schedule. Taking the HPR1000 reactor as an example, the construction duration has gradually decreased from approximately 68 months for the FOAK unit (Fuqing Unit 5) to around 60 months (e.g. Zhangzhou Unit 3, currently under construction). Factors contributing to this improvement include ongoing design optimizations, maturing construction management workflow and incentives for shortening schedules.

INTEREST RATE CHANGES

Throughout the long periods of NPP construction and loan repayment, unpredictable shifts may transpire within both domestic and international economic environments. When interest rates climb, this results in escalated financing costs for the project and exacerbated strain on loan repayments. As a common practice, a contingency provision is set in cost estimates and financial arrangements to manage this type of risk and any other unforeseen risks.

EXCHANGE RATE RISK

In light of the difference between the currencies of electricity sales and foreign currency debt, project companies must carefully consider exchange rate risk. In earlier projects, effective measures were taken by using forward foreign exchange contracts to hedge against future currency risks associated with debt repayment cash flows over several years. This strategy resulted in positive outcomes through effective foreign exchange hedging and has safeguarded against adverse impacts from currency movements.

Historical experience shows that strong support from governments will still be needed in the next decades to ensure a sufficient and sustained deployment of nuclear power. Governmental support is essential to establish a robust nuclear energy supply chain, mitigate construction and price risk and ensure that energy markets permit investments in low carbon technologies.

3.1.1.1. Export credit agencies (ECAs)

ECAs are financial institutions or agencies established by governments to support the export of capital goods and services and to promote jobs in their economies. ECAs provide financial instruments and services with the objective of removing or mitigating some of the political or commercial risks faced by the seller of technology when exporting, in exchange for a premium. There are two main forms of support: 'official financing support', which includes direct credits to foreign buyers, refinancing and interest-rate support, and 'pure cover support', which encompasses export credit insurance and guarantee cover for credits issued by private financial institutions.

Since 1978, the Organization for Economic Co-operation and Development (OECD) has provided a standardized financial framework for export credit, the Arrangement on Officially Supported Export Credits (the Arrangement)[4] [51], to ensure fair competition among OECD exporting countries. The Arrangement provides guidelines and terms of export credit finance; it defines the terms of a loan (drawing and repayment periods, maximal loan term, commercial interest reference rates, etc.) and the principles for calculating the insurance premiums. For several sectors, including nuclear power, specific guidelines and regulations are established by sector understandings.

The Sector Understanding on Export Credits for Nuclear Power Plants (the NSU) [51] was established by the OECD in 1984 and contains more flexible terms and conditions for officially supported export credits intended for financing nuclear power projects. The latest update of the NSU in 2023 introduced extended maximum repayment terms and additional repayment flexibilities. The maximum repayment term under the NSU is aligned with the maximum repayment term under the Sector Understanding on Export Credits for Climate Change, which was updated in 2023, as well [51]. The main characteristics of financial arrangements for nuclear projects are summarized below, and a schematic example of an ECA agreement is given in Fig. 9.

[4] The participants in the Arrangement as of April 2024 are Australia, Canada, the European Union, Japan, the Republic of Korea, New Zealand, Norway, Switzerland, Türkiye, the UK and the USA.

Main characteristics of ECA financial arrangements for nuclear projects

Scope of application:

- → Export of complete NPPs or parts thereof, comprising all components, equipment, materials and services, including the training of personnel directly required for construction and commissioning
- → Modernization of existing NPPs
- → Supply of nuclear fuel and enrichment
- → Provision of spent fuel management

Not applicable

- X Items located outside of NPP site (infrastructure development)
- X Decommissioning of NPP

Terms and conditions:

Export cost to be covered — up to 85% of export contract value

Down payment — minimum 15% of export contract value

Local costs to be covered — up to 40–50% of export contract value

Repayment amount = Principal sum of an export credit + CIRR[5] + MPR[6]

Repayment terms

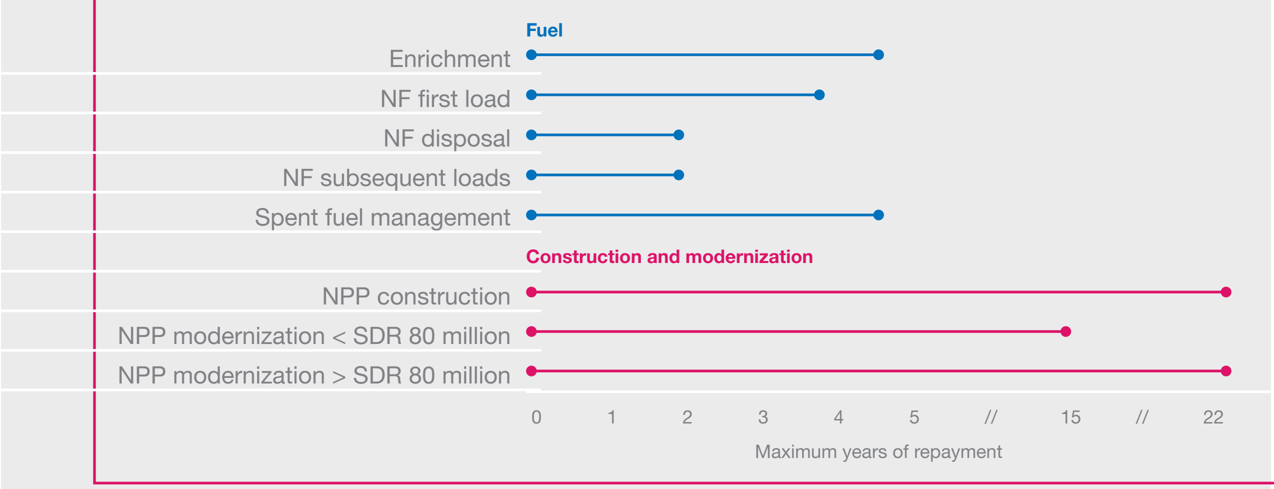


FIG. 8.

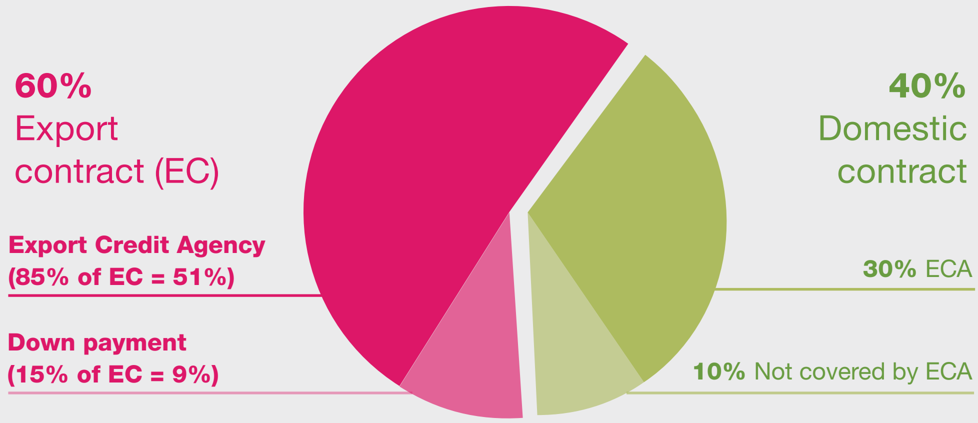
Repayment terms established by the Sector Understanding on Export Credits for Nuclear Power Plants [51].

[5] CIRR — commercial interest reference rates, which are fixed for each currency of participants to the Arrangement and reviewed every month.

[6] MPR — minimum premium rates, which are charged for the credit risk in addition to CIRR. MPR depend on the level of risk, which includes the country risk (rules set for calculation), time at risk ('horizon of risk') and political/commercial risks.

FIG. 9.

Example of an export credit agency supported facility agreement [51].



Export credit backed by ECAs has become increasingly important for all parties involved in nuclear energy projects. For technology exporters, the ability to provide financial solutions has become a critical competitive advantage, especially in new or emerging markets that lack the access to the large funding required in nuclear energy projects. For lenders, insurance against political risk and commercial risk (insolvency or default by the debtor, etc.) are critical features to be able to commit funding on a long term basis. Recent examples include support from the ECAs in France and Sweden in providing loan guarantees for the Olkiluoto-3 NPP construction project in Finland [52], while ECAs from the Republic of Korea provided financing for the Barakah NPP construction project in the United Arab Emirates [53]. Japan's ECA has special consideration in place for supporting nuclear sector projects [54].

3.1.2. Public–private partnerships

Nuclear power projects have the potential to be attractive to private investors, given their long term stability and predictability in energy generation, which can deliver consistent revenue. Although private investors have historically been averse to the unique risks of nuclear energy projects, several financial mechanisms may provide additional risk mitigation to make nuclear projects more attractive to private sector capital. These include loan guarantees that could come from project sponsors (typically host or vendor governments as described in Section 3.1.1) or multilateral financing institutions, and insurance coverage from ECAs or the private insurance market, for example with political risk insurance.

BOX 8: CONTRIBUTION FROM THE INTERNATIONAL BANK FOR NUCLEAR INFRASTRUCTURE

Scaling nuclear energy for a sustainable and secure net zero world

Multilateral international financing institutions can play a critical role in providing supplemental pooled and blended funding and financing solutions that bridge the gaps between public/government support for nuclear and the global financial markets. These institutions can play a unique role in promoting early dialogues between policy makers, industry and financial markets that enable frameworks to ultimately promote bankability in the nuclear sector:

- **Provider and catalysts of long term patient capital** – bridge the near term funding, financing and risk gaps
- **Largest global issuer and global benchmark for high grade nuclear-specific bonds and other securities** – creating and broadening markets and deepening liquidity across sustainable and environmental social governance (ESG) nuclear financing markets
- **Enabler and accelerator of nuclear infrastructure and technologies** – facilitating rapid global nuclear market expansion and providing supplemental funding, financing, services, resources and other support
- **Global demand aggregator for nuclear generation technologies and their global supply chains** – enabling accelerated bankability
- **Global aggregator of harmonized nuclear specific standards, criteria and frameworks** – promoting a high degree of standardization and harmonization of policy, regulatory, market, ESG/financing, commercial, contractual and risk allocation frameworks

To this end, an initiative exists to establish a new, nuclear-specific international financing institution called the International Bank for Nuclear Infrastructure (IBNI) [55]. IBNI's exclusive focus and role would be to provide multidimensional solutions, including specialized nuclear funding and financing. This support could help enable global nuclear generation capacities to grow at the speed and scale necessary to attain global net zero by 2050 and complimentary policy aims [56].

BOX 9: CONTRIBUTION FROM THE EUROPEAN BANK FOR RECONSTRUCTION AND DEVELOPMENT

EBRD's nuclear financing strategy in a shifting energy landscape

In 2023 the European Bank for Reconstruction and Development (EBRD) engaged in extensive consultations on its energy sector strategy with shareholders and the public. EBRD will continue to consider financing for nuclear safety improvements, decommissioning of nuclear installations and the management of radioactive waste, building on the 30 years of experience in managing large nuclear safety donor funds. EBRD has taken note of statements of some shareholders, including countries of operation, which wish to start, continue or increase the use of nuclear energy as part of their net zero commitments and energy security considerations. Safety will remain of paramount importance in all of these scenarios, in particular with regard to the long term operation of existing nuclear power plants. EBRD is committed to actively monitoring developments in the nuclear sector, including new technologies. Any financing of new nuclear capacity would, however, require explicit approval of the Bank's shareholders.

3.1.3. Offtake contracts

Offtake contracts that exchange early financial contributions for decreased project cost are crucial for financing new nuclear energy projects and can have large benefits for long term operations of nuclear projects. These contracts provide revenue certainty and mitigate financial risk during operations.

Offtake agreements during operations, such as power purchase agreements, may also act as a guarantee for future revenues to be used to secure additional sources of funding. These short or long term agreements offer many benefits that enhance project bankability. By establishing fixed or indexed pricing mechanisms, these contracts insulate nuclear power projects from merchant market turbulence, ensuring predictable revenue streams and financial stability.

KATHRYN HUFF

Former Assistant Secretary for Nuclear Energy, US Department of Energy

"To realize our net zero goals by 2050, the US and 24 other countries launched the Declaration to Triple Nuclear Energy at COP28, inviting shareholders of the World Bank and international financial institutions to encourage the inclusion of nuclear energy in energy lending policies. The United States government prioritizes activities that expand international nuclear energy cooperation to enable a more sustainable, equitable, and reliable energy system."

This risk mitigation not only safeguards investors' interests but also incentivizes a broader spectrum of private finance such as pension funds to participate in nuclear energy ventures, reassured by the prospect of steady returns and reduced exposure to market risks. This stability enables nuclear energy developers to secure financing at competitive rates, unlocking access to private capital and fostering sustainable project development.

While renewable energy technologies offer lower upfront cost and shorter construction times, nuclear power offers unique advantages, offering low carbon, reliable and scalable energy. Demonstrating the value proposition of nuclear energy projects can help to attract potential offtakers. Offtakers with high energy needs should be engaged early in the development process, allowing developers to understand the offtakers' energy needs, preferences and risk tolerance, facilitating the design of tailored offtake agreements. Providing offtake contracts that account for price risk — for example, with indexed prices that can rise with inflation or commensurate with the spot market price for electricity — can help to facilitate long term contracts, assuring stable cash flows and isolating the project price from market fluctuations.

Tripling Nuclear Energy by 2050, Net Zero Nuclear Event, at COP28, Expo City Dubai, United Arab Emirates.

BOX 10: CONTRIBUTION FROM KPMG

Recent experience with offtake agreements in the UK: the Contract for Difference scheme and Regulated Asset Base model

The Contract for Difference (CfD) scheme and Regulated Asset Base' (RAB) mechanism have been used to finance recent nuclear energy projects in the UK. Both aim to provide financial stability for nuclear energy projects. However, they differ in how they distribute costs, manage risks and impact consumers' electricity bills.

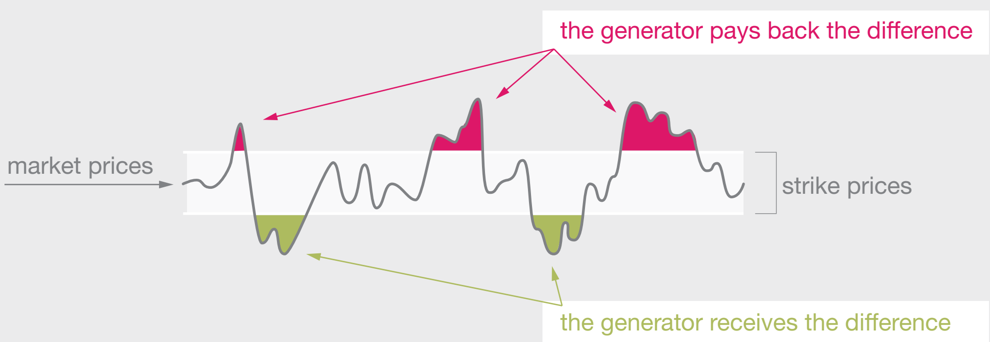
Hinkley Point C was financed under a CfD arrangement, under which the UK government agrees to pay the nuclear energy project operator the difference between a predetermined strike price and the market price for electricity. For Hinkley Point C, the CfD strike price was set at the approximate equivalent of US $150/MW·h [57], compared to the average UK day-ahead wholesale price of US $121/MW·h in 2023 [58]).

Shifting policy in Europe: The European Electricity Market Reform >>

The nuclear CfD developed for HPC has not since been replicated, but it may now be replaced by an adapted mechanism. The 2024 European Market Reform is the EU's long term response to the energy crisis experienced in 2022 [59]. A key element of the reform is the introduction of the two-way CfDs, which will provide more stable revenue for power producers of wind energy, solar energy, geothermal energy and hydropower (without reservoir). Importantly, after much debate, nuclear energy has been included in this list. This will likely be the way new nuclear is funded in the EU, given a condition in the reform that states that the two-way CfD will be mandatory for all publically funded projects.

FIG. 10.

Representative example of a two-way Contract for Difference



Under a two-way CfD, the generator sells the electricity on the market but then settles the difference between the market price and the strike price agreed in advance with the public entity. Any excess revenues are distributed to final customers, with some flexibility for member states (see Fig. 10).

The first application of this model to nuclear new builds is the Dukovany II project in the Czech Republic, the latest new nuclear plant to receive EU State aid approval [60]. The remuneration mechanism will provide revenue stability and limit excess remuneration through a yearly ex-post settlement. This contract will last for 40 years, with a clawback mechanism that lasts the duration of the operational life to mitigate the risk of overcompensation by the beneficiary (ČEZ a.s.). The presence of additional state aid mechanisms suggests that future nuclear developments will continue to need additional state support in addition to offtake contracts in order to reach financial close.

RAB for new nuclear >>

Sizewell C is intended to be the first project to use the RAB financing mechanism, in which the project's capital interest payments during construction are included in the rate base used to calculate electricity tariffs [57]. The Nuclear Energy (Financing) Act 2022 introduces the RAB model as a potential tool used to finance new nuclear projects [61]. This model allows investors to share some of the scheme's construction and operating risks with the consumers, which will reduce the overall cost of a scheme, as it avoids a build-up of interest. This method allows for the recovery of both capital and operating costs along with a regulated return on investment. Consumers ultimately bear the costs through their electricity bills, but the RAB mechanism provides stability and predictability in financing. Risks associated with cost overruns and delays may be transferred to consumers through capped tariff adjustments similar to the regular reassessments of the CfD strike price [57].

The RAB approach proposed for Sizewell differs from the CfD model that was used for Hinkley Point C. Under the CfD, the developer agrees to pay the construction costs and takes on all the construction risks in return for an agreed fixed price during operation. Analysis by the Department for Business, Energy & Industrial Strategy has shown that the use of the RAB model should produce a cost saving of between US $38 billion and $102 billion for the new nuclear programme compared with the CfD approach [62].

3.1.3.1. Fostering collective investments

Collaborative financing models, such as consortia based funding and joint ventures, are gaining prominence in the nuclear energy industry. By pooling resources, sharing risks and leveraging complementary expertise, multiple stakeholders can collectively invest in nuclear energy projects, spreading financial burdens and enhancing project feasibility. These shared financing models foster collaboration, diversify funding sources and expedite project development, thereby facilitating greater access to private capital and optimizing project economics.

For example, the Mankala model is an ownership arrangement deployed primarily in Finland to facilitate investments and shared ownership in large, capital intensive assets such as electricity generation plants. Currently about two thirds of nuclear electricity production in Finland is based on the Mankala model.[7] For such projects, a group of investors, typically large energy consumers such as energy wholesalers, electricity intensive companies and municipalities, form a cooperative entity where capital is pooled to finance the development of a power plant. Shareholders are committed to bearing the fixed and variable operating costs of the Mankala company and, in exchange, receive the power and heat generated “at cost”, which they can use for their own operations or sell to the market.

One of the key strengths of the Mankala model lies in its ability to distribute risk and rewards among investors, allowing shareholders to undertake and finance a project together that would be too large or too risky for any of them individually. The Mankala structure also provides shareholders with the benefits of lower and stable electricity prices, thus providing a long term hedge against electricity price volatility while ensuring revenue certainty for the project company. Also, many institutional financers perceive a Mankala company as less risky, as all shareholders are collectively liable for debts, and are therefore likely to provide third-party finance on more favourable terms [63].

In Poland, the SaHo model has been proposed as one option for innovative nuclear financing. Under this framework, governments collaborate with private investors to finance nuclear power projects. The government typically provides funding support, regulatory oversight and guarantees, while private investors contribute capital and expertise. The SaHo model relies on public–private partnerships without an equity contribution and involves a centralized approach with government involvement [64].

---

[7] A publication on this subject is currently in preparation.

The SaHo model capitalizes on the strengths of both public and private sectors, leveraging governmental stability and resources alongside private sector efficiency and innovation. By spreading the financial burden between public and private entities, it minimizes investment risks and ensures the alignment of interests towards achieving common objectives [64]. Additionally, the involvement of government entities enhances credibility and fosters public trust in the project.

BOX 11: CONTRIBUTION FROM EDF

Powering partnerships: EDF's innovative approach to nuclear energy collaboration in Europe

In the 1970s and 1980s, EDF signed several power purchasing agreements with European energy companies. EDF created production allocation contracts by which a portion of the French nuclear fleet's capacity was reserved for partners, who in turn assumed a proportional share of fixed costs, encompassing construction, operational expenses, decommissioning and relevant taxes. In turn, these partners recieved a corresponding fraction of the energy generated by the reactors at the variable fuel cost over the lifespan of the units.

As of 31 December 2023, some portion of ten of EDF's nuclear units were covered by this type of contract, with total contracted capacity of up to 1 GW. Noteworthy partnerships included EnBW's share in Cattenom units 1-2 (5%); Électricité de Laufenbourg's stake in Bugey 2-3 (17.5%); Electrabel's share of Tricastin 1-4 (12.5%); and Luminus, EDF's Belgian subsidiary, in Chooz B1-B2 (3.3%). Expanding beyond this model, EDF engaged in a second type of agreement centered on a fleet of power plants with capacity of around 2 GW. While fixed costs and contract durations remained tied to specific units, the volume of energy sold at variable fuel cost was determined by the contract share as a percentage of the total availability of the broader reference fleet. This second type of contract is applicable for Electrabel's stake in Chooz B1-B2 (21.7%) in addition to the Electricité de Laufenbourg (7.8%) and Swiss electricity group CNP (21.8%) shares of Cattenom 3-4 [65].

This diversified approach allows for a sharing of industrial risks during fleet development. Despite assuming no operational role for EDF's partners, these alliances underscore a collaborative commitment toward advancing nuclear energy in Europe, fostering innovation and collectively addressing industry needs. In the future, EDF could sign long term nuclear power offtake contracts like power purchase agreements or contracts for difference to private sector companies with significant energy needs.

3.1.3.2. Collaborative financing initiatives for first-of-a-kind projects

The collaborative financing landscape for FOAK projects is rapidly evolving, marked by innovative partnerships and initiatives aimed at accelerating the transition to advanced clean electricity technologies. Both public and private sector entities have the potential to aggregate their demand and resources to support the advancement of FOAK and early commercial projects while addressing critical aspects essential for their successful implementation. These initiatives provide insights into the evolving landscape of sustainable energy development and the pivotal role of collaborative efforts in driving innovation and progress.

Technology companies like Microsoft and Google plan to utilize all clean energy technologies in order to achieve 24/7 carbon free or annual carbon negative targets by 2030 [66, 67]. As electricity consumption by data centres, cryptocurrencies and artificial intelligence companies is expected to double from 2022 to 2026 [68], these companies are seeking the next generation of clean energy technologies that can help to meet their goals.

MELANIE NAKAGAWA

Corporate Vice President and Chief Sustainability Officer, Microsoft

“At Microsoft, we know a 100% decarbonized grid will require firm, dispatchable clean electricity sources. Yet, these advanced clean electricity projects face challenges in getting built fast enough, in part because some of these early projects are FOAK or have risks that make it difficult to secure the necessary financing.

“In March 2024, Microsoft, Google, and Nucor announced a collaboration to accelerate the deployment of advanced clean electricity projects, including advanced nuclear. These technologies can provide firm, dispatchable power that can fill the gaps in wind and solar production and help decarbonize the grid.

“We are at a moment of truth for advanced clean electricity: there is a lot of exciting technological progress and new policy thinking, but that needs to translate into long term, sustainable commercial success. This advanced market commitment is a demonstration of how companies across multiple industries can come together to aggregate demand for carbon free electricity, support the development of new business models, and seek to reduce the risks and costs for early commercial projects.”

The EFI Foundation presents a comprehensive policy framework intended to facilitate the development of SMR designs, addressing critical aspects essential for their successful implementation (see Section 4 for more information on SMRs). The EFI framework outlines key elements designed to streamline the process and mitigate risks associated with SMR projects. Central to this proposal is the establishment of a FOAK orderbook for multiple builds of a specific SMR design, ensuring a steady pipeline of projects. Additionally, the framework advocates for the creation of a special purpose vehicle to facilitate collective undivided ownership, with capital contributions from project sponsors in the form of a mix of equity and debt. Cost containment measures are proposed through an integrated project delivery agreement, incorporating a shared incentive structure to align stakeholder interests.

The framework suggests a tiered cost-sharing mechanism, where project sponsors bear initial costs, followed by funds to address estimated contingencies and, finally, a government-provided backstop through a credit facility allocated to the special purpose vehicle. This government backstop agreement is envisioned as a loan with flexible repayment terms, subject to negotiation, further bolstering investor confidence and project viability [69].

3.1.4. Other financing instruments

Emerging financial instruments, such as green bonds designed to support environmentally sustainable projects, can also play a role. Global issuance of such sustainable finance instruments[8], including the ESG-focused loans and bonds have grown fiftyfold in the past ten years, reaching over US_{2022} \$1.5 trillion in 2022 with a slight increase in 2023 [70].

3.1.4.1. Sustainable financing mechanisms

While renewable energy projects have traditionally been the primary recipients of energy sector sustainable finance, sustainable loans and bonds are being successfully deployed to finance a growing number of nuclear energy projects. Sustainability linked finance brings many benefits ranging from broadening access to capital and investor support to helping to gain trust from stakeholders and demonstrating alignment with Sustainable Development Goals, among others. Some of the first examples of sustainable loans for nuclear projects include the ESG-linked loans provided by two Russian commercial banks in 2021 for the construction of the Akkuyu NPP in Türkiye (totalling US_{2021} \$800 million) [71] and the bilateral green loan provided by Crédit Agricole CIB to EDF in 2022 to finance the maintenance of the nuclear energy fleet in France (€1 billion, or US_{2022} \$1.1 billion) [72]. More recently, in May 2024, EDF signed green loans with several major international banks for a total amount of €5.8 billion (US_{2024} \$6.3 billion) [73].

[8] Sustainable finance instruments include green, social, sustainability, sustainability-linked and transitional financing.

Outside of Europe, two leading Emirati banks provided AED 8.89 billion (US_{2024} $2.24 billion) as a green loan facility for refinancing the Barakah NPP construction project in March 2024 [74].

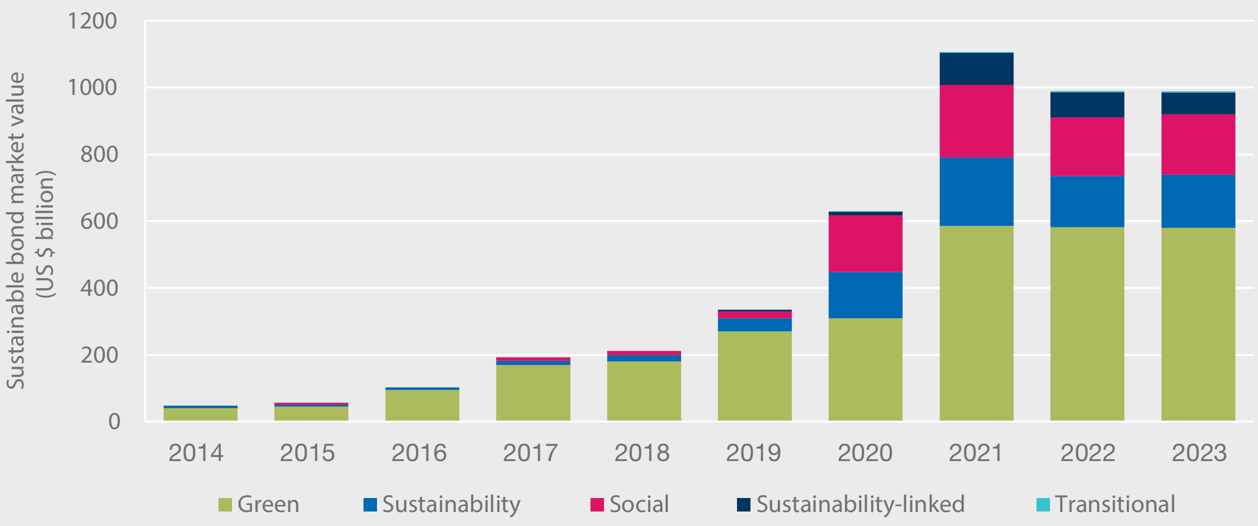
MOHAMED AL HAMMADI
Managing Director and Chief Executive Officer, Emirates Nuclear Energy Corporation

"The recent refinancing of Barakah having been verified as meeting Green Loan status requirements firmly establishes the essential role of nuclear energy in the clean energy transition and its bankability for finance and investment organizations. We are breaking new ground as one of the first nuclear plants globally to be backed by Green Loan funding, paving the way for others, as we continue to offer a new model as an example for new nuclear programs globally."

The inclusion of nuclear power in sustainable taxonomies (e.g. the EU Taxonomy [75]) and national sustainable bond frameworks (e.g. Canada [76] and Japan [77]) is further boosting acceptance of nuclear energy technologies and reassuring ESG-conscious investors. These developments support increasing recognition and growth in the number and volume of green bonds for nuclear energy projects in the broader burgeoning sustainable bond[9] market [78] (see Table 2). Green bond issuance has more than doubled over the past five years to US_{2023} $575 billion [79] and now makes up about 60% of sustainable bonds on offer (see Figs 11 and 12).

FIG. 11.

Sustainable bond market value, 2014–2023 [78]

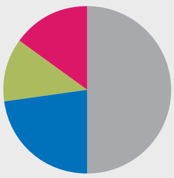


[9] Sustainable bonds include green, social, sustainability, sustainability-linked and transitional bonds.

Akkuyu nuclear power plant, Türkiye. Courtesy of Akkuyu Nuclear Joint Stock Company

FIG. 12.

Green bond proceeds by sector (US_{2023} $) [78]



23% Energy

12% Buildings

15% Transport

50% Other

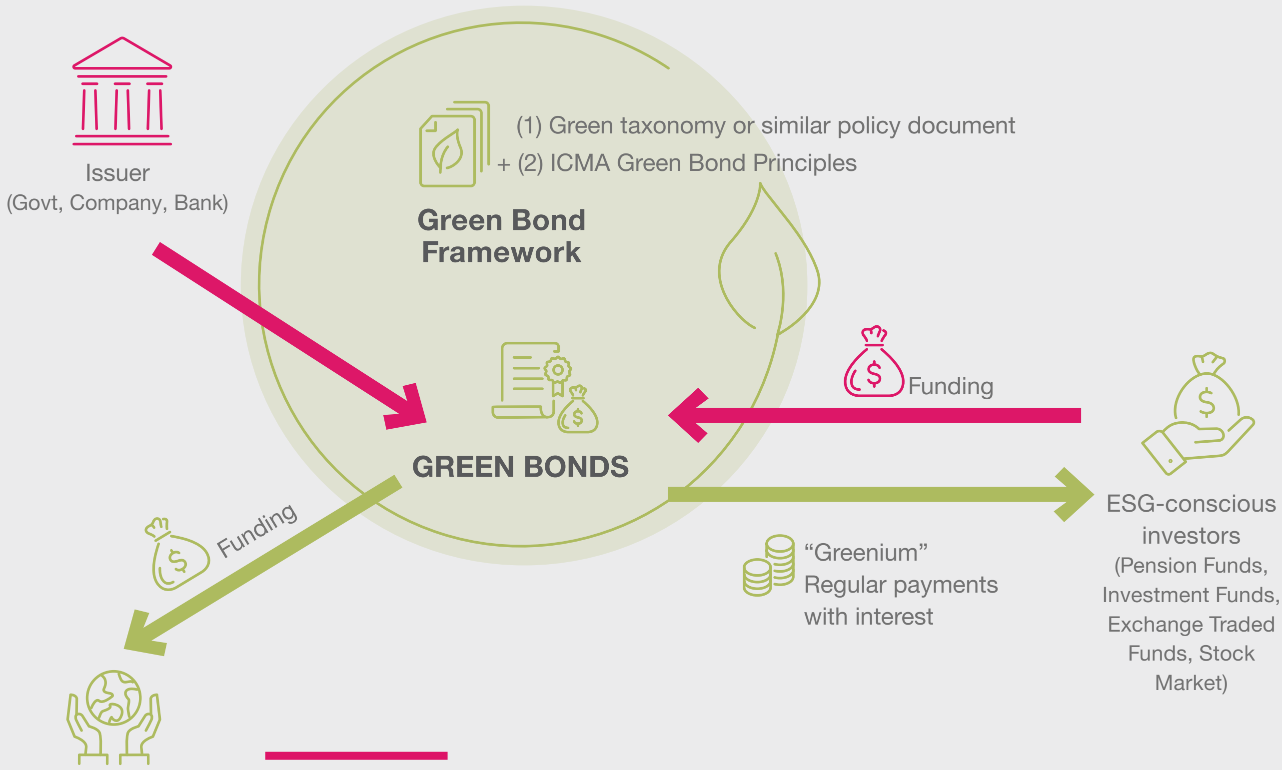
Nuclear energy industry corporates are also playing their part, with many adopting their own corporate green bond frameworks under the technology-neutral Green Bond Principles (GBP) established by the International Capital Market Association (an association of financial institutions) in 2021 and revised in 2022 [80] (see Fig. 13 for a representation of key players and the green bond issuing process). Companies such as Bruce Power [81] and Ontario Power Generation [82] in Canada, Teollisuuden Voima Oyj in Finland [83], EDF [84] in France, the Russian State Development Corporation VEB.RF [85] and Constellation [86] in the USA are among the trailblazers adopting green bond frameworks to provide transparency and accountability for environmentally minded investors, underpinned by stringent compliance procedures and second party opinions – independent evaluation by rating agencies.[10]

Although some issuers claim that green labels on their bonds help them lower the cost of borrowing, data show that the discount is rare [87]. The so called ‘greenium’ — the interest rate premium for green bonds over conventional bonds — is limited [88]. Nevertheless, green bonds appear to be a promising instrument to attract financing, providing a straightforward option for institutional investors to achieve ESG objectives across their portfolios along with reputational benefits for both issuers and investors.

[10] These include the Japan Credit Rating Agency, DNV Business Assurance Japan and the Russian Analytical Credit Rating Agency, alongside global entities like Sustainalytics, S&P Global Ratings, ISS Corporate Solutions and Climate Bond Initiative.

FIG. 13.

Representation of key players and the green bond issuing process.



KEY PLAYERS:

- Government (establishing national regulatory framework)
- Issuer (developing Green Bond Framework, providing information about the projects to be financed, requesting second party opinion)
- Second party opinion provider (providing an independent assessment of a bond in terms of accuracy and integrity)
- Bookrunner (underwriting or coordinating a bond’s issuance)
- Investor (willing to invest in climate-related projects)

Recent developments in regulatory standards have further paved the way for nuclear energy to expand in the green bond arena. In 2023, the European Union introduced a new regulation establishing the European Green Bond (EGB) standard [89], under which nuclear energy deployment can qualify as environmentally sustainable if compliant with transparency requirements in the EU Taxonomy [75]. The EU Taxonomy also informs national European policies, for example the French Ministry of Ecological Transition and Ministry for Energy Transition revised the Greenfin label, which establishes criteria for labelling investment funds as green, to include funding activities enabling nuclear technologies [90].

TABLE 2.

Sustainable bonds[11] issued for nuclear energy.

COUNTRY	ISSUER	BOND TYPE	FRAMEWORK ESTABLISHMENT DATE	ISSUANCE DATE	VOLUME	COUPON	ALLOCATION OF PROCEEDS
Argentina	Nucleoeléctrica Argentina SA	Sustainability-linked	established 2023	January 2023	US $30 mn	2% (4 years)	Long term operations of Atucha I; construction of the second dry storage facility for spent nuclear fuel at the Atucha site.
				April 2023	US $80 mn	5% (10 years)	
				July 2023	US $ 69 mn	5%[12] (10 years)	
Canada	Government of Canada	Green	established 2022, updated 2023	February 2024	$C 4 bn (US $2.96 bn)	3.5% (10 years)	Eligible uses of proceeds include measures supporting the deployment of nuclear energy to generate electricity and/or heat, such as: 1) investments in new NPPs; 2) refurbishments of existing NPPs; 3) research and development; 4) some supply chain activities. Canada expects to allocate proceeds from this bond to eligible nuclear activities but has not committed specific amounts.
	Province of Ontario	Green	established 2014, updated 2024	February 2024	$C 1.5 bn (US $1.1 bn)	4.1% (9 years)	Eligible uses of proceeds include measures supporting the deployment of nuclear energy to generate electricity and/or heat. No nuclear projects have been funded to date.
	Bruce Power	Green	established 2021, updated 2023	November 2021	$C 500 mn (US $397 mn)	2.68% (85 months)	Extending the life and increasing efficiency of the nuclear generation facility, Finance or refinance new / existing green investments and expenditures.
				March 2023	$C 300 mn (US $220 mn)	4.70% (57 months)	
					$C 300 mn (US $220 mn)	4.99% (117 months)	
				March 2024	$C 600 mn (US $444 mn)	4.7% (87 months)	
	Ontario Power Generation	Green	established 2018, updated 2024	July 2022	$C 300 mn (US $230 mn)	4.92% (10 years)	Eligible uses of proceeds include maintenance and / or refurbishment of existing nuclear energy facilities.

>>>

[11] Sustainable bonds include green, social, sustainability, sustainability-linked and transition bonds.
[12] Interest rate reduction of 1.5% subject to incentives.

TABLE 2.

Sustainable bonds issued for nuclear energy.

COUNTRY	ISSUER	BOND TYPE	FRAMEWORK ESTABLISHMENT DATE	ISSUANCE DATE	VOLUME	COUPON	ALLOCATION OF PROCEEDS
Finland	Teollisuuden Voima Oyj	Green	established 2023	December 2023[13]	€105 mn (US $115 mn)	5.19% (10 years)	Financing or refinancing of construction and safe operation of new NPPs, electricity generation from existing NPPs.
					€85 mn (US $93 mn)	5.30% (12 years)	
					€90 mn (US $98 mn)	5.40% (15 years)	
				May 2024	€600 mn (US $650 mn)	4.25% (7 years)	
France	Electricité de France	Green	established 2016, updated 2022	December 2023	€1 bn (US $1.08 bn)	3.75% (3.5 years)	EU taxonomy aligned nuclear energy capital expenditures in existing French nuclear reactors in relation to their lifetime extension.
				June 2024	€1 bn (US $1.07 bn)	4.125% (7 years)	
					€750 mn (US $802 mn)	4.375% (12 years)	
					€1.25 bn (US $1.34 bn)	4.750% (20 years)	
Japan	Kyushu Electric Power Co.	Transition	established 2022	May 2024	JPY 10 bn (US $63.63 mn)	0.858% (5 years)	Refinancing of investments in safety measures for existing nuclear power plants.
					JPY 20 bn (US $127.253 mn)	1.425% (10 years)	
Russian Federation	State Development Corporation VEB.RF	Green	established 2022	November 2023	RUB 40 bn (US $470 mn)	floating rate (6.5 years)	Climate change adaptation projects, including refinancing construction of an NPP.
USA	Constellation Energy Generation LLC	Green	established 2024	March 2024	US $900 mn	5.75% (30 years)	incl. Maintenance, expansion and life extensions of facilities licensed by the US Nuclear Regulatory Commission[14].

[13] The issue was done in US Private Placement format.
[14] Not all proceeds are expected to be invested in nuclear energy projects.

Olkiluoto nuclear power plant, Finland.

In February 2024, the Government of Japan issued 10-year Japan Climate Transition Bonds and 5-year Japan Climate Transition Bonds (Japan's GX bonds) in the amount of JPY 800 billion (US $5.5 billion) each [91]. Japan's GX bonds can be used for R&D of fast nuclear reactors and high-temperature gas reactors (pink hydrogen) [92].

BOX 12: CONTRIBUTION FROM ROSATOM

Refinancing of an NPP construction using green bonds

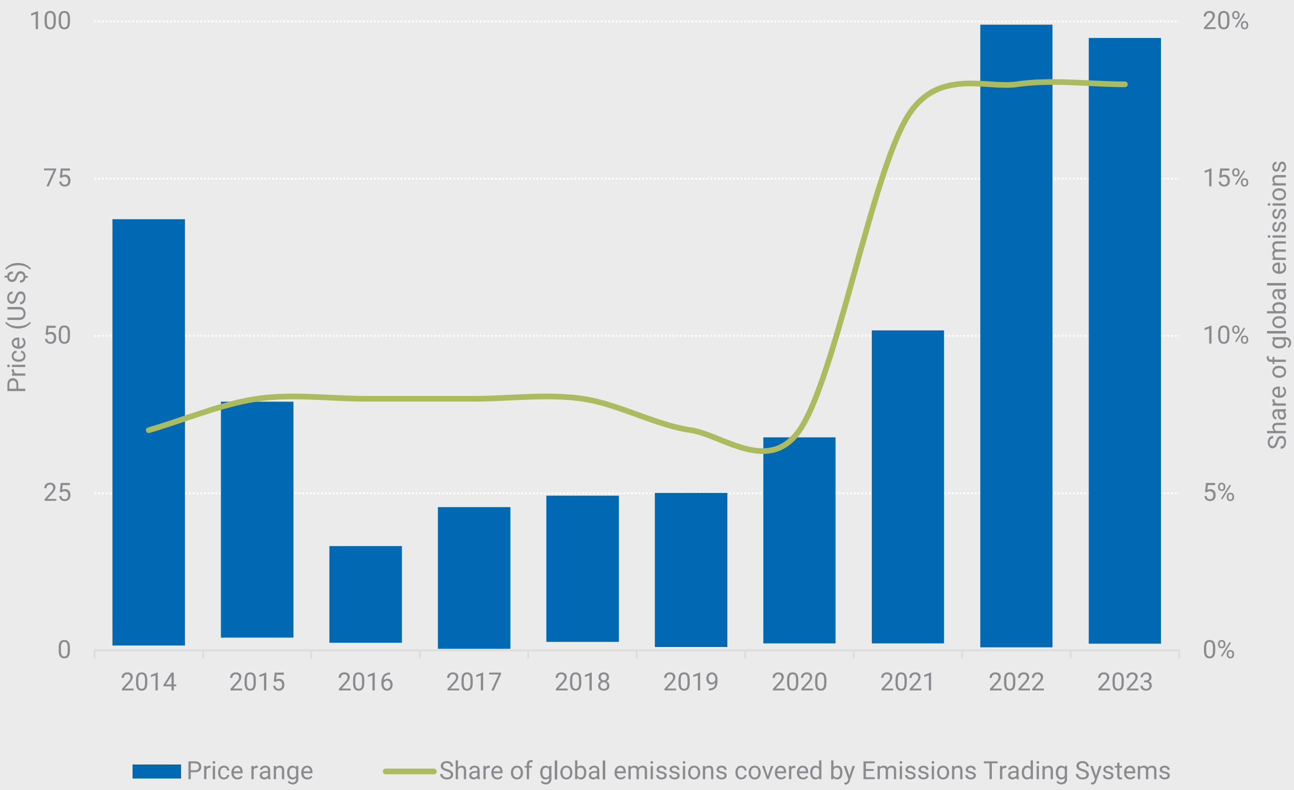
In 2013 the Russian development bank VEB RF provided a credit for the construction of an NPP in Belarus in the amount of US $500 million (16 billion RUB in 2013), which was carried out by ROSATOM. The major amount of financing for the project was structured as an intergovernmental credit from the Russian Federation to Belarus in the amount of US $10 billion.

Later in 2023 VEB RF issued green bonds on the Moscow Exchange (MOEX) amounting to RUB 40 billion (US $470 million in 2023) for the purpose of refinancing green related credits, including a residual sum of credit for the Belarus NPP. The issue was verified by the independent agency AKRA on compliance with the Russian taxonomy of green projects, which includes nuclear power [93]. The conclusion of the verifier highlights that the green effect of the NPP project is a decline in GHG emissions by 8.7 million tons of CO_2eq per year or 522 million tons of CO_2eq for the operating lifecycle [94].

3.1.4.2. Carbon markets

Carbon pricing is an economic signal to GHG emitters that facilitates global energy transition and takes different forms. Compliance mechanisms are administrated by governments and take the form of emissions trading systems and carbon taxes. Such mechanisms operate at every level of government — in cities, provinces and states, countries and at the supranational level [95]. Each government sets its own regulations regarding carbon allowances for direct GHG emissions (scope 1): sectors covered, allocation approached, price rate established, etc. The power sector is included in almost all emissions trading systems around the globe, as the sector is well-suited for facilitating the clean energy transition via this mechanism. Allowance cost is reflected in the price for end consumers; hence, carbon-intensive goods become more expensive and low carbon alternative more attractive. However, such incentives of carbon pricing usually cannot be fully implemented, as energy markets are often regulated, partially or fully [96] (see Fig. 14).

FIG. 14.



Emissions trading system price ranges and share of global GHG emissions covered, 2018–2023 (US $/t$CO_2$eq) [95].

The voluntary carbon markets (VCMs) set up a crediting mechanism, which allows companies to offset their carbon emissions by purchasing emission reduction credits from projects aimed at GHG emission reduction or GHG removal. There are various VCMs, including governmental crediting mechanisms, with no centralized regulation and many third parties providing standards, verification and ratings [97]. The two largest registries with widely used VCM standards are the Verified Carbon Standard and the Gold Standard; neither sets rules and requirements for nuclear energy projects.

At this stage of carbon market development, the nuclear energy industry does not seem to benefit from them. There is no straightforward exclusion of nuclear energy from carbon markets, nor are there positive signals or success stories for nuclear energy technologies. Carbon pricing is beneficial for nuclear power in terms of increasing its competitiveness compared with coal- and gas-fired power generation facilities, all else being equal.

3.1.4.3. Green certificates

Green certificates serve as an instrument to verify that energy was generated from a low carbon energy source. By purchasing green certificates, consumers can offset or reduce the carbon footprint of goods produced or of the company itself, and can declare it in nonfinancial annual reporting, state it in information about goods and use it for marketing purposes. Strictly speaking, green certificates are not a financial instrument. However, power plant owners — if the energy source is eligible under relevant regulations — can attract financing by selling green certificates, along with highlighting their input to the climate change mitigation.

Every jurisdiction establishes its own policy for green certificates, including energy sources that fall within its scope. Nuclear energy is not always included as eligible; however, there are positive examples for the nuclear industry. Nuclear power is recognized as a source of clean energy in several green certificate policies, for example, guarantees of origin in France [98], clean energy certificates in Abu Dhabi (United Arab Emirates) [99], clean energy credits in Ontario (Canada) [100–103], non-fossil certificates in Japan [104] and emission free energy certificates under PJM EIS GATS in the USA [105].

International carbon pricing started with mechanisms under the Kyoto Protocol, later replaced by the Paris Agreement. Article 6 of the Paris Agreement was designed to facilitate the deployment of an international carbon market, and 36 bilateral cooperation agreements have been signed under its auspices, with four authorizations provided by buyer and seller countries for corresponding adjustment.

Ikata nuclear power plant, Japan.

BOX 13

Nuclear energy under Article 6 of the Paris Agreement

Article 6 of the Paris Agreement outlines high level principles for countries to engage in collaborative efforts to reach their climate targets. While detailed rules for implementation are still pending, Article 6 encompasses both market and non-market approaches to emissions reduction (Fig. 15), and could theoretically represent a new mechanism to mobilize funding low carbon options such as nuclear energy.

MARKET APPROACHES

Article 6.2.

Cooperative Approaches

Enables bilateral/plurilateral emissions trading agreements between countries

- Establishes opportunity to trade emissions upon agreement of countries without supervision of COP
- Requires carbon market infrastructure in involved countries
- Includes transparency criteria such as reporting requirements and proof of robust accounting
- Encourages Parties to transfer a share of proceeds to the Adaptation Fund

Article 6.4.

Sustainable Development Mechanism

Framework to create a global carbon market supervised by the Conference of the Parties (COP)

- Establishes mechanisms for the validation, verification and issuance of carbon credits
- Supports a centralized carbon registry overseen by a UN supervisory body
- Develops standards and procedures for operationalizing the clean development mechanism
- Establishes administrative and cancellation fees and requires Parties to transfer a share of proceeds to the Adaptation Fund

For activities to be eligible under Articles 6.2 and 6.4, they must mitigate GHGs, contribute to meeting Sustainable Development Goals, ensure environmental integrity, and meet transparency and additionality criteria.

NON-MARKET APPROACHES

Article 6.8.

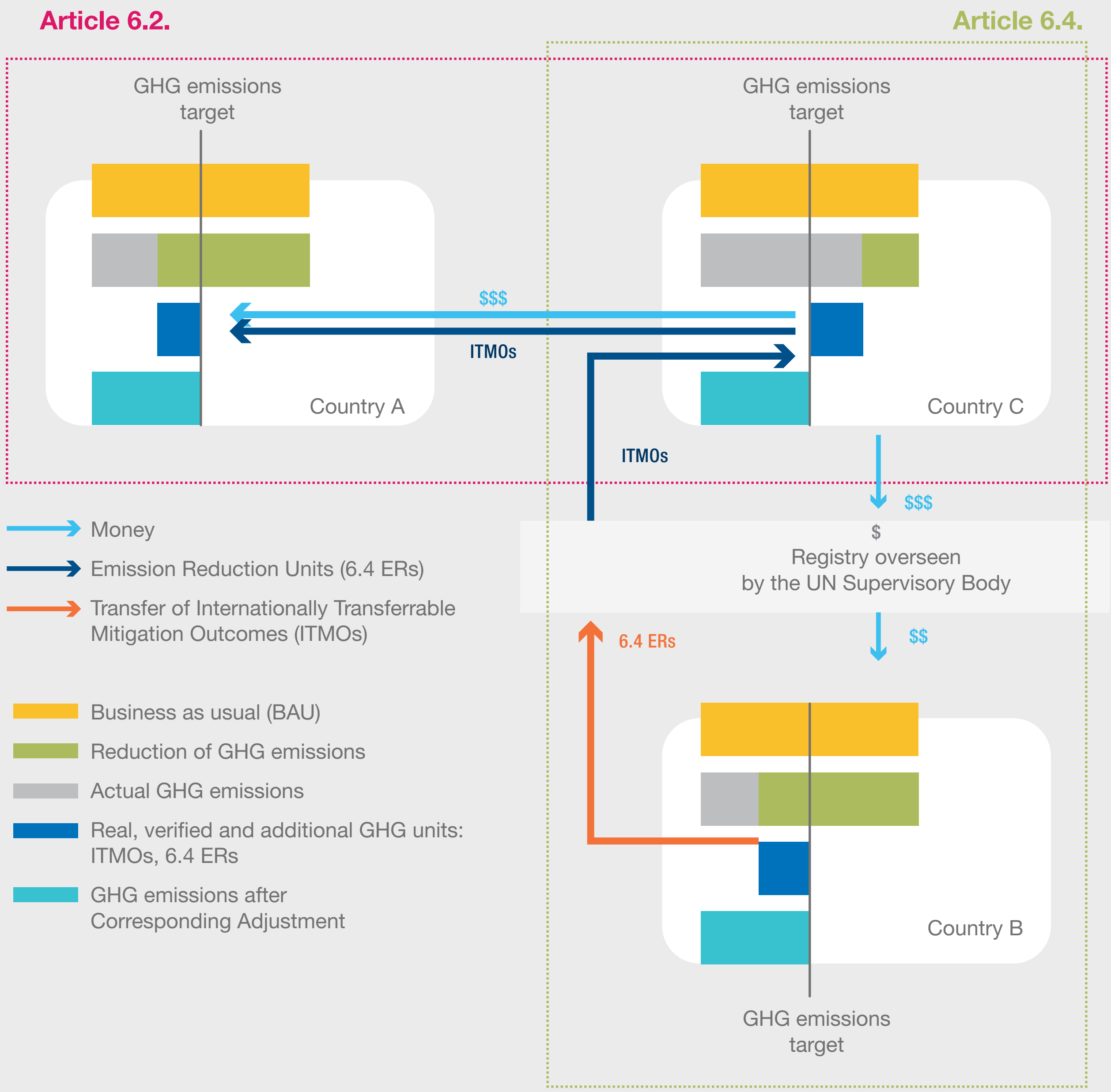
Non-market Approaches

Promotes assistance in the implementation of NDCs, including mitigation, adaptation, finance, technology transfer and capacity building

- Web based platform to provide information and share experience
- Potential to provide financial assistance to underfunded regions and areas on a non-transactional basis
- Bolsters cooperation and avoids financial obligations by matching projects with financial and technological support

FIG. 15.

Article 6 of the Paris Agreement: Market and non-market approaches



Articles 6.2 and 6.4 establish mechanisms for VCMs. Under Article 6.2, countries can choose to bilaterally exchange carbon credits, subject to transparent reporting and adjustment protocols. Meanwhile, Article 6.4 envisions a centralized carbon credit mechanism, though specifics are yet to be finalized. Article 6.8 provides a mechanism for non-market approaches, including the provision of financial resources, technology transfer and capacity-building support.

While the potential for nuclear energy to contribute to emissions reductions is clear, the current lack of explicit rules and guidelines for projects under Article 6 poses challenges. However, a specific project structure is likely to require extensive legal work as well as monitoring, reporting and verification to comply with all necessary requirements, which remain ambiguous.

3.1.4.4. Policy incentives for net zero energy technologies

Low carbon energy technologies are at the centre of strong geostrategic interests and a global technological race. Countries are showing signs of being eager to secure their supply of the most advanced technologies in order to safeguard the resilience of their energy systems and create quality jobs by heavily investing and rolling out support measures to innovate and strengthen their manufacturing capacities. The US Inflation Reduction Act (IRA) — see Box 14—and the EU Net Zero Industry Act (NZIA) are exemplars of transformative approaches being adopted around the world.

The IRA, enacted in 2022, provides substantial fiscal incentives to promote investment in nuclear and other clean energy technologies, including tax credits and loan guarantees. In comparison, the 2024 EU NZIA focuses on boosting innovation and scaling up manufacturing capacity of net zero energy technologies, including nuclear energy and fuel cycle technologies [106].

Rather than focusing on fiscal measures (tax incentives, grants and loans) like the US IRA, the EU NZIA, approved by the EU Parliament in April 2024, seeks to build net zero manufacturing capacity (with a target benchmark of 40% of annual deployment needs of strategic net zero technologies by 2030) to leverage existing fiscal support measures.[15] Some specific measures in the NZIA also aim to accomplish the following:

- → Ensure the free movement of net zero technologies in the single market, with faster permit-granting processes to construct, extend changes and operate net zero manufacturing projects (i.e. 12 months for projects with an annual manufacturing capacity less than 1 GW and 18 months for larger projects) and access to markets and public procurement;
- → Foster innovation by creating net zero regulatory sandboxes in which net zero technologies can be tested “in a controlled real-world environment, under a specific plan, developed and monitored by a competent authority” [106];
- → Enhance coordination, information exchange and sharing of best practices by establishing a Net Zero Europe Platform coordinated by the EC;
- → Develop the skilled workforce and quality jobs for the EU net zero industry by establishing Net Zero Industry Academies coordinated by the EC.

[15] Examples of EU Funds mentioned in the NZIA are the Recovery and Resilience Facility, the Modernization Fund, REPowerEU, the European Social Fund Plus, Just Transition Fund, European Regional Development Funds and the Single Market Programme.

BOX 14: CONTRIBUTION FROM US NET ZERO WORLD INITIATIVE

Financing mechanisms for new and existing nuclear power plants in the USA

FINANCING MECHANISMS FOR NEW NUCLEAR PROJECTS

In the USA, several recently announced federal and state financing mechanisms support the deployment of new clean energy technologies, including nuclear reactors. The IRA, enacted in 2022, provides the largest set of federal incentives to date:

- Electricity production tax credits of US $25-33/MW·h and investment tax credits in clean energy projects equal to 30-50% of the total capital expenditures (under Sections 45Y and 48E, respectively). Taxpayers can elect to receive only one of the tax credits if certain requirements are met [28].
- Loans to advance innovative energy projects, manufacturing processes, State-supported initiatives and energy infrastructure reinvestment, including for projects on former coal sites, up to US $250 billion in total loans (under Title 17), including direct loans backed by US DOE guarantees or partial guarantees of commercial debt, with flexible financing options tailored to project needs [107, 108]. In 2024, the Palisades reactor in Michigan awarded a conditional US $1.52 billion loan guarantee to support its recommissioning and operation until at least 2051 [109]. In Georgia, the DOE Loan Programs Office has provided loan guarantees of up to US $12 billion for the construction of two nuclear reactors as part of the Vogtle nuclear project, the first new nuclear construction project in the USA in over three decades [110].

FINANCING MECHANISMS FOR EXISTING NUCLEAR POWER PLANTS

The IRA provides funding intended to extend the operating life of existing nuclear power plants or supporting uprates investment:

- Production credits for existing nuclear power facilities, that is, conventional nuclear power facilities in service before 2022 (under Section 45U). The credits can be received until 31 December 2032 [111]. Final guidance is pending on whether facilities are eligible for both these Section 45U credits and tax credits for H2 (Section 45V) [112].
- Credits for continued NPP operation under the US $6 billion Civil Nuclear Credit Program [113]. NPP owners or operators can bid for credits to sustain operations, with selected certified reactors receiving credits for four years with the possibility of extension [114]. For instance, under the Civil Nuclear Credit Program, the Diablo Canyon reactors in California were awarded US $1.1 billion to extend their operation past their previously scheduled cessation of commercial operation of 2024–2025 [115].
- Tax credits for hydrogen production using renewables alongside current nuclear power plants (under Section 45V). Hydrogen projects may also be eligible for tax credits when they are couple with clean electricity generation (under Section 45Y and 48E or under Section 45U).

3.2. Financing Long Term Operations

Extending the operational lifespan of nuclear power plants through possible refurbishments is a strategic response to climate imperatives. By retrofitting ageing components, plants increase generation capacity and maximize resource utilization. Moreover, plant refurbishments are typically more economical than building a new power plant of any energy technology, positioning nuclear power as a sustainable cornerstone of the energy transition.

Long term operations may also be an opportunity to enhance the economics of power uprates, when technically achievable, which would help meet the increasing electricity demand until new units are built.

While both long term operations and new builds share the objective of expanding nuclear power capacity in the future energy mix, they differ significantly in terms of financing approaches and project timelines, as follows:

- **RISK PROFILE:** Long term operations of existing nuclear energy facilities entail lower capital expenditures and regulatory risks compared to new builds. Investors prioritize stable cash flows and operational efficiency over the uncertainties associated with greenfield projects.
- **PROJECT DURATION:** Investments in long term operations primarily focus on extending the operational lifespan and enhancing the performance of existing nuclear energy assets. In contrast, new build projects involve constructing entirely new facilities, requiring substantial upfront investments and longer lead times.
- **REGULATORY COMPLEXITY:** New build projects encounter more extensive regulatory review and approval processes, resulting in prolonged development timelines and heightened uncertainty. Investments in long term operations, however, navigate relatively circumscribed regulatory review, leveraging existing infrastructure, operating license and experience.

Financing long term operation of nuclear power plants, particularly those that involve major refurbishment, requires a multifaceted approach encompassing government support, public–private partnerships and innovative financing mechanisms. Financing the long term operations of a nuclear energy project is associated with significantly less financial risk, as the projects are already operational and upgrades or maintenance for long term operations are much less expensive compared to building a new reactor. The costs of NPP long term operations compared to new build can vary depending on existing infrastructure, regulatory requirements and reactor technology, but average LTO costs can range from US $300 to 2700/kW [41, 65, 116, 117], typically less than 10% of the cost of new build. Costs associated with long term operations may be spread over many years and in some cases could be counted as operations and maintenace costs during the operational life of the project.

As a less risky and less expensive way to mitigate climate change, long term operations of nuclear power plants is a compelling case for green financing. Green bonds were used to finance lifetime extention, maintenance and refurbishment of existing nuclear facilities in Canada, Finland and France. More information on sustainable bonds can be found in Section 3.1.4.1. and Table 2.

Wind turbines on a mountain in Heyuan, Guangdong, China.

BOX 15: CONTRIBUTION FROM NUCLEOELÉCTRICA ARGENTINA S.A.

Financial strategy for the life extension projects of Atucha I nuclear power plant and dry storage of spent nuclear fuel

The financing cases for the Atucha I lifetime extension and construction of the second dry storage facility underscore the importance of international, public and private sector collaboration and innovative financing mechanisms in advancing nuclear energy projects. By leveraging partnerships and resources effectively, Argentina secured the necessary funding to propel its nuclear ambitions forward, paving the way for a more sustainable energy future.

INTRODUCTION

The Atucha I nuclear power plant began construction in June 1968, becoming the first nuclear power plant in Latin America, and was connected to the Argentine grid in March 1974. Studies have concluded that Atucha I could continue to generate clean and safe energy for two additional decades, maintaining or even increasing its installed nuclear power from 362 MW to 370 MW, with zero CO_2 emissions. This extension will directly benefit over a million inhabitants, diversify Argentina's energy matrix by replacing hydrocarbons, contribute to a reduction in greenhouse gas emissions, preserve technological expertise in natural uranium and heavy water, stabilize energy prices and create employment opportunities through the direct generation of 2000 jobs between 2024 and 2027.

As part of the lifetime extension, the dry storage project aims to ensure the continuous operation of nuclear power plants by increasing the capacity for storing spent fuel elements. The engineering development for this project is 100% Argentine, with 90% of goods and services sourced domestically.

FINANCING STRATEGY

In 2023, Argentina's nuclear utility, Nucleoeléctrica Argentina SA, released three tranches of sustainable bonds to extend the lifetime of Atucha I and construct a second dry storage facility for spent nuclear fuel at the Atucha site. The tender was available to qualified investors and raised US $179 million in total. The upgrades and maintenance for Atucha I are expected to take 30 months and cost US $463 million, while the dry storage facility construction is estimated to cost US $137 million.

These bonds are backed by a Power Purchase Agreement and carry a fixed interest rate of 2% for the first tranche and 5% for the second and third tranches. It is important to highlight that the bonds have been classified as sustainability-linked bonds in the terms of the International Capital Market Association. The tranche III bonds feature the possibility of an interest rate reduction of 1.5% based on net electricity generation targets for the plant. In this case, the investor would still receive 3.5% interest on the purchased bond. This incentive is designed to reward the company for its contribution to CO_2 emissions reductions.

Maintenance, upgrades and refurbishments constitute core elements of long term operations, ensuring the continued reliability and efficiency of nuclear power plants in the face of climate risks. In response to rising temperatures and the increasing frequency and intensity of extreme weather events, nuclear energy facilities are implementing proactive maintenance strategies to safeguard critical infrastructure. From comprehensive inspections to predictive analytics, these measures detect and address potential vulnerabilities, bolstering plant reliability and ensuring operational continuity.

The pursuit of climate resilience also drives continuous upgrades and modernizations across nuclear power plants. Enhanced cooling systems and fortified structures exemplify the innovative solutions employed to fortify safety- and production-related infrastructure against climate related risks. These upgrades not only enhance safety and performance but also future-proof nuclear energy facilities against evolving environmental challenges [118, 119].

Overall, the industry's proactive response to climate change not only enhances resilience but also reaffirms nuclear energy's vital role in the clean energy transition.

Deploying the levels of nuclear energy projected in decarbonization scenarios requires a collaborative effort among industry, government and financial institutions. These organizations can work together to overcome challenges, seize opportunities and realize the vision of a carbon-neutral future.

Atucha II reactor, Argentina.
Photograph by Mcuklio/Wikipedia.org, distributed under a CC-BY 3.0 licence.

Considerations for Small Modular Reactors

4.

In recent years, SMRs have gained attention among policy makers and industrial players as anuclear energy technology that could complement renewable sources and large reactors in low carbon energy systems. SMRs, able to deliver flexible, scalable and dispatchable low carbon energy, may be suitable for a wide range of applications, including remote locations, smaller grids and non-electrical applications. Navigating the financing and economic landscape for SMRs requires a nuanced understanding of their unique characteristics and challenges. This section describes the unique attributes of SMRs in the context of energy systems, highlighting the potential for new financing pathways and lessons learned from efforts to commercialize the first generation of SMRs.

SMRs are generally defined as nuclear reactors that produce up to 300 MW of electricity, much less than conventional large-scale nuclear power plants. Most SMR concepts are characterized by a simpler, more standardized and modular design compared with traditional large reactors. Hence, SMRs are expected to have a substantially smaller footprint than that of convential large-scale nuclear power plants. Structures, systems and components of SMRs can be manufactured in a factory controlled environment using advanced manufacturing techniques, assembled in modules and then transported and mounted onsite, potentially reducing construction costs and project timelines.

Currently, there are more than 90 SMR designs at different stages of development and deployment, differing in terms of technology and technical characteristics. Roughly half of the SMR designs represent an evolution of current light water reactors (Gen III or Gen III+ designs), while the remaining designs correspond to more advanced Generation IV reactor technologies using alternative coolants and advanced fuel types. The various designs are at different stages of development, technological readiness and licensing. In general, LWR-type SMRs are at a more advanced stage of development and technical maturity than more advanced concepts and benefit from a more established regulatory basis and experience in licensing. The majority of SMR designs are still at a conceptual or pre-conceptual design level. Only a few SMRs are currently in operation or under construction, while some other concepts have completed the design certification and are in the process of starting the construction of a FOAK unit. This section focuses on SMRs that are at a more advanced stage of development and close to industrial deployment.

4.1. Economics of Small Modular Reactors

The cost structure of SMRs in many ways mirrors that of their larger counterparts. Both have relatively high upfront capital investment requirements and stable and predictable operating expenses. However, SMRs offer the potential for simplification, standardization and predictability that holds the key to unlocking their economic competitiveness, overcoming their main disadvantage compared with traditional large reactors, which have evolved towards larger units to take advantage of economies of scale. The time to generate a return for investors is also anticipated to be shorter for SMRs due to reduced construction duration.

By embracing simplified modular designs, standardized components and passive safety features that require fewer components and reduce the overall complexity of the plant, SMRs hold the promise of streamlined manufacturing processes and reduced construction timelines, thus achieving ‘economies of volume’ (see Fig. 16). Modularity, standardization and factory based construction are also expected to increase labor productivity and construction quality, leading to cost reductions and shorter construction times. This has a favorable impact on the overall economics of SMRs by reducing the interest accrued during construction (and thus the capital cost) and the construction risk for investors compared to large reactors. This predictability in project delivery can be a crucial factor in attracting investors and securing financing.

ERNEST J. MONIZ
13th United States Secretary of Energy

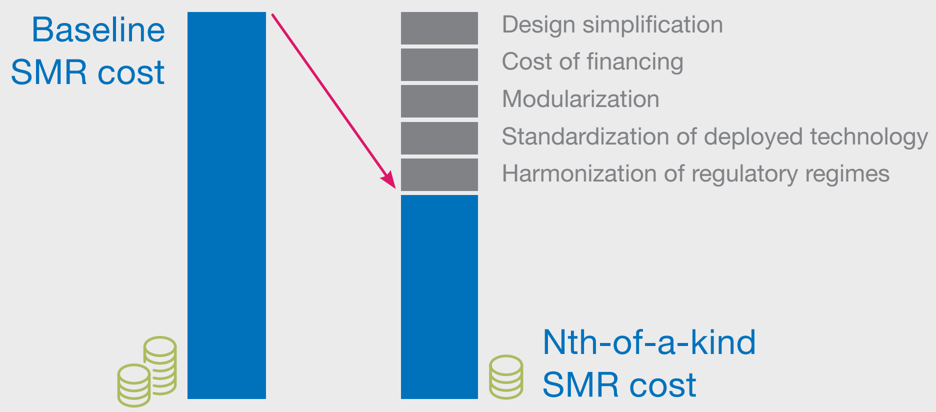
“The key attraction of nuclear power—firm carbon-free electricity—has put tailwinds behind the drive to triple global deployment by midcentury. This will require improved bankability of nuclear supply chains. Demand aggregation in orderbooks for specific reactor designs, as well as public-private partnerships, can greatly advance risk-sharing for accelerated deployment. Successfully moving from a project to a product approach would transform the industry.”

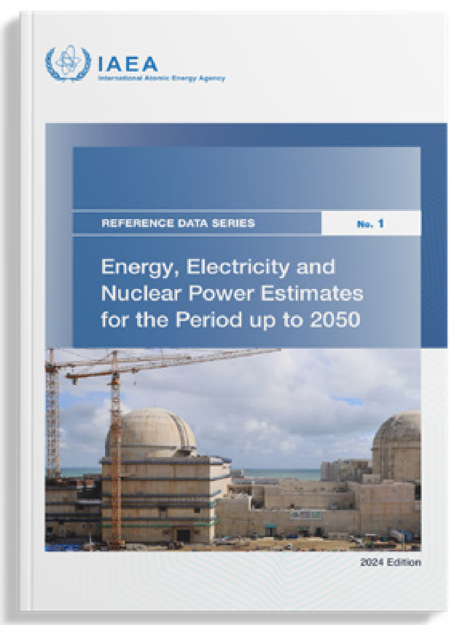
Despite this potential of SMRs, the technology is still in an early stage of commercialization, and the overall economics of NOAK SMRs is uncertain. It remains to be seen whether the economies of volume promised by SMRs will fully compensate for the diseconomies of scale. FOAK cost estimates are likely to be inaccurate, but appropriate data capture and benchmarking such as reference class forecasting can improve SMR cost and construction duration estimates over time.

Today's SMR companies tend to operate like startups, meaning that the construction phase of SMR deployment will be accompanied by a rapid company scale-up, which introduces additional risk for investors due to the lack of proven governance, corporate processes and procedures. Successful SMR deployment will depend on both a sound technology and the company's ability to mature and deliver the project.

FIG. 16.

Relationship between SMR economic drivers. Adapted from [120, 121].





For the fourth year in a row, IAEA global nuclear electric capacity projections for 2050 have been revised upwards. In the high case scenario, nuclear capacity is set to rise by 150%, reaching 950 GW, up from 372 gigawatts at the end of 2023. Even in the low case, capacity is expected to grow by 40% to 514 GW. **SMRs will play a significant role, contributing about 25% of the added capacity in the high case and 6% in the low case.**

Learn more:

4.2. Opportunities for SMRs to Access New Financing Pathways in the Transition to Low Carbon Energy Systems

SMRs offer a promising solution for applications and sectors currently served by fossil fuels, for which other low carbon alternatives such as large nuclear reactors and renewables face constraints. The smaller size of SMRs makes nuclear energy projects attractive in regions and markets not accessible to traditional large nuclear power plants. These include remote and isolated areas, regions with a low electricity demand or where grid development is challenging or economically unfeasible, or areas with limited suitable sites for large reactors. SMRs offer a means to extend nuclear power capabilities to these regions with the possible reduction of transmission losses, replacing high emission energy sources that frequently incur elevated costs due to logistical complexities.

SMRs offer an effective option to replace a large fleet of ageing coal power plants that are reaching the end of their lifetime or are expected to be phased out in the next decade in order to achieve climate goals. Currently over 2 TW of coal power plant capacity is in operation worldwide, with plant unit sizes ranging between a few MW and 700 MW. The similar size of SMRs potentially allows for one-to-one replacement of such plants, taking advantage of the existing electrical infrastructure and access to cooling water, and avoiding the challenges associated with expanding or enhancing grid infrastructure.

As a result of their ability to replace fossil generators and meet demand in remote and isolated locations, SMRs may present a more attractive option for investors. Their scalable nature and reduced initial capital requirements open new avenues for financing, potentially accelerating the transition to a low carbon future. For example, the Export-Import Bank of the United States (EXIM) offers a toolkit for potential buyers of US SMR systems and components. It contains additional offerings for SMRs, including financing options for fees and interest payments during construction, pre-export loan disbursements to finance SMR components in production and co-financing options with other ECAs [122].

Coal to nuclear projects may also attract specific investments, especially where policy incentives exist to facilitate the transition. For example, Project Phoenix is a US funded programme that supports feasibility studies and technical assistance to support the conversion of coal-fired power plants to SMRs globally [123]. Additionally, the Inflation Reduction Act in the USA provides an option for up to US $250 billion in total loans for the purpose of energy infrastructure reinvestment, including for clean energy projects on former coal sites (see Box 14)

Other organizations are considering how to create an enabling environment for SMRs [124]. For example, the European Industrial Alliance on SMRs was designed to identify investment barriers, analyse funding opportunities and explore new financial blending options for SMR deployment in the European market [125].

SMRs can also provide heat for various applications, such as district heating, desalination, hydrogen production and many industrial processes that currently rely on fossil fuels. Oil extraction and refining, chemical synthesis and ammonia production could be among the first industrial applications in which SMRs are deployed for decarbonization. Also, several advanced SMR designs operate at a higher temperature range, thus making them more suitable for industries requiring higher heat temperatures. Although large reactors could also serve some of these markets and applications, the smaller thermal output of SMRs may be a better fit with the energy needs of many industrial facilities, while their smaller footprint allows for easier co-location with industrial sites [126–128].

BOX 16

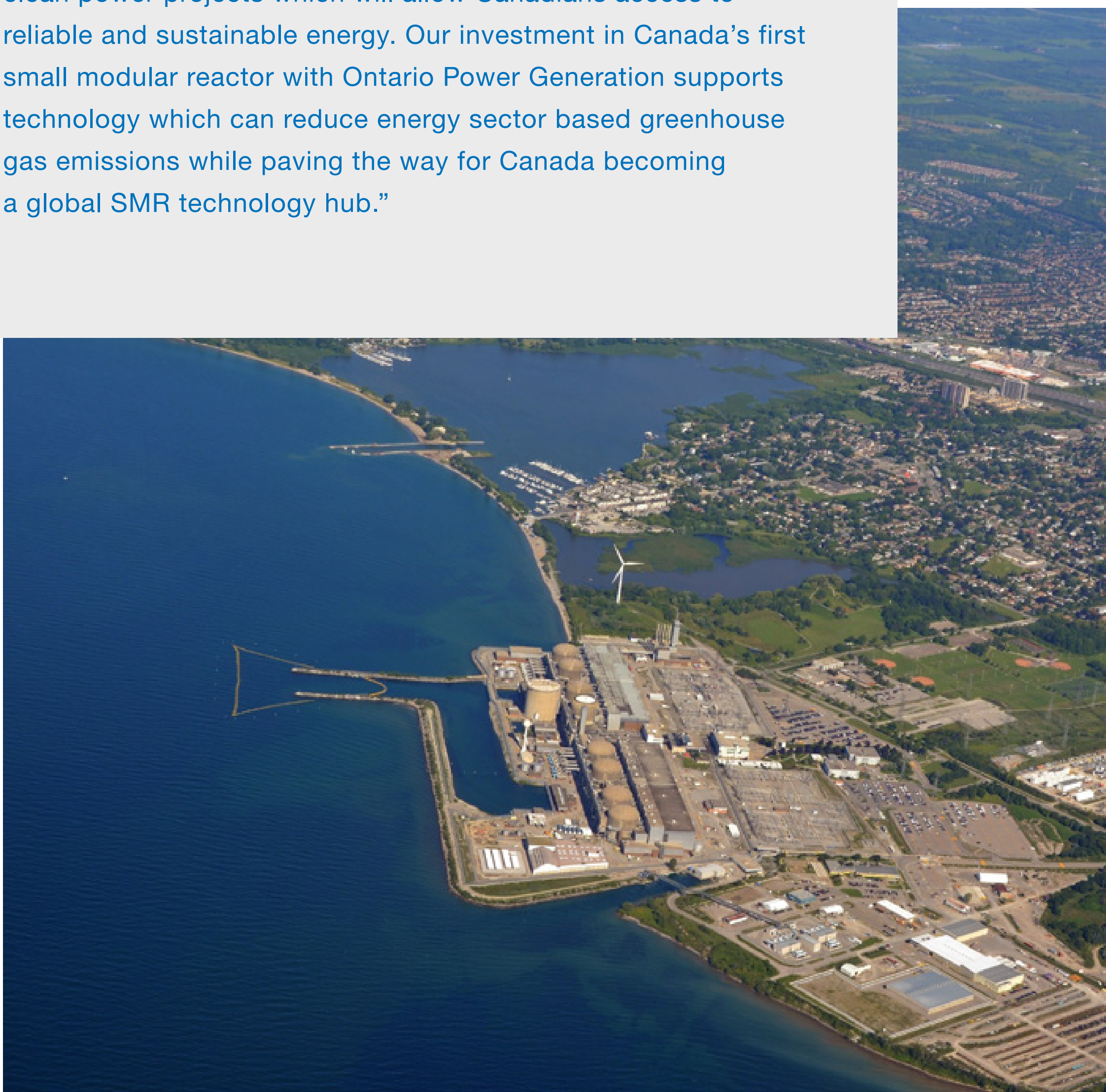
Oil and gas industry explores nuclear energy opportunities

International and national oil companies see nuclear energy as a means to enhance energy security and contribute to job creation. These partnerships offer access to new markets and revenue streams, leveraging the financial resources and project management expertise of oil and gas firms. Examples include TotalEnergies joint involvement with GDF Suez, Areva and EDF in an unsuccessful bid to build nuclear reactors in Abu Dhabi, UAE [129], more recent interest from the same company for long term power purchase agreements for nuclear power [130] and ExxonMobil's commitment to achieving net zero emissions by 2050, emphasizing the potential role of small reactors to electrify processes [131]. Smaller energy companies like Viaro Energy and newcleo are also exploring partnerships to decarbonize oil and gas infrastructure using nuclear technology [132]. In the Russian Federation, discussions on the construction of SMRs are underway between Rosatom and potential commercial partners, including the country's largest oil and gas companies [133].

Finally, SMRs could be deployed alongside large reactors to provide baseload electricity in large, well interconnected power systems. In such markets, however, SMRs do not offer a significant advantage over larger nuclear reactors, and their deployment would generally make economic sense only if they reach a comparable or lower electricity generation cost. However, for a country with a growing demand, building a series of smaller reactors instead of a single large unit could provide a different approach to matching demand growth or available financial resources. Target revenues for SMRs may differ from large reactors due to the markets they could serve. For example, a market may be more willing to earn a lower rate of return if they face a shortage of available land, or consistent sun or wind.

SASHEN GUNERATNA
Managing Director, Canada Infrastructure Bank

"As an impact investor, the Canada Infrastructure Bank enables clean power projects which will allow Canadians access to reliable and sustainable energy. Our investment in Canada's first small modular reactor with Ontario Power Generation supports technology which can reduce energy sector based greenhouse gas emissions while paving the way for Canada becoming a global SMR technology hub."



Pickering nuclear power plant, Canada.

BOX 17

Achieving cost-effective SMRs: the path from FOAK to NOAK

To achieve the desired cost reductions and widespread adoption of SMRs, the industry must focus on achieving NOAK deployments. This concept entails moving beyond the FOAK projects, which are often characterized by higher costs and longer lead times due to regulatory uncertainties, design iterations and lack of experience in construction. NOAK deployments leverage standardized designs, streamlined regulatory processes and serial production to drive down costs and increase predictability. This approach requires collaboration among industry stakeholders, regulators and policy makers to establish a conducive environment for SMR commercialization.

As SMR designs progress from FOAK to NOAK, factors such as establishing a resilient supply chain for fuel manufacturing, navigating complex regulatory processes and attracting financing become increasingly important. The traditional nuclear energy supply chain must be rethought to produce cost-effective SMRs predicated on factory fabrication. Close collaboration among industry stakeholders, regulators and policy makers is essential to create a favorable regulatory environment for novel SMR designs. This collaboration may involve clarifying regulatory requirements, ensuring regulatory certainty and expediting licensing processes, where possible. The IAEA's Nuclear Harmonization and Standardization Initiative (NHSI) supports these efforts with the objective of streamlining regulatory and industrial processes [134].

The NHSI's Regulatory Track focuses on harmonizing safety standards and licensing processes among national regulatory bodies, reducing duplication of efforts and accelerating SMR project approvals. The Industry Track aims to establish standardized approaches for SMR design, manufacturing and construction, lowering costs and shortening deployment timelines [134]. By creating a more predictable and unified regulatory environment, the NHSI can make SMR projects more attractive to investors.

Financing demonstration projects and FOAK projects requires exploring avenues such as public–private partnerships, which can facilitate the sharing of risks and mobilize resources for early stage development. The NHSI's efforts to standardize and harmonize processes could reduce financial risks associated with SMR development, potentially leading to increased funding and investment in SMR technology. This initiative is a crucial step towards achieving global climate goals and enhancing energy security through the use of advanced nuclear technologies.

Policy measures like loan guarantees, tax incentives and research grants further incentivize private investment in SMR demonstration projects, which fosters accelerated commercialization and paves the way for more affordable SMR options in the future. For example, the UK launched Great British Nuclear, which will address barriers to entry such as pursuing a flexible approach to siting and launching a consultation on how to make regulation more efficient [135].

The economies of scale that typically drive down costs in large reactors may not be as pronounced in SMRs, at least in the early stages of deployment. Achieving cost competitiveness with other energy sources, particularly renewables, is critical for garnering investor interest and securing financing.

BOX 18: CONTRIBUTION FROM US NET ZERO WORLD INITIATIVE

Financing of US reactor projects

Recent US administrations have supported advanced nuclear reactor technology development through recent or ongoing funding of a wide range of demonstrations and test platforms by various government agencies:

- The Kilopower Reactor Using Stirling Technology (KRUSTY) was developed by Los Alamos National Laboratory under a NASA funded project as a prototype of a 5-kilowatt thermal (kW_{th}) space reactor [136]. It was assembled within 3 years for a cost of less than US $20 million and completed successful testing in 2018 [137].
- Under the Strategic Capabilities Office (SCO) initiative Project Pele, the Department of Defense granted a contract to BWXT in 2022 to complete the engineering design and construction of a portable 1-5 MW_e nuclear microreactor [138]. The prototype reactor is expected to be shipped to Idaho National Laboratory (INL) for initial testing in 2025 [139].
- As part of the Department of Energy (DOE) Microreactor Program, INL is leading the development of a 85 kW_{th} nuclear microreactor applications test bed (MARVEL). The reactor operation is expected by 2027 [140].

The US government provides financial support to US reactor vendors to demonstrate different advanced reactor concepts through the DOE Advanced Reactor Demonstration Program (ARDP). Initial funding of US $160 million was appropriated in the Office of Nuclear Energy budget in fiscal years 2020 and 2021. The 2022 Bipartisan Infrastructure Law moved the two demonstration projects to the Office of Clean Energy Demonstrations and provided the largest batch of federal funding to date, with approximately US $2.5 billion committed through fiscal year 2025 for the ARDP demonstration projects.

The projects will permit the demonstration of advanced reactors designed by X-energy and TerraPower by the end of the decade. Each company is responsible for at least 50% of the cost of the demonstration reactor through non-federal funding (private equity, loans, potential supplemental state funding). TerraPower's Natrium Reactor is a single-unit sodium-cooled fast reactor technology with a net capacity of 345 MW_e and will be built in Kemmerer, Wyoming, near the retiring Naughton coal plant [141]. The expected total cost and DOE contribution for Natrium is US $4 billion and US $2 billion, respectively [142]. X-energy is partnering with Dow (one of the largest chemical producers in the world) to build four high temperature gas-cooled reactor units of 80 MW_e Xe-100 at one of Dow's US Gulf Coast sites near Seadrift, Texas [143]. The expected total cost and DOE contribution for the Xe-100 project are US $2.46 billion and US $1.23 billion, respectively [142].

An additional five risk reduction projects were funded through ARDP and three Advanced Reactor Concepts awards were funded through the Advanced Reactor Technology program, with a minimum of 20% cost-share required from private sector funding. In particular, Kairos Power received a $303 million ARDP award over a span of seven years to build a 35 MW thermal fluoride-salt high temperature reactor called Hermes in Oak Ridge, Tennessee. The NRC approved its construction permit in 2023 [144].

DOE-NE has also provided financial support for the Carbon Free Power Project (CFPP), a FOAK commercial demonstration of the NuScale SMR technology. Unfortunately, despite significant efforts by both parties, on 8 November 2023, Utah Associated Municipal Power Systems and NuScale mutually decided to terminate the CFPP owing to challenges with receiving the necessary subscriber support to continue toward deployment. However, the work accomplished to date on CFPP will be valuable for future nuclear energy projects. Through this work, the project partners were able to complete a thoroughly vetted cost estimate and project schedule that reflect the pricing of nuclear in today's economy in the USA and the schedule challenges present due to supply shortages. Further, the licensing actions achieved to date paved the way for the broader nuclear industry to implement unique advancements of SMRs, including the following:

- The right-sizing of emergency planning zones, which can facilitate pairing nuclear energy technology with other clean energy sources;
- The use of dry cooling technologies to support flexible siting of nuclear reactors where they will be no longer be tied to large sources of water; and
- The ability to use a nuclear power plant to help start a power grid after grid disruption.

A 'lesson learned' document for the CFPP is in development and will be made available upon completion.

Diablo Canyon nuclear power plant, USA.

4.3. SMR Financing Considerations and Challenges

Once SMRs reach technical maturity and are commercially proven through successful deployment on an industrial scale, that is to say, Nth-of-a-kind, the following characteristics could be attractive for investors and lenders, potentially easing the financing process and leading to a lower cost of capital compared to traditional large reactors:

- **LOWER INITIAL CAPITAL COST:** The lower aggregate cost of an SMR would make it easier to raise the required smaller amount of capital from different sources. The reduced capital requirements could also ease balance sheet funding from the project owners, which would benefit from a more limited impact on their credit ratings.
- **REDUCED DELIVERY TIME AND CONSTRUCTION RISK:** The modular design and reliance on factory fabrication is expected both to reduce the construction duration (to 3–5 years compared with the 5–10 years for a large plant) and to provide more certainty on delivery time and construction costs. A shorter construction period lowers the amount of interest accrued during construction, the equity hold period for investors and allows a reduction in the time before revenue generation. More importantly, reducing the uncertainty on project delivery and cost, if proven, would contribute to reducing the construction risk, and thus the financial costs, compared with large reactors.
- **COST RECOVERY AND REVENUE GENERATION:** The ability to diversify revenue streams across different products (sale of electricity, heat and other by-products) could enhance the economy of the project and reduce revenue risk for investors.

While these characteristics can help to reduce or manage some of the intrinsic and common level risks of nuclear energy (see Fig. 6), potentially reducing financing costs, SMRs will still face additional risks compared with non-nuclear low carbon energy sources that can significantly influence project viability.

5. Considerations for New Nuclear Programmes in Emerging Markets and Developing Economies

Investing in nuclear power is a complex and capital intensive endeavor, especially for EMDEs. The substantial capital required for new nuclear projects remains tied up for several years until the plant becomes operational and starts generating revenue. However, the potential macroeconomic benefits and the role of nuclear power in meeting clean energy targets make it a compelling option.

Joint investments and financial collaboration across countries are essential to mobilize the necessary capital for nuclear projects. These collaborative efforts can help overcome the significant financial barriers that individual countries might face.

Current policies fall short of the spending needed to meet clean energy targets. For instance, existing policies cover only about two thirds of the investment required to triple installed renewable capacity by 2030. EMDEs, in particular, need substantial annual investments to bridge this gap and achieve their energy goals.

5.1. Considerations for Nuclear in EMDEs

Several challenges hinder financing for energy transition projects in EMDEs:

- **HIGH CAPITAL COSTS:** Clean energy projects, including efforts to shut down existing coal-fired power plants, face high capital costs.
- **EXTERNAL FINANCING:** Often necessary due to inadequate domestic savings, low liquidity and limited fundraising capabilities.
- **PUBLIC BUDGET CONSTRAINTS:** Long term financing conditions are strained by public budget limitations.
- **RISKY DEBT CONDITIONS:** High financing costs due to weak sovereign credit ratings, lack of long term loans and other structural economic weaknesses.
- **LACK OF PRIVATE INVESTMENTS:** Insufficient private investments and guarantees from multilateral development banks to allow for such investments.

Itaipu Dam located between Brazil and Paraguay.

Despite these challenges, there are significant regional opportunities. Nuclear power offers a viable solution for countries seeking to meet their increasing energy needs with clean, reliable baseload electricity. However, introducing nuclear power involves several challenges, including technical complexity, high capital requirements and strict safety standards. Successful project implementation will be facilitated by the following considerations:

- **CAPITAL INVESTMENT:** Availability of substantial upfront financing to limit strain on fiscal resources.
- **PROJECT LEAD TIMES:** Adherence to construction timelines for realization of benefits and returns on investment.
- **HUMAN CAPITAL:** Development of a highly skilled workforce to safely and efficiently operate the nuclear power plant (NPP).
- **REGULATORY FRAMEWORK:** Establishment of stringent safety regulations and robust non-proliferation measures for civil nuclear power generation.
- **NUCLEAR WASTE MANAGEMENT:** Development of a long term plan for safe and secure nuclear waste management.
- **GRID AND OTHER PHYSICAL INFRASTRUCTURE:** Significant upgrades of the existing electricity grid to accommodate the NPP's substantial capacity. Enhancement of other physical infrastructure at the site and in its surroundings, including roads and ports.
- **LOCAL PARTICIPATION:** Upgrade of national industrial capabilities to permit the supply of various products and services demanded by the project.

While the path to financing nuclear power in EMDEs is fraught with challenges, the potential benefits make it a worthwhile pursuit. With the right investments and collaborative efforts, nuclear power can play a crucial role in meeting the world's growing energy demands and achieving clean energy targets.

5.2. Funding Infrastructure Development

Apart from financial considerations for NPP construction in embarking countries, it is especially important for governments in embarking EMDEs to make certain that funding for nuclear infrastructure development is ensured (more information on government backing is provided in Section 3.1.1). While project developers are responsible for the mitigation of construction risks, embarking countries should note that successful nuclear power programme implementation requires substantial involvement of the government and required resources.

Some of the basic elements of nuclear infrastructure in embarking EMDEs include the following:

- **LEGAL AND REGULATORY FRAMEWORK:** National legislation should cover all aspects of the programme, taking into consideration existing legal practices, adherence to relevant international instruments, current economic situation and other national circumstances. Commitment and involvement of national authorities is required for the successful integration of a comprehensive nuclear law into a national legal system.
- **HUMAN RESOURCE DEVELOPMENT:** National capabilities in specific knowledge and skills need to be developed and preserved in the embarking country. A sustainable workforce is critical for the safe and secure operation of an NPP as well as for the performance of regulatory functions by a competent authority throughout the lifecycle of a nuclear facility.
- **STAKEHOLDER ENGAGEMENT:** Consistent communication involves transparency and open dialogue among the government, competent authorities, operator, media, interested institutions and individuals, as well as the general public. Information and educational activities can help to build knowledge and an understanding of nuclear technology, based on a foundation of transparency and trust. This communication can be developed as part of a strategy that reflects specific cultural contexts.

5.3. Access and Cost of Financing

The financing hurdle new NPP projects worldwide face due to their high upfront capital costs is leading countries to consider innovative financing solutions in project delivery. The solutions include government support and loan guarantees, such as in NPP projects in China and India to lessen lender risk and incentivize investment; green loan facilities, such as in the refinancing of the Barakah NPP in the United Arab Emirates; public–private partnerships that spread the financial requirements across public and private capital; international collaboration with established nuclear countries in co-financing NPP projects; and long term power purchase agreements guaranteeing revenue for the NPP operator such as at the Akkuyu NPP in Türkiye. Notably, these solutions require a clear and long term government commitment to the nuclear power programme and NPP project to reduce perceived risks and increase investor confidence. Government support may also aid in attracting financing from lenders, including regional development banks such as the Asian Development Bank, African Development Bank and Development Bank of Latin America and the Caribbean, which have historically not financed NPP projects.

Additionally, multilateral development banks could potentially provide not only financial support — particularly in embarking countries with less mature financial markets and limited public resources — but also expertise and oversight, potentially supporting adherence to construction deadlines and safety standards. For example, the World Bank provides fiscal policy, investment climate and green growth development policy loans, which act as a mechanism to enhance legal frameworks and strengthen electricity sector regulation. This type of loan could work in tandem with the IAEA Milestones Approach, setting best practices for energy development alongside the technical cooperation support the IAEA already provides to its Member States.

Access to nuclear energy financing remains a significant challenge for many EMDEs, despite developing countries' vast and unmet energy needs. The imbalance between the growing energy demand and clean energy investment presents a critical challenge; while Africa accounts for almost one fifth of the world's population, it attracts less than 5% of global energy investment [68]. Consequently, limited energy investments impede the ability of many EMDEs to bridge the increasing electricity demand and the energy poverty gap through viable pathways including nuclear energy. The dominance of variable renewable energy alongside the impacts of climate change, losses related to transmission and distribution of electricity, ageing power plants, and disproportionately high tariffs, explain why several EMDEs have expensive electricity costs [145]. The extensive upfront capital costs and relatively long construction timelines associated with nuclear power projects exacerbate the perception of investment risks. To bridge these gaps, addressing political risks, lowering the cost of capital (multilateral development banks and other investors providing loan guarantees, etc.), enhancing capacity building to facilitate robust policy maker frameworks in EMDEs in order to reduce the risk associated with nuclear projects (set clear policy guidelines, collaborate with other countries to create regulatory bodies for nuclear, etc.) is critical as this will enhance more clean energy financing in EMDEs [146].

As one example to bridge these gaps, Africa could leverage Article 6 of the Paris Agreement financing opportunities, as demonstrated by prior successful agreements between Switzerland and Ghana, Morocco and Senegal [147]. Initiatives such as the Africa Carbon Markets Initiative launched at COP27 with the goal of substantially expanding Africa's participation in VCMs present another example [148]. These viable clean energy financing pathways in lower income EMDEs should be explored, bearing in mind the need for equitable distribution efforts and energy diversification, given that clean energy investments in Africa remain concentrated in a handful of markets [149]. The new collective quantified goal on climate finance (NCQG), which takes into consideration the growing need and priorities of EMDEs, discusses the possibility of increasing the financing goal for EMDEs to over US $6 trillion at COP29 to ensure that vulnerable economies implement their climate action (see Section 1.2) [150].

Alternatively, Africa's pension funds, which amounted to over US $300 billion in 2019 and are projected to grow [147], present an unexplored source of clean energy financing. Utilizing untapped financing sources, governments could directly serve as a guarantor for loans, de-risk energy investments, and foster public–private partnerships. Multilateral and development financial institutions such as the World Bank, International Finance Corporation and African Development Bank can also provide crucial support through financing and by providing risk guarantees to encourage investment [151]. Blended financing solutions combining public and private sector sources could help to fill the clean energy financing gap.

Collaboration with nuclear countries, particularly in the utilization of uranium deposits, presents further opportunities for both financing and nuclear technology transfer. Africa could also utilize the presence of uranium deposits to collaborate with developed countries in exchange for assistance in building nuclear power plants given that uranium demand will increase and new mines will be needed. For all these considerations to take place, enabling factors such as reskilling the workforce to enhance the technical, economic and policy needs would allow a more robust data system on the amount of private capital endowments and make it easier for providers to analyse investments. Therefore, addressing the cost and financing challenges of clean energy transition in

EMDEs requires multifaceted approaches that include policy reforms, innovative financing approaches and domestic–international partnerships. By fostering a conducive investment environment, embarking EMDEs can accelerate their nuclear energy transitions and attain Sustainable Development Goals.

BOX 19: CONTRIBUTION FROM NUCLEAR POWER & ENERGY AGENCY OF KENYA

Policy and financing considerations for new nuclear projects in Kenya

Kenya aims to diversify its energy portfolio with reliable and sustainable sources such as nuclear power. The national long term energy master plan, Least Cost Power Development Plan (LCPDP), considers nuclear power as part of the energy mix and it indicates deployment of nuclear power in 2034 with a choice for SMR technology due to the size of the grid, currently with installed capacity of 3244 MW.

Kenya has conducted technical review studies on various financing models for nuclear power plants. The most feasible financing options are vendor equity and public–private partnerships. The vendor equity arrangements offer various benefits such as access to capital, risk sharing, and enhanced collaboration, but they entail potential drawbacks such as dilution of ownership, valuation challenges, and conflicts of interest. The public–private partnership option offers the country potential for more efficient and innovative delivery of public services and infrastructure. However, it also comes with risks and challenges that the country has to put up a mitigation management plan.

To this end, Kenya has evaluated the pros and cons of the aforementioned options and is seeking professional advice to ensure that the arrangement aligns with its strategic objectives and mitigates potential risks.

By combining these financing options, Kenya seeks to mobilize the necessary resources and expertise to advance its nuclear power programme in a sustainable manner. Additionally, Kenya will engage stakeholders, conduct thorough feasibility studies and adhere to stringent safety and regulatory standards throughout the project.

BOX 20: CONTRIBUTION FROM THE PERMANENT MISSION OF BANGLADESH TO THE UNITED NATIONS

Bangladesh's nuclear–renewable energy blend to achieve climate goals

At COP28, Bangladesh acknowledged the urgent need for deep and rapid cuts in greenhouse gas emissions to achieve the 1.5°C target established in the Paris Agreement. The decision recognized nuclear power alongside renewables for the first time, signifying a growing consensus on the importance of a diverse clean energy portfolio to achieve ambitious climate goals.

Bangladesh is actively transitioning towards cleaner energy sources. With two nuclear power reactors (2x1200 MW_e) under construction and a goal of 10% nuclear and 30% renewable energy by 2041, the nation seeks to reduce dependence on fossil fuels.

To triple the share of global renewable energy capacity and double the rate of energy efficiency by 2030, nuclear power can play a crucial role alongside renewables. Nuclear reactors provide a reliable, baseload source of clean energy, complementing the variable nature of solar and wind power. Moreover, next-generation reactors are expected to improve thermal efficiency and cogeneration capabilities, where waste heat could be used for additional energy production. By integrating nuclear power with a robust renewable energy mix, Bangladesh could achieve a more stable and sustainable low carbon energy grid.

SMRs could offer developing countries new opportunities. These could be more economical and safer and offer a replacement for retired medium-sized coal or gas based plants. It could also open up the option for public–private partnerships. However, the operational competitiveness of SMRs must be thoroughly evaluated before investing in FOAK initiatives. Bangladesh will benefit from cutting-edge nuclear technologies to combat climate change and reduce carbon footprints while achieving socioeconomic benefits.

Ruppur nuclear power plant, Bangladesh.

BOX 21: CONTRIBUTION FROM GHANA ATOMIC ENERGY COMMISSION

Nuclear power deployment in Ghana: policy considerations and financing options

Ghana's ambition for rapid economic growth has been the focus of successive governments. The Long Term National Development Plan recognizes a reliable and sustainable supply of electricity as a key enabler for meeting set targets. Nuclear energy is considered one of the major energy sources to provide the required secure, reliable and sustainable electricity supply [152].

The quest for nuclear energy deployment is driven by several factors. Key among these drivers are Ghana's long term vision to be ranked among upper-middle or high income countries in the world by 2057 [153], the projected increase in Ghana's electricity demand to 41 192 GW·h by 2040 (approximately 65% increase from current demand) due to population growth and industrialization [154], the variability of hydropower and renewable output [154], the price volatility of fossil fuels [155], and a desire to diversify power generation sources to avoid overreliance on any one technology.

In relation to financing, the Ghana Nuclear Power Planning Organisation has conducted extensive work to analyse how a nuclear power project can be financed in the Ghanaian context. Various models suggested by experts and financing options previously used in other countries were considered and thoroughly analysed. These include Government financing through counter-trade arrangements, vendor financing, joint venture utility models, international financing (capital and money markets), investor finance or cooperative model and financing through consortia [156–161].

Accra, Ghana.

BOX 22:

Building nuclear in embarking countries

The IAEA's Milestones Approach enables a sound development process for a nuclear power programme. It is a phased comprehensive method that splits the activities necessary to establish the infrastructure for a nuclear power programme into three progressive phases of development, with the duration of each dependent on the degree of commitment and resources applied in the country. The completion of each phase is marked by a specific Milestone, at which progress can be assessed and a decision can be made about the readiness to move on to the next phase. The Milestones Approach includes 19 nuclear infrastructure issues, requiring specific actions during each of the three phases. The IAEA, through its Nuclear Infrastructure Development Section, coordinates comprehensive support across the 19 infrastructure issues for Member States embarking on new nuclear power programmes.

To effectively build a nuclear energy programme will require funding and availability of a diverse nuclear energy workforce that is suitably qualified and experienced. This workforce will be needed to not only support institutions that perform regulatory and safety roles but will also be required to support operating facilities while simultaneously building the skillsets needed for the next generation of reactors. The IAEA supports Member States in their application of nuclear knowledge management and human resource development strategies and approaches through the development and dissemination of IAEA methodology, guidance and tools. The IAEA offers a range of services, including peer reviews and expert missions, to Member States to mitigate the risk of losing critical nuclear knowledge and to strengthen and enhance university education in nuclear technology management, nuclear engineering and nuclear science and its applications. As part of capacity building efforts, the IAEA offers Nuclear Knowledge Management Schools and Nuclear Energy Management Schools, and facilitates knowledge sharing through regional education networks.

6. Recommendations and Conclusions

- Nuclear energy can be a significant contributor to low carbon transitions, offering a scalable, climate resilient, dispatchable source of low carbon electricity and heat while supporting affordability and contributing significantly to energy security. Nuclear energy has the potential to expand into many markets with the development of SMRs, including in new applications delivering clean heat and electricity to the industrial sector.
- To support ambitious climate change goals, investments in nuclear power, for both nuclear new build and long term operation of existing reactors, must be significantly scaled up from current levels to around US $125 billion annually. Mobilizing this scale of investment requires a combination of financing and risk management approaches. While government backing is necessary for nuclear power projects, there are opportunities for financing to be shared and even driven by private sector investors and energy users. Investment and multilateral development banks can help to facilitate private sector involvement with tools such as grants, loan guarantees and insurance coverage. Multilateral development bank involvement can be particularly beneficial in EMDEs which often face additional challenges in attracting affordable financing.
- Since 2021, there has been an increase in private sector financing of nuclear energy projects, mainly to extend the operating lifetimes of existing power plants or refinance construction, using financial tools such as green bonds and offtake agreements. While these developments have been critical for building confidence in the finance sector and in ensuring that existing plants continue delivering low carbon electricity, realizing the potential of nuclear energy to support global 2050 climate goals will likely need private financial sector engagement on a much larger scale across the entire nuclear energy project lifecycle.
- Against this backdrop, the nuclear energy sector stands at a pivotal crossroads. With the need to ramp up investments in nuclear power projects to meet both climate objectives and growing energy needs, the industry faces a critical challenge in many markets: bolstering investor confidence to secure the capital needed for these ambitious projects, first in the operational phase and ultimately during construction. Options such as shared ownership models could be key to securing private sector engagement, since they can distribute project risk and cost while offering a more efficient utilization of capital and expertise. As nuclear projects re-establish a proven track record of financial performance, it may become increasingly possible to attract private sector financing even during construction, the highest risk project phase.

- With technological, financial and regulatory risks posing the largest challenge to perceived bankability by potential investors in nuclear energy projects, risk migitation — achieving construction and cost predictability — is arguably more important than overall project cost. In particular, with construction and investment costs accounting for nearly two thirds of generation cost, it is crucial for both vendors and project owners to demonstrate that projects can be delivered on time and on budget. This predictability can serve to reduce perceived risk by investors and ultimately lower the cost of capital for successive nuclear projects.
- Mitigating technological risks, including potential delays in deploying new reactor technologies, requires robust investments in project development and international collaboration. Financial risks, such as funding shortfalls, can be addressed through diversified financing models, including public–private partnerships and green bonds. Regulatory risks require proactive engagement with policy makers to streamline approval processes and ensure compliance with international safety standards.
- This publication establishes a roadmap for reaching time and cost predictability in nuclear energy projects, as observed in historical nuclear programmes. Accurate estimation of delivery time and cost is vital to deploying the necessary resources to complete construction on time and on budget. The commitment of a host country (or countries working in tandem) and/or private sector actors like industrial manufacturers or large technology companies to deploy multiple reactors of the same design (whether it be large reactors or SMRs) can turn FOAK challenges — such as building or rebuilding supply chains, developing the required workforce and engaging with regulators — into an opportunity to invest in lowering the cost of future projects.
- Thanks to their lower overall upfront cost compared with large reactors and their ability to potentially meet distinct and unique market needs, SMRs have the potential to attract a different, and new, set of investors, such as industrial energy users and investment banks. A wider array of potential financers can help to facilitate SMR deployment in new markets, including for EMDEs. SMRs could also be attractive to regions or countries wishing to include nuclear in their clean energy transitions without the need to significantly build up a complete domestic supply chain with the necessary trained workforce and infrastructure required for large reactors.

REFERENCES

[1] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, Geneva, Switzerland (2003), https://www.doi.org/10.59327/IPCC/AR6-9789291691647

[2] UNITED NATIONS DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS, The Sustainable Development Goals Report: Special Edition, United Nations, New York, NY (2023), https://unstats.un.org/sdgs/report/2023/

[3] INTERNATIONAL ENERGY AGENCY, CO_2 Emissions from Fuel Combustion Statistics: Greenhouse Gas Emissions from Energy, International Energy Agency, Paris (2024), https://www.doi.org/10.1787/co2-data-en

[4] INTERNATIONAL ENERGY AGENCY, World Energy Outlook 2023, International Energy Agency, Paris (2023), https://doi.org/10.1787/827374a6-en

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Climate Change and Nuclear Power 2022: Securing clean energy for climate resilience (2022), https://www.iaea.org/sites/default/files/iaea-ccnp2022-body-web.pdf

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Energy in Climate Resilient Power Systems, Outlooks, IAEA, Vienna (2023), https://doi.org/10.61092/iaea.47gr-efvv

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Energy for a Net Zero World (2021), https://www.iaea.org/sites/default/files/21/10/nuclear-energy-for-a-net-zero-world.pdf

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Energy and Climate Change: Questions and Answers on Progress, Challenges and Opportunities, Outlooks, IAEA, Vienna (2023), https://doi.org/10.61092/iaea.5q95-dx0f

[9] INTERNATIONAL ENERGY AGENCY, Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach, IEA, Paris (2023), https://www.iea.org/reports.

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Energy, Electricity and Nuclear Power Estimates for the Period up to 2050, Reference Data Series No. 1, IAEA, Vienna (2024), https://www.iaea.org/publications/15756/energy-electricity-and-nuclear-power-estimates-for-the-period-up-to-2050

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Energy in Mitigation Pathways to Net Zero, Outlooks, IAEA, Vienna (2023), https://doi.org/10.61092/iaea.pf2q-c1y0

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Power Reactors in the World, Reference Data Series No. 2, IAEA, Vienna (2024), https://doi.org/10.61092/iaea.e3qb-hsrr

[13] INTERNATIONAL ENERGY AGENCY, World Energy Investment 2024, International Energy Agency, Paris (2024), https://www.iea.org/reports/world-energy-investment-2024

[14] US DEPARTMENT OF ENERGY, At COP28, Countries Launch Declaration to Triple Nuclear Energy Capacity by 2050, Recognizing the Key Role of Nuclear Energy in Reaching Net Zero (2023), https://www.energy.gov/articles/cop28-countries-launch-declaration-triple-nuclear-energy-capacity-2050-recognizing-key

[15] OECD NUCLEAR ENERG AGENCY, Meeting Climate Change Targets: The Role of Nuclear Energy, OECD Publishing, Paris (2024), https://www.oecd-nea.org/jcms/pl_69396/meeting-climate-change-targets-the-role-of-nuclear-energy

[16] OECD NUCLEAR ENERGY AGENCY, Net zero needs nuclear energy: Tripling nuclear energy needs finance, OECD Publishing, Paris (2023), https://www.oecd-nea.org/upload/docs/application/pdf/2023-12/financing.pdf

[17] INTERNATIONAL ENERGY AGENCY, Nuclear Power and Secure Energy Transitions, International Energy Agency, Paris (2022), https://doi.org/10.1787/aca1d7ee-en

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Power Reactor Information System (PRIS) (2023), https://pris.iaea.org/pris

[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Financing Nuclear Power in Evolving Electricity Markets, IAEA, Vienna (2018).

[20] US DEPARTMENT OF ENERGY NATIONAL RENEWABLE ENERGY LABORATORY, Flexible Nuclear Energy for Clean Energy Systems, September 2020, NREL/TP-6A50-77088.

[21] BYERS, E., KREY, V., KRIEGLER, E., RIAHI, K., SCHAEFFER, R., et al., AR6 Scenarios Database hosted by IIASA, International Institute for Applied Systems Analysis, Laxenburg (2022), https://data.ece.iiasa.ac.at/ar6

[22] RIAHI, K., SCHAEFFER, R. et al., "Mitigation pathways compatible with long-term goals" Climate Change 2022: Mitigation of Climate Change, Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge (2022), https://doi.org/10.1017/9781009157926.005

[23] INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS, AR6 Scenario Explorer and Database (2022), https://iiasa.ac.at/models-tools-data/ar6-scenario-explorer-and-database

[24] INTERNATIONAL ENERGY AGENCY, World Energy Balances and Statistics, International Energy Agency, Paris (2023), https://doi.org/10.1787/enestats-data-en

[25] UN FRAMEWORK CONVENTION ON CLIMATE CHANGE, Outcome of the first global stocktake, Decision -/CMA.5, UN Framework Convention on Climate Change, Bonn (2023).

[26] UN FRAMEWORK CONVENTION ON CLIMATE CHANGE, Nationally Determined Contributions Registry, UN Framework Convention on Climate Change, Bonn (2024), www.unfccc.int/NDCREG

[27] UN FRAMEWORK CONVENTION ON CLIMATE CHANGE, Communication of long term strategies. UN Framework Convention on Climate Change (2024), www.unfccc.int/process/the-paris-agreement

[28] THE WHITE HOUSE, Building a Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action (2023), https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf

[29] EUROPEAN COMMISSION, Net-Zero Industry Act, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan/net-zero-industry-act_en

[30] GOVERNMENT OF CANADA, Green Bond Framework, Government of Canada, Ottawa (2023), https://www.canada.ca/content/dam/fin/publications/green-bond/Green%20Bond%20Framework%20Report%20EN%20v02.pdf

[31] HUNT, J., Spring Budget 2023 Speech, Her Majesty's Treasury and The Right Honourable Jeremy Hunt (2023), https://www.gov.uk/government/speeches/spring-budget-2023-speech

[32] ENERGY & CLIMATE INTELLIGENCE UNIT, Net Zero Scorecard, Energy & Climate Intelligence Unit, London (2024), https://eciu.net/netzerotracker

[33] STIELL, S., From Vision to Reality, Getting the Job Done: Executive Secretary Speech (2024), https://unfccc.int/news/from-vision-to-reality-getting-the-job-done-executive-secretary-speech

[34] FINANCIAL TIMES, UN COP29 host says his country is suffering from climate change, 9 March 2024, https://www.ft.com/content/3116e340-8b59-44cd-b394-16391aa1a44a

[35] FINANCIAL TIMES, Climate finance must be COP29 summit priority, UN leaders says, 14 March 2024, https://www.ft.com/content/2c0ccb47-fdad-43b9-997e-37ef08675591

[36] UN FRAMEWORK CONVENTION ON CLIMATE CHANGE, New Collective Quantified Goal on Climate Finance, UN Framework Convention on Climate Change, Bonn (2024), https://unfccc.int/sites/default/files/resource/UNFCCC_NCQG2023_flyer_web.pdf

[37] AL JABER, A., Appointment of Co-Chairs of the ad hoc work programme on the New Collective Quantified Goal on Climate Finance for 2024, Letter issued by President of COP28 UAE, 17 January, Abu Dhabi (2024), https://unfccc.int

[38] AZERBAIJAN STATE NEWS AGENCY, Azerbaijani FM addresses Nuclear Energy Summit, 21 March 2024, https://azertag.az/en/xeber/azerbaijani_fm_addresses_nuclear_energy_summit-2954239

[39] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessing National Economic Effects of Nuclear Programmes, IAEA Technical Document, IAEA, Vienna (2021).

[40] US DEPARTMENT OF ENERGY NATIONAL RENEWABLE ENERGY LABORATORY, Nuclear Energy – Providing Power, Building Economies, April 2022, https://www.nrel.gov/docs/fy22osti/82419.pdf

[41] NUCLEAR ENGINEERING INTERNATIONAL, Flamanville 3 ready to start commissioning, 2 April 2024, https://www.neimagazine.com/news/flamanville-3-ready-to-start-commissioning-11649648/

[42] EDF, Update on the Flamanville EPR, EDF France Press release (2022), https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/update-on-the-flamanville-epr-0

[43] EURONEWS, Finland's new nuclear reactor: what does it mean for climate goals and energy security?, 17 April 2024, https://www.euronews.com/green/2023/04/17/finlands-new-nuclear-reactor-what-does-it-mean-for-climate-goals-and-energy-security

[44] INSTITUTE FOR ENERGY ECONOMICS AND FINANCIAL ANALYSIS, Southern Company's Trouble Vogtle Nuclear Project (2022), https://ieefa.org/wp-content/uploads/2022/01/Southern-Companys-Troubled-Vogtle-Nuclear-Project_January-2022.pdf

[45] KOREA HYDRO & NUCLEAR POWER, Financial Info: Past Data, KHNP (2024), https://www.khnp.co.kr/eng/contents.do?key=467

[46] CONCA, J., China shows how to build nuclear reactors fast and cheap, Forbes, 22 October 2015, https://www.forbes.com/sites/jamesconca/2015/10/22/china-shows-how-to-build-nuclear-reactors-fast-and-cheap

[47] DAY, P., Finding a workforce may be nuclear's largest challenge, Reuters, 3 October 2022, https://www.reuters.com/business/energy/finding-workforce-may-be-nuclears-largest-challenge-2022-10-03

[48] EDF, Hinkley Point C Update, EDF France Press release, 23 January 2024, https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/hinkley-point-c-update-1

[49] GOVERNMENT OF THE UNITED KINGDOM, Cost Estimatnig Guidance: A best practice approach for infrastructure projects and programmes, Infrastructure and Projects Authority (2021), https://assets.publishing.service.gov.uk/media/6050c9528fa8f55d324b0c84/IPA_Cost_Estimating_Guidance.pdf

[50] INSTITUTE FOR ENERGY ECONOMICS AND FINANCIAL ANALYSIS, A half-built, high-priced nuclear white elephant, 1 October 2017, https://ieefa.org/resources

[51] ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, Arrangement on Officially Supported Export Credits, 17 July 2023, https://one.oecd.org/document/TAD/PG(2023)7/en/pdf

[52] EUROPEAN UNION, Commission Decision of 25 September 2007 on measure C 45/06 (ex NN 62/A/06) implemented by France in connection with the construction by AREVA NP of a nuclear power station for Teollisuuden Voima Oy, Official Journal of the European Union, 2008/281/EC, 1 April 2008, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32008D0281

[53] EMIRATES NUCLEAR ENERGY CORPORATION, ENEC and KEPCO Announce Financial Close for Barakah Nuclear Energy Plant, Press release, 20 October 2016, https://www.enec.gov.ae/news/latest-news/enec-and-kepco-announce-financial-close-for-barakah-nuclear-energy-plant/

[54] NIPPON EXPORT AND INVESTMENT INSURANCE, Guidelines for Information Disclosure Considerations for Nuclear Sector Projects in Trade Insurance, 21 December 2017, https://www.nexi.go.jp/en/environment/pdf/ins_kankyou_gl-f.pdf

[55] IBNI, Initial Report and Action Plan, International Bank for Nuclear Infrastructure - Implementation Organization Strategic Advisory Group (2021), www.nuclearbank-io-sag.org

[56] IBNI, Briefing Note on IBNI Cooperation with Existing International Financing Institutions, International Bank for Nuclear Infrastructure - Implementation Organization Strategic Advisory Group (2023), www.nuclearbank-io-sag.org

[57] MATTHEW, C., WALKER, A., Nuclear energy in the UK, POSTnote 687, UK Parliament (2022), https://researchbriefings.files.parliament.uk/documents/POST-PN-0687/POST-PN-0687.pdf

[58] OFGEM, Electricity prices: day ahead baseload contracts – monthly average (GB), Wholesale market indicators (2024), https://www.ofgem.gov.uk/energy-data-and-research/data-portal/wholesale-market-indicators

[59] EUROPEAN COUNCIL, Reform of electricity market design: Council and Parliament reach deal, 14 December 2023, https://www.consilium.europa.eu/en/press/press-releases/2023/12/14/reform-of-electricity-market-design-council-and-parliament-reach-deal

[60] EUROPEAN COMMISSION, Commission approves State aid to support construction of nuclear power plant in Czechia, 30 April 2024, https://ec.europa.eu/commission/presscorner/detail/en/ip_24_2366

[61] UK LEGISLATION, Nuclear Energy (Financing) Act 2022, UK Public General Acts (2022), https://www.legislation.gov.uk/ukpga/2022/15/contents

[62] GOVERNMENT OF THE UNITED KINGDOM, Future funding for nuclear plants, Department for Business, Energy & Industrial Strategy, 26 October 2021, https://www.gov.uk/government/news/future-funding-for-nuclear-plants

[63] OECD NUCLEAR ENERGY AGENCY, Nuclear New Build: Insights into Financing and Project Management, OECD Publishing, Paris (2015), https://doi.org/10.1787/9789264241749-en

[64] SAWICI, Ł., HORBACZEWSKA, B., Role of the state in implementation of strategic investment projects: The SaHo Model for nuclear power, International Journal of Management and Economics, Vol. 57, Issue no. 4, (2021) pp.343-359. https://doi.org/10.2478/ijme-2021-0020

[65] EDF, Universal Registration Document 2023: Including the Annual Financial Report (2023), https://www.edf.fr/sites/groupe/files/2024-04/edf-urd-annual-financial-report-2023-en-updated-2024-04-11.pdf

[66] Smith, B., Microsoft will be carbon negative by 2030, Official Microsoft Blog, 16 January 2020, https://blogs.microsoft.com/blog/2020/01/16/microsoft-will-be-carbon-negative-by-2030

[67] GOOGLE SUSTAINABILITY, Operating on 24/7 Carbon-Free Energy by 2030, Carbon-Free Energy (2023), https://sustainability.google/progress/energy/#:~:text=We've%20been%20working%20hard,energy%2C%20on%20an%20annual%20basis

[68] INTERNATIONAL ENERGY AGENCY, Electricity 2024, IEA, Paris (2024) https://www.iea.org/reports/electricity-2024

[69] MONIZ, E.J., HEZIR, J.S., COMELLO, S.D., BROWN, J.D., A Cost Stabilization Facility for Kickstarting the Commercialization of Small Modular Reactors, EFI FOUNDATION (2023), https://efifoundation.org/wp-content/uploads/sites/3/2023/10/20231011-CSF-FINAL-1.pdf

[70] ING Bank N.V., Sustainable Finance Pulse, Issue 1, 2024, https://www.ingwb.com/binaries/content/assets/insights/themes/sustainable-finance/ing-sustainable-finance-pulse---issue-1.pdf

[71] ROSATOM NEWSLETTER, #273 Nuclear Needs Finance, January 2024, https://rosatomnewsletter.com/2024/01/27/nuclear-needs-finance/

[72] EDF, EDF and Credit Agricole CIB sign a financing agreement dedicated to the maintenance of French nuclear power plants, Press release, 18 November 2022, https://www.edf.fr/sites/groupe/files/epresspack/4003/PR_EDF-and-Credit-Agricole-CIB-sign-a-financing-agreement.pdf

[73] EDF, EDF announces the signature of green bank loans dedicated to the financing of the existing nuclear fleet, for an amount of c. 5.8 billion euros, EDF Press Release, 13 May 2024, https://www.edf.fr/sites/groupe/files/epresspack/7584/PR_New-bank-loans.pdf

[74] ABU DHABI MEDIA OFFICE, Barakah Nuclear Energy Plant receives recognition as first green loan facility in Asia and Africa, and second globally, 12 March 2024, https://www.mediaoffice.abudhabi/en/energy/barakah-nuclear-energy-plant-receives-recognition-as-first-green-loan-facility-in-asia-and-africa-and-second-globally/

[75] COMMISSION DELEGATED REGULATION (EU) 2022/1214, amending Delegated Regulation (EU) 2021/2139 as regards economic activities in certain energy sectors and Delegated Regulation (EU) 2021/2178 as regards specific public disclosures for those economic activities, 9 March 2022, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022R1214

[76] GOVERNMENT OF CANADA, Green Bond Framework, November 2023, https://www.canada.ca/content/dam/fin/publications/green-bond/Green%20Bond%20Framework%20Report%20EN%20v02.pdf

[77] GOVERNMENT OF JAPAN, Japan Climate Transition Bond Framework, November 2023, https://www.mof.go.jp/english/policy/jgbs/topics/JapanClimateTransitionBonds/climate_transition_bond_framework_eng.pdf

[78] ENVIRONMENTAL FINANCE, Sustainable Bonds Insight 2024, https://www.environmental-finance.com/content/downloads/sustainable-bonds-insight-2024.html

[79] S&P GLOBAL RATINGS, Sustainability Insights | Research: Sustainable Bond Issuance to Approach $1 Trillion in 2024, 13 February 2024, https://www.spglobal.com/_assets/documents/ratings/research/101593071.pdf?ref=csofutures.com

[80] INTERNATIONAL CAPITAL MARKET ASSOCIATION, The Green Bond Principles: Voluntary Process Guidelines for Issuing Green Bonds, June 2021 with June 2022 Appendix 1, https://www.icmagroup.org/assets/documents/Sustainable-finance/2022-updates/Green-Bond-Principles-June-2022-060623.pdf

[81] BRUCE POWER L.P., Green Financing Framework, November 2023, https://www.brucepower.com/wp-content/uploads/2023/11/214440A_Green-Financing-Report-2023_R001_AX.pdf

[82] ONTARIO POWER GENERATION INC., Green Bond Framework, November 2021, https://www.opg.com/investor-relations/green-bonds/

[83] TEOLLISUUDEN VOIMA OYJ, Green Bond Framework, 19 April 2023, https://www.tvo.fi/material/collections/20230621093700/HtlXlYQ8h/TVO_-_Green_Bond_Framework.pdf

[84] EDF, Green Financing Framework, 12 July 2022, https://www.edf.fr/sites/groupe/files/2022-07/edf-green-bond-framework-2022-07-12.pdf

[85] STATE DEVELOPMENT CORPORATION VEB.RF, Green Bond Framework, 2023, https://xn--90ab5f.xn--p1ai/en

[86] CONSTELLATION ENERGY CORPORATION, Green Financing Framework, February 2024, https://investors.constellationenergy.com/static-files/b34642b4-c2b8-4dd8-bf55-947672e1633a

[87] THE ECONOMIST, Do green bonds actually reduce carbon emissions?, Article, https://www.economist.com/graphic-detail/2020/09/17/do-green-bonds-actually-reduce-carbon-emissions

[88] J.P. MORGAN ASSET MANAGEMENT, O ‘Greenium’, Where Art Thou? The European green, social and sustainable (GSS) investment grade corporate bond market and a quantitative analysis of its ‘greenium’, 18 January 2024, https://am.jpmorgan.com/us/en/asset-management/adv/insights/portfolio-insights/fixed-income/fixed-income-perspectives/ogreenium-where-art-thou/

[89] REGULATION (EU) 2023/2631 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on European Green Bonds and optional disclosures for bonds marketed as environmentally sustainable and for sustainability-linked bonds, 22 November 2023, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202302631

[90] FRENCH MINISTRY FOR ECOLOGICAL TRANSITION AND TERRITORIAL COHESION, FRENCH MINISTRY FOR ENERGY TRANSITION, Greenfin Label, Criteria Guidelines, January 2024, https://www.ecologie.gouv.fr/sites/default/files/Label_TEEC_Criteria%20Guidelines.pdf

[91] JAPAN CREDIT RATING AGENCY Ltd., Climate Transition Bond Evaluation Results, 27 February 2024, https://www.mof.go.jp/english/policy/jgbs/topics/JapanClimateTransitionBonds/jcr_Evaluation_Results_eng.pdf

[92] CLIMATE BONDS INITIATIVE, Briefing Note, Japan's Climate Transition Bond, 14 February 2024, https://www.climatebonds.net/files/reports/japan-transition-bond-briefing-note-14022024.pdf

[93] GOVERNMENT OF THE RUSSIAN FEDERATION, Resolution No. 1587 on the Approval of the Criteria for Sustainable (including Green) Development Projects in the Russian Federation and the Verification System Requirements for Sustainable (including Green) Development Projects in the Russian Federation, 21 September 2021, (unofficial translation), https://xn--90ab5f.xn--p1ai/files/?file=b5409866c0b23504e0b497ea37cb4c3d.pdf

[94] ANALYTICAL CREDIT RATING AGENCY, Press Release, ACRA Confirms the Compliance of the Planned Bond Issue of State Development Corporation "VEB.RF" with the ICMA's Green Bond Principles and National Green Bond Standards, 22 November 2023, https://www.acra-ratings.ru/upload/iblock/759/endakaimhi3vqx1uy7ry6g0zu8xfzl2i/20231122_zelenye-obligatsii-VEB.RF_press_reliz_en.pdf

[95] THE WORLD BANK, State and Trends of Carbon Pricing Dashboard (2023), https://carbonpricingdashboard.worldbank.org/compliance/instrument-detail

[96] INTERNATIONAL ENERGY AGENCY, Implementing Effective Emissions Trading Systems: Lessons from international experiences, July 2020, https://doi.org/10.1787/b7d0842b-en

[97] DELOITTE, Recent Developments in the Voluntary Carbon Market: Key Implications, Article, 21 November 2023, https://www2.deloitte.com/uk/en/blog/emea-centre-for-regulatory-strategy/2023/navigating-challenges-within-the-voluntary-carbon-market.html

[98] ASSOCIATION OF ISSUING BODIES OPERATING EUROPEAN ENERGY CERTIFICATE SYSTEM, EECS Electricity Domain Protocol for EEX France, AIB-2023-DPFR-EEX-FRANCE, 20 November 2023, https://www.eex.com/fileadmin/EEX/Downloads/Registry_Services/Guarantees_of_Origin_Documentation/AIB-2023-DPFR-v6-2023-1048_Domain_Protocol_Vdef.pdf

[99] ABU DHABI DEPARTMENT OF ENERGY, About Clean Energy Certification, https://www.doe.gov.ae/en/Clean-Energy-Certification/About-Clean-Energy-Certification

[100] GOVERNMENT OF ONTARIO, Ontario Launches Clean Energy Credit Registry to Boost Competitiveness and Attract Jobs, News Release, 29 March 2023, https://news.ontario.ca/en/release/1002876/ontario-launches-clean-energy-credit-registry-to-boost-competitiveness-and-attract-jobs

[101] INDEPENDENT ELECTRICITY SYSTEM OPERATOR, Clean Energy Credits, Ontario Program, https://ieso.ca/Corporate-IESO/Regulatory-Accountability/Regulatory-Reliability-Oversight

[102] BRUCE POWER LTD, Clean Energy Credits (CECs), https://www.brucepower.com/cec/

[103] ONTARIO POWER GENERATION INC, Clean energy credit program, https://www.opg.com/projects-services/services/clean-energy-credits/

[104] RENEWABLE ENERGY INSTITUTE, Non-fossil Certificate Qualified by RE100 with a Condition: Issues of Complying with International Standards, Digest Edition, 10 April 2019, https://www.renewable-ei.org/en/activities/column/REupdate/20190315.php

[105] PJM-EIS GENERATION ATTRIBUTE TRACKING SYSTEM, Terms and conditions of issuance of emission free energy certificate, https://www.pjm-eis.com/-/media/pjm-eis/documents/schedule-f.ashx

[106] EUROPEAN COMMISSION, Framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act), https://www.europarl.europa.eu/doceo/document/TA-9-2024-0378_EN.pdf

[107] US DEPARTMENT OF ENERGY, Inflation Reduction Act of 2022, Loan Programs Office (2023), https://www.energy.gov/lpo/inflation-reduction-act-2022#:~:text=The%20President%27s%20Inflation%20Reduction%20Act,energy%20manufacturing%2C%20and%20putting%20the

[108] US DEPARTMENT OF ENERGY, Title 17 Frequently Asked Questions, Loan Programs Office (2024), https://www.energy.gov/lpo/title-17-frequently-asked-questions

[109] US DEPARTMENT OF ENERGY, LPO Announces Conditional Commitment to Holtec Palisades to Finance the Restoration and Resumption of Service of 800-MW Nuclear Generating Station, Loan Programs Office, 27 March 2024, https://www.energy.gov/lpo/articles/lpo-announces-conditional-commitment-holtec-palisades-finance-restoration-and

[110] US DEPARTMENT OF ENERGY, Advanced Nuclear Energy Projects Solicitation Fact Sheet, Loan Programs Office (2024), https://www.energy.gov/lpo/articles/advanced-nuclear-energy-projects-solicitation-fact-sheet-unpublished

[111] US TITLE 26-INTERNAL REVENUE CODE, 26 USC 45U: Zero-emission nuclear power production credit (2024), https://uscode.house.gov/view.xhtml?req=(title:26%20section:45U%20edition:prelim)

[112] US FEDERAL REGISTER, Section 45V Credit for Production of Clean Hydrogen; Section 48(a)(15) Election To Treat Clean Hydrogen Production Facilities as Energy Property, Proposed Rule by the Internal Revenue Service, 26 December 2023, https://www.federalregister.gov/documents/2023/12/26/2023-28359/section-45v-credit-for-production-of-clean-hydrogen-section-48a15-election-to-treat-clean-hydrogen

[113] US CONGRESS, H.R.4366 - 118th Congress (2023-2024): Consolidated Appropriations Act, 2024 (2024), https://www.congress.gov/bill/118th-congress/house-bill/4366

[114] US DEPARTMENT OF ENERGY, Civil Nuclear Credit Program, Grid Deployment Office (2024), https://www.energy.gov/sites/default/files/2023-02/Civil%20Nuclear%20Credit%20Program%20Fact%20Sheet%20%28February%202023%29.pdf

[115] US DEPARTMENT OF ENERGY, Civil Nuclear Credit Award Cycle 1, Grid Deployment Office, https://www.energy.gov/gdo/civil-nuclear-credit-award-cycle-1

[116] OECD NUCLEAR ENERGY AGENCY, The Economics of Long-term Operation of Nuclear Power Plants, OECD Publishing, Paris (2012), https://www.oecd-nea.org/upload/docs/application/pdf/2019-12/7054-long-term-operation-npps.pdf

[117] ONTARIO POWER GENERATION, Darlington Refurbishment performance update Q2 2022, 20 September 2022, https://www.opg.com/news/darlington-refurbishment-performance-update-q2-2022

[118] INTERNATIONAL ATOMIC ENERGY AGENCY, Evaluation of Design Robustness of Nuclear Installations Against External Hazards, TECDOC-2043, Vienna (2024), https://www.iaea.org/publications/15458/evaluation-of-design-robustness-of-nuclear-installations-against-external-hazards

[119] INTERNATIONAL ATOMIC ENERGY AGENCY, Implementation and Effectiveness of Actions Taken at Nuclear Power Plants following the Fukushima Daiichi Accident, TECDOC-1930, Vienna (2020), https://www.iaea.org/publications/14743/implementation-and-effectiveness-of-actions-taken-at-nuclear-power-plants-following-the-fukushima-daiichi-accident

[120] OECD NUCLEAR ENERGY AGENCY, Unlocking Reductions in the Construction Costs of Nuclear: A Practical Guide for Stakeholders, OECD Publishing, Paris (2020), https://doi.org/10.1787/33ba86e1-en

[121] OECD NUCLEAR ENERGY AGENCY, Small Modular Reactors: Challenges and Opportunities, OECD Publishing, Paris (2021), https://doi.org/10.1787/18fbb76c-en

[122] EXPORT-IMPORT BANK OF THE UNITED STATES, U.S. EXIM Small Modular Reactor Financing Toolkit, EXIM Bank Policies (2023), https://www.exim.gov/policies/small-modular-reactor-financing

[123] US DEPARTMENT OF STATE, Project Phoenix, 7 September 2023, https://www.state.gov/project-phoenix

[124] PAVLOVIC, I., BENOIST, E., SMRs: Missing Link for a Successful Energy Transition?, Natixis Research, 26 April 2024, https://home.cib.natixis.com/financing-energy-transition-are-small-modular-reactors-poised-to-bridge-the-gap

[125] EUROPEAN COMMISSION, European Industrial Alliance on SMRs (2024), https://single-market-economy.ec.europa.eu/industry/strategy/industrial-alliances/european-industrial-alliance-small-modular-reactors_en

[126] RUTH, M., CUTLER, D., FLORES-ESPINO, F., STARK, G., JENKIN, T., SIMPKINS, T. and MACKNICK, J., (2016) 'The Economic Potential of Two Nuclear-Renewable Hybrid Energy Systems' US Department of Energy National Renewable Energy Laboratory, NREL/TP-6A50-66073.

[127] RUTH, M., CULTER, D., FLORES-ESPINO, F., STARK, G. and JENKIN, T., (2016) 'The Economic Potential of Three Nuclear-Renewable Hybrid Energy Systems Providing Thermal Energy to Industry', US Department of Energy National Renewable Energy Laboratory, NREL/TP-6A50-66745.

[128] RUTH, M., CUTLER, D., FLORES-ESPINO, F. and STARK, G., (2017) 'The Economic Potential of Nuclear-Renewable Hybrid Energy Systems Producing Hydrogen', US Department of Energy National Renewable Energy Laboratory, NREL/TP-6A50-66764.

[129] REUTERS, EDF to head French nuclear deal in Abu Dhabi, Reuters (2009), https://www.reuters.com/article/idUSGEE5B80GF/

[130] DE BEAUPUY, F., TotalEnergies Seeks Long-Term Nuclear Power Purchase Deal With EDF, Bloomberg (2024), https://www.bloomberg.com/news/articles/2024-01-19/totalenergies-seeks-long-term-nuclear-power-purchase-deal-with-edf

[131] SQUAWK CNBC, ["Is there a shot at making nuclear energy technology not only work but be politically palatable?"], CNBC (2023), https://twitter.com/SquawkCNBC/status/1684894816344088576

[132] NEWCLEO, ["Newcleo and Viaro Energy Sign MOU to Deploy Clean Nuclear Technology to Decarbonise Oil and Gas Sector"], Newcleo (2024), https://bebeez.it/wp-content/uploads/2024/03/2024-03-04-Viaro-Energy-and-newcleo-MOU-announcement-FINAL-.pdf

[133] INTERNATIONAL INFORMATION GROUP, Rosatom discussing with number of companies, particularly Lukoil, construction of small NPPs to supply energy to projects – CEO, 28 February 2024, https://interfax.com/newsroom/top-stories/99893/

[134] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Harmonization and Standardization Initiative (2024), https://www.iaea.org/services/key-programmes/smr-platforms-nhsi

[135] GOVERNMENT OF THE UNITED KINGDOM, Civil nuclear: roadmap to 2050, Department for Energy Security & Net Zero (2024), https://www.gov.uk/government/publications/civil-nuclear-roadmap-to-2050/civil-nuclear-roadmap-to-2050-accessible-webpage

[136] NASA, Kilopower Reactor Using Stirling Technology (KRUSTY) Nuclear Ground Test Results and Lessons Learned, NASA Scientific and Technical Information Program (2018), https://doi.org/10.2514/6.2018-4973

[137] US DEPARTMENT OF ENERGY, KRUSTY Reactor Design, OSTI (2020), https://doi.org/10.1080/00295450.2020.1725382

[138] US DEPARTMENT OF DEFENSE, DoD to Build Project Pele Mobile Microreactor and Perform Demonstration at Idaho National Laboratory, 13 April 2022, https://www.defense.gov/News/Releases

[139] AMERICAN NUCLEAR SOCIETY, Project Pele in context: An update on the DOD's microreactor plans, 28 August 2023, https://www.ans.org/news

[140] AMERICAN NUCLEAR SOCIETY, MARVEL microreactor start-up now expected in 2027, as fuel fabrication begins, 8 February 2024, https://www.ans.org/news

[141] US DEPARTMENT OF ENERGY, Advanced Reactor Demonstration Projects, Office of Clean Energy Demonstrations, https://www.energy.gov/oced

[142] US GOVERNMENT ACCOUNTABILITY OFFICE, DOE Should Institutionalize Oversight Plans for Demonstrations of New Reactor Types, 15 September 2022, https://gao.gov/products

[143] X ENERGY, Dow and X-energy Advance Efforts to Deploy First Advanced Small Modular Nuclear Reactor at Industrial Site Under DOE's Advanced Reactor Demonstration Program, 1 March 2023, https://x-energy.com/media/news-releases

[144] KAIROS POWER, Nuclear Regulatory Commission Approves Construction Permit for Hermes Demonstration Reactor, 12 December 2023, https://kairospower.com/exernal_updates

[145] THE WORLD BANK, Making Power Affordable for Africa and Viable for Its Utilities, 2024, https://www.worldbank.org/en/topic/energy/publication/making-power-work-for-africa

[146] UNDESA, Seeking Synergy Solutions: A New Financial System to Enable Both Climate and SDG Action, United Nations Department of Economic and Social Affairs (2024), https://sdgs.un.org/sites/default/files/2024-06/Thematic%20Report%20on%20Finance-060824.pdf

[147] INTERNATIONAL ENERGY AGENCY, Africa Energy Outlook 2022, IEA, Paris (2022), https://doi.org/10.1787/2abd9ce2-en

[148] CLIMATE CHAMPIONS, Africa Carbon Markets Initiative launched to dramatically expand Africa's participation in voluntary carbon market, 2022, https://climatechampions.unfccc.int/africa-carbon-markets-initiative/

[149] GLOBAL COMPLIANCE NEWS, Africa: Boosting energy transition - initiatives, funding and investment, 7 July 2023, https://www.globalcompliancenews.com

[150] UN FRAMEWORK CONVENTION ON CLIMATE CHANGE, From Billions to Trillions: Setting a New Goal on Climate Finance, 2024, https://unfccc.int/news/from-billions-to-trillions-setting-a-new-goal-on-climate-finance

[151] OMOROGBE, Y., ORDOR, A., Ending Africa's Energy Deficit and the Law: Achieving Sustainable Energy for All in Africa, Oxford University Press (2018), https://doi.org/10.1093/oso/9780198819837.001.0001

[152] GOVERNMENT OF GHANA, National Development Planning Commission, Ghana and the Sustainable Development Goals, NDPC Ed, Accra (2015).

[153] GHANA NATIONAL DEVELOPMENT PLANNING COMMISSION, National Infrastructure Plan, NDPC (2017).

[154] GHANA MINISTRY OF ENERGY, Ghana's National Energy Transition Framework (2022-2070) (2021), https://www.energymin.gov.gh/sites/default/files/2023-09/FINAL%20GHANA%27S%20NATIONAL%20ENERGY%20TRANSITION%20FRAMEWORK_2023_compressed%20%281%29_compressed%20%282%29.pdf

[155] GOVERNMENT OF GHANA, Gas Masterplan, Ministry of Petroleum (2016).

[156] INTERNATIONAL ATOMIC ENERGY AGENCY, Managing the financial risks associated with financing new nuclear power projects, IAEA Nuclear Energy Series, No. NG-T-4.6 (2017).

[157] INTERNATIONAL ATOMIC ENERGY AGENCY, Costs and financing of nuclear power programmes (1986), http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/18/006/18006451.pdf

[158] INTERNATIONAL ATOMIC ENERGY AGENCY, Financing of nuclear power projects in developing countries (1990), http://www.iaea.org/inis/collection/NCLCollectionStore/_ Public/22/081/22081404.pdf

[159] INTERNATIONAL ATOMIC ENERGY AGENCY, Financing arrangements for nuclear power projects in developing countries – a reference book, Technical Reports Series No. 353, Vienna (1993).

[160] OECD NUCLEAR ENERGY AGENCY, The financing of nuclear power plants, OECD Publishing, Paris (2009), https://www.oecd-nea.org/ndd/reports/2009/financing-plants.pdf

[161] QUANSAH, F. B., DADZIE, E., DOE-ASIDENU, G., FIAGBE, F., DEBRAH, S.K., ACHEAMPONG, J., BOAKYE, C. and ALLOTEY, N. K., (2017) 'Financing Options for Ghana's Nuclear Power Project: Analysis and Proposals' Ghana Nuclear Power Planning Organisation, NPID-127560-ANL-101.

LIST OF ABBREVIATIONS

CO_2, CO_2eq	carbon dioxide, carbon dioxide equivalent
COP	Conference of the Parties to the UNFCCC
ECA	export credit agency
EMDEs	emerging markets and developing economies
FOAK	first-of-a-kind
GHG	greenhouse gas
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRA	US Inflation Reduction Act
[kW, kW·h, MW, GW, MW·h, GW·h, TW·h]	Measurements of energy capacity or generation [kilowatt, kilowatt-hour megawatt, gigawatt, megawatt-hour, gigawatt-hour, terawatt-hour]
NCQG	new collective quantified goal
NDC	nationally determined contribution
NOAK	Nth-of-a-kind
NPP	nuclear power plant
NZE	IEA Net Zero Emissions by 2050 Scenario
NZIA	EU Net Zero Industry Act
SMR	small modular reactor
UNFCCC	United Nations Framework Convention on Climate Change
VCM	voluntary carbon market

CONTRIBUTORS TO DRAFTING AND REVIEW

Afanasyeva, T.	International Atomic Energy Agency
Beville, T.	DOE Office of Clean Energy Demonstrations (USA)
Binnie, N.	KPMG
Brunner, E.	Idaho National Laboratory (USA)
Cantero, C.	Nucleoeléctrica Argentina S.A.
Collet, M. S.	EDF (France)
Cometto, M.	International Atomic Energy Agency
Cotignola, M.	Nucleoeléctrica Argentina S.A.
Dalzell, P.	Bruce Power
Davis, H.	KPMG
Dean, D.	International Bank for Nuclear Infrastructure (IBNI) Implementation Organization
Gan, S.	China Nuclear Power Engineering Co. Ltd
Guaita, N.	Idaho National Laboratory (USA)
Hu, J.	China Nuclear Power Engineering Co. Ltd
Kendrick, J.	KPMG
Krager Hahn	A., Department of Energy (USA)
Larsen, L.	Idaho National Laboratory (USA)
Lazerwitz, B.	International Atomic Energy Agency
Lindauer, B.	European Bank for Reconstruction and Development
Lion, P.	Rosatom
Maduri, C.	Nucleoeléctrica Argentina S.A.
Masters, K.	KPMG
Mberia, N.	International Atomic Energy Agency
Masters, K.	KPMG
Nyawinda, B.	Nuclear Power and Energy Agency (Kenya)
Ohayon, D.	International Atomic Energy Agency
Paillere, H.	International Atomic Energy Agency
Pessez Hublot, L.	BNP Paribas
Qu, J.	China Nuclear Power Engineering Co. Ltd
Quansah, F. B.	Ghana Atomic Energy Commission
Rogers, P.	Equilibrion
Sacchetta, F.	Nucleoeléctrica Argentina S.A.
Salvetti, C.	Nucleoeléctrica Argentina S.A.
Sayeeram, M.	KPMG
Shi, N.	China Nuclear Power Engineering Co. Ltd
Siam, A. A.	Permanent Mission of Bangladesh to the United Nations
Simpson, A.	Equilibrion
Stauff, N. E.	Argonne National Laboratory (USA)
Turton, H.	International Atomic Energy Agency
White, D.	KPMG
	Canadian Nuclear Association
	Teollisuuden Voima Oyj (TVO) Treasury

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ANTIGUA AND BARBUDA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHAMAS
BAHRAIN
BANGLADESH
BARBADOS
BELARUS
BELGIUM
BELIZE
BENIN
BOLIVIA, PLURINATIONAL STATE OF
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BRUNEI DARUSSALAM
BULGARIA
BURKINA FASO
BURUNDI
CABO VERDE
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHAD
CHILE
CHINA
COLOMBIA
COMOROS
CONGO
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DJIBOUTI
DOMINICA
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ESWATINI
ETHIOPIA
FIJI
FINLAND
FRANCE
GABON
GAMBIA
GEORGIA
GERMANY
GHANA
GREECE
GRENADA
GUATEMALA
GUINEA
GUYANA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LAO PEOPLE'S DEMOCRATIC REPUBLIC
LATVIA
LEBANON
LESOTHO
LIBERIA
LIBYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA
MAURITIUS
MEXICO
MONACO
MONGOLIA
MONTENEGRO
MOROCCO
MOZAMBIQUE
MYANMAR
NAMIBIA
NEPAL
NETHERLANDS, KINGDOM OF THE
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORTH MACEDONIA
NORWAY
OMAN
PAKISTAN
PALAU
PANAMA
PAPUA NEW GUINEA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
RWANDA
SAINT KITTS AND NEVIS
SAINT LUCIA
SAINT VINCENT AND THE GRENADINES
SAMOA
SAN MARINO
SAUDI ARABIA
SENEGAL
SERBIA
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
TOGO
TONGA
TRINIDAD AND TOBAGO
TUNISIA
TÜRKİYE
TURKMENISTAN
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VANUATU
VENEZUELA, BOLIVARIAN REPUBLIC OF
VIET NAM
YEMEN
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
tel.: +43 1 2600 22529 or 22530
email: sales.publications@iaea.org
www.iaea.org/publications

Printed by the IAEA in Austria
September 2024
https://doi.org/10.61092/iaea.sgyh-rjoq

IAEA LIBRARY CATALOGUING IN PUBLICATION DATA

Names: International Atomic Energy Agency.

Title: Climate change and nuclear power 2024 : financing nuclear energy in low carbon transitions / International Atomic Energy Agency.

Description: Vienna : International Atomic Energy Agency, 2024. | Includes bibliographical references.

Identifiers: IAEAL 24-01707

Subjects: LCSH: | Nuclear energy — Environmental aspects. | Renewable energy sources. | Climatic changes — Economic aspects. | Climate change mitigation.

Classification: UDC 621.039:504 | CCANP-24

EDITORIAL NOTE

24-03052E

The 2024 edition of Climate Change and Nuclear Power delves into the dynamics of financing nuclear projects to unlock much needed nuclear energy capacity as ambitious climate targets draw nearer. We explore the imperative for robust financial frameworks to propel the adoption of nuclear energy as a cornerstone of global decarbonization efforts.

This publication seeks to inform those at the intersection of sustainability and finance — climate negotiators, government officials, commercial and multilateral financiers, energy and climate policy makers, experts, non-governmental organizations and media representatives — about the potential of nuclear energy in mitigation and highlight challenges and best practices in financing nuclear projects.

International Atomic Energy Agency
Vienna, 2024
www.iaea.org