Nuclear Power Generation in Asia-Pacific

- Current Policies and Future Perspectives

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Asia Pacific Energy Research Centre

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Foreword

In May 2016, the Asia Pacific Energy Research Centre (APERC) launched the 6th Edition of *APEC Energy Demand and Supply Outlook* to help inform policy makers about the major trends and challenges facing the energy sector in the Asia-Pacific Economic Cooperation (APEC) region. According to our projection, energy demand in APEC significantly grows in the next decades, with China and Southeast Asia being the main drivers, and the region remains reliant on fossil fuels. Secure, low-emission as well as cost-efficient energy sources become more important for sustainable development in the APEC region.

Nuclear power generation, which has been contributing to the electricity sector in the APEC region since the 1950s, is one of the key technologies to realize low-emission electricity supply. However, after the Fukushima Daiichi Nuclear Accident in 2011, the attitude towards nuclear power significantly varies by economy in the APEC region. Several economies has decided to reduce their reliance on nuclear power or abandoned construction plans for new reactors, while some others maintain their policy to expand nuclear generation. This study attempts to summarize these recent policy updates and assess the effects of different nuclear development scenarios on the future APEC generation mix.

This report is published by APERC as an independent study and does not reflect the views or policies of the APEC Energy Working Group or individual APEC member economies. APERC recognizes and respects the position of some APEC member economies that do not consider nuclear power an option for their energy systems.

We hope this report contributes to the ongoing discussion about the future of nuclear power generation in the APEC region.

Takato OJIMI

President

Asia Pacific Energy Research Centre

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Glossary and abbreviations

ABWR	Advanced Boiling Water Reactor, a Generation III boiling water reactor designed by GE Hitachi Nuclear Energy (GEH) and Toshiba
AFCR	Advanced Fuel CANDU Reactors
AP1000	Advanced Passive Power Reactor, a Generation III nuclear power reactor designed by Westinghouse Electric Company, the United States
APEC	Asia-Pacific Economic Cooperation
APERC	Asia Pacific Energy Research Centre
APR1400	Advanced Pressurized Reactor, a Generation III pressurized water reactor designed by Korea
BATAN	The National Nuclear Energy Agency, Indonesia
BWR	Boiling water reactor
CANDU	Canadian Deuterium Uranium. Registered trade name for the Canadian designed power reactor developed by Atomic Energy of Canada Limited and using natural uranium as fuel and deuterium oxide (heavy water) as moderator.
CNEN	National Commission of Nuclear Energy, Mexico
COL	Construction and operating license
EAR	Estimated additional resources
EPR	European Pressurized Reactor, a Generation III pressurized water reactor designed and developed mainly by Framatome (now Areva NP) and Électricité de France (EDF) in France
ESBWR	Economic Simplified BWR designed by GE Hitachi
FBR	Fast breeder reactor
FEC	Final Energy Consumption
FOAKE	First-of-a-kind-engineering costs
FY	Fiscal Year
GDP	Gross domestic product
GHG	Greenhouse gases
GIF	Generation IV International Forum. International organization collaborating on the development of six innovative reactor and fuel cycle system designs for deployment in the period 2030-2040
HTGR	High temperature gas-cooled reactor
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IEA	International Energy Agency

IEEJ	Institute of Energy Economics, Japan
INDC	Intended Nationally Determined Contribution
INPO	Institute of Nuclear Power Operations
LCOE	Levelized cost of electricity
LILW	Low and intermediate level radioactive waste
LLW	Low level radioactive waste
LNG	Liquefied natural gas
MNPC	Malaysia Nuclear Power Corporation
MOX	Mixed oxide fuels, nuclear fuels manufactured from a mix of uranium and plutonium oxides
Mtoe	Million tonnes of oil equivalent
MTR	Materials testing reactor
NDC	Nationally Determined Contributions
NEA	Nuclear Energy Agency of the OECD
NPP	Nuclear power plant
NRA	The Nuclear Regulation Authority, Japan
NRC	Nuclear Regulatory Commission, the United States
NSSS	Nuclear steam supply system
PHWR	Pressurized heavy water reactor
PWR	Pressurized water reactor
RAR	Reasonably assured resources
R&D	Research and development activities
SMR	Small modular reactor
SR	Speculative resources
TEPCO	Tokyo Electric Power Company
TPES	Total primary energy supply
UNFCCC	United Nations Framework Convention on Climate Change
VVER	Water-cooled, water-moderated vessel-type pressurized power reactor, a Russian designed pressurized water reactor
WANO	The World Association of Nuclear Operators
WNA	World Nuclear Association

Executive summary

Nuclear power generation, which has been contributing to the electricity sector in the APEC region since the 1950s, is one of the key technologies to realize low-emission electricity supply. However, after the Fukushima Daiichi Nuclear Accident in 2011, the attitudes toward nuclear power significantly vary by economy. Some economies have decided to reduce their reliance on nuclear power, while other economies maintain their policies to expand nuclear generation.

"*How will these recent nuclear policies affect the APEC region? What is the role of nuclear power in the future?"*—they are the main research questions of this study. This report, therefore, aims to summarize recent nuclear policies (Chapter 2), quantify their impacts on the APEC generation mix (Chapter 3), as well as discuss the major challenges for nuclear power generation (Chapter 4). The quantitative assessment in Chapter 3 examines three nuclear scenarios (the BAU = Business-as-Usual, the Low Nuclear and the High Nuclear Scenarios), employing a long-term electricity supply model.

The modeling analysis suggests that, in any scenario, China becomes the main driver in terms of new reactor additions, increasing its presence in nuclear generation in the APEC region. Nuclear contributes from the 3E—Environment, Energy security and Economic efficiency—perspective, although economic benefits for the region, as a whole, are estimated to be modest. Stronger emissions policies, such as a higher level of carbon prices, would be important to improve the economics of nuclear power. Our analysis also implies that a large amount of spent fuel is generated even in the Low Nuclear Scenario. Economies need to implement policies to construct sufficient facilities for storage and final disposal.

Nuclear power development is surrounded by large uncertainties due to various challenges, including waste management and public acceptance. The accident in Fukushima negatively impacted on these challenges in most of the economies, according to several surveys (Chapter 4). Sustained efforts for transparency, public communications, as well as trust building become more important to continue to utilize nuclear power in the future.

Chapter 1 Introduction

1.1 Background

With 21 economies individually and collectively facing the energy challenges of the early 21st century, the Asia-Pacific Economic Cooperation (APEC) has an opportunity to influence global trends. Currently, APEC represents nearly 60% of the world's primary energy demand and more than half of the real gross domestic product (GDP); the region also includes major energy exporters (such as Australia, Canada, Russia and United States), as well as consumers that import nearly all of their energy supply (such as Chile, Japan, Korea and Singapore.) The drivers of energy use differ significantly among the economies, reflecting the wide range of climates, geographical conditions, population and economic structures. Despite these differences, APEC economies share many energy goals, including a strong focus on enhancing energy security and environmental sustainability while supporting economic growth.

In May 2016, APERC published *APEC Energy Demand and Supply Outlook*, 6th Edition, which presents the latest energy trends and evaluates major energy challenges and opportunities through 2040 for the APEC region (APERC, 2016a). Targeting policy makers, the report aims to foster understanding among APEC economies of the key drivers of both domestic and regional energy demand and supply, the need for energy infrastructure development and related policy issues. The *Outlook* indicates that energy demand in APEC significantly grows in the next decades, with China and Southeast Asia being the main driver, and the region remains reliant on fossil fuels. Secure, low-emission as well as cost-efficient energy sources become more important for sustainable development in the APEC region.

Since the 1950s, nuclear power generation has contributed to electricity supply in the APEC region as one of major options of low-carbon electricity. APEC economies include major nuclear utilizing economies as well as nuclear expanding economies. As of November 2016, approximately 60% of reactors in operation (265 reactors out of 449 globally) and under construction (39 out of 61 globally) are in the region (Figure 1). However, after the Fukushima Daiichi Nuclear Accident in 2011, nuclear power development is surrounded by large uncertainties. In the APEC, the attitude toward nuclear significantly vary by economy. Some economies, such as Japan and Chinese Taipei, have decided to shift their policies to reducing nuclear dependencies, while some others, such as China, maintain their policy to expand nuclear generation. These policy changes may significantly impact the middle- to long-term electricity supply in the APEC region.

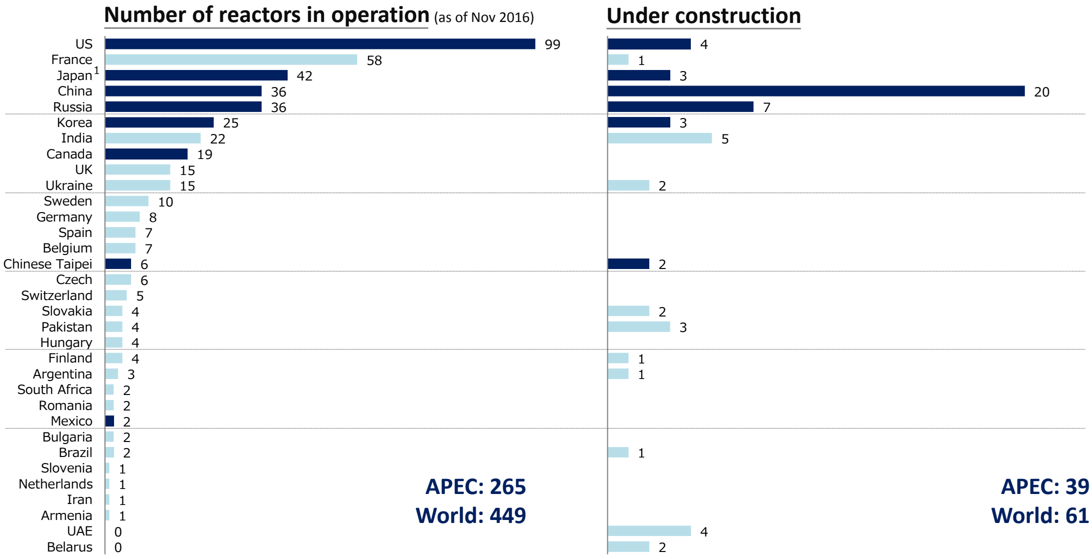

Figure 1 Number of reactors in operation and under construction, as of November 2016

Sources: IAEA PRIS system and APERC[1].

1.2 Objective and outline of this report

The objective of this study is to summarize the current nuclear policies in APEC member economies, and to analyze their impacts on long-term electricity supply in the APEC region in a quantitative manner. This study first conducts a survey on the current policies as well as plans for the future development (Chapter 2). Then, with that information in hand, we develop three nuclear scenarios with the projection period to 2040, and quantify the potential impacts of the scenarios on the APEC generation mix (Chapter 3). Then, we discuss the important issues for nuclear power development in APEC, including nuclear safety, technology progress and nuclear waste disposal (Chapter 4). Lastly, we explore the potential for regional cooperation, including, for example, information sharing network, under the APEC framework and offer suggestions for policy makers and stake holders in the APEC region (Chapter 5).

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[1] We refer to IAEA PRIS, but adjusted data in several economies; for example, in Japan, Ikata unit 1 is excluded from the figure in operation, and the number of reactors under construction is revised from 2 to 3.

Chapter 2 Current nuclear policies in the APEC region

Asia-Pacific is the most important regions in the world where there has been significant growth of nuclear power in the past and that has sizeable plans for the construction of more NPPs (Figure 1). To better understand the current situation, this chapter aims to summarize the current policy in each relevant APEC economy that has nuclear power or is considering nuclear power as an option for electricity supply.

2.1 Nuclear power in the world and APEC

Nuclear power is one of the largest sources of low-carbon electricity in the world. As of November 2016, there were 449 reactors operable around the world and 61 under construction; and Asia-Pacific is considered to be the key driver for nuclear expansion in the next decades, with about 60% of operating reactors as well as under construction in the world located in this region. Nuclear power has experienced a setback after the Fukushima Daiichi Nuclear Power Plant accident in March 2011, though changes in nuclear energy policies were limited to a few countries.[2] Generated electricity from nuclear dropped mainly due to subsequent shutdown of the nuclear fleet in Japan after the accident, as well as the closure of eight reactors in Germany the same year (Figure 2); yet, nuclear generation is gradually reviving driven by the growth in East Asia, in particular in China.

Nuclear policies and situations after the Fukushima accident significantly differ by economy. For example, China remains committed to nuclear power and has restarted new construction projects. Eight new nuclear reactors were approved in 2015, and additional projects are under evaluation and will seek approval in the near future. Whereas Chinese Taipei has decided to phase out all nuclear capacity by 2025. Nuclear reactors in the United States, both operating and under construction, suffer from economic-competitiveness challenges due to low-cost fossil fuel resources. Southeast Asian economies are still considering their first nuclear power project, and the preparatory works are ongoing. However, uncertainties still remain due to political issues and public decision. In November 2016, Viet Nam recently cancelled a nuclear project. According to the IAEA milestone standard, all the APEC newcomer economies are in the process of Phase 1 (see Figure 3). Challenges for

[2] https://www.oecd-nea.org/ndd/pubs/2017/7212-impacts-fukushima-policies.pdf

newcomers include public acceptance, legal and regulatory system building, human resource development, as well as financial issues.

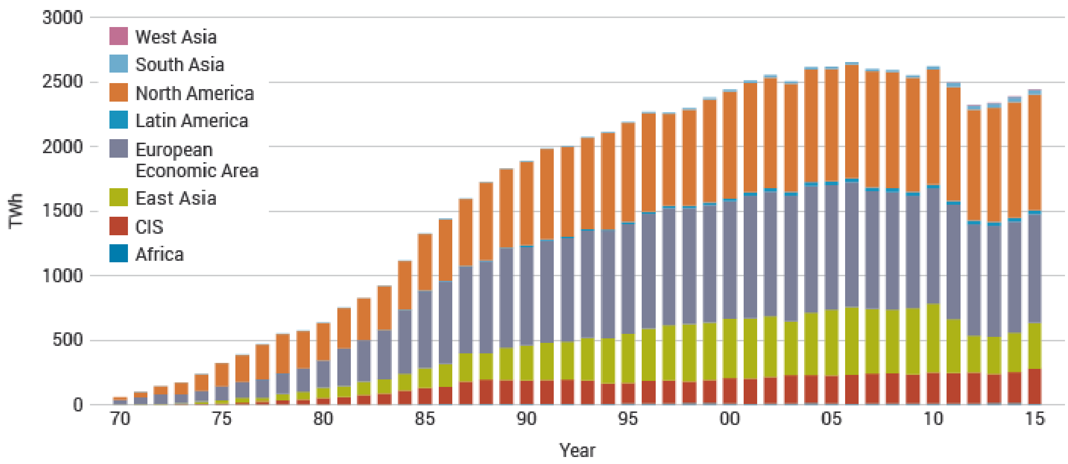

Figure 2 Nuclear generation by regional grouping, from 1970 to 2015

Source: World Nuclear Association[3].

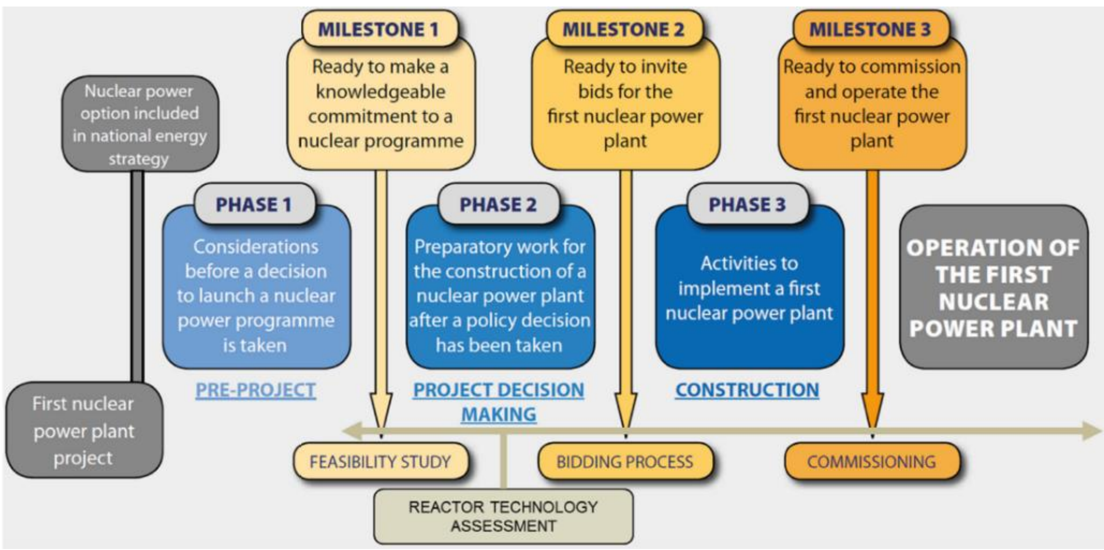

Figure 3 IAEA's assessment system for nuclear power deployment

Figure from IAEA (2007).

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[3] http://www.world-nuclear.org/information-library.aspx

The Paris Agreement, adopted in December 2015, is an important milestone toward a sustainable society. Among the thirteen economies covered in the next Section (Section 2.2), three economies—China, Japan and Korea—explicitly mention nuclear generation in their NDCs (Nationally Determined Contributions) submitted to the UNFCCC (United Nations Framework Convention on Climate Change). China and Japan show their intention to continue utilizing nuclear generation (Table 1). China aims to develop nuclear power in a safe and efficient manner, as well as to strengthen research and development for advanced nuclear technologies. Although Japan aims to reduce its dependency on nuclear, the economy plans to utilize nuclear power over the long-term (20-22% in fiscal year 2030), as long as nuclear safety is confirmed. Whereas, Korea highlighted public acceptance issues following the nuclear accident in Fukushima.

Table 1 Selected statements related to nuclear generation in NDCs (Nationally Determined Contributions) submitted to the UNFCCC

Economy	Statement
China	● "*to develop nuclear power in a safe and efficient manner*" ● "*to strengthen research and development (R&D) and commercialization demonstration for low-carbon technologies, such as … advanced nuclear technologies*"
Japan	● "*Utilizing nuclear power generations whose safety is confirmed*" ● The share of nuclear power in total power generation: approximately 20-22% in fiscal year 2030. Assumed total power generation is approximately 1 065 billion kWh.
Korea	● "*Given the decreased level of public acceptance following the Fukushima accident, there are now limits to the extent that Korea can make use of nuclear energy, one of the major mitigation measures available to it*"

Source: UNFCCC.

Pressurized water reactors (PWRs) account for about 60% of the total number of nuclear reactors, while boiling water reactors (BWRs), located mainly in the United States, Japan and Chinese Taipei, for about a quarter. Pressurized heavy water reactors (PHWRs), or Canadian Deuterium Uranium (CANDU) reactors, which were first developed in Canada in the late 1950s, are the third most popular reactor type in the APEC region, with reactors in Canada, China, and South Korea. Three fast breeder reactors (FBRs) are currently operating in the APEC region; the Russian designed BN-600 at Beloyarsk 3 has achieved a lifetime capacity factor to date of 74.1%, a promising result for this design and future fast reactors. In addition to the reactors commercially operated, there are a total of 165 research reactors in 16 APEC member economies. Those economies without commercial reactors that operate research reactors include Australia, Chile, Indonesia, Malaysia, Peru, the Philippines, Thailand and Viet Nam. Research reactors are used for nuclear research in a number of fields such as health, agriculture, materials research and radiation research; note that having a research reactor does not necessarily indicate that the host economy has an interest in pursuing nuclear power electricity generation.

2.2 Economy overview

2.2.1 Canada

Highlights

- ✓ Canada is the sixth largest economy in the APEC region in terms of the number of operating commercial reactors.
- ✓ There are 19 commercially operating reactors, mostly in Ontario, accounting for about 15% of the economy's electricity generation mix.
- ✓ Canada is a leader in nuclear technology research and development, specifically with respect to the CANDU technology.
- ✓ Canada was the world's largest uranium producer prior to 2009. It currently ranks second following Kazakhstan.

Nuclear is an important component of Canada's energy mix. Canada generated some 635 TWh in 2015, of which 96 TWh (15%) was from nuclear, compared with 373 TWh (59%) from hydro, 61 TWh from coal and 59 TWh from gas. Annual electricity use is about 15 000 kWh per person, one of the highest levels in the world. Net exports in 2015 were 60 TWh to the US. Total generating capacity in 2014 was 137 GW, more than half of this being hydro.

The Canadian nuclear sector consists of a mixture of private sector firms and public sector organizations at both the federal and provincial levels, and covers the entire nuclear energy fuel cycle, including research and development activities (R&D), uranium mining, fuel fabrication, nuclear reactor design, NPP construction, maintenance, waste management, and decommissioning. The Canadian nuclear energy industry is concentrated in a few provinces: nuclear power generation occurs in Ontario and New Brunswick, uranium is mined and milled in Saskatchewan, and uranium is refined, converted and fabricated into fuel in Ontario. Of the 24 nuclear power reactors built in Canada, 19 reactors are currently in full commercial operation. Eighteen of the operating reactors are in Ontario, and one is in New Brunswick. Quebec decided to shut down their NPP in December 2012.

Unlike other energy sources, nuclear energy falls under federal jurisdiction in Canada. The federal government is responsible for all regulation of nuclear materials and activities, along with supporting nuclear R&D. Concerned with the impact of nuclear activities on health, safety, security and the environment, the federal government has put in place a comprehensive nuclear legislation framework. The latter is comprised of the *Nuclear Safety and Control Act 1997*, the *Nuclear Energy Act 1985*, the *Nuclear Fuel Waste Act 2002* and the *Nuclear Liability and Compensation Act 2015*. They provide the framework for developing nuclear energy in Canada.

While nuclear legislation and regulation take place at the federal level, the decision to invest in NPPs for electricity generation rests with the provinces (in concert with relevant provincial energy utilities). While rising fossil fuel prices, aging reactors, and climate change concerns stirred discussion of new reactors throughout Canada during the early 2000s, given the current context and the outlook of each provincial electricity utility, no new nuclear capacity is projected in the near-term. However, a number of existing operational plants will undergo refurbishment. Ontario will invest more than CAD 25 billion between 2016 and 2031 to refurbish and extend the lives of 10 nuclear reactors: four at the Darlington Nuclear Generating Station and six at the Bruce Nuclear Generating Station. These refurbishments will maintain the province's nuclear power capacity at 9.9 GW and add about 25–30 years to the operational life of each unit. Refurbishment at Darlington started in 2016 with one reactor, and commitments on subsequent reactors will take into account the cost and timing of preceding refurbishments, with appropriate off-ramps in place. Refurbishment at Bruce is to start in 2020. The New Brunswick reactor, as well as two units (units 1 and 2) at the Bruce nuclear power plant, were refurbished and brought back online in 2012.

The continued use of nuclear energy in Ontario will displace approximately 30 million tonnes per year of CO2 or 3.8% of expected emissions in 2030 (as compared with natural gas) (WNA, 2017).

CANDU Technology

Canada has developed a successful nuclear energy sector based on the unique heavy water natural uranium reactor system (well known as ‘Canadian Deuterium Uranium’, or CANDU), which uses pressurized fuel channels instead of a pressure vessel, natural instead of enriched uranium, and heavy water as coolant/moderator instead of light water, as found in PWR designs (Figure 4). By the end of 2016, there were 31 CANDU nuclear power reactors in seven economies worldwide, with more being built and new variations of CANDU technology being developed. For example, SNC-Lavalin (a private company that purchased the CANDU Reactor Division from Atomic Energy of Canada Limited in 2011) and Chinese partners led by China National Nuclear Corporation are currently working to develop and build the Advanced Fuel CANDU Reactor (AFCR) in China and abroad. The AFCR is designed to use recycled uranium from light water reactors (LWRs), and would thus complement, rather than compete with, fleets with PWR and BWR designs.

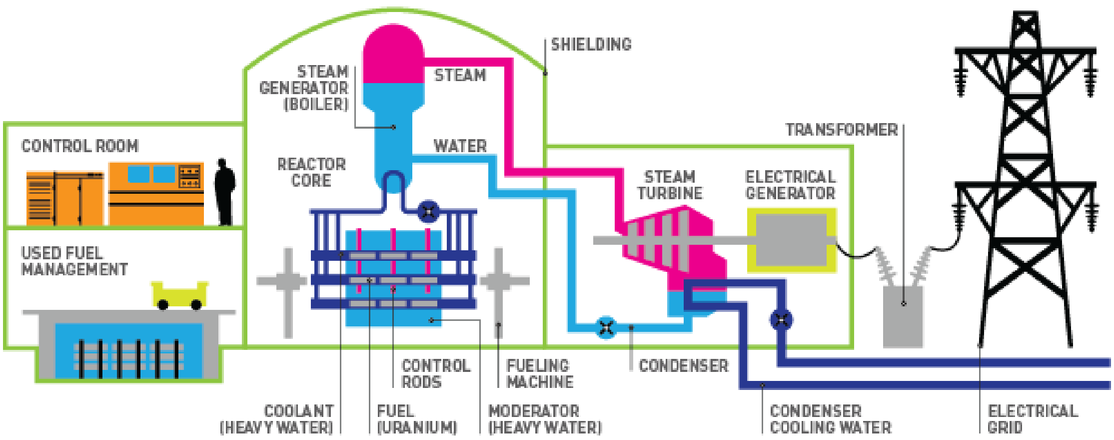

Figure 4 CANDU nuclear power reactor schematic diagram

Canada has exported 12 CANDU units to date to Korea (4 units), Romania (2 units), India (2 units), Pakistan (1 unit), Argentina (1 unit) and China (2 units), along with the engineering expertise to build and operate them. Three of the exported units are undergoing major refurbishment. In Canada in 2015, CANDU reactors supply approximately 60% of Ontario's electricity and 15% of Canada's overall electricity requirements.

2.2.2 People's Republic of China

Highlights

- ✓ China is the third largest economy in terms of the number of reactors in operation. Nuclear contributed about 3% of the economy's electricity supply in 2015.
- ✓ The economy drives the growth of future nuclear capacity in the world, with more than 20 reactors under construction representing 40% of the world.
- ✓ China has a plan to increase its nuclear power capacity to 58 GW by 2020.

China started nuclear power research in the late 1970s. Its first nuclear reactor, a 30MW reactor at the Qinshan Nuclear Power Plant, was connected to the grid in 1991. China also imported the French nuclear technology M310, and built the first commercial NPP - Daya Bay Nuclear Power Plant, of which the first unit was connected to the grid in 1993.

China is aiming to construct more NPPs, as the economy is striving to reduce air pollution from coal-fired power plants. By the end of March 2016, 30 nuclear power reactors are in operation with 24 under construction and more to be constructed (Figure 5)[4]. In 2015, the electricity generation output of nuclear was 169 TWh, which was approximately 3% of total power generation. The installed capacity was 26 GW. The year of 2015 also saw the beginning of the greatest number of nuclear power projects in a single year in China since the 2011 crisis, with eight new units being approved for construction (Figure 6).

Following Japan's Fukushima Daiichi crisis in early 2011, China reviewed its NPP safety requirements, and required that all the newly built reactors meet the Generation III safety criteria. Now, all of the NPPs are located in the coastal provinces. China has approved three inland NPP sites along Yangtze River, and was to begin the construction using AP1000 technology in 2011. However after Fukushima, all the inland projects were suspended, and the restart date is still unclear.

[4] As of November 2016, 36 nuclear power reactors are in operation with 20 under construction (Figure 1).

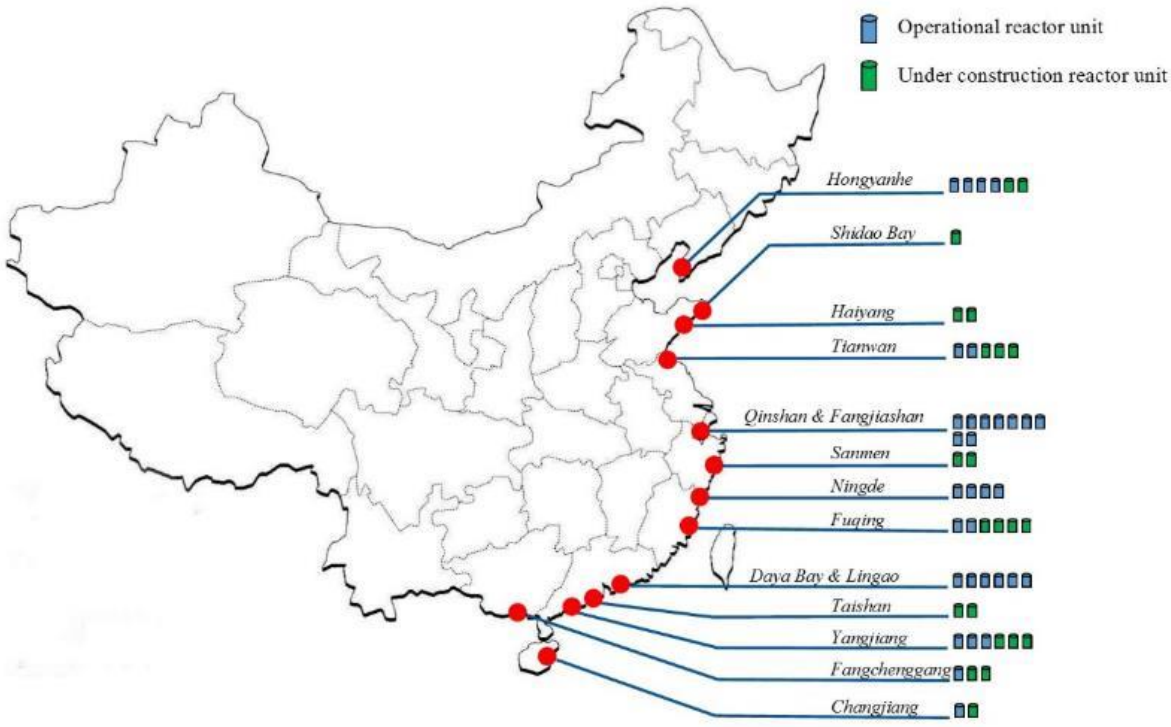

Figure 5 China nuclear reactors by the end of March 2016

The fast reactor is excluded. Data from IAEA. Figure by APERC.

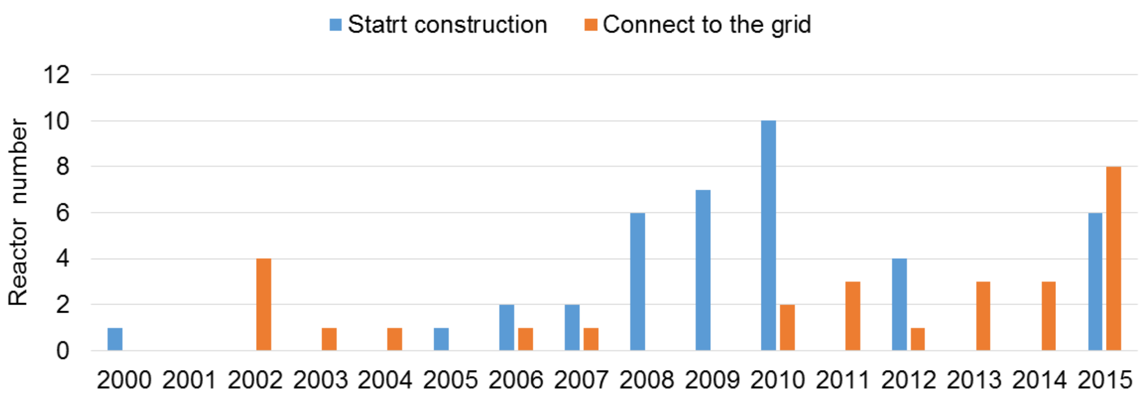

Figure 6 China nuclear reactor construction statistics between 2000 and 2015

The fast reactor is excluded. Data from IAEA. Figure by APERC.

China is seeking more advanced nuclear technology, some of which were provided by foreign companies. In September 2004, the State Council approved plans for four new nuclear reactors in eastern China, with the requirement that participants bid using 1 GW to

1.5 GW reactors of Generation III or higher technology. China's State Nuclear Power Technology Corp. (SNPTC) was tapped to select the foreign technology to use at these plants. During an open bidding process, three foreign companies submitted bids: US-based Westinghouse Corp. (AP1000 reactors); AREVA (European pressurized reactor [EPR] reactors); and AtomStroyExport (water-cooled, water-moderated vessel-type pressurized power reactor [VVER]-1000 reactors). In December 2006, after months of bidding and technical exchanges, Westinghouse's AP1000 design was selected for four plants in Sanmen, Zhejiang; and Haiyang, Shandong. AREVA was later selected to build two separate units in Taishan, Guangdong, using its latest EPR design.

With rapid development in nuclear R&D, there is a strong desire among Chinese leaders to become a global supplier of nuclear power "created in China". On the basis of imported technology, China has developed its own Generation III technology. The advanced reactors Hualong-one (also called HPR-1000 in China), CAP1400, and a high-temperature gas-cooled reactor design (HTGR) are supposed to conquer international markets.

Future perspectives and development plan

China aims to expand its nuclear power industry to reduce air pollution and meet rising demand for electricity. The China nuclear power policy has moved from "moderate development" of nuclear power to "positive development" since 2004, and in 2011-12 to "steady development with safety". In 2007, the Chinese central government approved the "Nuclear Power Medium- and Long-Term Development Plan (2005-2020)", which was drafted by the National Development and Reforms Commission (NDRC). The plan set a target of more than 40 GW capacity for the year of 2020, which would account for about 3% of electricity generation in the economy.

After the Fukushima accident, China started to inspect and review its NPPs and revise its development plan. In October 2012, based on the inspections and reviews, the State Council issued a new development plan that represents a serious and cautious revaluation of safety issues and the pace of development. It is called the Medium- and Long-term Nuclear Power Development Plan (2011-2020), which prioritizes safety and quality in Chinese regulations and set the target of 58 GW of nuclear capacity by 2020.

In April 2016, China signed the Paris Agreement on climate change, giving a strong push to the international efforts against global warming. To fulfill its commitment, China need to increase non-fossil fuel sources in primary energy consumption to about 20%, and peak its carbon emissions by 2030. China recognizes nuclear power and renewables as an important way to achieve these targets, and drafted a plan to expand these capacities.

However, there are still some challenges and uncertainties for China’s nuclear power development. The growth rate of the Chinese economy has seen a slowdown in recent years, which has been referred to as the “new normal”. The slowing economic growth will further contract energy demand in heavy industries, and for the first time the Chinese government worries about the issue of excess capacity. Nuclear now has to compete against low-cost coal-fired generation. Furthermore, nuclear has a lower priority for dispatch in the winter than combined heat and power plants, which are typically coal-fired or gas-fired.

2.2.3 Indonesia

Highlights

- ✓ Uncertainties exist in the future nuclear power utilization. The government has stated that nuclear power will be the last option to meet the economy’s demand.
- ✓ Three research reactors were installed and a fourth is being planned.

With an industrial production growth rate of 10.5%, electricity demand is estimated to reach 450 TWh in 2026. More than one-third of Indonesia's electricity is generated by oil and gas. Therefore, as well as catering for growth in demand in its most populous region, the move to nuclear power will free up oil for export. However, in mid-2012, the National Energy Council (DEN) stated that nuclear power was an unlikely last resort in the economy.

In 2007, the government of Indonesia established the Nuclear Power Development Preparatory Team, whose task is to take the necessary preparatory measures and create plans to build Indonesia’s initial NPPs; however, to date the team has not conducted any significant activities or performed relevant tasks. The legal basis of Indonesia’s nuclear power development includes Law 17/2007 on Long Term Development, Years 2005–15 and Government Regulation 43/2006 on the Licensing of Nuclear Reactors.

Indonesia has developed an indigenous nuclear fuel cycle, although certain stages are still at the laboratory stage. The economy has a well-established nuclear research program, which spans nearly five decades. The National Nuclear Energy Agency (BATAN) currently operates three nuclear research reactors, specifically: the GA Siwabessy 30MW materials testing reactor (MTR), pool-type reactor in Serpong; the Kartini-PPNY 100kW Triga Mark-II reactor in Yogyakarta; and the Bandung 1 000 kW Triga Mark-II reactor in Bandung. A fourth 10MW pool-type research reactor is being planned for development in the near future.

A 2014 review of laws and regulations confirmed that BATAN had the authority to develop and operate the RDNK/RDE reactor in accordance with the Nuclear Energy and Government Regulation Law 1997 and the License of Nuclear Installation and Utilization of Nuclear Materials Law 2014.

In March 2015 the government issued a white paper on national energy development policy to 2050. According to the white paper, nuclear power is expected to provide 5 GW by 2025, alongside other new and renewable sources providing 12 GW. In September 2015 Rusatom Overseas signed an agreement with BATAN on the construction of large NPPs in Indonesia. However, in December the National Energy Council completed the national energy plan to 2050 which awaited presidential signature. This is reported to exclude major nuclear capacity, but has major increases in oil, gas and renewables. In January 2016 BATAN announced that a nuclear energy program implementation organization (NEPIO) was planned for launch in 2016, to move towards having up to four large reactors online by 2025.

In 2017, the Directorate General of New, Renewable Energy and Energy Conservation will set up a roadmap of NPPs as mandated also by the national energy master plan. The roadmap includes: Preparing the technological aspects of NPP; Fuel type; Location; Safety; Legal system (regulation, standard, etc.); and Readiness funding and human resources.

Small scale nuclear power project

At the same time, Indonesia is also seeking the opportunity to deploy small reactors. In April 2015 Rusatom announced that a consortium of Russian and Indonesian companies led by NUKEM Technologies had won a contract for the preliminary design of the multi-purpose 10MW high temperature reactor (HTR) in Indonesia, which would be “a flagship project in the future of Indonesia’s nuclear program”, to deploy a pebble-bed HTR at Serpong.

In August 2016 China Nuclear Engineering Corporation (CNEC) signed a cooperation agreement with BATAN to develop HTRs in Indonesia. CNEC reported that Indonesia aimed to construct small HTRs on Kalimantan and Sulawesi from 2027.

Despite the above developments, the Fukushima Daiichi nuclear accident in 2011 generated negative perceptions discouraging prospects for building NPPs in Indonesia. At the same time, people resisted development on candidate sites, thereby making development uncertain. Hence, the government has stated that nuclear power will be the last option used to achieve Indonesia's energy demand, which implies that the government prioritizes renewable energy sources.

2.2.4 Japan

Highlights

- ✓ In 2010, before the Fukushima Daiichi nuclear accident, nuclear power accounted for more than one-fourth in the generation mix.
- ✓ The year 2014 was the first year without nuclear generation since 1966, when the first commercial nuclear operation started.
- ✓ In July 2015, the government decided the Long-Term Energy Supply and Demand Outlook where nuclear accounts for 20-22% in generation mix in FY2030. This energy mix is the basis for Japan's NDC (Nationally Determined Contributions)

Despite being the third largest economy in terms of GDP and fifth largest energy consumer in the world, Japan imports nearly all of its fossil fuels and uranium due to modest indigenous energy resources. Since the two oil crises in the 1970s, diversifying fuel sources has been the economy's main strategy for improving energy security. Nuclear generation, as quasi-domestic energy, has expanded in this context. Japan had 42 commercial nuclear reactors as of November 2016. While the government reaffirmed the importance of nuclear in the future generation mix, nuclear generation faces mounting public pressure to retire after the Fukushima Daiichi nuclear accident in 2011.

The nuclear program in Japan started in the mid-1950s. The Atomic Energy Basic Law, which outlines the basics of nuclear utilization in Japan, was passed in 1955. Tokai Power Station, which has a gas-cooled reactor, is Japan's first commercial nuclear power station, connected to the grid in 1966 and operated until 1998. The commercial reactors, installed after Tokai, are all LWRs, either BWR or PWR. Tsuruga I, installed in 1970, is the first commercial LWR in Japan.

During the two oil crises of the 1970s, the government realized the vulnerability of its energy supply structure. Since then, the economy has been putting strong efforts into fuel diversification and energy conservation. In 2010, the year before the earthquake, the number of reactors reached 54, with a total capacity of 48.8 GW. Nuclear generation accounted for 27% in the generation mix. After the Fukushima accident, the number of reactors declined to 42 in June 2016 (41.5 GW; see Figure 7), due to the decommissioning of Fukushima Daiichi Nuclear Power Plant and six other reactors: Tsuruga unit 1, Mihama units 1 and 2, Shimane unit 1, Genkai unit 1 and Ikata unit 1. The decommissioning of these six reactors is mainly because of huge investments required for additional safety measures under the new regulatory requirements from July 2013. The electricity generated from nuclear has significantly declined after the earthquake. The year 2014 was the first year without nuclear generation since 1966, when the first commercial nuclear operation started.

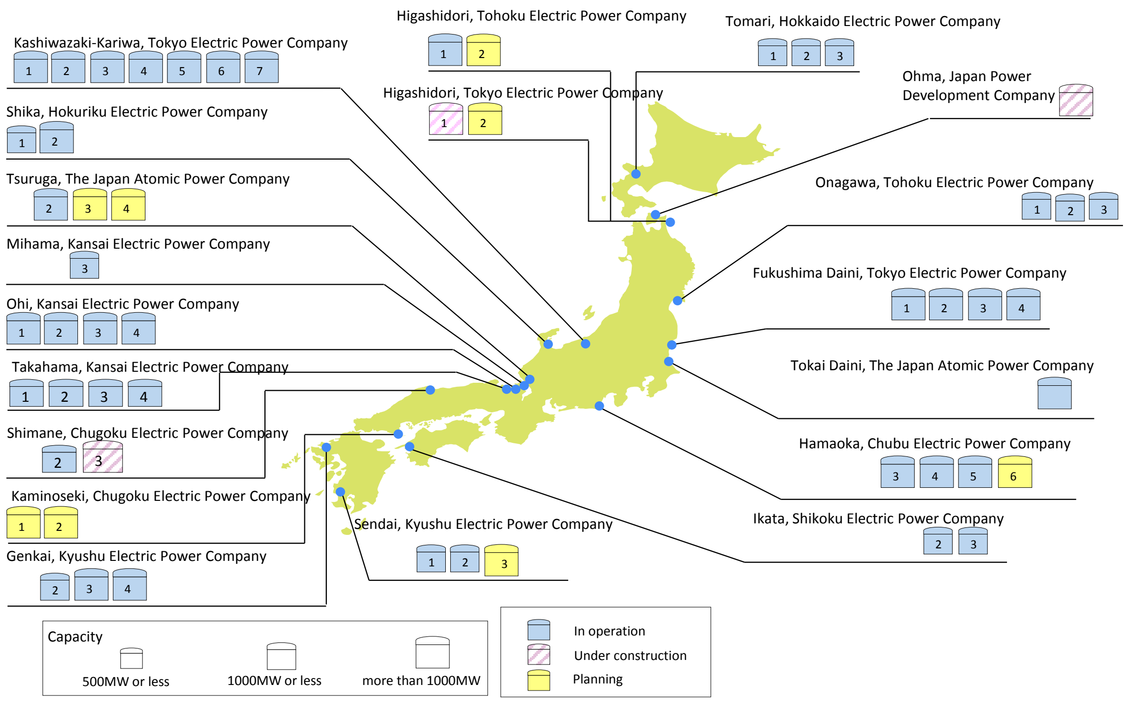

Figure 7 Nuclear power reactors in Japan, as of June 2016

Figure by APERC and IEEJ.

To provide medium- and long-term policy directions after the accident, the Ministry of Economy, Trade and Industry (METI) revised its Strategic Energy Plan in April 2014. This is the fourth plan based on the 2002 Basic Law on Energy Policy. The latest plan mentions that Japan will lower nuclear dependence to the extent possible, while the plan reaffirms the importance of nuclear as a low carbon and quasi-domestic energy source.

Accordingly, in July 2015, the Long-Term Energy Supply and Demand Subcommittee of the Advisory Committee for Natural Resources and Energy of METI approved Japan's Long-Term Energy Supply and Demand Outlook. The government's outlook aims to ensure the "3E+S" policy, and shows a well-balanced generation mix where nuclear accounts for 20-22% in FY 2030. The projected share is lower than the level before the accident (approximately 30%); yet, nuclear still holds a certain share, implying that nuclear will remain one of the important options for Japan's energy policy. This energy mix is the basis for Japan's NDC.

In October 2012 the new Nuclear Regulation Authority (NRA), which had taken over from the Nuclear & Industrial Safety Agency (NISA) and the Nuclear Safety Commission (NSC), announced that henceforth reviews on restarting NPPs would comprise both a safety assessment by NRA and a briefing of affected local governments by the operators. The assessment would be based on the safety guidelines in the New Regulatory Requirements formulated by NRA in July 2013 after public consultation. In rulemaking, NRA commissioners referred to the guidelines of the IAEA, Finland, France and the US, as well as former NISA's July 2011 stress test rules and provisional 30-point measures, issued in April 2012, that were applied to the restarts of Ohi 3 & 4.

Since NRA's establishment, legislation on the regulation of reactors has been consolidated (see Figure 8). The regulatory authority has developed stringent new regulations, incorporated associated agencies to centralize regulatory functions and prepared a plan for emergency responses. The authority also reviews applications for assessing conformity of reactors and fuel cycle facilities to the new regulatory regime.

In the fuel cycle area, Japan has devoted considerable effort to localizing fuel production and closing the nuclear fuel cycle, as well as fuel cycle R&D, including fast reactors. Japan has no domestic uranium production or conversion capabilities. However, Japan Nuclear Fuel Ltd (JNFL) operates a commercial enrichment facility at Rokkasho, and capacity has been built up towards the goal of 1 500 ton separated work units (SWU) per year by 2022. In

2010, installed capacity of 1 150 ton SWU/yr is less than 20% of the annual requirements in the economy; thus, the economy relies on imports to meet nuclear fuel demand. On the other hand, fuel fabrication services are mainly sourced domestically.

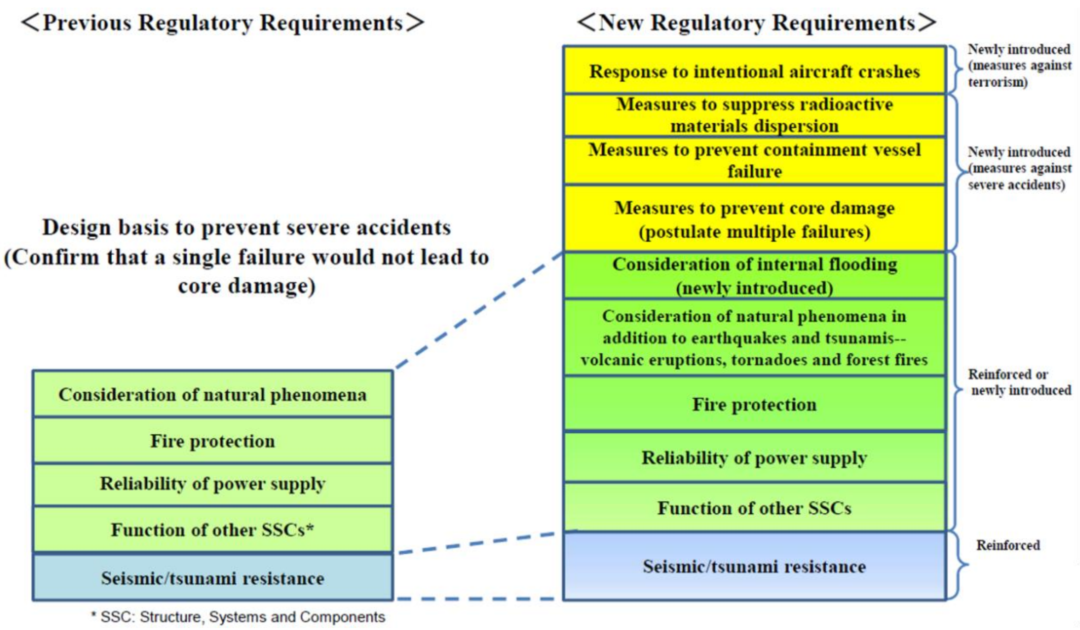

Figure 8 Comparison of regulatory requirements before and after the Fukushima accident
Source: NRA.

As for waste management, low-level radioactive wastes are currently sent in cemented drums for disposal in a shallow underground pit at the low-level radioactive waste disposal facility in Rokkasho operated by JNFL. Geological disposal is a necessity given the accumulation of high-level radioactive waste (HLW) in Japan. The fourth Strategic Energy Plan in 2014 stated that the government "*will take the initiative in dealing with high-level radioactive waste and proceed with measures toward final disposal*"; "*reinforce its efforts to increase the capacity of storing spent fuels*"; as well as "*promote development of technologies for reducing the volume and harmfulness of radioactive waste in order to secure a wide range of options in the future*". In 2014, the Nuclear Waste Management Organization of Japan (NUMO) re-started public outreach activities on an economy-wide scale in 2014; yet, since no host facilities had volunteered by early 2015, the government decided to help siting activities and conducted economy-wide scientific screening for geological disposal.

Challenges

Nuclear power faces various types of challenges in Japan, such as social, technical, institutional and financial. This subsection points out two major challenges. The first challenge concerns waste management, in particular, siting of final disposal facilities for HLW. As mentioned above, despite the efforts over the last decade, NUMO could not even reach the first step of siting procedure. The government partly revised the process after the earthquake, and will increase its involvement. Yet, given that the share of “anti-nuclear” has been increasing year by year in Japan (Figure 9), waste management issues will remain difficult issues, posing significant challenges for long-term utilization of nuclear energy.

Another challenge concerns financing to NPPs. Japanese electricity markets were deregulated in April 2016. In general, market liberalization leads utilities to pursue short-term gains. Without mechanisms to recover capital costs, utilities are less inclined to make long-term investments in capital-intensive infrastructures, including nuclear power. In addition, future integration of renewables would lower wholesale prices, reducing the profitability of other types of generation facilities and creating a further disincentive for investment. These market situations would make it difficult to construct new reactors in Japan.

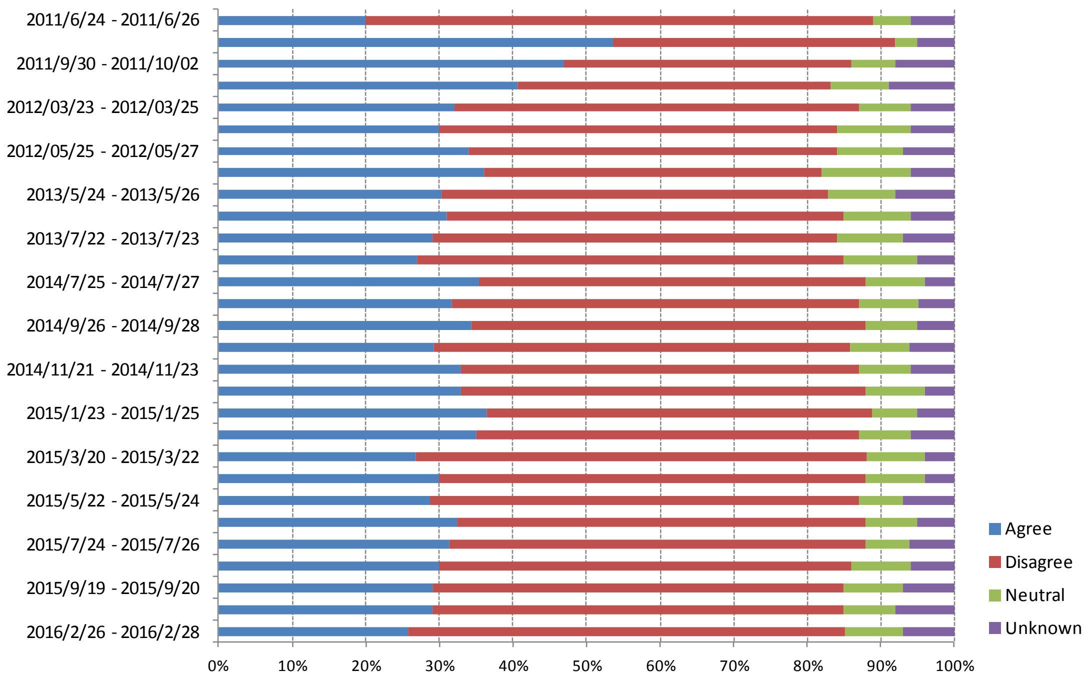

Figure 9 Trends in public opinion on nuclear power in Japan

Survey by Nikkei. Figure by IEEJ.

2.2.5 Korea

Highlights

- ✓ Nuclear is one of the important source for electricity accounting for more than one-fourth in 2013.
- ✓ Nuclear energy remains a strategic priority for Korea; the plan is to increase capacity from 21.7 GW in 2015 to 38 GW by 2029.
- ✓ However, the Moon administration from May 2017 “pledged” nuclear phase out; uncertainties exist in terms of new reactor additions.

Korea is an APEC economy with one of the highest percentages of electricity coming from nuclear power (26% in 2013). It generated 138 TWh by nuclear means in 2013 and currently has an installed nuclear capacity of 21.7 GW coming from 24 reactors, the last of which began commercial operation only recently at Wolsung in July 2015 (Figure 10) (WNA, 2017). Currently four reactors are under construction and six more are scheduled for construction.

Figure 10 Nuclear power reactors in Korea

Figure from WNA[5].

[5] http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx

The reactors, along with the hydro plants in Korea, are owned and operated by Korea Hydro and Nuclear Power Company (KHNP), a state owned utility. Korea embarked in the construction of Kori Unit 1, its first commercial nuclear reactor, in 1971. Eight reactors followed in the 1980s, seven in the 1990s and eight more after the year 2000.

The First Energy Master Plan in 2008 suggested that NPPs should supply energy up to the minimum load point in order to maximize the use of low-carbon nuclear energy. However, in the Second Energy Master Plan in 2014, the government revised the nuclear energy share in the total power generation downward from 41% by 2030 in the first Plan to 29% by 2035 in view of the changes in the conditions of electricity demand, public acceptance and grid stability. A total of 43 GW of installed capacity will be required to raise the share of nuclear energy to 29% by 2035.

In July 2015, the government's seventh basic long-term power development plan of electricity supply and demand was released by the Ministry of Trade, Industry and Energy (MOTIE), which set forth that 12 new reactors would be in operation by 2029 and Kori 1 closed by then. Electricity demand is expected to increase 2.2% annually to 2029, reaching 657 TWh/yr, with peak demand at 112 GW. Nuclear capacity would increase to 38.3 GW, 23.4% of total, up from 21.7 GW in 2015.

However, the Moon administration (from May 2017) "pledged" nuclear phase out on 19th June 2017. Uncertainties exist in terms of new reactor additions in Korea.

Nuclear power technology development – APR 1400

The APR1400 (Advanced Power Reactor 1400) is an advanced pressurized water nuclear reactor designed by the Korea Electric Power Corporation (KEPCO), originally known as the Korean Next Generation Reactor (KNGR). This Generation III reactor was developed from the earlier OPR-1000 design and also incorporates features from the US Combustion Engineering (C-E) System 80+ design. Currently there is one unit in operation (Shin Kori unit 3) and seven units under construction, four of which are in the UAE at Barakah and three in Korea: one at Shin Kori and two at Shin Hanul. The construction of two more units is planned but has yet to commence at Shin Kori (WNA, 2017). In June 2010 Doosan signed a USD 3.9 billion contract to supply heavy reactor components and turbines to KEPCO for four APR1400 reactors in UAE.

The APR1400 has been further developed into the APR+ design, which received its official type certification on August 14, 2014. The reactor design features improved safety and among others "a core damage frequency an entire order of magnitude lower than that calculated for the APR1400 design that it supplants". The APR+ core uses 257 fuel assemblies (16 more than APR1400) to increase output to 1550 MW.

Nuclear power technology development – SMART reactors

The Korea Atomic Energy Research Institute (KAERI) has been developing the SMART (System Integrated Modular Advanced Reactor) – a 330 MWt PWR with integral steam generators and advanced passive safety features. It is designed for generating electricity (up to 100 MW) and/or thermal applications such as seawater desalination – up to 40 000m^3/day. Design life is 60 years, with a three-year refueling cycle. In mid-2010 a consortium of 13 Korean companies led by KEPCO pledged KRW 100 billion (USD 83 million) to complete the design work. US-based engineering company URS provided technical services to KAERI. Nuclear Safety and Security Commission (NSSC) licensed the design (standard design approval) in 2012 and KAERI incorporated post-Fukushima modifications in 2016, making cooling fully passive. Cost is expected to be about 5 000 USD/kW. It has 57 fuel assemblies very similar to normal PWR ones but shorter, and it operates with a 36-month fuel cycle.

2.2.6 Malaysia

Highlights

- ✓ Malaysia has developed a research reactor since 1982.
- ✓ Malaysia has established the Nuclear Power Development Steering Committee and Nuclear Agency; current preparatory activities focus on detailed studies to identify issues and to assess the economy’s capability for nuclear development

Malaysia is currently exploring the option of deploying nuclear energy in order to meet future energy supply demand, and is also seeking to provide for a diversified energy mix for Peninsular Malaysia. Historically Malaysia is not a newcomer to the nuclear industry. The history of nuclear technology in Malaysia started in 1970 when, following a visit to the Nuclear Research Centre in Indonesia, Malaysia's former Deputy Prime Minister mooted a nuclear power program for the economy. He proposed to the government that Malaysia should play a role in the development of nuclear science and technology for peaceful purposes. The proposal was accepted, leading to the establishment of the Centre for Application of Nuclear Energy (CRANE) in the same year. CRANE focused on manpower development for various nuclear isotope applications in medicine, agriculture and industry, eventually expecting to lead to a nuclear power program as a future energy resource.

In 1972 CRANE was renamed the Atomic Research Centre (PUSPATI—Pusat Penyelidikan Atom). Towards the realization of the nuclear power program a 1 MW swimming pool-type research reactor was purchased, with technical assistance provided by IAEA. Feasibility studies and site evaluation started in 1978 and construction began in 1979. The reactor was commissioned in 1982. When oil and gas was discovered, the priority for a nuclear power program subsequently diminished, and research and training for the nuclear power program slowly shifted to other areas of technology. In addition to the nuclear power program, PUSPATI (now re-established as the Malaysia Nuclear Agency [MNA]) focused its efforts on research and applications in the agriculture, food, medicine and industry sectors.

To fulfill the new energy policy objectives, nuclear energy was reconsidered as an alternative energy source in the Tenth Malaysia Plan, seeking to diversify its energy mix for future sustainability. A Nuclear Power Development Steering Committee, headed by the Ministry of Energy, Green Technology and Water, was set up in June 2009 to plan and coordinate the preparatory efforts for deploying a nuclear power program for electricity generation (Figure 11). The committee was tasked with conducting various studies towards preparing a Nuclear Power Infrastructure Development Plan (NPIDP), targeted to be ready by 2013. Prior to conducting these studies, a nuclear power pre-feasibility study and initial site selection study were already under way.

In accordance with a tentative timeline, the pre-project activities are being spearheaded by the Malaysia Nuclear Power Corporation (MNPC) and the Nuclear Energy Programme Implementing Organization (NEPIO), with MNA as the Technical Support Organization (TSO). MNPC is a fully government-owned company under the jurisdiction of the Prime Minister's Department, and was officially launched by the Prime Minister under the Economic Transformation Programme (ETP) on 11 January 2011. Current preparatory activities in MNPC and MNA focus on detailed studies to identify issues and to list considerations to objectively determine and assess the current level of national capability and state-of-preparedness pertaining to the development of a national nuclear power program.

Figure 11 Target milestones for Malaysia nuclear power development

Figure from MNPC.

2.2.7 Mexico

Highlights

- ✓ Mexico has two reactors in operation, contributing 4% of generation mix.
- ✓ Upgrades for both reactors are finished in 2015, resulting in additional capacity of 110 MW each. Total nuclear capacity increase from 1400 MW to 1620 MW.

While nuclear-based generation formally started in Mexico in 1990, the economy's plans for nuclear development date back to at least the late 1950s. At the time, the federal government decided to embark on the development of nuclear energy largely because of the Atoms for Peace Program fostered by the United States; although the much smaller estimates of domestic oil/gas resources back then and the desire to join the growing group of economies pursuing the nuclear path might have also played a significant role in this decision.

In 1956 Mexico's interest in nuclear energy was made official with the creation of its National Commission of Nuclear Energy (CNEN), which became responsible for the peaceful application of nuclear power for energy and non-energy uses and the research on these subjects. By 1968, CNEN had acquired the first nuclear reactor in Mexico, a TRIGA Mark III of small capacity specifically designed for training and research purposes. To hasten Mexico's progress in nuclear development, in 1972 CNEN became the National Institute of Nuclear Energy (INEN), and in 1979 a new Law for Nuclear Energy split INEN's functions into several bodies: the National Institute for Nuclear Research (ININ), the National Commission for Nuclear Safety and Safeguards (CNSNS), and Mexican Uranium (Uramex). In 1985 Uramex was absorbed by the Ministry of Energy. It was also in 1972 that Mexico approved the installation of its first and thus far only NPP, amid substantial operational delays. In fact, the construction of the Laguna Verde nuclear power plant started in 1976 and it came online only in 1990. Laguna Verde has two reactors, both are BWR with a capacity of 810 MW currently.

The operation licenses for Laguna Verde's units are valid for 30 years and were approved in July 1990 for Unit 1 and in April 1995 for Unit 2. The plant is owned and operated by the Federal Electricity Commission (CFE), Mexico's state-owned and largest electricity utility. As shown in Figure 12, it is located in the southern state of Veracruz, which borders the Gulf of Mexico. While upgrades and maintenance could extend Laguna Verde's lifespan, unless further time extensions are requested by CFE to CNSNS beyond the current licenses, Unit 1 will stop operation by 2020 and Unit 2 by 2025.

Figure 12 Nuclear power reactors in Mexico.

Figure from APERC.

With a total capacity of 1 510MW and an output of 11.6 TWh/yr in 2015, the Laguna Verde nuclear power plant accounted for little more than 2% of Mexico's electricity generation capacity and over 4% of its electricity production.

Prior to the 2013 energy reform, Mexico passed the Law for the Use of Renewable Energy and Financing of Energy Transition in 2008, in order to reduce the dominance of fossil fuels in the economy-wide electricity mix through renewable and environmentally sustainable energy solutions. To that end, the Law mandated the maximum share of fossil energy in Mexico's total electricity generation at 65% by 2024, 60% by 2035 and 50% by 2050. This Law was overridden by the Law for Energy Transition passed in December 2015 which largely preserved these goals, and mandates the minimum share of economy-wide electricity generation based on clean energy (renewables and nuclear) at 25% by 2018, 30% by 2021 and 35% by 2024. Against this background of legal instruments and mandates, the Mexican government has not put forward any actions suggestive of a large expansion of its nuclear-based electricity generation, although the upgrade of both reactors finished in 2015 resulted in 110 MW of additional capacity each.

2.2.8 The Philippines

Highlights

- ✓ Nuclear power was considered as a solution to the 1973 oil crisis in the Philippines.
- ✓ The Bataan Nuclear Power Plant was finished in 1984, but did not start operation.
- ✓ Whether or not to go nuclear is still being discussed, but last October 2016, the economy's Nuclear Energy Program Implementing Organization (NEPIO) was created.

In 1973, the Philippine economy was under a lot of pressure due to the oil crisis. With the intention of finding an alternative energy source, President Marcos decided to construct an NPP. Workers started building the power plant in 1976. Construction was put on hold in 1979 because of the Three Mile Island accident that happened in the United States. The President of the Philippines issued Executive Order No.539 creating a Presidential Commission (Puno Commission) to conduct an inquiry on the safety of the Bataan Nuclear Power Plant (BNPP). The results of the Commission's inquiry were outlined in the Puno Commission Report whereby added safety features and procedures were recommended to be installed at BNPP. Hence, BNPP was upgraded to incorporate post TMI recommendations. The BNPP was completed in 1984. Upon payment of its loan by the Philippine Government in April 2017, the plant costs rose from its original figure of USD 1.9 Billion to USD 2.3 billion. With its Westinghouse PWR, BNPP was supposed to generate 621 MW of electric energy. It took 10 years to build but it has been on "preservation mode" or mothballed since 1986 when a new government took over the reign from then President Marcos. Despite never having been commissioned, the plant has remained intact, including the nuclear reactor, and has continued to be maintained.

On 29 January 2008, Energy Secretary Angelo Reyes announced that an IAEA team inspected the BNPP on rehabilitation prospects. In preparing their report, the IAEA made two primary recommendations. First, it advised that the power plant's status be thoroughly evaluated by technical inspections and economic evaluations conducted by a committed group of nuclear power experts with experience in preservation management. Second, the IAEA mission advised the Philippines government on the general requirements for starting its nuclear power program, stressing that the proper infrastructure, safety standards and knowledge be implemented. The IAEA's role did not extend to assessing whether the power plant is usable or how much the plant may cost to rehabilitate. On 1 February 2010, the National Power Corporation (NAPOCOR) started evaluating the financial plan of KEPCO which assessed that it may cost USD 1 billion to rehabilitate the NPP. In October 2016, again upon takeover of the new government, interest in BNPP rehabilitation was renewed, as well as consideration for new additions emerged. The Department of Energy (DOE) formally established the NEPIO that composed of officials initially all came from various bureaus of the DOE. The organization currently considers various proposals for the possible rehabilitation of BNPP as well as cooperation initiatives for new reactor additions.

The Philippines has one research reactor built by General Electric of the US in August 1963 with a rating of 1 MW thermal. It was converted to TRIGA reactor in 1988 but due to leaks detected at the pool, the reactor’s full capacity of 3 MW cannot be attained. It can only be used at low power operation (250 kW), and the Philippine Nuclear Research Institute, the operator/owner of the reactor, decided to decommission it. The country is now looking at constructing a new research reactor with a rating of 10 MW.

2.2.9 Russia

Highlights

- ✓ In 2015, nuclear power contributed 19% of electricity supply in Russia. As of November 2016, the economy has 36 reactors with 27 GW capacity in operation.
- ✓ According to Rosatom's plan, nuclear is expected to expand in the mid- to long-term.
- ✓ The economy is also carrying out research on fast neutron reactor technology.

Nuclear power plays an important role in Russia's energy mix, accounting for about 19% of the total power generation in 2015, according to data from Rosenergoatom (WNA, 2017). There are 36 reactors as of November 2016, including Generation I VVER-440-similar PWRs, Generation II VVER-440 PWRs, Generation III VVER-1000 PWRs with a full containment structure, RBMK light water graphite reactors, as well as small graphite-moderated BWR reactors in eastern Siberia constructed in the 1970s for cogeneration.

In November 2009, the government's Energy Strategy 2030 was published, projecting investments for the next two decades. It envisaged a possible doubling of generation capacity from 225 GW[6] in 2008 to 355-445 GW in 2030. A revised scheme in mid-2010 projected demand of 1 288 TWh in 2020 and 1 553 TWh in 2030, requiring 78 GW from new plants by 2020 and building a total of 178 GW new capacity by 2030, including 43.4 GW nuclear. The scheme also included decommissioning 67.7 GW of capacity by 2030, including 16.5 GW of NPP (about 70% of present capacity). New investment by 2030 was estimated to be RUR 9 800 billion for power plants and RUR 10 200 billion for transmission (WNA, 2017).

In July 2012 the Energy Ministry (Minenergo) published draft plans to commission 83 GW of new capacity by 2020, including 10 GW nuclear, to total 30.5 GW producing 238 TWh/yr. A year later Minenergo reduced the projection to 28.2 GW in 2019. Total investment envisaged was RUR 8 230 billion, including RUR 4 950 billion on upgrading power plants, RUR 3 280 billion on new grid capacity and RUR 1 320 billion on nuclear. According to WNA (2017), in January 2015, Rosatom published the plan for new reactor additions and retirements of existing reactors (Figure 13).

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[6] This figure indicates total generation capacity, including nuclear, fossil fuels as well as renewables.

Figure 13 Russian reactors' planned additions and retirements to 2035. Figure from Country Profiles - WNA.

After the Fukushima accident, safety reviews were conducted for NPPs in Russia. Following these, in June 2011 Rosenergoatom announced a RUR 15 billion (USD 530 million) safety upgrade program for additional power and water supply back-up. By the end of 2015, Rosenergoatom has spent RUR 2.6 billion on 66 mobile diesel generator sets, 35 mobile pumping units and 80 other pumps, to enhance nuclear safety, especially emergency preparedness.

2.2.10 Chinese Taipei

Highlights

- ✓ Nuclear power has six reactors, contributing 19% of generation mix in 2015.
- ✓ After the accident in Fukushima, the government decided to phase out all nuclear capacity by 2025.

Chinese Taipei has six nuclear reactors, totaling 5 GW and representing 19% of its electricity generation as of 2015. Taipower, Chinese Taipei's state-owned power utility, accounts for approximately 80% of the electricity supply in the economy, and IPPs for the remaining. The control over nuclear and hydro plants is maintained by Taipower. Six reactors in operation were commissioned in between 1977 and 1985, consisting of four BWRs and two PWRs (Figure 14). Construction of the Lungmen Nuclear Power Plant using the ABWR design has encountered public opposition and a host of delays, and in April 2014 the government decided to suspend construction.

In response to the Fukushima accident in 2011, Chinese Taipei released the New Energy Policy on 3 November 2011 to "*ensure nuclear security, steadily reduce nuclear dependence, create a low-carbon green energy environment and gradually move towards a nuclear-free homeland*". This policy aims to steadily reduce nuclear dependence by lowering electricity demand and peak loads, and by promoting alternative energy sources to ensure a stable power supply. The new policy prohibits lifetime extensions for existing NPPs and outlines decommissioning plans as follows: Units 1 and 2 of the first plant will be decommissioned in 2018 and 2019; Units 1 and 2 of the second plant, in 2021 and 2023; and Units 1 and 2 of the third plant, in 2024 and 2025.

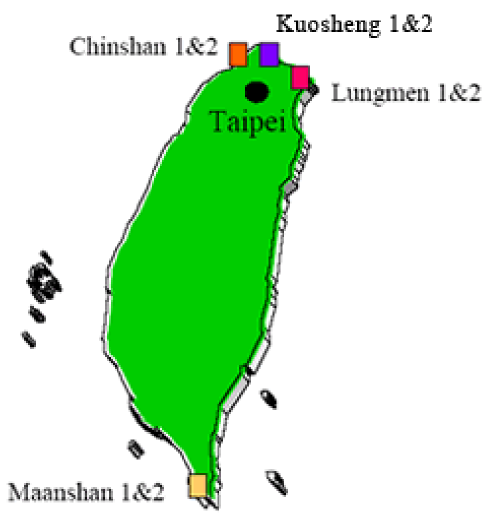

Figure 14 Nuclear power plants in Chinese Taipei

Figure from Taipower. Note: Lungmen 1&2 has not yet commissioned, and construction of the reactors are suspended.

In June 2016, the new leader of Chinese Taipei stressed again that the administration’s goal to phase out nuclear power by 2025 "*has never changed and will never change*". However, the administration also admitted that many challenges remain on the road toward that goal, as evidenced by the tight electricity supply situation in the preceding weeks due to high demand caused by high temperatures.

2.2.11 Thailand

Highlights

- ✓ Thailand is considering to embark on nuclear power as an option in their energy mix, to reduce its natural gas consumption.
- ✓ Public acceptance remains the key challenge for nuclear power installation.

In 2007, The National Energy Policy Council (NEPC) appointed the Nuclear Power Infrastructure Preparation Committee (NPIPC) and the Nuclear Power Programme Development Office (NPPDO) to prepare Nuclear Power Infrastructure Establishment Plans (NPIEP) and a nuclear utility plan. During 2008-2010, the appointed organizations collaborated and completed the pre-project activities in phase 1 in line with IAEA milestones. The activities included the setup of NPPDO, the preparation of infrastructure work, the dissemination of nuclear information to gain public acceptance, the feasibility study and the site selection evaluation of the NPPs. Self-assessment on 19 issues of the economy’s nuclear infrastructure was also conducted, and in December 2010, the IAEA accomplished the Integrated Nuclear Infrastructure Review (INIR) Mission in Thailand. Based on the results from the self-assessment and IAEA’s INIR, Thailand was ready to make a knowledgeable commitment to install NPPs in the economy. According to IAEA, however, there are several major gaps to be addressed in developing the nuclear power infrastructure. In the short term, the government should make a concrete commitment for safe and secure implementation of nuclear power. The national nuclear legislations and regulations are needed to be standardized in order to comply with the international legal instruments. Also, the details of human resource development plan (HRDP) are required to support the nuclear power project. In early 2011, a “readiness report” was submitted for the government to make the decision to “Go Nuclear.”

After the Fukushima Daiichi Nuclear Power Plant incident caused by the earthquake and tsunami in March 2011, the Second Revision Power Development Plan (PDP) 2010 postponed the scheduled commercial operation date (SCOD) of the first unit of the nuclear power project by three years (from 2020 to 2023). Subsequently, the Third Revision PDP 2010 further shifted the SCOD of the first unit out to 2026 and revised the commencement of the second unit operation to 2027. However, in 2014, NEPC reformulated a PDP 2015 with a new framework and assumptions of power generation consistent with the newly developed Thailand Integrated Energy Blueprint (TIEB). The latest PDP 2015, which encompasses the timeline of 2015-36, includes 1 GW of nuclear power to the grid in 2035 and another 1 GW in 2036. By 2036, nuclear power would comprise approximately 5% of total generation capacity in Thailand.

2.2.12 The United States

Highlights

- ✓ The US is the largest nuclear power economy in the world, with 99 commercial nuclear reactors accounting for more than 30% of global nuclear generation, as of 2016.
- ✓ Nuclear power is expected to remain as the important source for electricity in the mid- to long-term, but decreasing its share due to gradual demand growth.
- ✓ Once-through fuel cycle is current policy for spent fuel management.

Nuclear power plays a major role in the US power supply. As of November 2016, the United States had 99 nuclear power reactors, which contributed about 20% of its electricity supply in 2015. These plants have achieved an average capacity factor of 90% since 2001. The industry invests about USD 7.5 billion per year in maintenance and upgrades of the plants. Existing reactors are mainly located around north-east, south and mid-west part of the economy (Figure 15). According to the Reference case in EIA (2017), nuclear remains as the important source for electricity in the mid- to long-term, but decreasing the share, from 20% in 2015 to 16% by 2040, due to gradual demand growth (Figure 16).

Currently, there are 65 PWRs with combined capacity of about 64 GW, and 34 BWRs with combined capacity of about 35 GW. Almost all the US nuclear generating capacity comes from reactors built between 1967 and 1990. Until 2013 there had been no new construction starts since 1977, largely because for a number of years gas generation was considered more economically attractive and because construction schedules during the 1970s and 1980s had frequently been extended by opposition, compounded by heightened safety fears following the Three Mile Island accident in 1979 (WNA, 2017).

Figure 15 Nuclear power plants in the United States

Figure from World Nuclear Association.

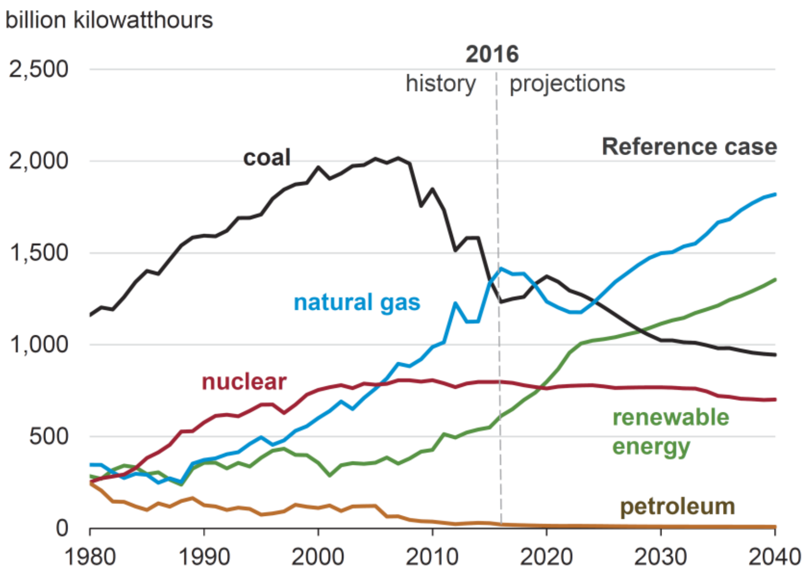

Figure 16 Projected power generation, the United States

Figure from Annual Energy Outlook 2017 (EIA, 2017).

Despite a near halt in new construction of more than 30 years, US reliance on nuclear power has grown. In 1980, NPPs produced 250 TWh, accounting for 11% of the economy's generation. In 2008, that output had risen to 809 TWh and nearly 20% of electricity, providing more than 30% of the electricity generated from nuclear power worldwide. Much of the increase came from 47 reactors, all approved for construction before 1977, which came on line in the late 1970s and 1980s, more than doubling US nuclear generation capacity. The US nuclear industry has also achieved remarkable gains in power plant utilization through improved refueling, maintenance and safety systems at existing plants.

The future of nuclear power in the United States will depend on several factors including reduction of nuclear construction costs, greater regulatory certainty, development of favorable government policies, and the relative costs of other energy options as well as resolution of nuclear waste disposal issues. Recently, the greatest commercial challenges to the continued operation of the nuclear power industry include:

- The low price and relatively high availability of natural gas from shale deposits;
- Slow economic growth; and
- Slow growth in overall electricity demand.

Although nuclear power faces various challenges in the United States, it is expected to remain an important element of the present government's "All-of-the-Above" strategy for energy – helping to advance a sustainable, clean energy future. Accordingly, the DOE is pursuing five strategic goals:[7]

- Extend the useful life, improve the performance, and maintain the safety of the current fleet of NPPs. This is the objective of the Light Water Reactor Sustainability Program;
- Enable new NPPs to be built for electricity production and improve the affordability of nuclear energy. The Nuclear Plant 2010 (NP2010) Program[8] is a joint government/ industry cost-shared effort to identify sites for new NPPs, develop and bring to market advanced NPP technologies, evaluate the business case for building new NPPs and demonstrate untested regulatory processes. Two project areas are active: GE Hitachi

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[7] Statement of Dr Peter Lyons, Assistant Secretary for Nuclear Energy, US Department of Energy: https://energy.gov/sites/prod/files/2015/01/f19/12-11-14_Peter%20Lyons%20FT%20HSST.pdf

[8] https://energy.gov/sites/prod/files/Presentation%20-%202010%20Program%20 Overview%20-%20Presentation%20to%20the%20NEAC.pdf

Nuclear Energy detailed design work, and Nustart construction and operating licenses (COL) application development;

- Reduce the carbon footprint of transportation and industry. The heat generated by nuclear energy can be harnessed for process heat, thus reducing or eliminating the need to burn fossil fuels for this purpose. Developing this capability is one objective of the Next Generation Nuclear Plant (NGNP) initiative;
- Develop a sustainable fuel cycle. The Fuel Cycle Research and Development Program is developing ways to make used fuel less radiotoxic, recycle it and create widely acceptable solutions to the challenges of nuclear waste; and
- Prevent proliferation. Developing techniques and materials to prevent proliferation are objectives of the Fuel Cycle Research and Development Program.

Advanced nuclear technology development

The United States is leading the world's advanced nuclear technology development, especially in the Generations III and IV reactor design. The Generation III reactor designs now having US design certification include:

- The GE Hitachi ABWR of 1 300-1 500 MW. Several ABWRs are now in operation in Japan, with more under construction there and in Chinese Taipei. Some of these have had Toshiba involved in the construction, and more recently it has been Toshiba that promoted the design most strongly in the US;
- The Westinghouse AP1000 is the first Generation III+ reactor to receive certification. It is a scaled-up version of the Westinghouse AP600 which was certified earlier. It has a modular design to reduce construction time to 36 months. The first four of many are being built in China, and four more in the US (two units at the Vogtle nuclear station and two units at the V.C. Summer). Note that there still exist uncertainties regarding the construction at the V.C. Summer. On 31st July 2017, South Carolina Electric & Gas (SCE&G), one of the utilities that owns the new units, announced that "*it will cease construction of the two new nuclear units*" and will promptly file a petition seeking approval of its abandonment plan after considering the additional costs, as well as the

amount of anticipated guaranty settlement payments from Toshiba Corporation.[9] However, on 15th August 2017, the company announced that "*it will voluntarily withdraw its Abandonment Petition*" in response to the concerns from various stakeholders and members of the South Carolina General Assembly, and to allow for adequate time for governmental officials to conduct their reviews[10]; and

- GE Hitachi's Economic Simplified BWR (ESBWR) of 1 600 MW gross, developed from the ABWR. The ESBWR has passive safety features and is currently included in the COL applications of two companies in the US. GE Hitachi submitted the application in August 2005, was notified of design approval in March 2011 and received design certification in September 2014. The first COL with it was approved in May 2015.

In addition, several designs of small modular reactors (SMRs) are proceeding towards NRC design certification application, including the Holtec SMR-160 PWR, the NuScale multi-application small reactor and the X-energy's Xe-100 pebble-bed SMR.

Nuclear fuel cycle and waste management

It is important to mention the activities of nuclear fuel cycle in the United States. Currently, most of the commercial nuclear fuel cycle activities are conducted in the United States, except reprocessing. Spent fuel reprocessing for waste management in the United States has been discouraged by public policy, and the once-through fuel cycle is the present policy along with an active research and development program on advanced fuel cycle alternatives. Each fuel cycle stage is subject to competition and supply from international sources, which in many cases dominate the industry segment. At present, the US nuclear fuel supply is highly dependent on imports for mined uranium concentrates, uranium conversion and enrichment. Virtually all fuel fabrication requirements are met by domestic sources. The EIA

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9 SCANA (2017): "South Carolina Electric & Gas Company to cease construction and will file plan of abandonment of the new nuclear project", https://www.scana.com/docs/librariesprovider15/pdfs/press-releases/07312017-sce-amp-g-to-cease-construction-and-will-pursue-abandonment-of-the-new-nuclear-project---scana-reaffirms-earnings-guidance.pdf?sfvrsn=0

10 SCANA (2017): "South Carolina Electric & Gas Company to voluntarily withdraw its new nuclear abandonment petition to accommodate the legislative review process", https://www.scana.com/docs/librariesprovider15/pdfs/press-releases/08152017-sce-amp-g-to-voluntarily-withdraw-its-new-nuclear-abandonment-petition-to-accommodate-the-legislative-review-process.pdf?sfvrsn=0

publishes data on the nuclear fuel cycle in its Domestic Uranium Production Report and its Uranium Marketing Annual Report.

Since the beginnings of the commercial use of nuclear power in the US, spent fuel assemblies have been stored under water in pools (and later in dry casks as well) at reactor sites, and remained the responsibility of the plant owners. The prohibition of spent fuel reprocessing in 1977, combined with the continued accumulation, brought the question of permanent underground disposal to the forefront. The 2012 spent fuel inventory in the United States was approximately 70 000 metric tonnes of uranium, with around 2 800 tonnes stored at sites that have shutdown reactors. Approximately one-third of this material is stored in dry casks with the remainder in hardened pools; the share of fuel in dry storage will continue to grow as pools reach their capacities. The NRC licenses dry storage containers for 20 years and has said that fuel can safely be stored at reactor sites for at least 100 years.

2.2.13 Viet Nam

Highlights

- ✓ Viet Nam was considered to become the first Southeast Asian economy to embark on nuclear power.
- ✓ However, in November 2016, Viet Nam's National Assembly abandoned the plan to build NPPs, considering the decreasing electricity demand and rising financial costs.

Viet Nam was considered to be the first Southeast Asian economy that would embark on nuclear power. In the early 1980s, two preliminary nuclear power studies were undertaken in Viet Nam. In 2006, firm proposals surfaced and the Vietnamese government announced that a 2 GW NPP should be on line by 2020. This general target was confirmed in a nuclear power development plan approved by the government in August 2007, with the target being raised to a total of 8 GW nuclear by 2025. A general law on nuclear energy was passed in the middle of 2008, and plans for developing a comprehensive legal and regulatory framework were envisaged (APERC, 2016b).

In October 2008, two major locations in Ninh Thuan Province, namely Phuoc Dinh and Vinh Hai, were confirmed by the Vietnamese government as the sites to implement its first ever nuclear power projects, with two reactors with a capacity of 1 GW on each site, totaling nearly 4 GW of power output. In June 2010, Viet Nam announced that it plans to build 14 nuclear reactors at eight sites in five provinces by 2030, to satisfy at least 10% of the power generation of the economy.

In October 2010, Viet Nam signed an intergovernmental agreement with Russia for the construction of the economy's first NPP - Ninh Thuan 1 at Phuoc Dinh, using the VVER-1000 or 1200 technologies. Also, an intergovernmental agreement with Japan was signed for construction of a second NPP using Japanese technology. However, in January 2014 it was reported that Viet Nam decided to delay construction by six years, to permit improved safety and efficiency in the plants.

In January 2006, the Prime Minister approved the Strategy for Peaceful Applications of Atomic Energy to 2020 with the overall objective to gradually build and develop the atomic technology industry to increasingly and effectively contribute to socioeconomic development and strengthen the economy’s scientific and technological capacity. The subsequent Prime Minister's Decisions No. 114/2007/QD-TTg (issued in July 2007) and No. 957/QD-TTg (issued in June 2010) detailed the government’s action plans for the implementation of this strategy. In regard to nuclear power investment, the government stipulates to select proven/accredited safe and modern nuclear technologies. The Ministry of Industry and Trade (MOIT) is responsible for formulating a detailed policy and road map for acquiring, mastering and developing nuclear power technologies.

The Viet Nam Power Development Master Plan for the period 2010–20, with a perspective to 2030 (PDP7) (for both approved versions in 2011 and its revision in 2016 by the Prime Minister), promotes nuclear power development to ensure Viet Nam’s electricity supply security in the future, when domestic primary resources becomes exhausted. The government of Viet Nam has been actively cooperating with other governments and international organizations to accelerate nuclear power construction and development programs. According to the PDP7 issued in 2011, the first introduction of 2 GW of nuclear power was scheduled in 2020; the capacity would gradually increase to 10.7 GW in 2030, so that the nuclear power source could produce annually about 70.5 TWh, accounting for 10.1% of total power generation.

Since October 2008, two reactors totaling 2 GW have been planned at Phuoc Dinh in the southern Ninh Thuan province. A further 2 GW was planned at Vinh Hai nearby, followed by a further 6 GW by 2030. Both locations are based particularly on geological suitability.

In July 2011 the government issued a master plan specifying Ninh Thuan 1&2 NPPs with a total of eight 1GW-class reactors, one coming on line each year between 2020-27, followed by two larger ones to 2029 at a central location. MOIT is responsible for the actual projects, while the Ministry of Science and Technology (MOST) supports the program, developing a master plan and regulation.

However, in November 2016, Viet Nam's National Assembly voted to abandon plans to build the NPPs, considering the decreasing demand for nuclear power and rising costs. They will be replaced with 6GW of LNG and coal by 2030, based on short-term cost considerations; and imports of power mainly from Laos and renewables will also supplement this.

2.3 Uranium resources and production

Uranium resources are classified according to the degree of their geological assurance and the economic feasibility of their recovery. The OECD Nuclear Energy Agency (NEA) together with IAEA in their biennial report on the world's uranium reserves, define four categories according to the confidence levels of occurrence. Reasonably assured resources (RAR) occur in known mineral deposits of delineated size, grade and configuration and can be recovered within given cost ranges with currently existing mining and processing technology (NEA, 2014; 2016).

Estimated additional resources-Category I (EAR-I) are resources that are inferred to occur based on direct geological evidence in extensions of well-explored deposits or in deposits where geological continuity has been established. Category II of estimated additional resources (EAR-II) are expected to occur in deposits for which the evidence is mainly indirect and which are believed to exist in well-defined geological trends or areas of mineralization with known deposits. Speculative resources (SR) are resources that are thought to exist mostly based on indirect evidence and geological extrapolations in deposits discoverable with existing exploration techniques. Their location can only be characterized as being somewhere within a given region or geological trend. In general terms, while RAR and EAR-I include known or delineated resources, EAR-II and speculative resources have yet to be discovered. A further categorization is required to reflect differences in the recovery costs of resources. The cost of recovery depends on both the quality of the resource and on mine-operating costs.

By the beginning of 2015, the economies in the world with the largest proven reserves are, in order: Australia, Canada, Kazakhstan, Niger and Namibia (Figure 17). APEC economies that reported resources to this survey own over 2 million tonnes of these proved reserves. APEC economies Australia, Canada, Russia and China account respectively for 29%, 9%, 9%, and 5% of the world's total (RAR plus Inferred Recoverable Resources, to 130 USD/kg U) (NEA, 2016).

According to the OECD NEA report, global uranium production in 2014 has decreased by 4% since 2013, yet still above 2011 levels. Kazakhstan, the world's leading producer, continues to increase production, but at a slower pace. APEC produced more than 30% of the uranium in the world. More detailed information could be found in Figure 18.

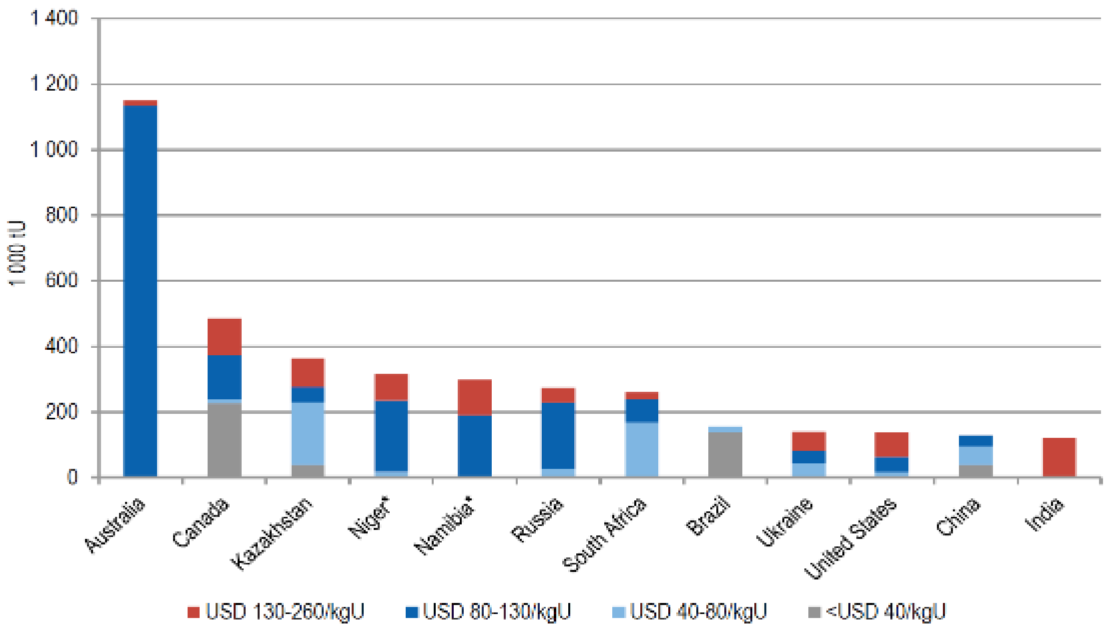

Figure 17 Distribution of reasonably assured resources, selected economies, as of January 2015

Estimated by OECD NEA and IAEA. Figure from OECD NEA.[11]

[11] http://www.oecd-nea.org/ndd/pubs/2016/7301-uranium-2016.pdf

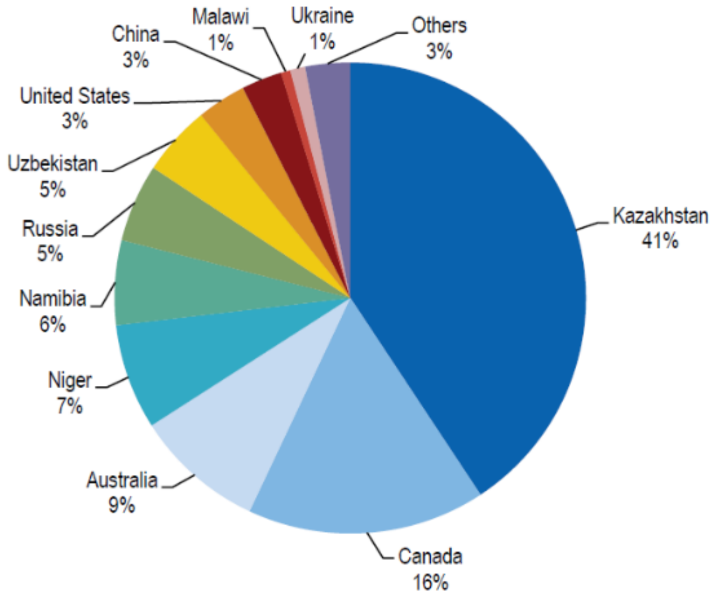

Figure 18 Share of global uranium production, 2014

Estimated by OECD NEA and IAEA. Figure from OECD NEA.

Uranium production in APEC economies

Although uranium production in the APEC region has decreased slowly since 2004 (Figure 19), it still accounts for one-third of the global production. Kazakhstan has expanded uranium production in recent years, and has exceeded Canada, which ranked first in the world. Among the 21 APEC economies, Canada and Australia are the main uranium producers, and the US, Russia and China also contribute to the uranium production as described below:

- Canada has lost its standing as the world's largest producer since 2009 as a result of production increases in Kazakhstan. However, it remains the dominant North American producer, the second largest producer in the world, and of course the largest in the APEC region. Production at the McArthur River mine, the world's largest high-grade uranium mine, was 7 684tU and 7 312tU in 2013 and 2014, respectively.
- Australia is the second largest uranium producer in APEC. Production decreased dramatically from 7 009tU in 2012 to 6 432tU in 2013, and further decreased to 4 975tU in 2014. The Four Mile mine started production in 2014 with uranium processed at the Beverley plant. However, this new start-up was not enough to offset the decreases in production for this reporting period. Decreases were a result of completion of the Ranger

3 pit in December 2012, and though stockpiled ore was still being processed, the failure of a leach tank late in 2013 at the Ranger mine stopped operations several months. Further decreases were a result of production halting at the Honeymoon mine in 2013 and the Beverley/Beverly North mines in 2014;

- The United States produced 1 881tU in 2014, 13% more than in 2012 and 5% more than in 2013. Production in 2014 was from 10 mines: two underground mines and eight ISR mines. The main difference since the last production period is the increase in ISR facilities. Uranium ore from underground mines is stockpiled and shipped to the White Mesa Mill, to be milled into uranium concentrate;
- Russia's production amounted to 2 991tU in 2014, of which 1 970tU were produced using conventional underground mining methods and 1 021tU were produced using the in situ leach method;
- China, as the only producing economy in East Asia, reported a small but steady increase in production from 1 450tU in 2012 to 1 500tU in 2013 and 1 550tU in 2014 with six production centers in operation.

The next chapter discusses the long-term demand for uranium and nuclear fuels in the APEC region, and future uranium production is derived from OECD NEA's Uranium 2014. According to the production projection, with the largest uranium reserves in the world, Australia is expected to overtake Canada by 2040 as the lead producer in the APEC region.

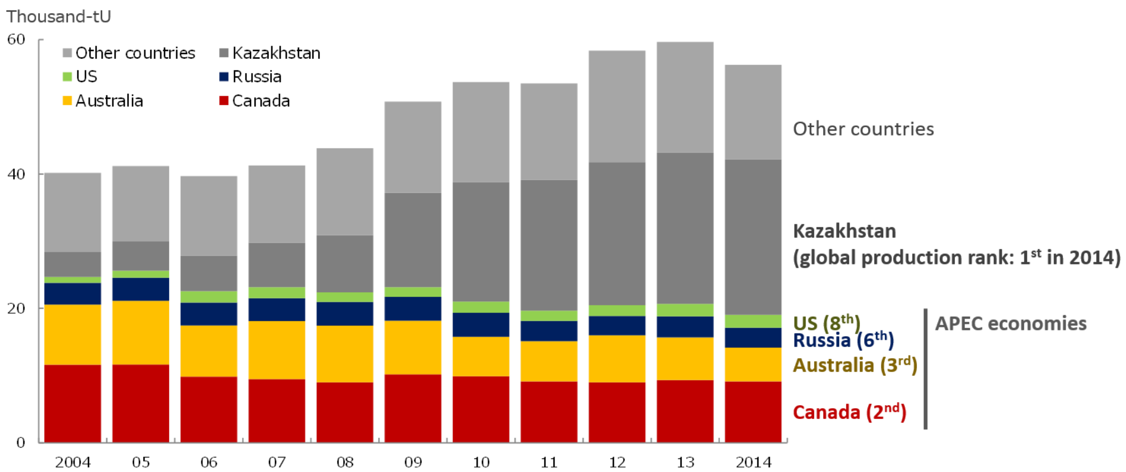

Figure 19 Global uranium production from 2004 to 2014

Data from World Nuclear Association. Figure by APERC.

Chapter 3 Future perspectives—A scenario analysis

This chapter aims to discuss the effects of future nuclear developments on the long-term APEC power mix. Nuclear power has contributed to the region's energy supply for more than several decades; yet, after the accident in Fukushima in 2011, nuclear has been experiencing a setback, and large uncertainties exist regarding the degree of future nuclear generation in some economies. Therefore, we designed three scenarios to explore the impacts of different development paths from economic and environmental viewpoints. Section 3.1 overviews methods and scenarios, then sections 3.3-3.4 summarize results and policy implications.

3.1 Scenarios and assumptions

3.1.1 Scenario settings

We designed three scenarios, including a Business-as-Usual Scenario (BAU), a Low Nuclear Scenario (Low) and a High Nuclear Scenario (High), considering recent energy policies (Table 2). The BAU acts as the reference scenario, and follows the current development plans and energy policies in APEC economies. Recent nuclear construction/retirement plants are taken into consideration, The Low Scenario assumes a slowdown of future nuclear expansion, with accelerated retirements of existing reactors. The High Scenario on the other hand embodies optimistic nuclear development plans and includes nuclear development in some other currently non-nuclear economies as well.

Table 2 Scenario definition

	Scenario summary
Business-as-Usual (BAU)	Current policies exist over the projection period. Recent nuclear construction and retirement trends are included, but proposed projects are not considered.
Low Nuclear (Low)	Proposed projects are included on top of the BAU. License extensions are applied to most of the existing reactors.
High Nuclear (High)	Slowdown of nuclear developments as well as accelerated retirements of existing reactors are assumed. South-East Asian economies do not deploy any reactors.

Source: APERC.

Nuclear capacity in the APEC region grows from about 230 GW in 2013 to 330 GW in the BAU and 480 GW in the High by 2040, while peaking out and declining to 220 GW under the Low (Figure 20). Note that nuclear capacities are expressed in gross capacities in this chapter. China and Korea, in particular, are assumed to expand their nuclear under the BAU, and, in the High Scenario, in addition to these two economies, Russia and Southeast Asian economies accelerate the capacity growth. In the Low Scenario, retirements of the existing reactors in Japan and the US as well as limited capacity additions result in the decreasing trend (See section 3.1.2 for more detailed assumptions). In any scenario, China increases its presence in nuclear capacity in the region (Figure 21).

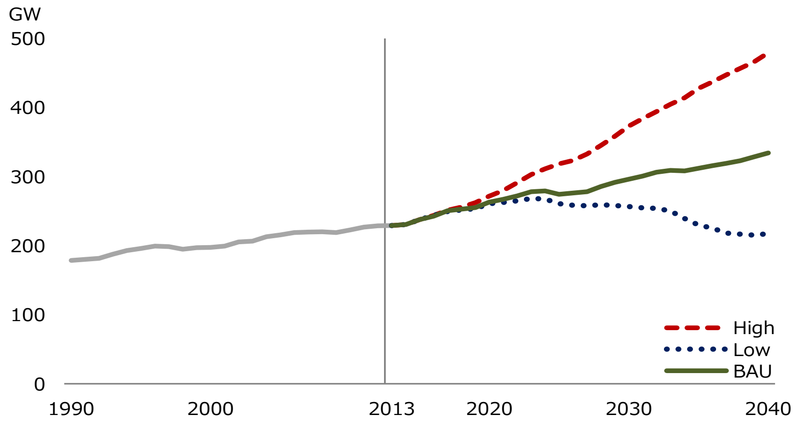

Figure 20 Nuclear capacity projection for APEC, 2013 to 2040

Figure by APERC.

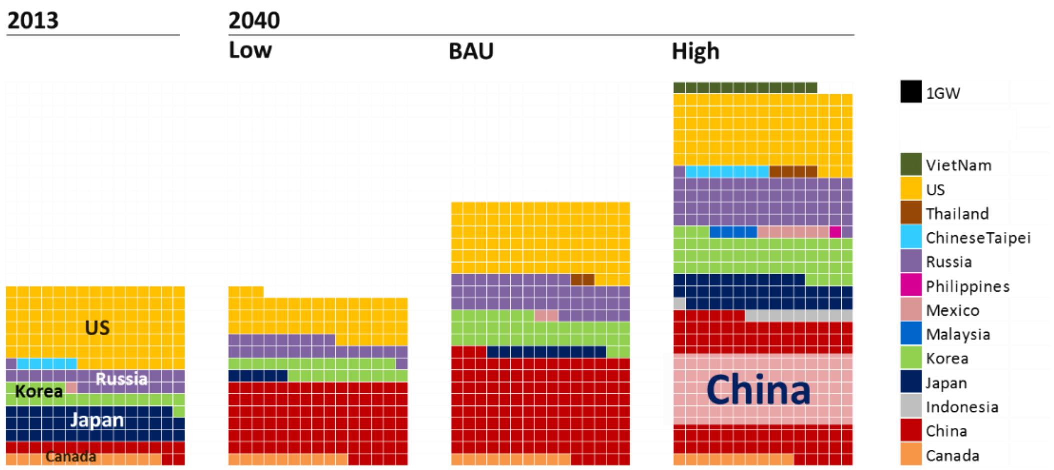

Figure 21 Nuclear capacity by economy, 2013 and 2040

Figure by APERC.

3.1.2 Economy assumptions

Canada

Considering that its provincial government and utilities have relatively clear nuclear refurbishment[12] and retirement plans, only one capacity projection was applied for Canada (Figure 22). Based on current NPPs, we assume that Bruce Power plans a 15-year project from 2020 to refurbish six nuclear reactor units in Bruce Nuclear Generating Station. OPG will refurbish four CANDU nuclear power units at Darlington Nuclear Generating Station, which will allow the reactors to operate for another 30 years. OPG also has a plan to retire Pickering Nuclear Power Generating Station; two reactors by 2022 and the remaining four reactors by 2024.

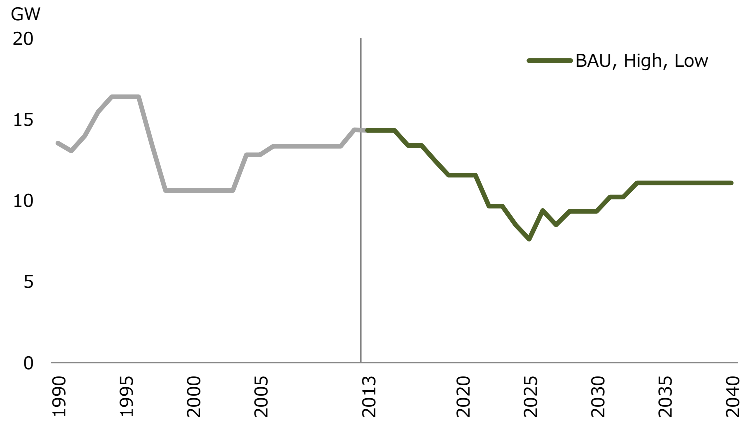

Figure 22 Nuclear capacity assumptions for Canada, 2013 to 2040

Figure by APERC.

China

Being the key driver for APEC nuclear power expansion, all the three scenarios were applied to China. The number of nuclear power reactors under construction in China reaches 20, which is the largest in the world. In the near future, all of the 20 nuclear power reactors will be connected to the grid. Also, China has prepared many nuclear power projects for future development. According to the economy's plan, China has a target of 58 GW capacity in operation and 30 GW under construction by 2020. The 58 GW operational target, which

[12] WNN: "OPG gets go-ahead for Darlington refurbishment", http://www.worldnuclearnews.org/COPGgetsgoaheadforDarlingtonrefurbishment1201167.html;

requires new additions of 5-6 reactors per year on average in the late 2010s, is assumed to be achieved in the all three scenarios. After 2020, the trend of new additions continues in the High Scenario (5-6 reactors per year), and moderated in the BAU (3-4 reactors per year). The Low Nuclear Scenario assumes a slowdown of nuclear capacity growth, with 1 or 2 additional nuclear power unit per year, as shown in Figure 23. By 2040, the nuclear capacity assumptions in the Low, BAU and High Nuclear Scenarios are 95 GW, 128 GW and 171 GW, respectively. The High Nuclear Scenario includes inland nuclear power projects, due to the limitation of coastal site capacity.

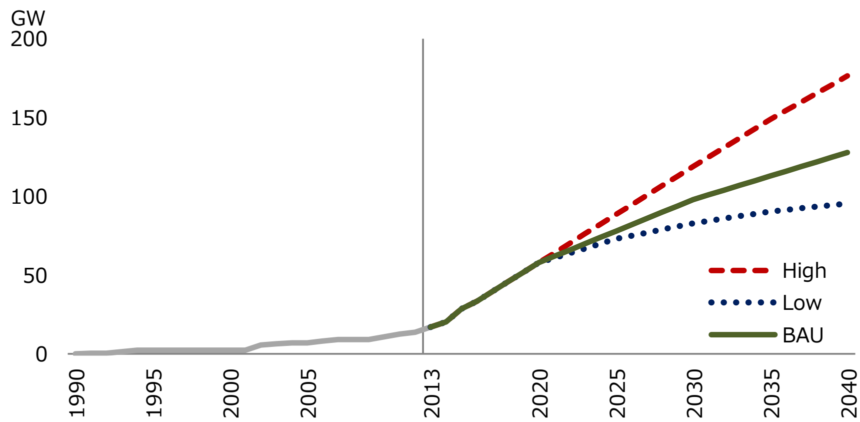

Figure 23 Nuclear capacity assumptions for China, 2013 to 2040

Figure by APERC.

Japan

The license expiration plan has significant impacts on the scenarios' design. The Nuclear Reactor Regulation Act[13], amended in 2012, limits the reactor lifetime to 40 years and allows an extension of a maximum of 20 years. The BAU Scenario follows the 40-year lifetime rule for all of the existing reactors, except for the three reactors whose lifetime extensions have been already approved (Takahama Unit 1-2 and Mihama Unit 3). The BAU also includes new additions of three reactors—Shimane Unit 3, Oma and Higashidori Unit1—whose construction was started before the Fukushima Daiichi nuclear accident. The High Nuclear Scenario assumes the 20-year lifetime extension for most of the existing reactors, while the

[13] http://law.e-gov.go.jp/htmldata/S32/S32HO166.html

Low Nuclear Scenario follows the 40-year retirement rule without any new additions. Capacities in the three scenarios are shown in Figure 24.

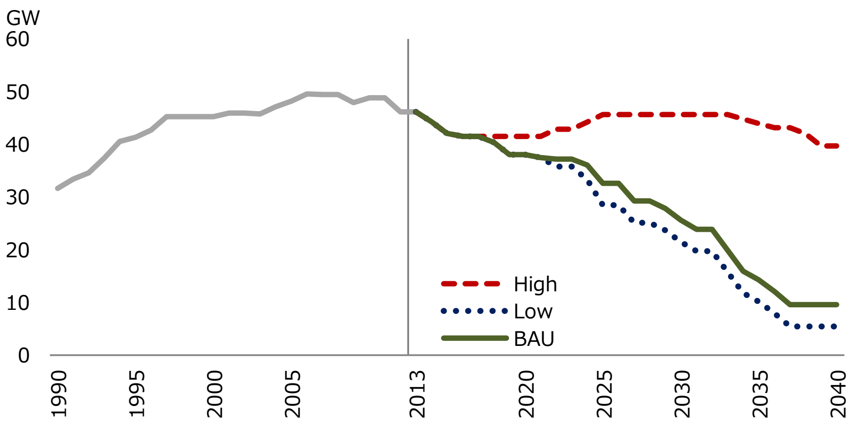

Figure 24 Nuclear capacity assumptions for Japan, 2013 to 2040

Figure by APERC.

Korea

Korea is projected to expand nuclear generation steadily, according to the latest government plan. In the short- to mid-term, the 7th Basic Plan for Long-term Electricity Supply and Demand[14], published in July 2015, listed new addition projects totaling 18.2 GW by 2029 and retirements of Kori Unit 1 by 2017. In regard to the long-term prospects, the 2nd Energy Master Plan[15] in January 2014 targeted having 42.7 GW by 2035. Korea does not have a legal limit for license extension, and the design life of existing reactors is as follows: 30 years for Kori Unit 1 and Wolseong Units 1-4; 50 years for Shin-Kori Units 3-4; and 50 years for other reactors.

New capacity additions in the BAU Scenario follow the 7th plan by 2029, and we assume the same expansion trend after 2030 (Figure 25). The BAU Scenario assumes the reactors will retire after design life. The High Nuclear Scenario considers a lifetime extension of 20 years for existing reactors, except for Kori Unit 1; whereas, the Low Nuclear Scenario assumes delays of new reactor additions by half compared to the BAU. The 20-year lifetime

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[14] MOTIE (2015): "The 7th Basic Plan for Long-term Electricity Supply and Demand".

[15] MOTIE (2014): "Korea Energy Master Plan outlook and policies to 2035".

extension, which is assumed in the High Nuclear Scenario, allows Korea to reach the level targeted in the 2nd Master Plan.

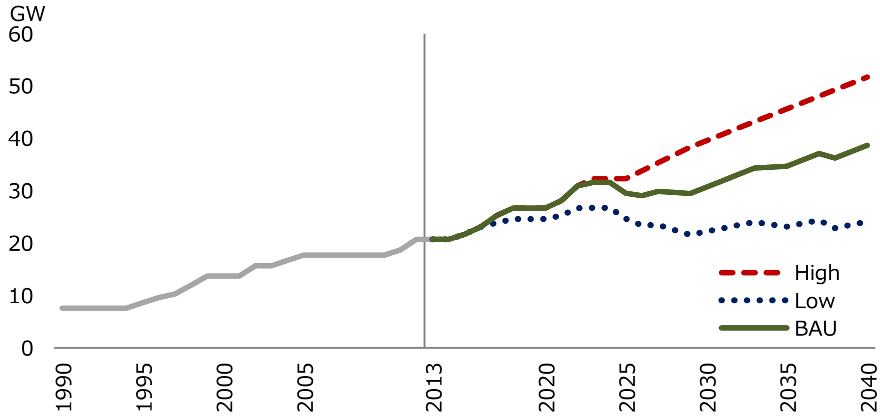

Figure 25 Nuclear capacity assumptions for Korea, 2013 to 2040

Figure by APERC.

Chinese Taipei

The current government has a nuclear phase-out policy by 2025, which is included in the BAU (Figure 26). The fourth nuclear power station, whose construction is suspended as of now, is assumed to be cancelled in the BAU. The High Nuclear Scenario hypothetically assumes the situation where the government and utility change their decisions and try to utilize existing as well as new reactors to the extent possible. This study assumes a lifetime extension of 20 years for existing reactors in the High Nuclear Scenario, which considers that the current policy would be changed, nuclear power would be maintained at the current level and the operation of No. 4 nuclear power plants would be restarted. The High Nuclear Scenario is the most optimistic case for nuclear power development in Chinese Taipei.

Mexico

Total nuclear capacity in the BAU remains constant after the NPP modernization in 2015, assuming further lifetime extensions for Laguna Verde nuclear power station by more than 10 years (Figure 27). The reactors retire at the current license expiration in the Low Scenario, resulting in nuclear phase-out in the 2030s. In contrast, the High Scenario includes the indicative projects[16] as well as lifetime extension of existing reactors; total capacity grows to about 5.7 GW by 2040.

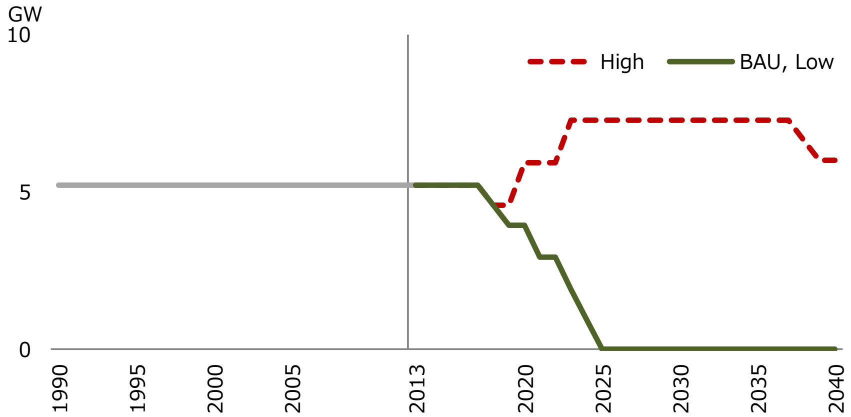

Figure 26 Nuclear capacity assumptions for Chinese Taipei, 2013 to 2040

Figure by APERC.

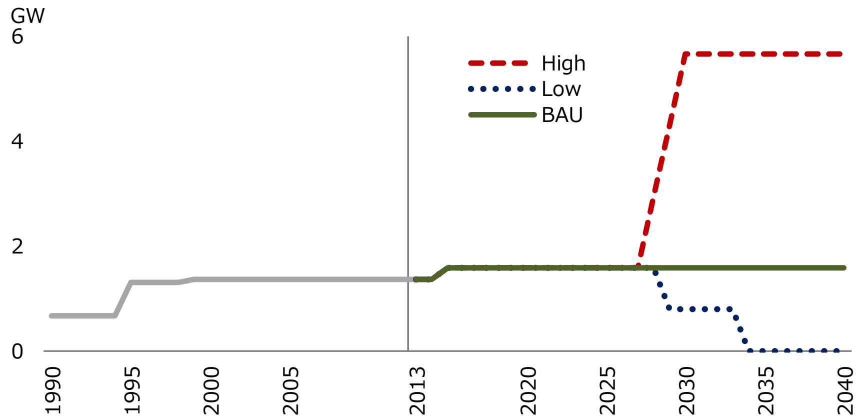

Figure 27 Nuclear capacity assumptions for Mexico, 2013 to 2040

Figure by APERC.

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[16] Secretaría de Energía (2016): "Programa de Desarrollo del Sistema Eléctrico Nacional".

Russia

Russia has developed and plans to install NPPs mainly in the west part to curb domestic gas consumption for power generation. According to the World Nuclear Association (WNA)[17], in January 2015, Rosatom published a long-term nuclear development plan towards 2035.

The BAU is based on Rosatom's plan for new additions and retirements by 2035. It assumes that the trend of reactor additions will continue and existing reactors will retire after 50-year operation. The High Scenario includes proposed projects on top of the BAU, while development slows down by half in the Low Scenario. Total nuclear capacity drops in around 2025 in each scenario (Figure 28) are due to planned retirements of eight reactors. Total nuclear capacity in Russia grows to more than 40 GW and 60 GW in the BAU and High Scenarios. The Low Scenario maintains around 20-25 GW over the projection period.

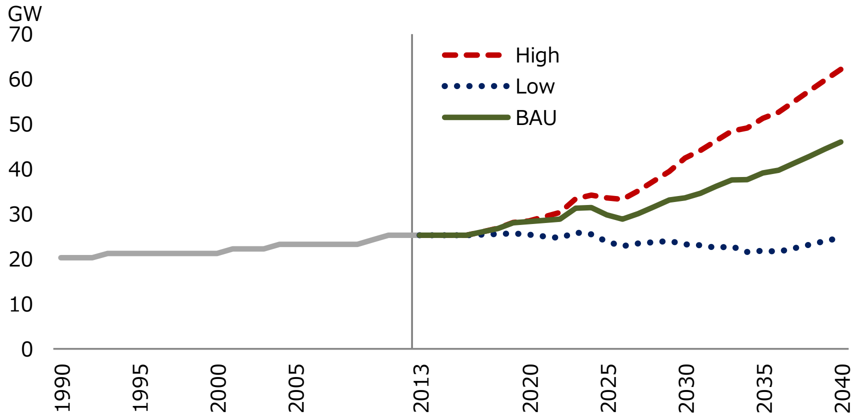

Figure 28 Nuclear capacity assumptions for Russia, 2013 to 2040

Figure by APERC.

The United States

Considering the energy situation and the future plan, only two projections are applied to the United States (Figure 29). We assume that the nuclear capacity will remain stable in the BAU Scenario, while it will significantly decline in the Low Nuclear Scenario. The difference between these scenarios is due to license expirations. As of November 2016, a 40-year

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[17] WNA (2016): "Nuclear Power in Russia", http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx.

license and an additional extension of 20 years are allowed under the regulations. The Nuclear Regulatory Commission (NRC) is preparing guidance for an 80-year lifetime ("Subsequent License Renewal")[18]. The BAU assumes that the 80-year operation would be permitted for all the operational reactors, except for those whose retirements are already announced, including Pilgrim, Oyster Creek and Diable Canyon Units 1-2. The BAU Scenario also includes new additions of four reactors which are currently under construction, such as Vogtle Units 3-4 and V.C. Summer Units 2-3[19]. The Low Nuclear Scenario, by contrast, is based on the current limit for license extension (60 years), resulting in a sharp decline in the 2030s.

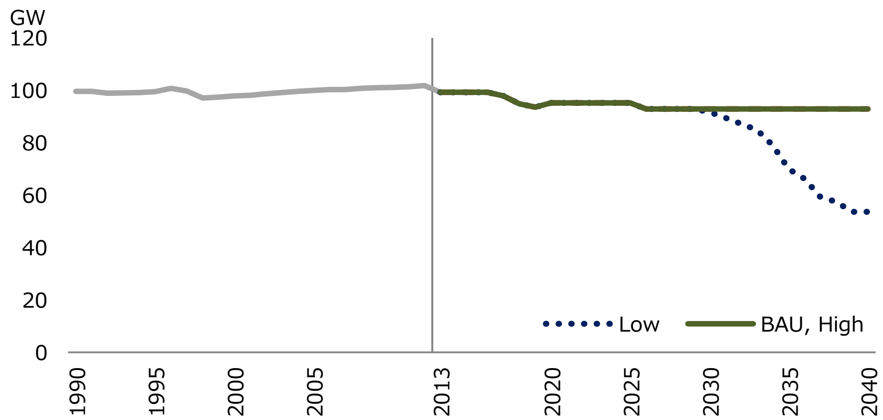


Figure 29 Nuclear capacity assumptions for the United States, 2013 to 2040

Figure by APERC.

Southeast Asian economies

This study assumes the following five "new comers" in Southeast Asia: Indonesia, Malaysia, The Philippines, Thailand and Viet Nam. Assumptions for these economies are summarized as below (Figure 30):

- **Indonesia**: In March 2015, the government issued a white paper projecting that nuclear power would be 5 GW by 2025. However, in December 2015, the Minister of Energy and

[18] NRC: "Subsequent License Renewal", https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html

[19] As summarized in the Section 2.2.12, there exist uncertainties and discussions are ongoing regarding the construction of the new units at the V.C. Summer nuclear station (see also the references listed in footnote 9 and 10).

Mineral Resources announced that the economy would not install NPPs until 2050. Based on these recent updates, this study includes nuclear power not in the BAU but in the High with a delay of 10 years. Nuclear capacity in the High Scenario reaches 5 GW by 2035, and the installation trend is assumed to continue over the outlook, reaching 10 GW by 2040.

- **Malaysia**: According to the energy commission's outlook[20], Malaysia plans to install 2 GW by 2024, although there does not exist concrete projects. However, the plan was delayed due to reasons introduced in the previous chapter. This study assumes no new installation in the BAU; instead, the High Scenario discusses the effects of that level of installation with a 10-year delay from the plan (2 GW by 2034). The High Scenario also assumes an accelerated situation, where additional 2 GW is installed in the late 2030s.
- **The Philippines**: The BAU Scenario does not include any nuclear power generation, while the High Nuclear Scenario assumes the revival of BNPP (600 MW) by 2030. The construction of BNPP was almost completed in 1984 but never fueled, partially due to the nuclear accident in Chernobyl. KEPCO conducted a feasibility study on the revival of the plant and estimated the cost for rehabilitation at 1 billion USD[21].
- **Thailand:** The BAU follows the PDP2015[22], which plans to newly install 2 GW nuclear capacity by 2036. The High Nuclear Scenario assumes accelerated developments, totaling 4 GW over the projection period: 2 GW by 2030 and additional 2 GW by 2040. The Low Nuclear Scenario assumes no nuclear power would be deployed by 2040.
- **Viet Nam**: Viet Nam has planned to deploy nuclear power for a long time. However, in November 2016, the National Assembly passed a resolution to cancel plans for two nuclear power stations, due to financing issues and lower electricity demand projections. The economy plans to replace the capacity by gas-fired, coal-fired, power imports from Laos and renewables. The BAU Scenario does not include any reactors, whereas the High Scenario assumes the revival of nuclear development policies, including not only

[20] Energy commission (2014): "Peninsular Malaysia Electricity Supply Industry Outlook 2014".

[21] CNN Philippines (2016): "Nuclear power: A go or no?"

[22] MOE (2015): "Thailand Power Development Plan 2015-2036 (PDP2015)".

two Russian and two Japanese reactors but also further installation (total 10 reactors by 2040).

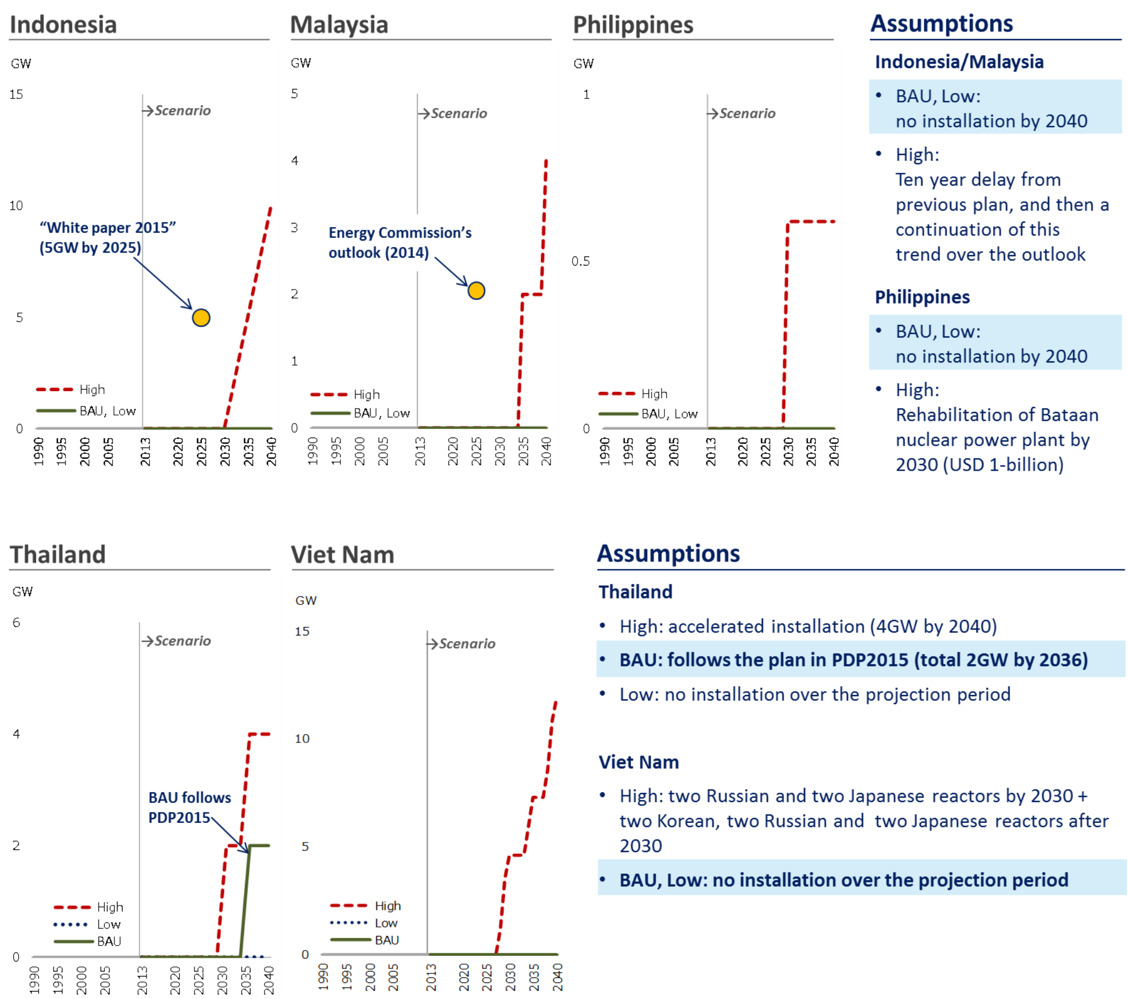


Figure 30 Nuclear capacity assumptions for Southeast Asian economies, 2013 to 2040 Figure by APERC.

3.1.3 Other assumptions

Assumptions for electricity demand in each economy is obtained from the BAU Scenario in the *APEC Energy Demand and Supply Outlook*, 6th Edition (APERC, 2016a). The *Outlook* projects a 70% growth from 2013 to 2040 in APEC total, driven by China and Southeast Asian economies. Fossil fuel prices (Table 3) and costs are from Table 1 of Annex I in APERC (2016a). Nuclear fuel costs are assumed to be around 15 USD/MWh. As for capital cost for nuclear power plants, which is the major cost-component for the technology, we assume as follows: 2 800 USD/kW for China, 4 500 USD/kW for Japan, 3 500 USD/kW for Korea and Russia, and 5 400 USD/kW for the United States.

Assumptions of a carbon price in each economy are based on existing policies and plans. Among the thirteen economies covered in Section 3.1.2, this study takes into account an economy-wide carbon price in the following economies: Canada[23], China[24], Japan[25], Korea[26] and Mexico[27]. Current or planned tax level is assumed to remain over the projection period. These assumptions allow us to discuss the economics of nuclear development under existing emissions policies; yet, analyzing the impacts of accelerated policies, such as a higher level of carbon prices, would also be an interesting research agenda and should be considered in future work.

Table 3 Fossil fuel assumption

	2013	2020	2030	2040
Crude oil [USD/bbl]	108	73	97	121
Natural gas in Japan [USD/Mmbtu]	15.9	10.4	12.4	13.7
Natural gas in the US [USD/Mmbtu]	3.6	4.4	5.4	6.6
Steam coal [USD/tonne]	110	86	103	128

Sources: APERC (2016a).

[23] The government of Canada plans to implement a carbon tax or a cap and trade scheme in all provinces and territories from 2018. The government plans a price of 10 CAD/t-CO_2 from 2018, rising to 50 CAD/t-CO_2 by 2022 (Canada, 2016).

[24] China plans to introduce an economy-wide emission trading system in 2017. Although uncertainties still remain regarding the timing of implementation and the level of carbon price, this study assume a price of 30 CNY/t-CO_2 (about 4.7 USD/t-CO_2) referring to the average level in the economy's pilot projects since 2013.

[25] The Tax for Climate Change Mitigation. This tax was introduced in October 2012, and raised in phases in April 2014 and 2016. The tax value, after April 2016, is 289 JPY/t-CO_2 (about 2.7 USD/t-CO_2).

[26] Korea established an emission trading system since 2015. Although the amount of emission transaction remains at the modest level, this study assume a price of 15 USD/t-CO_2 over the projection period.

[27] 5 USD/t-CO_2 from 2014 (excluding emissions from natural gas).

3.2 Methods: long-term electricity supply model

In this study we use a bottom-up, least-cost electricity supply model, which was also used in the *APEC Energy Demand and Supply Outlook*, 6th Edition. The model determines capacity expansion and the operation of each technology under technical and political constraints. Nuclear capacity is exogenously given in the scenarios, and renewable capacity in power sector is subject to government policies and recent development trends. The model takes into account the middle- and long-term energy policies to determine the future share of fossil fuel. The renewable capacity projection for the three Scenarios is the same as the BAU Scenario in the *Outlook* (APERC, 2016a). Electricity demand is modeled as representative yearly or daily load duration curves, depending on data availability for each economy. The model dispatches generation and storage technologies to balance demand and supply based on cost optimization. The cost of each technology includes capital costs (such as annual payments to recover initial investments and decommissioning costs), operation and maintenance (O&M) costs, fuel costs and carbon penalties (Figure 31). More detailed introductions about the model can be found in APERC (2016a).

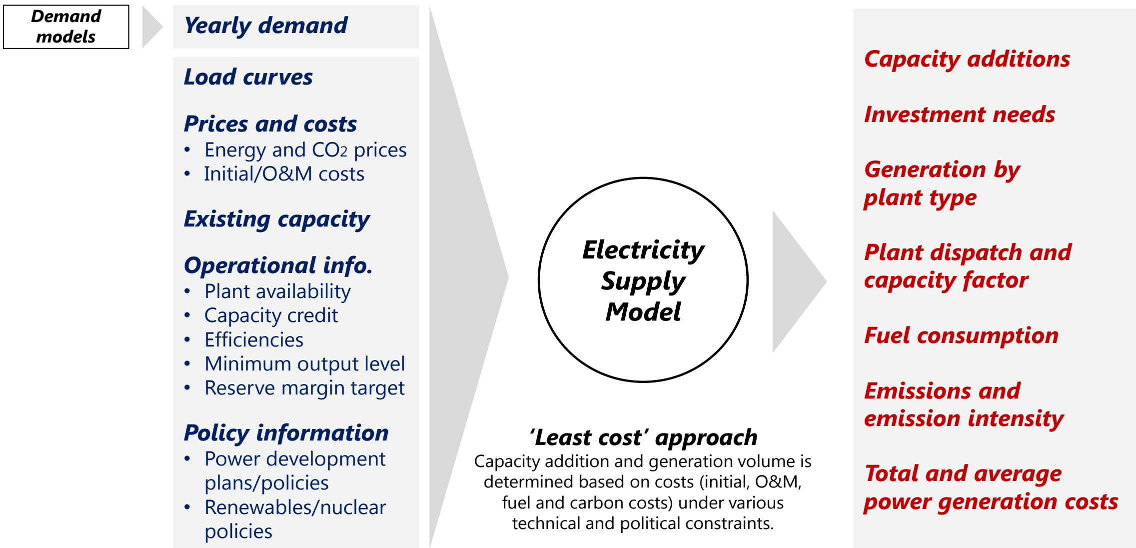


Figure 31 Electricity supply model structure

Figure by APERC.

3.3 Results and discussion

3.3.1 Generation

Under the BAU Scenario, low-carbon electricity is expected to grow in the APEC region, yet fossil fuels still dominate the APEC generation mix due to growing electricity demand (Figure 32), accounting for almost 70% in 2040. Although its share declines, coal remains as the largest energy sources for power generation. Renewables together show the strongest growth, more than doubling in absolute terms thanks to current environmental policies. Although nuclear capacity grows under the BAU Scenario with net-additional 100 GW by 2040, the share of nuclear remains around the current level due to rapid growth of total electricity demand in the APEC region. Accelerated nuclear development as well as lifetime extension of existing reactors would be necessary to expand the nuclear power's contribution as shown in the High Scenario.

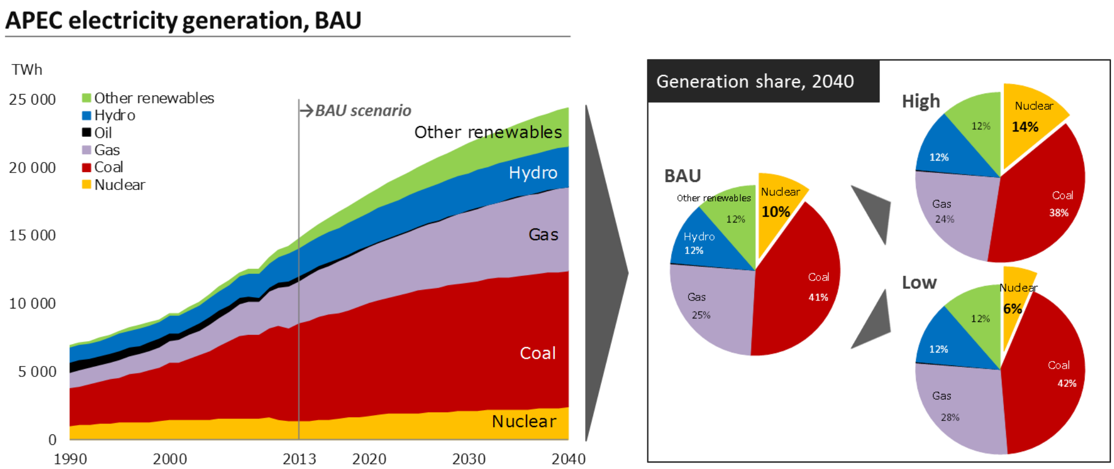


Figure 32 Power generation in the BAU Scenario and fuel share in 2040 by Scenario, APEC

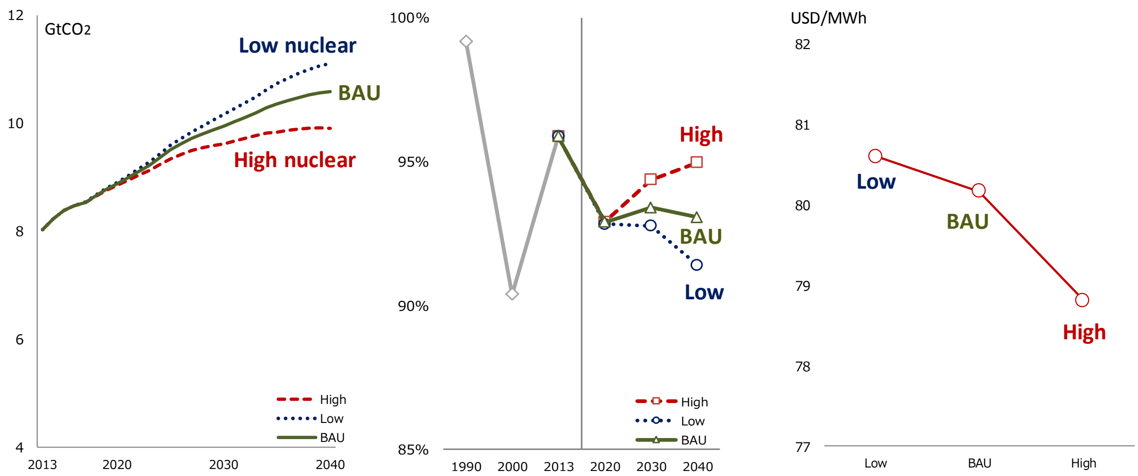
Figure by APERC.

Fossil fuels still hold the major share in APEC even in the High Scenario, although accelerated nuclear development contributes to reducing fossil fuels. The incremental share of nuclear (Figure 32) contribute to replacing coal-fired generation, resulting in the environmental benefits as depicted later in Section 3.3.2. On the other hand, nuclear power's share drops to 6% due to the slowdown of nuclear expanding economies, such as China, Korea and Russia, as well as due to accelerated retirements of existing reactors, in particular, in United States. It’s important to note again that nuclear and renewable capacity are exogenously given in this studies; future research needs to consider economic and technical compatibility considering cost-competition in power generation mix.

3.3.2 3E analysis

Balancing the 3E—Environment, Energy security and Economic efficiency—perspective is important to realize sustainable society. As a low-emission and non-fossil fuel electricity, nuclear is expected to play an important role in mitigating climate change and securing energy supply.

Although CO_2 emissions from electricity sector grow in the APEC region as a whole under the three scenario, nuclear power contribute to curbing the emission increase (Figure 33a). With higher shares of nuclear generation, annual emissions from power generation can be reduced, for example, by 7% in 2040 from the BAU to High Scenario by displacing coal and gas. The cumulative avoided CO_2 emissions amount to 7Gt-CO_2 by 2040 in the High Scenario, whereas the cumulative emissions increase by 5Gt-CO_2 in the Low Scenario.



(a) Annual CO_2 Emissions from power generation **(b) Energy self-sufficiency rate** **(c) Average generation cost in 2040**

Figure 33 “3E” results—Emissions, energy self-sufficiency and cost

Figure by APERC.

Reducing fossil fuel dependencies is one of the important challenges for the economies not only from the environmental but also the security perspective to construct a resilient energy system against volatile fossil fuel markets/prices and resource depletion. Nuclear power, which is regarded as a “quasi-domestic” energy source, would contribute to improving energy self-sufficiency rate in the APEC region (Figure 33b), while the rate remains at the similar level or decrease in the BAU and Low Scenario, respectively.

Our results also imply economic benefits in the form of generation cost savings in the APEC region (Figure 33c); yet, the estimated saving is relatively modest, for example, 1.4 cent USD/kWh (a saving of 1.7%) from the BAU to the High Scenario, due to various factors, including recent fossil fuel price drop (= improving the economics of fossil fuel plants) and expensive capital investments required for nuclear plants. As mentioned in Section 3.1.3, the level of emissions policies assumed in the scenarios, such as carbon prices, are based on existing policies and plans. Accelerated emissions policies would be necessary to largely improve the economic benefits of nuclear generation for the APEC region as a whole.

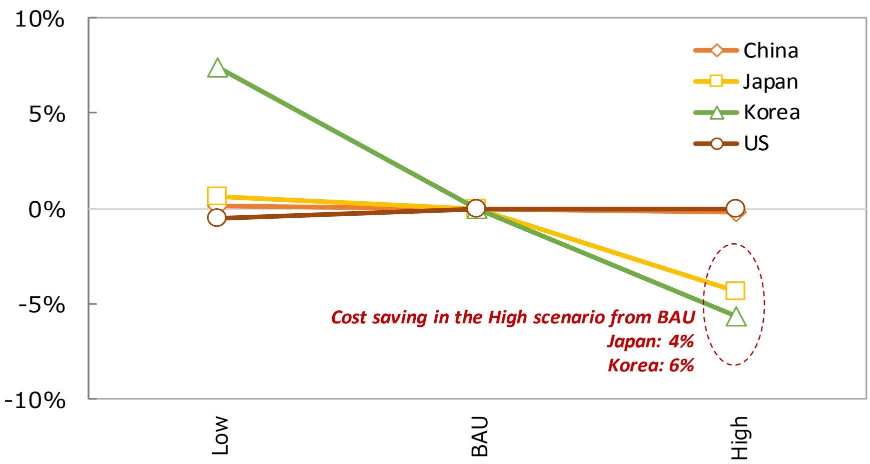


Figure 34 Generation costs changes relative to the BAU in 2040, selected economies Figure by APERC.

However, it’s important to note that economic benefits of nuclear vary by economy, reflecting its energy situation. In general, energy importing economies may enjoy larger cost reduction benefits with higher share of nuclear, by reducing high-cost energy imports. For example, our analysis suggests that average generation cost would decrease under the High

Scenario in Japan and Korea by 4% and 6%, respectively (Figure 34). Nuclear power would remain as a preferable option from the “3E” perspective for these energy importing economies. On the other hand, cost benefits are relatively limited in China and rather negative in the US, where low-cost fossil fuels are available. Economic supports, including stronger emissions policies, may need to improve the competitiveness of nuclear in these economies.

3.3.3 Uranium demand and spent fuel

With the growth of nuclear power capacity, demand for uranium is expected to continue to rise during the outlook period in the High Nuclear and BAU Scenarios, with the strongest expansion expected in China, Korea and Russia, as well as potential Southeast Asian economies. To estimate future uranium consumption, we constructed two front-end models, one for LWRs and another for HWRs. Figure 35 shows the model for LWRs. We conducted a backward calculation: first, we estimated UO_2 consumption for the projected nuclear generation (Figure 32), then enriched UF_6, natural UF_6 and U_3O_8. Assumptions for conversion losses, product/tail assay of enrichment process, conversion losses and fuel burnups are expressed in Figure 35. While the parameters may vary by economy, we simply used these assumptions for all economies due to data availability issues. Enrichment process is excluded in the HWR front-end model.

The APEC annual reactor-related uranium requirements are projected to rise from 36 000 tonnes of uranium metal (tU) at the end of 2013 to 53 000tU and 76 000tU by 2040 in the BAU and High Nuclear Scenarios respectively (as shown in Figure 36). APEC’s uranium demand may tighten the global uranium market in the long-term under the “lower production capability” case. OECD NEA estimated two cases with regard to uranium production capability by 2035: “A-II category” which only includes production capability of existing and committed centers with reasonably assured and inferred resources recoverable at cheaper than 130 USD/kgU; and “B-II category” which includes planned and prospective centers as well. Under the A-II categories, APEC’s uranium consumption exceeds global capability by 2035 in the High Nuclear Scenario, and reaches 75% of global capability in the BAU. The supply-demand balance would loosen with the planned and prospective resources. Uranium producing economies would need to ensure the feasibility of the “planned and prospective" resources well in advance to avoid the tightening situation and realize sufficient supply.

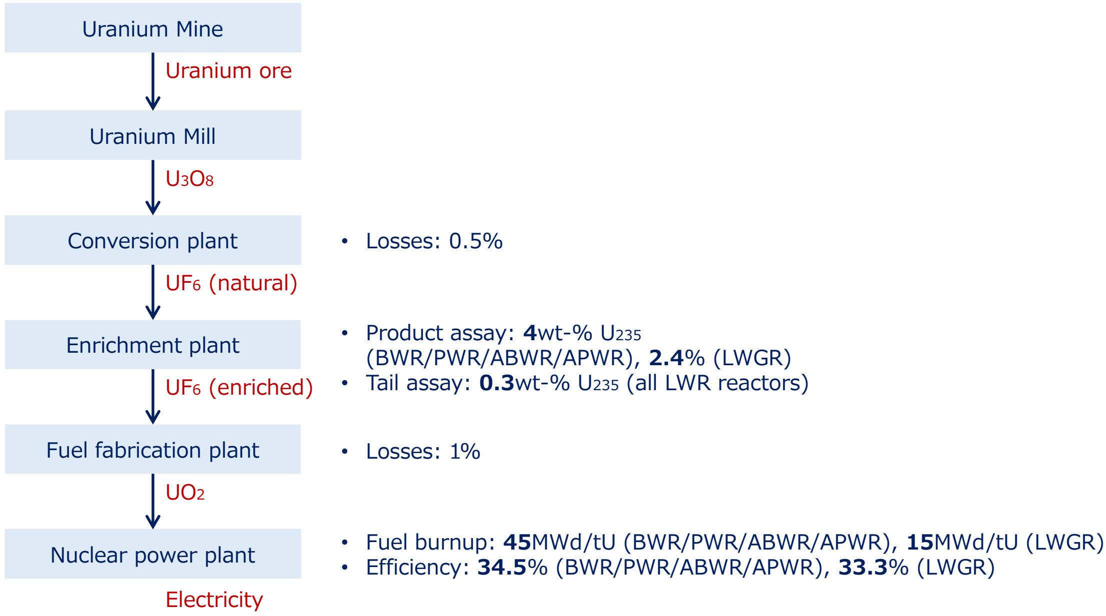


Figure 35 Front-end model for the fuel cycle (take LWR for example)

Figure by APERC.

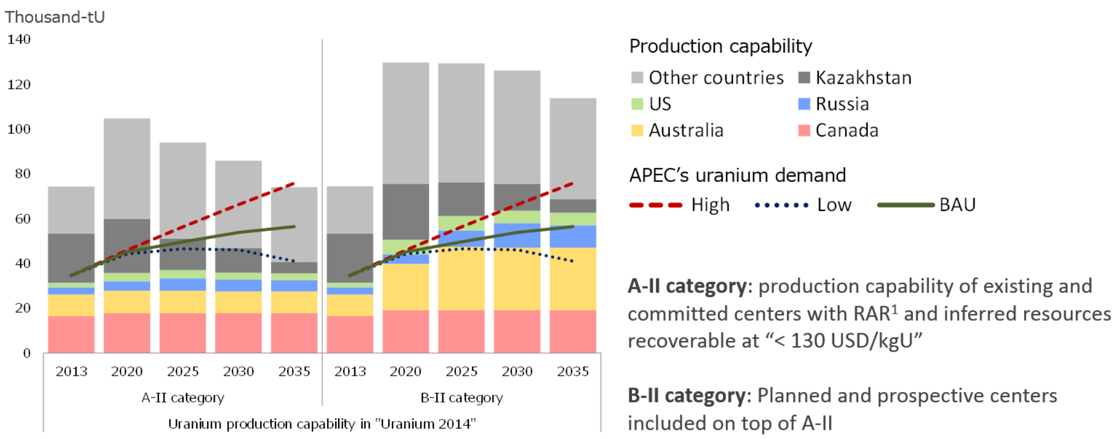


Figure 36 Global uranium production capability and APEC's uranium demand

Uranium production capability data from NEA (2014). Figure by APERC.

Waste management has been and will be one of the major challenges for economies using nuclear power. According to our estimation assuming a once-through fuel cycle for all economies (Figure 37), the estimated amount of spent fuel reaches 130 000 to 180 000t-U. Even the Low Scenario reaches 70% of the level in the High Scenario implying that, even if nuclear developments slow down (like the Low Scenario), spent fuel issues remain to be addressed by the economies. Given that the capacity of Onkalo, the final disposal facility in Finland, is 9 000t-U, the APEC region may need to construct large-scale intermediate or final disposal facilities to manage future spent fuel by 2040. However, it is important to note again that this estimation is based on a once-through fuel cycle system, and that future nuclear fuel cycle policies and reprocessing activities may affect the amount of nuclear waste.

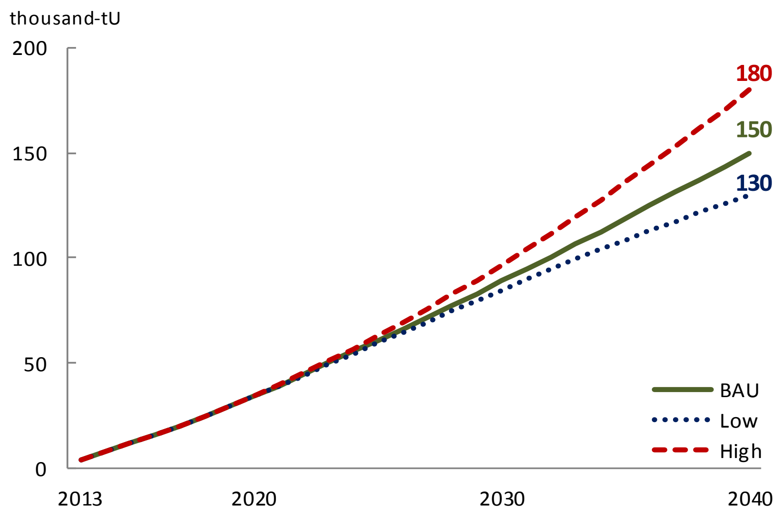


Figure 37 Spent fuel generation from NPPs in the APEC region, cumulative from 2013

Figure by APERC.

3.4 Conclusion

This chapter examined the impacts of three nuclear scenarios—the BAU, the Low and the High Scenario—on the APEC generation mix. In any Scenario, China becomes the main driver for new capacity installation, increasing its presence in the long-term. Although the BAU assumes a growth of nuclear capacity from about 230 GW to 330 GW, the share of nuclear power remains around the current level due to growing demand. Accelerated installation as well as lifetime extension of existing reactors (like the High Scenario) would be necessary to increase the share of nuclear in generation mix. According to our analysis, nuclear power contributes to the APEC region from the "3E" perspective, although economic benefits are estimated to be modest under the assumed fossil fuel and carbon prices (Section 3.1.3). Stronger emissions policies, such as a higher level of carbon prices, would be important to improve the economics of nuclear. A large amount of spent fuel is estimated even in the Low Scenario. Economies need to implement policies to construct sufficient facilities for storage and final disposal.

Chapter 4 Challenges for nuclear development

The modeling study in the previous chapter showed the contribution from nuclear power, especially to CO_2 reduction and energy security enhancement in the APEC region. However, after the Fukushima Daiichi nuclear accident, uncertainties remain regarding the way forward for nuclear power development. Many factors such as nuclear safety, technical constraints economic competitiveness, as well as public acceptance will be challenges for nuclear power development in this region. This chapter try to summarize an discuss these important issues for the future development of nuclear power

4.1 Challenges for nuclear power development in the APEC region

4.1.1 Nuclear safety

Highlights

- ✓ The aging nuclear power fleets in the APEC region pose challenges.
- ✓ After the nuclear accident in Fukushima, nuclear safety has been reviewed and enhanced by various measures.

According to the definition of IAEA, nuclear safety refers to "achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards". After more than 60 years of development, nuclear power has achieved a relatively high level of safety. However, currently concerns about safety still pose a major challenge for nuclear power in the APEC region.

One of the uncertainties with nuclear safety is the aging nuclear power fleet, most of which were designed and built in the 1960s and 1970s. Figure 38 shows the age distribution of the nuclear power fleet in the APEC region. Among the operational reactors, 159 reactors are more than 30 years old and account for more than 60%. And 212 reactors are more than 20 years old and account for more than 80%. It is noteworthy that in the 1980s, 97 power reactors started operations in the APEC region. These included 47 in the US, 18 in Japan and 14 in Russia. All the current operational nuclear reactors in the APEC region are Generation II or II+, which need safety improvements to address extreme external hazards such as tsunami and earthquake.

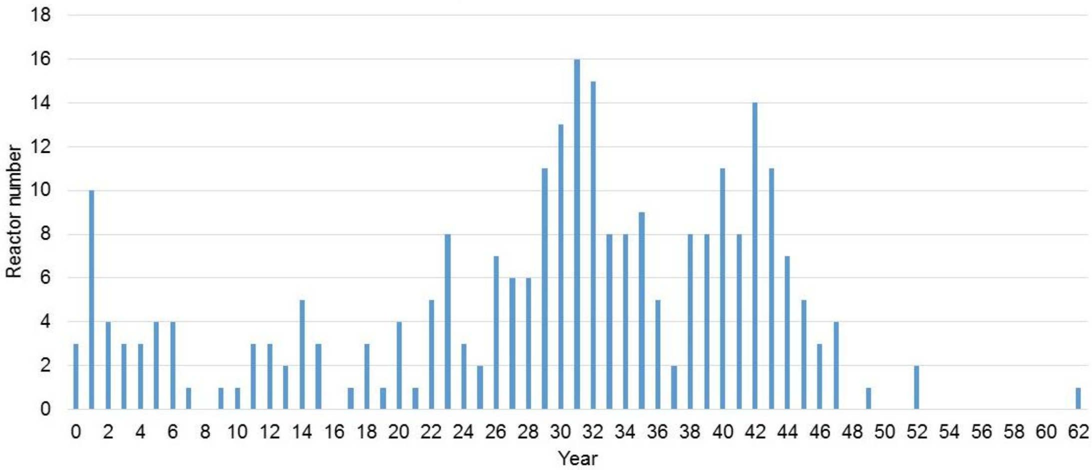


Figure 38 Age distribution of nuclear power fleet in the APEC region

Data source: IAEA PRIS system. Figure by APERC.

For newcomers to nuclear power in the APEC region, nuclear safety is one of the most important issues they need to consider. There are various barriers need to be overcome before they decide to deploy an NPP, including establishing an effective regulation system, conducting technology evaluations, implementing radioactive material control, ensuring environment protection and building up emergency response capability.

After the Fukushima Daiichi nuclear accident, APEC economies have been reviewing nuclear safety in each economy, and taking measures to enhance the safety, mainly in the following aspects:

- Safety Assessments – All the APEC economies that have NPPs undertook a safety assessment of the design of NPPs against site specific extreme natural hazards and implemented the necessary corrective actions in a timely manner.
- Emergency Preparedness and Response – All the APEC economies that have NPPs strengthened their emergency preparedness and response, in order to avoid a man-made catastrophe like Fukushima and regulatory capture that was its root cause. In 2011 the IAEA Incident and Emergency Centre launched a new secure web-based communications platform to unify and simplify information exchange during nuclear or radiological emergencies. The Unified System for Information Exchange in Incidents and

Emergencies[28] (USIE) has been under development since 2009 and was actually launched during the emergency response to the accident at Fukushima.

- Equipment, Facility and Operational Improvements – One of the lessons learned from the Fukushima accident is that the loss of power to maintain effective cooling represents a major challenge for existing NPPs. To address this issue, a power station's sea wall must be adequately tall and robust as the first defense line for the plant. In addition, the equipment ranges from diesel-driven pumps and electric generators to ventilation fans, hoses, fittings, cables and satellite communications gear, which have been deployed in most of the plants in the APEC region.

4.1.2 Technology development

Highlights

- ✓ Several APEC economies lead research and development in advanced technologies; Generation III reactors are expected to play an important role in the next decade;
- ✓ Generation IV and Small Modular Reactors also gain attention and are being researched for commercial applications.

The APEC region include economies leading research and development in advanced nuclear technologies, such as Generation III, Generation IV and Small Modular Reactors. This sub-section overviews current status of these technology developments.

Generation III Reactors

Generation III reactor designs feature improved fuel technology, superior thermal efficiency, a combination of active and passive nuclear safety systems and standardized design for reduced maintenance and capital costs. The core damage frequencies for these reactors are designed to be lower than for Generation II reactors – 60 core damage events per 100 million reactor-years for the EPR and 3 core damage events per 100 million reactor-years for the ESBWR, significantly lower than the 1 000 core damage events per 100 million reactor-years for BWR/4 Generation II reactors. Table 4 summarizes Generation III reactor

[28] https://iec.iaea.org/usie/actual/LandingPage.aspx

technologies in the selected APEC economies. The first Generation III reactors were built in Japan, in the form of ABWR designed by GE, while several others are under construction in Europe, including the EPR designed by Areva. The next Generation III reactor predicted to come on line is a Westinghouse AP1000 reactor, located at Sanmen Nuclear Power Station in China. The first AP1000 reactor unit is planned to be commissioned in early 2017, after a three-year construction delay. The world's first EPR reactor will be commissioned in Guangdong, China in around the middle of 2017, after a construction delay of 2.5 years.

Cost reduction of Generation III reactors is an objective shared by all vendors and operators which can be achieved through a number of options including design simplification, standardization, improved constructability, modularity and supply chain optimization, as well as by taking full advantage of the lessons learnt during the first-of-a-kind (FOAK) projects.

Table 4 Selected Generation III reactors in APEC economies

Economy	Reactor type
Canada	Advanced Fuel CANDU Reactor (AFCR)
China	CAP1400, HRP1000
Japan	ABWR (co-design with US), APWR
Korea	APR1400
Russia	VVER-1200, BN800
The United States	AP1000 (Westinghouse/Toshiba)

Sources: IAEA and APERC.

Generation IV Reactors[29]

Generation IV technology includes a set of nuclear reactor designs currently being researched for commercial applications by the Generation IV International Forum (GIF), with technology readiness levels varying between the levels requiring a demonstration, to economical competitive implementation. They are motivated by a variety of goals including improved safety, sustainability, efficiency and cost. An international collective representing governments of 13 countries and one international organization (Euratom), GIF was initiated

[29] http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power- reactors/generation-iv-nuclear-reactors.aspx

in 2000 and formally chartered in 2001. In 2002, GIF published the roadmap for the next generation reactors, and selected six systems which they believe represent the future shape of nuclear energy, including Gas-Cooled Fast Reactor System (GFR), Lead-Cooled Fast Reactor System (LFR), Molten Salt Reactor System (MSR), Sodium-Cooled Fast Reactor System (FSR), Supercritical-Water-Cooled Reactor System (SCWR) and Very-High-Temperature Reactor System (VHTR). The roadmap was updated in 2014 and confirmed the choice of six Generation IV concepts. Seven APEC economies are participants in GIF, including Australia, Canada, China, Japan, Russia, Korea and the United States.

Small Modular Reactors (SMRs)

SMRs are generally 300 MW equivalent or less, which may provide alternative low-carbon option for the economies with relatively small-scale power grids, such as Southeast Asian economies. In APEC economies, more than 20 types of SMRs have been designed (Figure 39). Its passive safety, adequate flexibility, modular production and less upfront investment make SMRs attractive; yet, the biggest challenge is that the economics have yet to be proven.

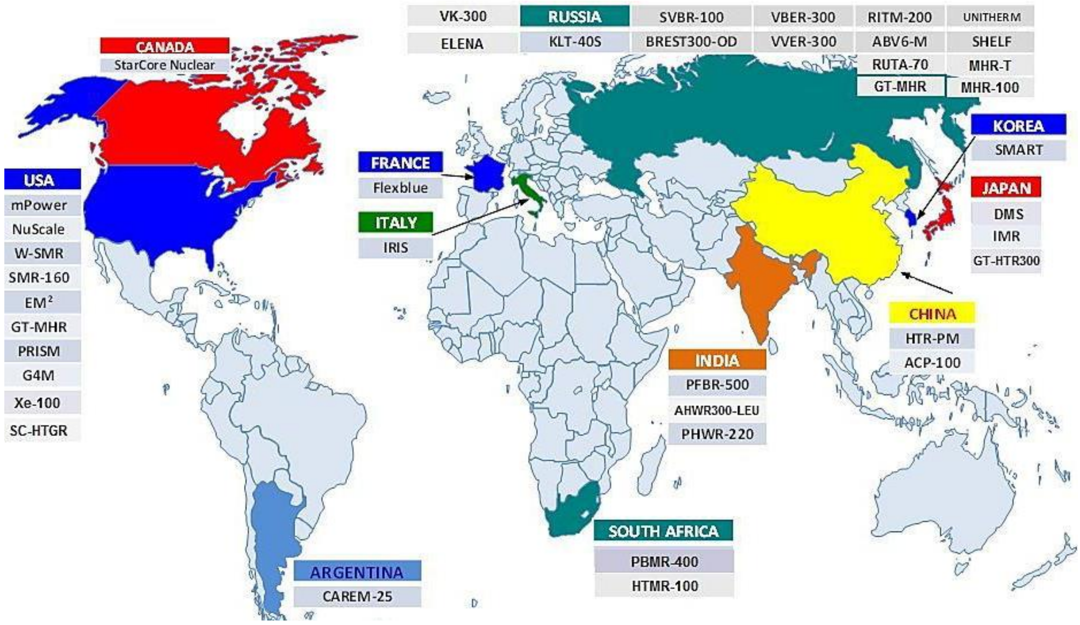


Figure 39 SMRs developed by different economies

Data source: IAEA[30]

[30] IAEA: https://aris.iaea.org/Publications/SMR-Book_2016.pdf

4.1.3 Waste management

Highlights

- ✓ APEC accounts for about two-thirds of the total nuclear waste in the world.
- ✓ Different strategies were implemented in APEC economies for nuclear waste and spent fuel disposal.
- ✓ For the newcomer economies, while it is not so critical at the beginning to deploy nuclear power, they should pay attention to and draft a long-term plan for this issue.

According to IAEA's estimation[31], spent fuel from nuclear reactors in storage amounted to around 266 000t HM (Heavy Metal) and is accumulating at a rate of around 7 000t HM/year. Spent fuel reprocessing from commercial reactors continued to be carried out at 10 facilities in five member economies of IAEA. The APEC region roughly accounts for two-thirds of the total amount in the world. Final disposal in Deep Geological Repositories (DGRs) is the recognized solution for all high level waste, whether it is spent fuel (direct disposal) or waste from reprocessing. Currently in the world, Finland is leading the way with the construction of the first DGR, which is expected to enter operation in the early 2020s (for direct disposal of spent fuel from the Olkiluoto and Loviisa nuclear power plants).

There are currently no operating disposal facilities for HLW in the APEC region, and the spent fuel inventories are therefore growing. All spent fuel is initially stored under water for cooling in storage pools at reactor facilities for between nine months and several decades, depending on the storage capacities of the pools. This is usually followed by a period of intermediate dry storage. Then, in a few economies, such as France, Russia and Japan[32], spent fuel is transported to a reprocessing facility and stored there in buffer storage pools before being fed into the process. And the spent fuel not destined for reprocessing remains stored in the original reactor storage pools or is transported to separate "away from reactor" (AFR) fuel storage facilities. Despite their name, the AFR facilities may be either on a part of the reactor site or at other dedicated sites. Currently there are around 120 operating commercial AFR spent fuel storage facilities around the world, most of them being dry storage facilities at reactor sites. The challenge is to accelerate progress on building HLW

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31 IAEA, Nuclear Technology Review 2016, https://www.iaea.org/About/Policy/GC/GC60/GC60InfDocuments/English/gc60inf-2_en.pdf

32 Spent fuel in Japan has been reprocessed in France and the United Kingdom. A reprocessing plant (800 t/yr) is under construction at Rokkasho in Aomori prefecture.

disposal facilities and expand AFR storage to accommodate the increased spent fuel inventories and extended storage times.

Table 5 Waste management policies, selected APEC economies

Economy	Policy	Facilities and progress towards final repositories
Canada	Direct disposal	● Nuclear Waste Management Organization set up 2002 ● Deep geological repository confirmed as policy, retrievable ● Repository site search from 2009, planned for use 2025
China	Reprocessing	● Central spent fuel storage at LanZhou ● Repository site selection to be completed by 2020 ● Underground research lab. from 2020, disposal from 2050
Japan	Reprocessing	● Underground laboratory at Mizunami in granite since 1996 ● Spent fuel and HLW storage facility at Rokkasho since 1995 ● Spent fuel storage constructed at Mutsu in 2013 ● NUMO set up 2000, site selection for deep geological repository under way to 2025, operation from 2035
Korea	Direct disposal, wants to change	● Waste program confirmed 1998, KRWM set up 2009 ● Central interim storage planned from 2016
Russia	Reprocessing	● Underground laboratory in granite or gneiss in Krasnoyarsk region from 2015, may evolve into repository ● Final repository sites under investigation on Kola peninsula ● Pool storage for VVER-1000 spent fuel at Zheleznogorsk since 1985 ● Dry storage for RBMK and other spent fuel at Zheleznogorsk from 2012 ● Various interim storage facilities in operation
The US	Direct disposal, but reconsidering	● DOE responsible for used fuel from 1998, accumulated USD 32 billion waste fund ● Considerable research and development on repository in welded tuffs at Yucca Mountain, Nevada ● The 2002 Congress decision that geological repository be at Yucca Mountain was countered politically in 2009 ● Central interim storage for used fuel now likely

Sources: World Nuclear Association and APERC.

Among the APEC economies, the US and Canada have currently opted for direct disposal (Table 5). Spent fuel is currently stored in dry cask systems at a growing number of power plant sites[33]. Dry cask storage is more limited in heat dissipation capability than wet storage[34], but has the advantage of being modular, which spreads capital investments over time, and, in the longer term, the simpler passive cooling systems used in dry storage reduce operation and maintenance requirements and costs. In the US, by the end of 2009, 13 856 metric tons of commercial spent fuel in dry casks. In Canada, some above-ground dry storage sites have been used and some are under construction. For the economies which have deployed NPPs for a relatively long time, such as the US, Russia, Korea and Japan, nuclear waste disposal and storage becomes a serious problem to be addressed, as storage space grows tight at plant sites and more storage sites are needed. However, for the newcomer economies, it is not so critical for the nuclear power development at the beginning, yet they should pay attention and draft a long-term plan to this issue before nuclear power deployment.

4.1.4 Decommissioning

As illustrated in Figure 38, majority of the nuclear reactors in the APEC region have been operated for more than 30 years. Therefore, decommissioning will become an increasingly important part of the nuclear power activity in the coming decades, as dozens of reactors are expected to be shut down in APEC. There are essentially two main strategies for decommissioning: immediate dismantling, where after the nuclear facility closes, equipment, structures, and radioactive materials are removed or decontaminated to a level that permits release of the property and termination of the operating license within a period of about 10 to 15 years; and deferred dismantling, where a nuclear facility is maintained and monitored in a condition that allows the radioactivity to decay – typically for about 30 to 40 years, after which the plant is dismantled and the property decontaminated. A third strategy exists called entombment, where all or part of the facility is encased in a structurally long-lived material. It is not a recommended option, although it may be a solution under exceptional circumstances (such as after a severe accident).

[33] https://www.nrc.gov/waste/spent-fuel-storage/dry-cask-storage.html

[34] Therefore, spent fuel assemblies are moved from reactor vessel to the spent fuel pool (wet storage) first, then the spent fuel that have already been cooled are stored in dry cask systems.

Case study: Nuclear power decommissioning in Japan

In order to better understand the decommissioning, this report takes Japan's experience and methodology as an example. The Nuclear Regulation Authority (NRA) defines the decommissioning of NPPs in Japan according to the following four activities: dismantling of the relevant reactor facilities, transfer of nuclear fuel, removal of irradiated material, and the disposal of radioactive waste (Figure 40). Within these boundaries designed by NRA, nuclear operators can design their own decommissioning strategies.

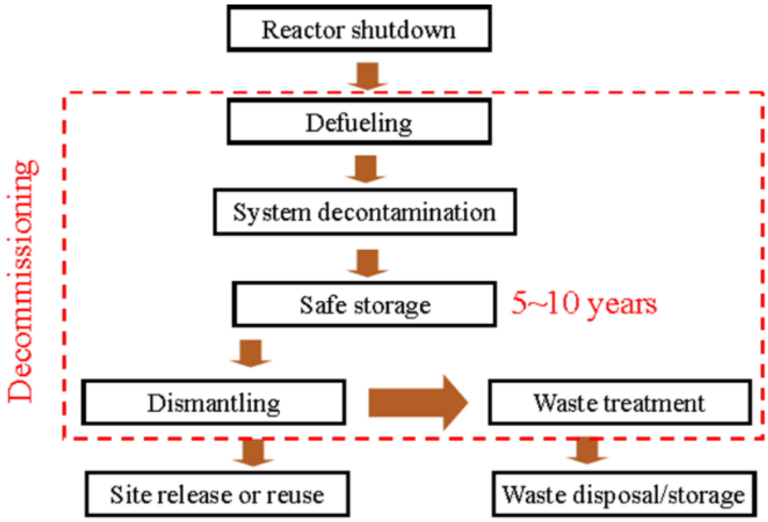

Figure 40 Example of nuclear power plant decommissioning process in Japan
Information from the report of JAPCO and University of Fukui[35]. Figure by APERC.

Based on the report of JAPCO and University of Fukui, the decommissioning of PWR-type reactors is expected to be less costly than BWR-type reactors (Figure 41). However, the majority of the current projects, including the reactors of the Fukushima Daiichi NPP, are BWRs. Expenses related to waste management make up around one-third of the total decommissioning costs, yet uncertainties exist in this part largely due to the unresolved question of radioactive waste disposal and spent fuel management. PWRs produce a smaller total volume of radioactive waste, but the quantity of highly irradiated material is higher. This makes the clearance system less effective for a PWR-type reactor.

[35] http://cdnsite.eu-japan.eu/sites/default/files/publications/docs/2016-03-nuclear-decommissioning-japan-schmittem-min_0.pdf

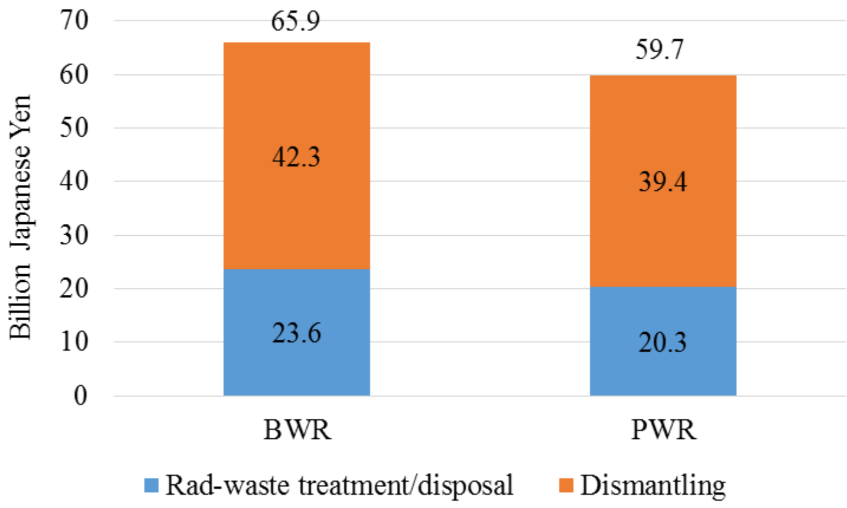

Figure 41 Estimated costs for decommissioning BWR and PWR (1.1 GW model-plant) in Japan

Data and introduction from the report of JAPCO and University of Fukui. Figure by APERC.

4.1.5 Economic competitiveness

Highlights

- ✓ Generally speaking, nuclear generation is cost-competitive in energy importing economies where there is limited access to low-cost fossil fuels.
- ✓ Capital costs is the major cost-component of nuclear generation; thus, lower capital costs, lower discount rate as well as higher capacity factor improve its economics.

Generally speaking, nuclear generation is cost competitive with other forms of electricity generation, except where there is direct access to low-cost fossil fuels. Fuel costs for nuclear plants are a minor proportion of total generating costs, though capital costs are greater than those for coal-fired plants and much greater than those for gas-fired plants. The World Nuclear Association early in 2017 published Nuclear Power Economics and Project Structuring[36]. The report notes that the economics of new nuclear plants are heavily influenced by their capital costs, which accounts for at least 60% of their levelised cost of electricity. Therefore, the competitiveness of nuclear power heavily relies on the low-cost

[36] http://www.world-nuclear.org/getmedia/84082691-786c-414f-8178-a26be866d8da/REPORT_Economics_Report_2017.pdf.aspx

capital costs. However, due to the construction delay as well as the first-of-a-kind-engineering costs, the capital costs of Generation III reactors are much higher than expected, which could be a challenge for future deployment.

Other factors, including discount rate as well as capacity factor, also affect the economics of nuclear generation, as capital cost is the dominant cost component. According to the OECD NEA and IEA estimations, nuclear would be cost-competitive option compared to coal and CCGT (Combined Cycle Gas Turbine) at a 3% discount rate (Figure 42); yet, the study also suggested that nuclear becomes less attractive option from an economic viewpoint at a higher rate, such as 7% and 10%. The median value of nuclear power is close to that of the coal at a 7% discount rate, and higher than CCGT and coal at a 10% rate. Note that these results include a carbon tax of USD 30/tonne, as well as the regional variations in assumed fuel costs. Higher capacity factor is important to payback the capital investments. However, growing intermittent renewables may results in lower capacity factor of other generation technologies, including nuclear, posing challenges from an economic perspective.

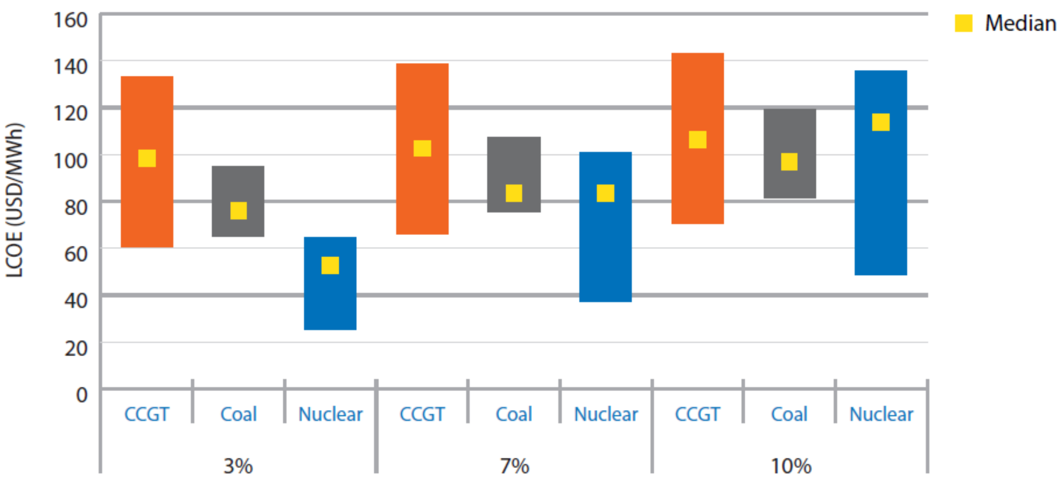

Figure 42 Levelized cost of electricity with different discount rate, selected technologies Data and figure from IEA/NEA (2015).

4.1.6 Public acceptance

Highlights

- ✓ In general, the nuclear accident at the Fukushima Daiichi station negatively impacted public acceptance rate in most of the economies, according to the surveys.
- ✓ The existing “nuclear utilizing” economies as well as new comers need to muster a sustained effort to provide the general public with transparent information.

Public concerns about reactor safety, nuclear waste disposal, and rising construction costs have had a particularly notable impact on state policies as well as the final determination for NPP projects, especially for the newcomer economies. Various surveys and research have been conducted by organizations, academic institutes and nuclear power stakeholders. However, mixed results have made it difficult to make reliable conclusions.

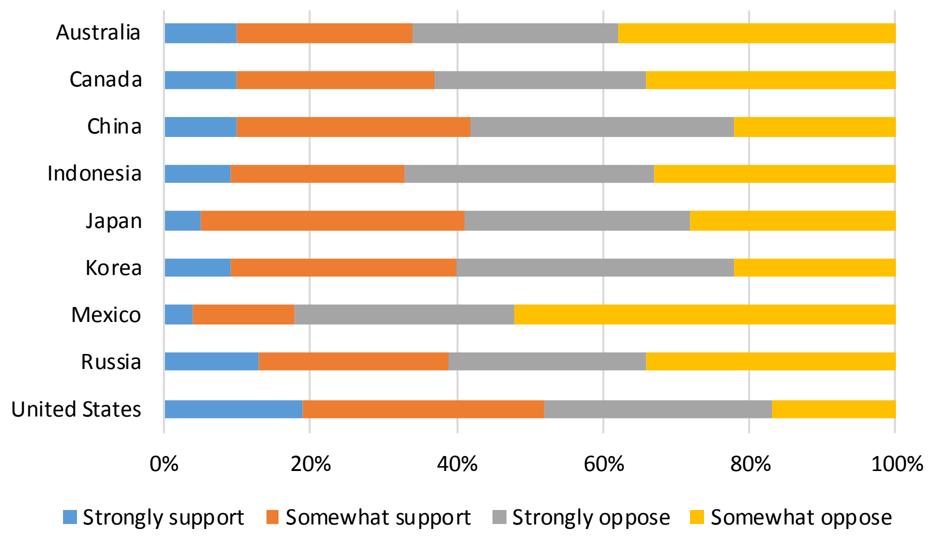

Figure 43 Public perception towards nuclear power in selected economies Survey by Ipsos 2011[25].

Here, we take a global survey by Ipsos Company as an example. The survey was conducted in May 2011 and included 24 economies. Figure 43 shows the results for the major nuclear economies in the APEC region. We can find that a majority support nuclear power in the United States, which accounts for more than 50% of the sample. For most of the economies, the support rate for nuclear power is around 40%. Details of the survey can be found in the Ipsos' report[37].

Sample results of public survey, selected APEC economies

In the United States, support for nuclear energy remains steady, according to a public opinion survey conducted by the Nuclear Energy Institute (NEI) in autumn. Sixty-five percent of the US public expressed support for nuclear energy, consistent with recent years where two-thirds of the public has reported favorability to nuclear energy (Figure 44). The poll was conducted in September and October 2016. The survey explored the role of nuclear energy in the 2016 presidential election and found bipartisan support. Sixty percent of Clinton supporters and 75% of Trump supporters reported support for nuclear energy. The survey also found: 84% think nuclear should be important in the future; 82% agree we should take advantage of all low-carbon energy sources, including nuclear, hydro and renewable energy; 95% agree it's important to maintain diverse electricity sources. More detailed information about this poll and the questionnaire can be found on NEI's website.

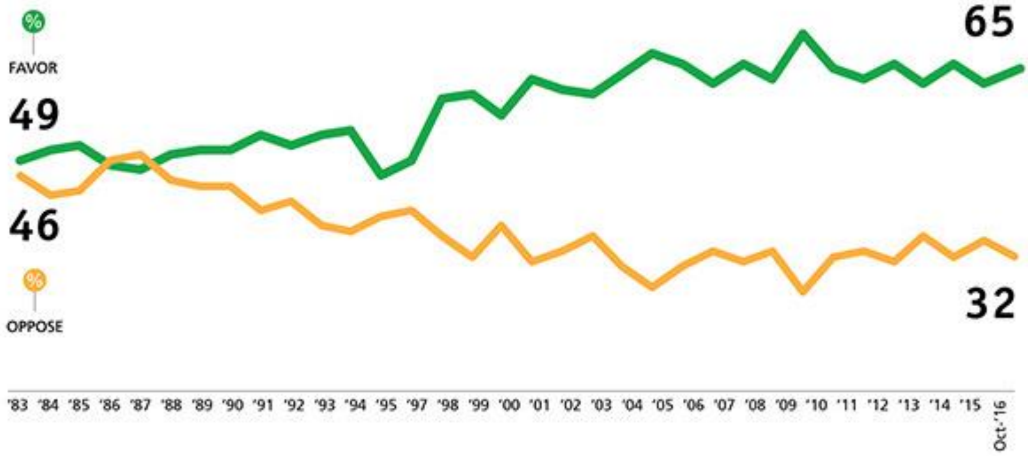

Figure 44 Favorability to nuclear power in the United States

Survey conducted by NEI. Data and figure from NEI.[38]

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37 https://www.ipsos-mori.com/Assets/Docs/Polls/ipsos-global-advisor-nuclear-power-june-2011.pdf

38 https://www.nei.org/Knowledge-Center/Public-Opinion

With regard to Japan, we have introduced the results of a survey conducted by Nikkei in Section 2.2.4. Since the nuclear accident in Fukushima, various researches have been carried out on public acceptance issues. Here we take another public poll conducted by the Japan Atomic Energy Relations Organization (JAERO) as an example. The results to the question "*Is Nuclear Energy Necessary?*" imply that the public acceptance rate for nuclear power has decreased sharply, with only more than a quarter of the population considering that nuclear power was necessary for Japan (Figure 45). Before the Fukushima Daiichi nuclear accident in 2011, this rate was more than 70%.

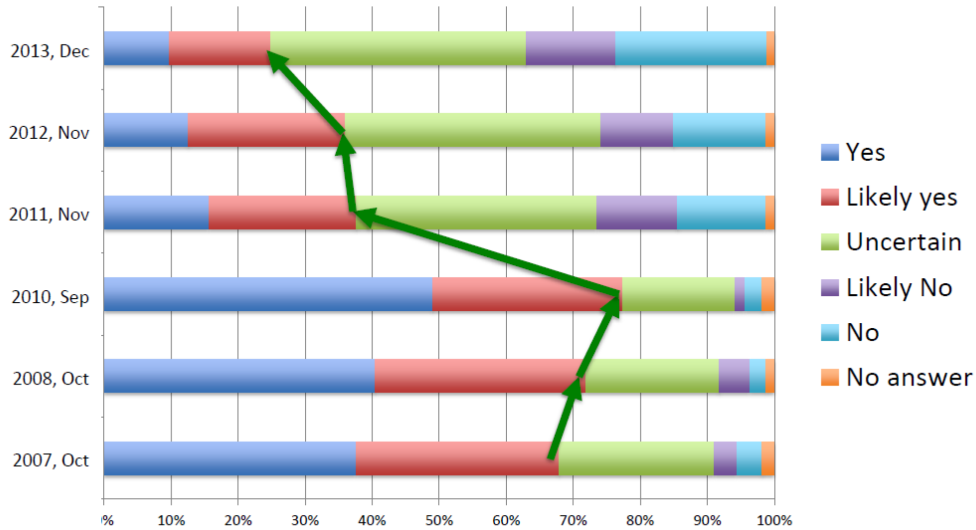

Figure 45 A survey on public acceptance for nuclear power in Japan

Survey conducted by JAERO. Data and figure from JAERO (in Japanese).[39]

As for new comer economies, such as Southeast Asian economies, there are several existing surveys summarized by the IAEA or the government as follows:

- **Indonesia**[40]**:** In order to survey public perception concerning utilization of NPP, in November 2010, a poll was conducted of 3 000 respondents, resulting in 59.7% agreeing with utilization of NPP, 26.1% not agreeing and 14.2% abstaining. After Fukushima's NPP accident in 2011, a poll was conducted with the same number of

[39] http://www.jaero.or.jp/data/01jigyou/tyousakenkyu.html

[40] https://cnpp.iaea.org/countryprofiles/Indonesia/Indonesia.htm

respondents and the percentage agreeing decreased to 49.5%. In 2012 a poll involving 5 000 respondents was conducted, which showed that public acceptance increased to 52%. A poll in 2013 showed that public acceptance for utilization of NPP in Indonesia increased to 60.4%. In a 2014 poll, public acceptance for utilization of NPP in Indonesia significantly increased, with 72% responding that they agreed. The newest poll in 2015 indicates that 75.3% of Indonesia's population support the construction of NPP.

- **Malaysia:** A public survey was conducted between 14 March and 10 May 2016 focusing on public acceptance and perception towards the implementation of nuclear energy in Malaysia. It was conducted online using social media advertisement as tools of dissemination. Public favorability to nuclear energy was divided, with 39.8% supporting and 40.1% opposing, while 20.1% of the respondents chose to be neutral with regard to nuclear power.
- **The Philippines:** No detailed information on public surveys in the Philippines could be found. Nuclear power is nevertheless a controversial topic, and the BNPP was a focal point for anti-nuclear protests since the beginning of its construction.
- **Thailand:** No clear figures were found for the public acceptance rate for nuclear power. The Electricity Generating Authority of Thailand (EGAT) has actively implemented a number of activities to disseminate information on the energy situation in Thailand and "why nuclear power is a viable option for electricity generation". The activities were aimed at reaching not only the local community, but also students, teachers, the media, religious leaders and others. EGAT has also collaborated with the office of non-formal and informal education in developing the textbook and teacher's guidebook of "Electricity Usage in Daily Life", which includes various types of electricity generation. Training for the teacher program has been conducted economy-wide for a sustainable learning process. It is expected that this program will help gain public acceptance for nuclear power.
- **Viet Nam:** The government's announcement on setting up four NPPs has heated a debate amongst pundits in Viet Nam. Some agree with this policy, stating that it is necessary for the development of the economy. However, a number of scientists, including nuclear experts, express fear over accidents and difficulties in storing waste, as well as concerns regarding human capacity to operate such advanced technology and the huge capital required.

4.2 Conclusion

This chapter overviewed several challenges for nuclear power development in the APEC region, including the nuclear safety, technical progress, waste management, decommission, economic competitiveness as well as public acceptance.

After the Fukushima Daiichi nuclear accident, nuclear safety was enhanced in all APEC economies that already embarked on nuclear power. In recent years, advanced nuclear power technologies have developed fast. The Generation III and Generation IV nuclear power designs saw rapid progresses, and some of the pioneer demonstration projects have been implemented. SMRs may attract interests in particular from Southeast Asian economies with relatively small-scale grids. Further researches in terms of economic performance and safety feature would be important for SMRs to be largely deployed.

Nuclear waste and spent fuel disposal is always a concern for the public. In the APEC economies that have deployed NPPs for a relatively long time, such as the US, Russia, Korea and Japan, nuclear waste disposal and storage has become a serious problem to be addressed, as storage space becomes limited at plant sites and more storage sites are needed. However, for the newcomer economies, this is not so critical for nuclear power development at the beginning. They should nevertheless pay attention to and draft a long-term plan for this issue before nuclear power deployment. Decommission is another challenge for the nuclear utilizing economies because of aging issues of existing reactors.

Economic competitiveness of nuclear generation varies by economy, reflecting its energy situation. In general, nuclear is relatively competitive in energy importing economies where there is limited access to low-cost fossil fuel resources, and *vice versa*. As capital costs is the major cost component for nuclear generation, capital costs, discount rate as well as capacity factor largely affect its competitiveness.

Public acceptance remains a significant challenge for all the APEC economies to deploy new NPPs. The nuclear accident in Fukushima negatively impacted the public acceptance rate in most of the economies, according to the surveys. The economies which will continue or start nuclear power generation need to muster a sustained effort to provide the general public with transparent and balanced information.

Chapter 5 Conclusion: potential for collaboration among the APEC economies

More than five years after the Fukushima Daiichi nuclear accident, many economies revised their nuclear policies. In order to better discuss the opportunities and challenges for nuclear generation after the accident, this study summarized current nuclear policies (Chapter 2) as well as conducted a quantitative analysis on future nuclear scenarios (Chapter 3). The modeling study suggested that the nuclear generation has a potential to contribute the APEC economies from the 3E—Environment, Energy security and Economic efficiency—perspective; however, nuclear also faces significant challenges as pointed out in Chapter 4. International cooperation can be one of the options to overcome the challenges. In order to create a better environment for nuclear power development in the APEC region, this chapter discuss the future cooperation possibilities among the APEC economies, as a concluding chapter.

5.1 Collaboration possibilities in the APEC region

5.1.1 Existing collaboration framework

Nuclear energy, embodying sophisticated and resource intensive technologies, presents different opportunities for collaboration among different economies in the world. International cooperation provides a forum for different stakeholders to work together to share and analyze data and experiences, gain consensus and develop approaches that can be applied within each economy's energy policy making. As nuclear power attracts more and more attention in recent years, there have been a lot of international organizations and frameworks dedicated to enhancing nuclear safety and conducting R&D for nuclear power.

Existing global cooperation frameworks

There are several international organizations dedicating to nuclear energy, such as IAEA, OECD NEA and WNA. They provide international cooperation frameworks in various areas, including nuclear safety, technology, science, environment, law, as well as knowledge sharing and management.

One of the most influential international organizations on nuclear energy would be the IAEA, which is responsible for implementing international agreements specific to nuclear power, notably the Nuclear Non-Proliferation Treaty that enables international collaboration on the peaceful uses of atomic energy while providing mutual assurance.

The OECD NEA, representing 31 economies[41] with 84% of the world's nuclear capacity, assists member countries in developing the scientific, technological and legal bases required for the use of nuclear energy. It fosters a number of international collaborative programs, and produces many publications arising from these.

In addition, there are a number of international collaboration initiatives which focus on reactor technology development, centralized international fuel cycle services, and development of nuclear licensing procedures and regulation. Collaboration on reactor technology development mainly focuses on reactor designs of regional interest and is set up along the lines of the GIF or the IAEA's INPRO programme. GIF is a 14-member forum set up in 2001 which has identified six reactor concepts for further investigation with a view to commercial deployment by 2030-2040. It is focused on new reactor technology. IAEA' INPRO is focused more on assessment methodology for developing economy needs. It involves users as much as technology holders and has 39 member economies including several which do not yet have nuclear power. INPRO supports economies as they develop long-range national nuclear energy strategies using INPRO's nuclear energy system assessment (NESA) and the INPRO Methodology. The five Southeast Asian economies in Chapter 2 are all INPRO members and have implemented pre-feasibility studies using INPRO's assessment system as a guideline.

On the industry side, there are also some international cooperation frameworks in order to enhance the connections among the whole nuclear industry. The most significant safety-related cooperation internationally is through the World Association of Nuclear Operators (WANO), which was formed over a couple of years following the Chernobyl accident to maximize the safety and reliability of NPP operation. Currently, WANO has five major programs, including peer reviews, performance analysis, member support and corporate communications, as well as training and development. The exchange of information (or

41 As of Aug 2017. Argentina and Romania is joining from 1st September 2017 and 15th October 2017, respectively.

Information sharing) on operating experience is one of the basis of WANO's various programs. Information and event reports are submitted by each operating organization to its regional center where they are reviewed for clarity and completeness and then distributed to all WANO members using an international exchange system.

Existing regional cooperation in the Asia-Pacific region

Since 1972, 15 economies in the Asia-Pacific region have cooperated under the Regional Cooperative Agreement (RCA) for Research, Development, and Training related to Nuclear Science and Technology. Over the past two decades RCA activities have covered agriculture, industry, medicine, radiation protection and basic nuclear science. In 1987, the program's scope was enlarged by the start of a project on energy and nuclear power planning.

The Forum for Nuclear Cooperation in Asia (FNCA) is a government-level cooperation forum in the Asia-Pacific region, proposed and led by Japan since 1990. It is a cooperation framework for peaceful use of nuclear technology in Asia. The cooperation consists of FNCA meetings and the project activities with participation from 11 economies. FNCA mainly focuses on the following fields: radiation utilization development (industrial utilization, environmental utilization and healthcare utilization), research reactor utilization development, nuclear safety strengthening and nuclear infrastructure strengthening.

Japan, Korea and China have agreed to form a network to cooperate on nuclear safety and change information in nuclear emergencies, especially those rating at level 2 or above on the International Nuclear Event Scale. At a meeting of nuclear regulators and other experts in Guangdong in December 2013, a framework was agreed despite regional tensions. In addition to exchanging information on civil nuclear accidents, the three countries will share standard information including safety. The agreement was signed by officials from Japan’s NRA, Korea's NSSC and China's National Nuclear Safety Administration (NNSA).

There are also a wide range of bilateral cooperation agreements between APEC economies. As Canada, China, Japan, Korea, Russia and the US all have nuclear power projects aboard, they have signed bilateral agreements with the target commercial partners.

5.1.2 Collaboration possibilities under the APEC framework

APEC has provided a more flexible platform for its member economies. The Energy Working Group, as a collaboration body for energy policy makers, plays an important role in fostering energy cooperation. APEC uses the term "*economy*" to describe its member regions; this enables the framework to include more areas, such as Chinese Taipei, than the other international organizations.

Information exchange

There are more than 260 nuclear power reactors in operation in the APEC region, and around 40 reactors under construction as of November 2016. As the "center of the gravity" of nuclear power generation is shifting to the Asia-Pacific, information exchange scheme, especially to share information about emergency preparedness as well as responses during the emergency period, becomes more important there. This scheme can also include information about daily operation plan and mid- to long-term nuclear development plans; sharing these plans of an economy may benefit the neighboring economies to enhance emergency preparedness, as some of the reactors are/will be located near the border among economies. Several international organizations such as IAEA and WANO have established emergency response mechanisms in order to exchange information and provide support for its member economies. However, there are no such inter-government platform for information exchange in the Asia-Pacific region, including Chinese Taipei; collaboration among the interested economies under APEC framework may contribute to a geographically-comprehensive scheme in the region.

Waste management and fuel cycle

There are cooperation possibilities in the area of waste technology, including firstly a multinational regional deep geological repository that in view of the technical, political and financial difficulties in their construction would make economic and practical sense to build jointly by several member economies. However, political and legal barriers will have to be overcome for implementation. Other cooperative projects could include collaboration on high level waste technology research, design and operation of LILW surface storage installations, LILW processing and preparation methods, waste standards and licensing, capacity building, and even the joint construction and operation of an underground research laboratory.

Cooperation in terms of fuel services would merit a closer look; for example, centralizing different stages of the nuclear fuel cycle would benefit non-proliferation by preventing the spread of sensitive technologies. Also, economies with full fuel cycle technologies could provide fuel services to other economies, including new comers which usually do not warrant investment in such resource intensive activities.

Future perspectives

In November 2016, APERC organized a workshop on nuclear power development, inviting representatives from 12 APEC economies and relevant international organizations. These representatives support the idea of future cooperation on nuclear power development in the APEC region, as it would benefit the wide range of stakeholders in this region, not only the current nuclear utilizing economies but also the newcomer economies.

In the short-term, we suggest relevant APEC economies establish a forum where policy makers, researchers and stakeholders in APEC can work together to share experiences and seek solutions to common problems. The collaboration activities could include: exchanging information on nuclear power development plans; sharing experiences with nuclear project preparation, construction and operation; and holding workshops or conferences on specific topics, such as public communication; financial issues and investment.

For long-term cooperation, relevant APEC economies could further the cooperation on the following topics: emergency preparedness and nuclear accident support mechanisms; nuclear waste and spent fuel disposal network; and financial frameworks, as well as cooperation with relevant multilateral organizations to support new NPP projects and preparatory works.

Nuclear power cooperation includes a sensitive and high-level political topic. Yet we believe these cooperation schemes would benefit the region and need to be discussed carefully but steadily.

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