Chapter 3

Status of Small Modular Reactor Development and Deployment in the World

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Chapter 3

Status of Small Modular Reactor Development and Deployment in the World

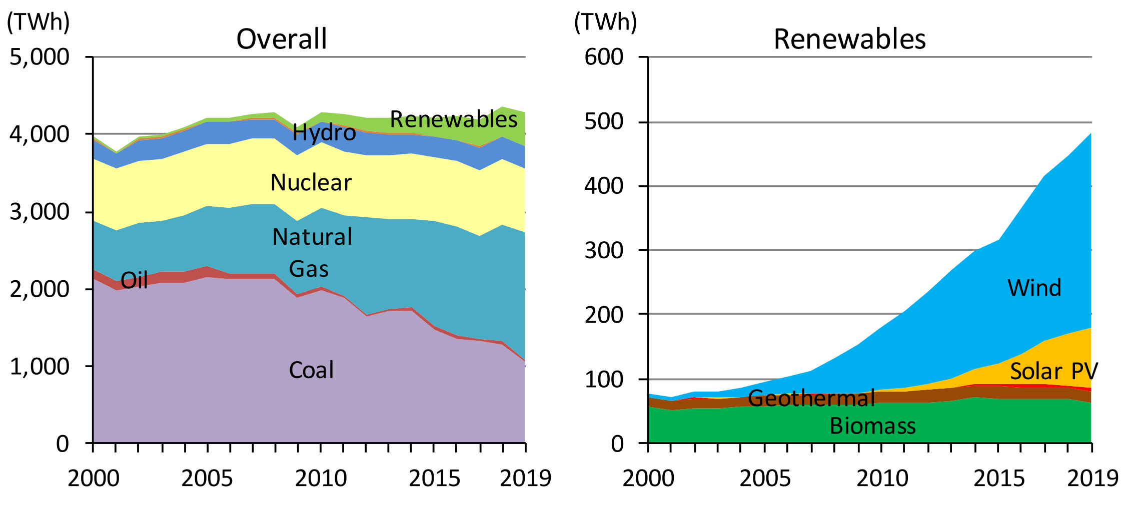
This chapter discusses nuclear energy policy and the status of small modular reactor (SMR) development in the leading countries in Europe and North America and several emerging economies in Asia and Africa, etc. The leading countries mentioned in this chapter are selected because of the efforts carried out by their governments and vendors to develop and deploy SMR technology. The emerging economies are selected based on their recent activities related to SMR feasibility studies.

1.SMR Development in the World

1.1.United States

(1) Nuclear energy policy

Figure 3.1. Electricity Generation by Source in the United States



PV = photovoltaics, TWh = terawatt hour.
Source: IEA (2020).

In the United States (US), nuclear energy provided about 19% of total electricity generation in 2019, which was the largest share amongst clean energy sources (Figure 3.1). Nuclear energy has been a reliable low-carbon energy source and has supported the country's energy security for more than 60 years. Therefore, the Department of Energy (DOE) of the Federal Government has promoted nuclear energy to meet the needs for energy supply, environmental protection, and energy security. The US electricity market is liberalised in many states today, and nuclear power generation is facing difficulties in its competitiveness and economic profitability because of the extremely low generation costs of natural gas and renewable energy (solar photovoltaics (PV) and wind). For this reason, some of the nuclear power plants (NPPs) have been closed before the expiration of their operating licence. However, the DOE has not changed its fundamental view that nuclear energy is important as a reliable low-carbon energy. It is trying to reinforce the competitiveness of nuclear energy by focusing on the development of advanced nuclear technologies. SMRs might be one of the most promising technologies amongst them. Compared to other advanced countries, there is a small number of large-scale electric power utilities in the US. For medium- or small-scale utilities that do not have enough budget to build a large-scale (around 1 GW) reactor, some of the features of SMRs would be very attractive because the total investment costs are relatively smaller than those of large-scale reactors (the total investment cost is calculated from the unit cost (US$/MW) multiplied by installed capacity (MW), and generally speaking, the total installed capacity of SMRs would be much smaller than 1 GW). The short construction time means they can soon begin power generation and collect their investment.

(2) SMR development

(a) Support for SMR research and development by the DOE

As mentioned above, the development of SMRs and other advanced reactors is an important objective for the US Federal Government. Formerly, the DOE provided the SMR Licensing Technical Support (LTS) programme to support advanced reactor development, but this has already ended. After the LTS programme, the DOE established a funding opportunity, Gateway for Accelerated Innovation in Nuclear (GAIN), for the promotion of advanced reactor development, in November 2015.

It can be said that GAIN is a form of public-private partnership. The main objective of the GAIN programme is to provide private companies with access to national research facilities, financial support, and regulatory process support. Therefore, selected companies can use experimental and testing facilities, modelling and simulation tools, important data, sample materials, and the sites of state-of-the-art national laboratories of the US. The DOE and the GAIN programme also give private companies instructions on the safety regulation of the Nuclear Regulatory Commission (NRC) so that the applicants can properly understand the regulatory process.

In addition to the GAIN programme, the DOE launched the Advanced Reactor Demonstration Program (ARDP) in May 2020 in accordance with the recommendations of the Nuclear Fuel Working Group, which was established by the Federal Government to restore US leadership in the global nuclear energy market (DOE, 2020). The ARDP identifies three pathways for support funding:

- Advanced reactor demonstrations, which are expected to result in a fully functional, advanced nuclear reactor within 7 years of the award.
- Risk reduction for future demonstrations, which will support up to five additional teams resolving technical, operational, and regulatory challenges to prepare for future demonstration opportunities.
- Advanced Reactor Concepts 2020, which will support innovative and diverse designs with the potential to commercialise in the mid-2030s.

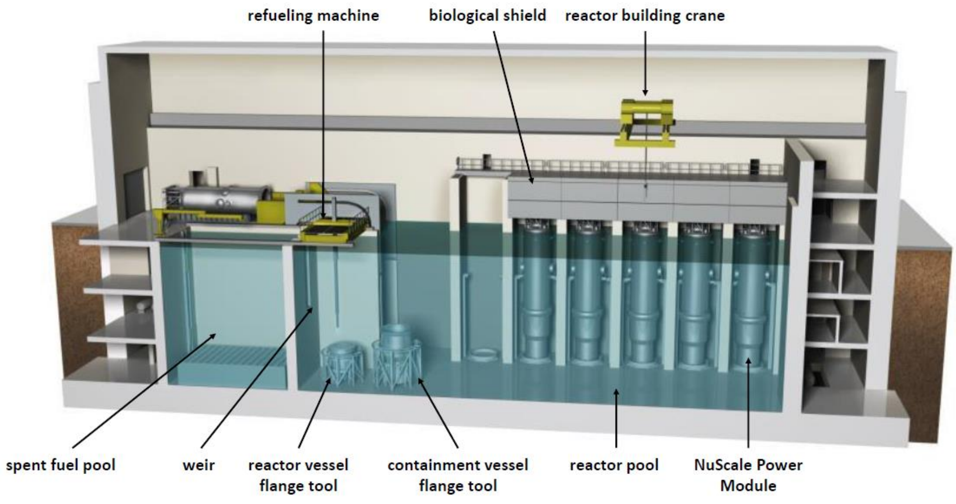
The DOE has already announced that the Natrium reactor (a sodium-cooled fast reactor) developed by TerraPower and GE-Hitachi and Xe-100 (a high temperature gas-cooled reactor) developed by X-energy were awarded US$80 million each under the ARDP scheme.

The DOE also promotes the research and development (R&D) of nuclear fuel for advanced reactors. The DOE aims to provide high-assay low-enriched uranium (HALEU) to private vendors. HALEU could be used in some advanced non-light water reactors (LWRs) that would be adopted by SMR vendors. In January 2019, the DOE announced the result of an environmental assessment which said that using DOE-owned HALEU stored at the Idaho National Laboratory (INL) will not result in a significant impact on the environment. Since this DOE-owned HALEU was produced from used fuel from the Experimental Breeder Reactor-II (EBR-II) which was already shut down in 1994, the amount is limited. On the other hand, in November 2019, the DOE signed with Centrus Energy, a nuclear fuel and services supplier, a three-year contract to deploy a cascade of centrifuges to demonstrate the production of HALEU fuel. Urenco USA, a supplier of uranium enrichment services and nuclear fuel cycle products, has also announced that they are exploring the construction of a dedicated HALEU production unit at their facility.

(b) NuScale SMR project

NuScale Power is one of the most famous reactor vendors engaged in SMR design development in the US. NuScale's SMR (Figure 3.2) consists of 60 MW power modules and adopts conventional light-water reactor technology, but it provides many advanced features, such as stability, small land usage, incremental power to match load growth, integration with renewable energy, and reduced capital costs and Levelised Cost of Electricity (LCOE) compared to large NPP and multiple commercial applications so it can decarbonise more than just electricity production.

Figure 3.2. Reactor Building Design of the NuScale SMR



Source: Reyes and Hopkins (2018).

NuScale Power is conducting a construction project for its SMR at a site at the Idaho National Laboratory (INL). It is planned to begin operation of the first module by 2029. This SMR plant consists of 12 reactor modules of 60 MW, and the total generation capacity will be 720 MW. Utah

Associated Municipal Power Systems (UAMPS), an electric power utility in the state of Utah, is the owner of the reactors. The generated electricity in the INL will be transmitted to Utah, and one of the NuScale reactor modules will provide electricity to meet the energy demand of the INL according to the agreement between UAMPS and Battel Energy Alliance, the manager of the INL. The DOE also provides a lot of funding support for NuScale. In 2013, through the LTS programme, the DOE awarded US$226 million to their five-year SMR project. In addition, in 2018, after the LTS programme, the DOE provided US$40 million in cost-sharing financial assistance for NuScale.

In December 2016, NuScale Power submitted a design certification application (DCA) to the NRC, which was the first DCA for an SMR. The DCA review by the NRC consists of six phases, and the fourth phase (advanced safety evaluation report) was completed in December 2019. NuScale Power is taking action not only in the US but has also submitted an application for a pre-licensing vendor design review by the Canadian Nuclear Safety Commission (CNSC).

(c) Other activities related to SMRs

In the US, not only the government but also lawmakers are making efforts to promote the development and deployment of advanced reactors, including SMRs. Table 3.1 shows the legislation, including bills enacted or introduced in Congress, in recent years. It is remarkable that these bills are introduced and supported by bipartisan members of Congress.

Table 3.1. Advanced Nuclear Energy Legislation in the United States

Title	Status	Main Objectives
Nuclear Energy Innovation Capabilities Act (NEICA)	Enacted in September 2018	•Provide DOE-owned sites and facilities to public parties •Cost-share grants for applicants for licences of the Nuclear Regulatory Commission (NRC)
Nuclear Energy Innovation and Modernization Act (NEIMA)	Enacted in January 2019	•Improve the predictability of NRC review for advanced reactors •Secure enough budget for the NRC to conduct new activities
[Bill] Nuclear Energy	Introduced in	•At least two demonstration projects led

Leadership Act (NELA)	Senate in March 2019 Introduced in House in June 2019	by the DOE of advanced reactors by 2025 •Additional 2–5 projects by 2035 •Establish HALEU transportation programme
[Bill] Integrated Energy Systems Act	Introduced in Senate in October 2019 Introduced in Senate in June 2020	•Establishment of DOE-led research and development programme that focuses on the integration of nuclear energy with other energy sources
[Bill] American Nuclear Infrastructure Act (ANIA)	Introduced in Senate in November 2020	•Prize for advanced nuclear reactor licensing •Credit allocation to certified reactors

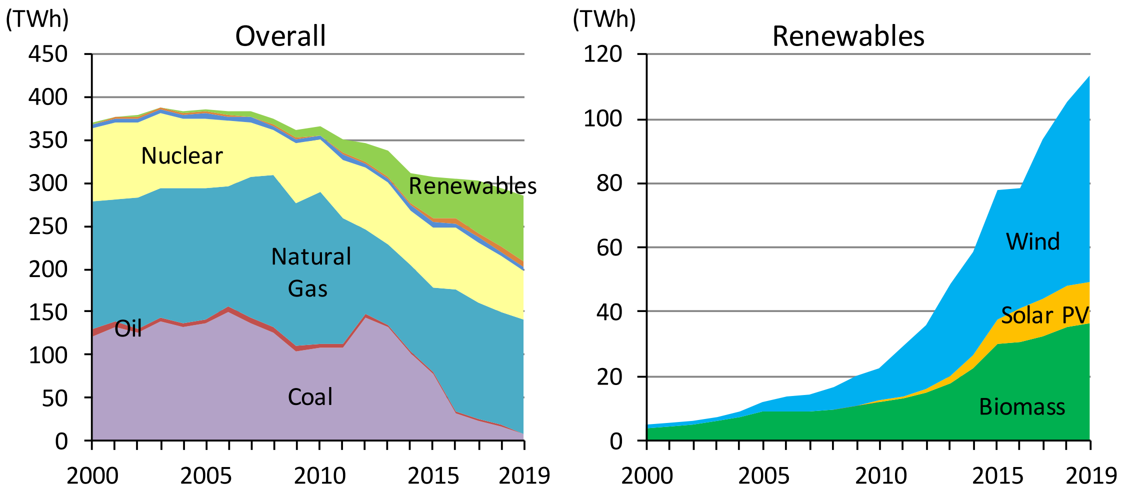
DOE = Department of Energy, HALEU = high-assay low-enriched uranium.
Note: NELA has not been passed in Congress but was partially adopted in the Consolidated Appropriations Act, 2021.
Source: Authors.

The attitude of the regulatory authority is also important for deploying advanced nuclear technology. In the US, the activities of the regulatory authority, the NRC, are supervised by Congress. As shown in Table 3.1, the NRC requires reforms so that it can cope with licensing new technologies. Therefore, the NRC has adopted a flexible and staged review process in which the NRC and applicants can intensively discuss and identify issues. The NRC is also making efforts for international cooperation. In August 2019, the NRC and CNSC signed a memorandum of cooperation that allows the two regulators to conduct common technical reviews on SMR and other advanced reactors. This will help the harmonisation of SMR regulation and encourage vendors to take action in the two countries because if they complete a review process in one country, they can easily expand their reactor to the other country.

1.2. United Kingdom

(1) Nuclear energy policy

Figure 3.3. Electricity Generation by Source in the United Kingdom



PV = photovoltaics, TWh = terawatt hour.
Source: IEA (2020).

In the United Kingdom (UK), nuclear provided 18% of total electricity generation in 2019 (Figure 3.3). The former Department of Energy and Climate Change (DECC) declared the basic nuclear energy policy of the UK government. The DECC (2013) said that nuclear energy has an important role to play in delivering its long-term objectives for a future with secure, low-carbon, and affordable energy. This attitude towards nuclear energy has not changed until today. The current government led by the Conservative Party emphasises the role of nuclear energy, and the Labour Party also insists on the need for nuclear energy.

This attitude is reflected in the contract for difference (CfD) policy scheme, one of the strategies of the Electricity Market Reform of 2011. It targets low-carbon electricity, including not only renewable energy but also nuclear energy. After introducing this mechanism, the first project for building a new NPP was Hinkley Point C. However, the National Audit Office (2017) criticised the Department for Business, Energy and Industrial Strategy (BEIS) for not sufficiently considering the costs and risks of the Hinkley Point C deal for consumers and for not assessing the potential value-for-money implications for bill-payers using alternative financing models. The BEIS then tried to introduce a new financing mechanism, the regulated asset base (RAB) model. This differs from the CfD in that it allows revenue that is not fixed but that is revised regularly and allows generators to receive revenue even before construction. The BEIS accepted a public consultation on the RAB model in 2019 and published its outcome in December 2020. Following the outcome, the BEIS (2020) said that RAB model with the high-level design principles remains a credible model for large-scale nuclear projects.

To resolve the expensive cost of building new NPPs, another policy was also launched. In 2018, the UK government published the Nuclear Sector Deal, which said that the government and industry need to make partnerships to reinforce the competitiveness of the nuclear industry of the UK. It includes a vision to reduce the costs of new construction projects by 30% up to 2030 and, thereafter, reduce them further if possible. The report mentioned that achieving this will depend on joint action on several fronts, including financing models and steps to address the main drivers of construction costs. Accordingly working groups under the Nuclear Industry Council (NIC) and the government have continued to seek cooperation between the government and industry.

(2) SMR development

The UK government's vision to develop SMRs and other advanced reactors has already been seen in the long-term strategy issued by the Department for Business, Innovation and Skills (BIS, 2013).

In 2014, the National Nuclear Laboratory (NNL, 2014) published a report on its SMR feasibility study that estimated the market potential of SMRs. According to the study, there is a very significant market for SMRs, and they fulfil a market need that cannot be met by large nuclear plants. The size of the potential SMR market is calculated to be approximately 65–85 GW by 2035, valued at £250 billion–£400 billion. In a regional assessment, the study also says that there could be a UK market for around 7 GW of power from SMRs by 2035, based on the demand for low-carbon generation and the site availability for small nuclear reactors (less than 300 MW). The study also conducts a technical assessment of some SMR designs. Their key criterion for suitability is the potential for deployment within a 10-year timescale, and they identify four reactors as promising designs that would meet both the technical and financial requirements: ACP100+ (China National Nuclear Corporation), mPower (B&W and Bechtel), Westinghouse SMR, and NuScale SMR. The NNL also shortlists two other designs by AREVA and Urenco, but they conclude that these designs should be considered in a longer timeframe.

In July 2016, the DECC and BIS were merged into the Department for Business, Energy and Industrial Strategy (BEIS). In November 2016, BEIS, advised by the Nuclear Innovation and Research Advisory Board and the Nuclear Innovation and Research Office, launched the Nuclear Innovation Programme (NIP) as a part of its Energy Innovation Programme (EIP). The EIP aims to accelerate the commercialisation of innovative clean energy technologies in the 2020s and 2030s and provides a budget of £505 million for 2015–2021, of which the BEIS allocates £180 million to nuclear innovation. The NIP provides funds for various kinds of projects, such as new-generation reactor design, advanced nuclear fuel development, fuel recycling, and technology development in advanced manufacturing and materials.

As for small-scale reactors, the BEIS focuses on advanced modular reactors (AMR) that adopt Generation IV (non-LWR) reactor technology. To this end, the BEIS announced its AMR Feasibility and Development (F&D) Project. This project consists of two phases:

Phase 1: Funding (up to £4 million) to undertake a series of feasibility studies for AMR designs. Contracts are worth up to £300,000.

Phase 2: Subject to phase 1 demonstrating clear value for money and government approval, a share of up to £40 million could be available for selected projects from phase 1 to undertake development activities. Up to a further £5 million may also be made available to regulators to support this.

BEIS revealed in September 2018 that eight companies had been awarded contracts to produce feasibility studies as part of phase 1 of the project. In July 2020, three of them were selected as successful projects for phase 2: Tokamak Energy Ltd., Westinghouse Electric Company UK, and U-Battery Developments Ltd.

The NIP also provides the Advanced Manufacturing and Materials Programme. This programme aims to reduce the capital costs and risks of advanced reactors by offering a number of benefits, including off-site fabrication which is one of the important features of SMRs. In July 2020, BEIS disclosed 11 successful projects for phase 2 (2A and 2B). Phase 2 aims to progress technologies, including those established in phase 1, towards demonstration and commercialisation.

It can be said that one of the most famous UK-based SMR vendors is the consortium led by Rolls-

Royce. They are developing a pressurised water reactor (PWR)-based design. Rolls-Royce has told the BBC that they plan to install and operate their first reactor by 2029 (BBC News, 2020).

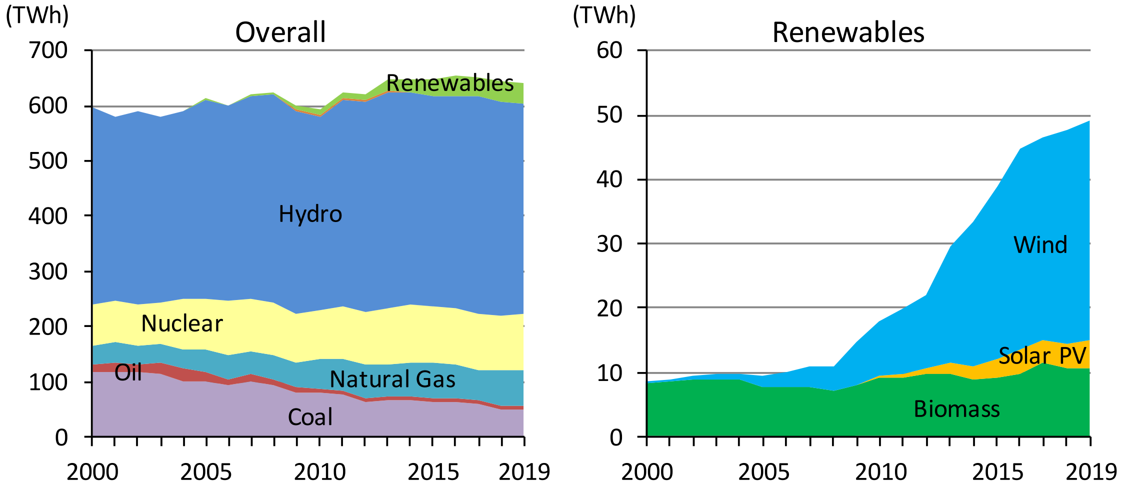
In the UK, the Office for Nuclear Regulation (ONR) and Environment Agency (EA) are responsible for nuclear safety review and licensing. The UK's regulatory scheme provides generic design assessment (GDA) in which the regulators get involved with reactor vendors and review the safety of their reactor designs at the earliest stage. As the GDA enables vendors to find any issues at an early stage, it can be said that the UK's regulatory scheme is basically favourable for new reactor vendors. The UK is also trying to improve regulatory systems so that they can deal with licensing for new types of reactors.

In October 2017, the UK government announced that it would invest up to £7 million (£5 million to the ONR and £2 million to the EA) to further develop the capability and capacity of the nuclear regulators to support and regulate the development of advanced nuclear technologies.

1.3. Canada

(1) Nuclear energy policy

Figure 3.4. Electricity Generation by Source in Canada



PV = photovoltaics, TWh = terawatt hour.
Source: IEA (2020).

In Canada, nuclear energy provided about 15% of total electricity generation in 2019, which was the second-largest amongst all electricity generation sources following hydro power (Figure 3.4).

There are four active nuclear power stations in operation, with 19 operating nuclear reactors.

The Government of Canada views nuclear energy as an important component of a diversified energy mix and a sustainable energy to meet current and future demand. Recently it has made a great deal of investment in SMRs, as the Minister of Innovation, Science and Industry said in October 2020, 'by helping to bring these small reactors to market, we are supporting significant environmental and economic benefits, including generating energy with reduced emissions, highly skilled job creation and Canadian intellectual property development'. (Government of Canada, 2020b)

The government has taken necessary measures to ensure the long-term development of nuclear energy, especially in R&D. Consequently, Canada is amongst the pioneers of nuclear power development with research efforts dating back to the 1940s and the establishment of Atomic Energy of Canada Ltd. (AECL) as a Crown corporation in 1952. AECL's National Research Universal reactor, built in 1957, is one of the oldest research reactors in the world and the most important source for medical radioisotopes for medical diagnosis and cancer therapy. Canada normally supplies approximately 75% of the world's supply of Cobalt-60 used to sterilise 45% of the world's single-use medical supplies. Additionally, Canada has exported AECL's nuclear power reactors, the heavy water-cooled and moderated pressurised-water reactors known as the Canadian Deuterium Uranium (CANDU) reactor.

Whilst the federal government has important responsibilities relating to nuclear energy, the decision to invest in electric generation rests with the provinces. It is up to the provinces, in concert with the relevant provincial energy organisations/power utilities, to determine whether or not new NPPs should be built. Although almost all new nuclear reactor construction plans have been held back recently, there has been a notable development in nuclear energy policy in Ontario, which is the main location of the nuclear energy industry in Canada. In 2015, Ontario decided to approve the refurbishment (lifetime extension) of the four nuclear units at Darlington and the remaining six units at Bruce.

(2) SMR development

In April 2017, the Canadian Nuclear Laboratory (CNL) announced its first long-term plan, which included building a demonstrational SMR at the Chalk River site by 2026. In October of that year, the CNL reported a strong response to a request for expressions of interest on the SMR programme. According to the second report published in October 2017, approximately 80 expressions of interest were submitted, of which 51 were from Canada, 11 from the UK, 9 from the US, and 9 from other countries. It was also reported why they were concerned with SMR development in Canada:

- the higher performance of nuclear technology development in Canada;
- the nuclear regulation policy and system in Canada; and
- the convenience of operation or international procurement, such as the supply chain in Canada.

In April 2018, the actual construction and operation project of the demonstrational SMR was asked about publicly. Until the deadline in June, there were four applications.

There has been another movement in parallel with this request for expressions of interest. In June 2017, the CNL and Terrestrial Energy set out a feasibility study for the siting of the first commercial Integral Molten Salt Reactor (IMSR) at the Chalk River site to identify a suitable location to construct the plant on the basis of the memorandum of understanding (MoU) of the IMSR engineering programme in 2016. For Terrestrial Energy's IMSR, the CNL has conducted its Pre-Licensing Vendor Design Review (VDR) since April 2016. Phase 1 of the Pre-Licensing VDR was already completed in November 2017, and phase 2 is in progress. (Details of the Pre-Licensing VDR are explained below.)

In addition, there has been a movement to promote discussions on SMRs all over the country. In 2018, the SMR Roadmap was issued in Canada to foster innovation and establish a long-term vision for the nuclear industry, as well as to assess the characteristics of different SMR technologies and utilities. Such a plan is rarely seen around the world, and is established through dialogues with the federal, provincial, and territorial governments, nuclear industries, utilities, indigenous communities, and local organisations, and so on. This involves extensive engagement with industry and other stakeholders through technical workshops, initial dialogues with indigenous communities and organisations, and expert analysis by five working groups to address the key questions around SMR deployment. The roadmap says that SMR is a small, low-carbon, and low-cost source, which is a key technology for achieving the greenhouse gas emission target (30% reduction below 2005 levels by 2030 and net-zero emissions by 2050). It also declares that Canada takes world leadership for promoting SMR development and confirms the global standard. It also emphasises the importance of strategic partnerships across sectors and countries. It proposes four pillars of action – demonstration and deployment; policy, legislation, and regulation; capacity, engagement, and public confidence; and international partnerships and markets – to guide the future actions needed for various stakeholders.

In December 2020, the SMR Action Plan was revealed to follow up the SMR Roadmap. The action plan summarises the latest status of each stakeholder's actions identified in the roadmap and states that the first units of SMRs should be in operation by the late 2020s.

The Canadian Nuclear Safety Commission (CNSC) stated at the US-Canada Nuclear Energy Leadership Summit in August 2018 that the current regulation was already suitable for regulating SMRs. They have begun discussions on how to regulate SMRs with the IAEA, the US, and the UK, etc. Furthermore, the CNSC has provided a new service, called the Pre-Licensing Vendor Design Review (VDR), for vendors designing new reactors. The details of this review service are below (CNSC, 2018a, 2018b):

a. Overview

It is an optional service provided by the CNSC when vendors request it. The review has three steps, each of which is conducted against related CNSC regulatory documents and Canadian code and standards.

- Phase 1: Pre-Licensing Assessment of Compliance with Regulatory Requirements. The CNSC judges the proposed plan considering updated regulations.
- Phase 2: Pre-Licensing Assessment for Any Potential Fundamental Barriers to Licensing
- Phase 3: Follow-up

b. Current status

As of April 2021, 10 vendors are proceeding with the review process of phase 1 or 2. Two vendors have signed an agreement with the CNSC for the vendor design review. The vendors who are in phase 2 are as follows: Terrestrial Energy (IMSR), Ultra Safe Nuclear Corporation (MMR-5 and MMR-10), Moltex Energy (Molten Salt Reactor), NuScale Power (NuScale PWR), GE-Hitachi (BWRX-300) and X-energy (Xe-100).

c. Benefit for vendors

They can get reliable feedback about compliance with the regulatory requirements early in the design process, which enables them to make future plans and compensate in advance. Additionally, CNSC staff can fully understand the vendor's SMR, which results in making efficient progress for the judgment.

d. Benefit for people in Canada

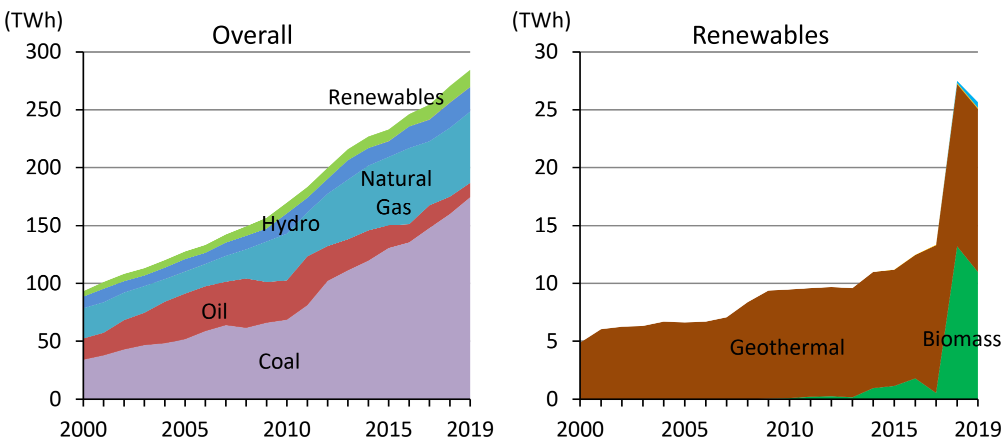
Through VDR, vendors can acknowledge their tasks clearly and make active implementation, which improves cost efficiency and safety.

2. SMR Potential in Developing and Emerging Economies

2.1. Indonesia

(1) Nuclear energy policy

Figure 3.5. Electricity Generation by Source in Indonesia



TWh = terawatt hour.
Source: IEA (2020).

Indonesia has currently no commercial nuclear reactors and most of their electricity supply depends on fossil fuels (Figure 3.5). They have long considered large-scale nuclear power deployment. In February 2014, the Government of Indonesia issued its National Energy Policy, in which nuclear is included as one of the new energy sources. The Directorate General of New Renewable Energy and Energy Conservation (2016) estimated that they would need 5,000 MW of installed nuclear capacity by 2025 to meet their growing energy demand. However, the National Energy General Plan to 2050, which was signed by the president in 2017 (Presidential Regulation No. 22, 2017), does not set a clear target for nuclear power generation capacity and regards nuclear energy as a last resort with strict attention to safety factors.

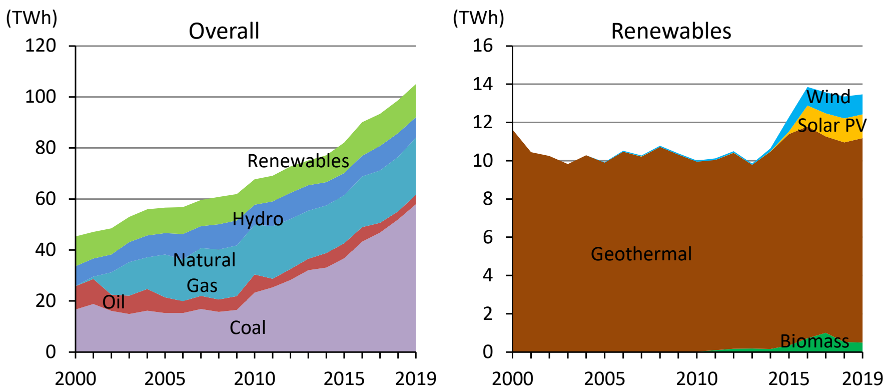
(2) Discussion on SMR development

In March 2018, the National Atomic Energy Agency (BATAN) launched a roadmap for developing a detailed engineering design for an experimental power reactor (Reaktor Daya Eksperimental, RDE), that adopts a high-temperature gas-cooled reactor (HTGR) and 10 MWth capacity. Apart from the experimental reactor, BATAN is also planning to deploy small HTGRs (up to 100 MW) in Kalimantan, Sulawesi, and other islands to supply power and heat for industrial use. A prototype unit is planned for West Kalimantan.

2.2. The Philippines

(1) Nuclear energy policy

Figure 3.6. Electricity Generation by Source in the Philippines



PV = photovoltaics, TWh = terawatt hour.
Source: IEA (2020).

The Philippines currently uses no nuclear power (Figure 3.6). However, in response to the 1973 oil crisis, they decided to build the two-unit Bataan Nuclear Power Plant (BNPP). The construction of Bataan-1 was completed in 1984, but due to financial issues and safety concerns related to earthquakes, the reactor was never loaded with fuel or operated. The government was considering converting it into a natural gas-fired power plant, but this seemed impractical, and the plant has simply been maintained without being operated. In 2010, Korea Electric Power Corporation (KEPCO) submitted a study result that said it would take US$1 billion to rehabilitate the BNPP (*The Manila Times*, 2020).

In 2016, the Department of Energy (DOE) of the Philippines reiterated that nuclear power was a live option, possibly to take over some of coal's base-load role. In March 2017, the DOE said it was exploring the potential of a small reactor in Sulu province, Mindanao, and would produce an overall nuclear programme for the country, including Bataan. The latest Philippine Energy Plan (PEP 2018–2040) includes a chapter on nuclear energy and states that they will be able to start nuclear power generation in 2027 in the earliest case.

(2) Discussion on SMR development

The DOE of the Philippines has discussed SMR technology with the Republic of Korea (henceforth, Korea). In 2019, a site characteristic survey was conducted by experts from Korean Hydro and Nuclear Power in Cagayan Economic Zone Authority. This pre-feasibility study was conducted in accordance with the MoU signed by the DOE and Korean Hydro and Nuclear Power. The final version of the study was turned over in December 2019.

Not only Korea but also Russia cooperates with the Philippines in the field of nuclear technology. The DOE signed an agreement with Rosatom in October 2019 to assess the feasibility of a small NPP, floating or on land, and probably using RITM-200 reactors.

Analysis: Advantages of SMR deployment in island countries

As the US DOE and other governments identify, there are many advantages of SMRs. They are divided into two groups: (1) modular design and (2) characteristics of the reactor.

(1) 'Modular design' includes the low capital investment and siting flexibility of SMRs. The simple design, low construction cost, and short construction period lead to lower capital investment than conventional large-scale reactors. An SMR can be built even on a small site. By adjusting the number of reactor modules, SMRs can meet the needs of a community such as in a remote area or microgrid. The number of reactor modules can be increased if energy demand in the community increases in the future. All these features of SMRs can be an attractive option for small island countries that do not have a huge budget or construction sites; they can begin with a small generating capacity and expand it in parallel with their economic growth. In such areas, however, they generally use diesel generators, etc. Therefore, it is important for SMR vendors to explain the advantages of their products compared with such conventional distributed power sources.

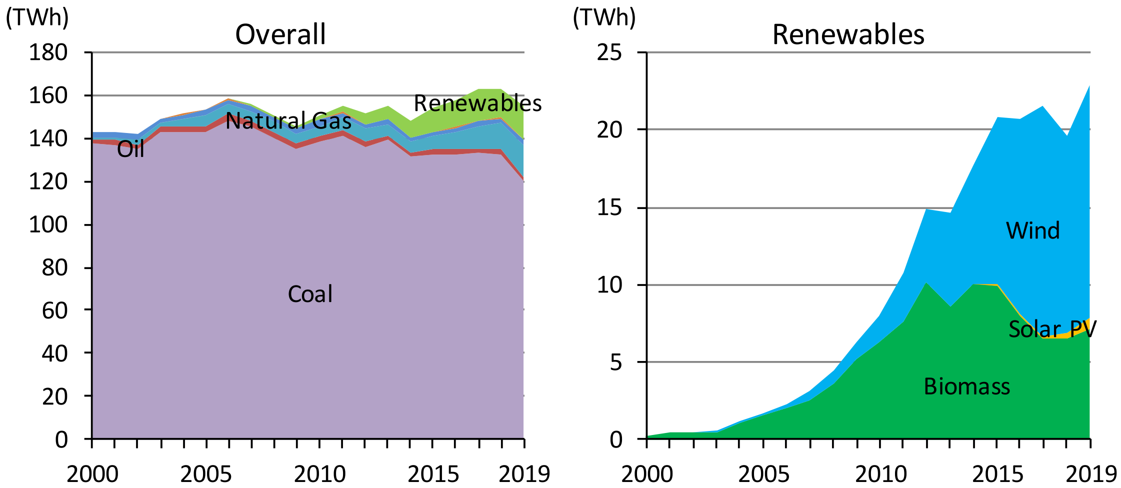
(2) The 'characteristics of the reactor' can bring high efficiency, as well as safety and security. Whilst SMRs can serve as either baseload or flexible power depending on the reactor technology adopted, in any case, they can be coupled with other energy sources to produce higher efficiency and increase grid stability and reliability. This feature of SMRs can become a great advantage, especially when a small island country has deployed huge amounts of variable renewable energy, such as solar PV or wind power generation. At the same time, many designs of SMRs have their own advanced safety features that ensure the safety of an NPP and been improved through the operating experiences of existing reactors. Moreover, some of the advanced reactors can be operated long-term without refuelling. Such designs of reactors will contribute to enhancing the security of fissile materials because they can minimise the amount of spent fuel extracted from the reactors. Long-term operation without refuelling also decreases the frequency of fuel transportation, which requires strict control and guards, which would decrease the burden on the local people.

Decreasing the frequency of refuelling and fuel transportation, however, also decreases the opportunities for related workers to move to a site, which does not have a positive impact on the local economies. It should also be kept in mind that imposing low-risk SMRs with stricter safety requirements than conventional large-scale reactors may mean losing the advantages derived from the modular design, although stricter safety requirements would increase the acceptability amongst the local people.

2.3. Poland

(1) Nuclear energy policy

Figure 3.7. Electricity Generation by Source in Poland



PV = photovoltaics, TWh = terawatt hour.Source: IEA (2020).

Poland currently has no commercial NPPs (Figure 3.7), but according to the Energy Policy of Poland until 2040 (PEP2040) approved by the cabinet in 2021, the Polish government has a plan to deploy the first one by 2033. It is planned to be a capacity of 1.0–1.6 GW, with the next ones launched within 2–3 years, which means that the entire nuclear programme assumes the construction of six units by 2043. PEP2040 also refers to the possibility of the deployment of HTGRs in the future that would be used mainly as a source of technological heat for industry.

Public support for the nuclear programme is high and even growing in Poland. PGE EJ1 (2020) shows that support for the construction of the first NPP in Poland amongst the residents of site communes (Choczewo, Gniewino, and Krokowa) was at 71% in 2019 (up from 69% in 2018).

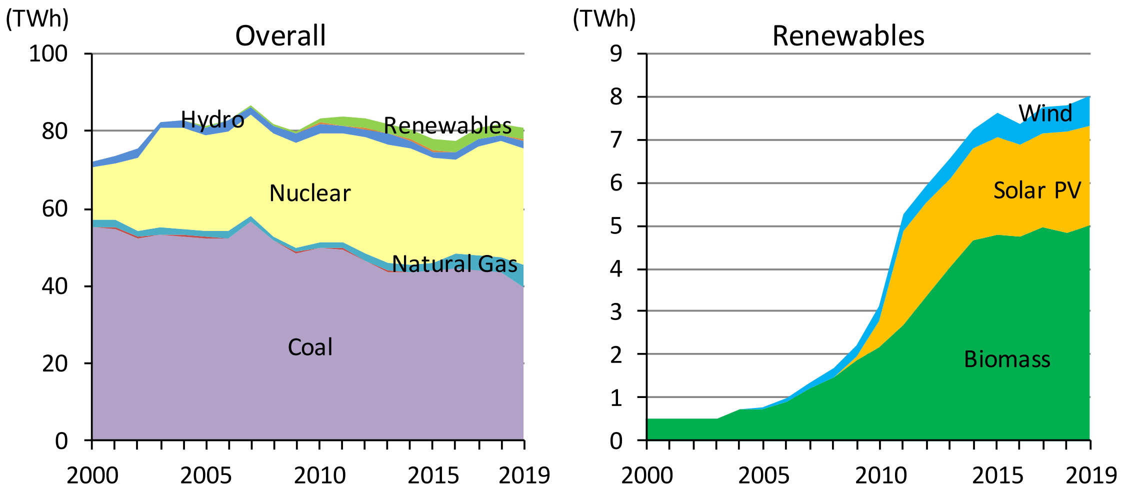
(2) Discussion on SMR development

In October 2019, GE Hitachi Nuclear Energy and Synthos SA, a chemical industry company based in Poland, agreed to collaborate on potential deployment applications for GE Hitachi's BWRX-300 SMR in Poland. Also, in November 2020, Synthos Green Energy, an affiliated company of Synthos SA, signed a cooperation agreement with Ultra Safe Nuclear Corporation to assess the feasibility of the Micro Modular Reactor (MMR) plant design to generate carbon-free hydrogen, heat, and power for use in Synthos Green Energy's chemical plants.

2.4. Czech Republic

(1) Nuclear energy policy

Figure 3.8. Electricity Generation by Source in the Czech Republic



PV = photovoltaics, TWh = terawatt hour.
Source: IEA (2020).

Nuclear energy has a large share today in the generation mix of the Czech Republic (Figure 3.8), and the government is planning to enlarge it. The 'State Energy Policy of the Czech Republic', adopted in 2015, sets the target for nuclear power generation share at 46%–58% by 2040. The policy foresees new reactors at Dukovany, and the government in 2019 gave preliminary approval for ČEZ subsidiary Elektrárna Dukovany II to build at least one new nuclear power unit. The first new reactor envisaged for the site would be of at least 1,200 MWe to replace the four units in operation there that are expected to be permanently shut down between 2035 and 2037.

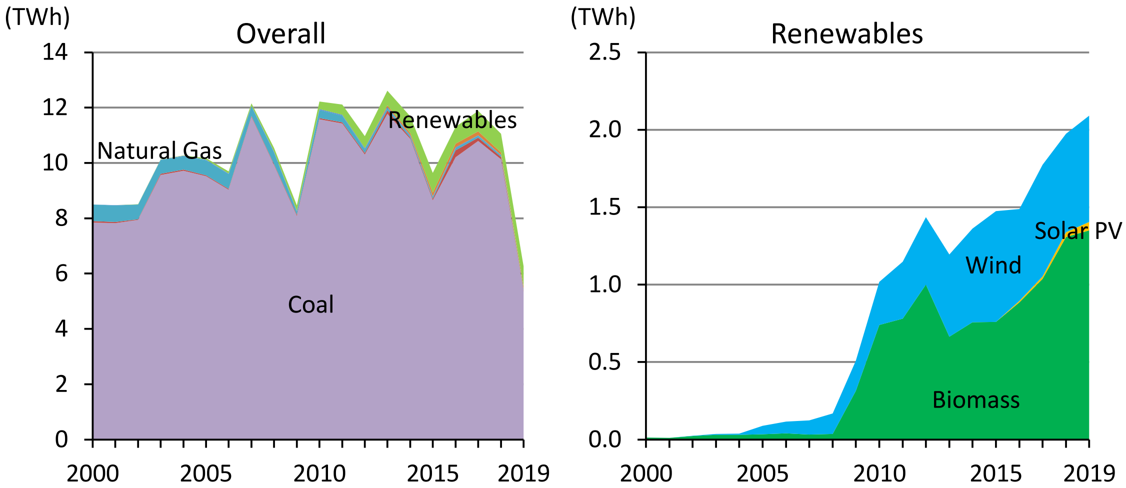
(2) Discussion on SMR development

In September 2019, NuScale Power signed an MoU with ČEZ to explore applications for its SMR in the Czech Republic. In February 2020, GE Hitachi Nuclear Energy and Czech utility ČEZ signed an MoU on examining the economic and technical feasibility of potentially constructing a BWRX-300 in the Czech Republic.

2.5. Estonia

(1) Nuclear energy policy

Figure 3.9. Electricity Generation by Source in Estonia



PV = photovoltaics, TWh = terawatt hour.
Source: IEA (2020).

Estonia has no experience of operating nuclear power generation, and most of their electricity supply depends on coal (Figure 3.9), but recently they have begun considering the option of SMRs, as stated in the next section.

(2) Discussion on SMR development

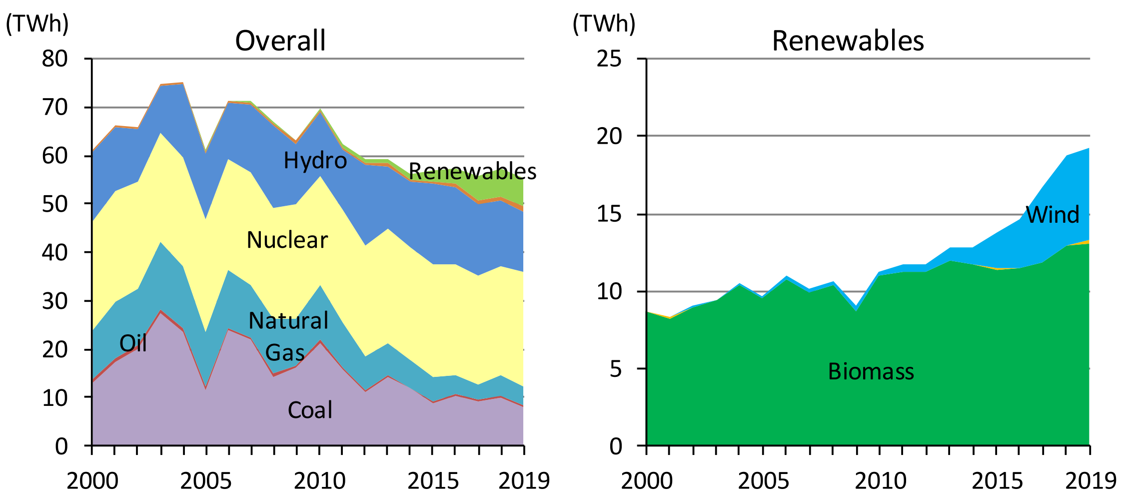
In March 2019, Fermi Energia of Estonia selected Moltex Energy as its preferred technology for its plans to establish carbon-free energy production in the Baltic region. In June 2019, Fermi Energia launched a feasibility study on the suitability of SMRs for Estonia's electricity supply and climate goals beyond 2030, following a financing round of €260,000 (US$290,076) from investors and shareholders. Fermi Energia selected four innovative SMR designs to be included in the feasibility study: Moltex Energy SSR-W300, Terrestrial Energy IMSR-400, GE Hitachi BWRX-300, and NuScale SMR. In October 2019, GE Hitachi Nuclear Energy and Fermi Energia agreed to collaborate on potential deployment applications for GE Hitachi's BWRX-300 SMR in Estonia.

In January 2020, Fermi Energia signed an MoU with Finnish power company Fortum and Belgian engineering firm Tractebel to cooperate on studying the deployment of SMRs in the Baltic country. In March 2020, Swedish utility Vattenfall participated in a study on the deployment of SMRs in Estonia.

2.6. Finland

(1) Nuclear energy policy

Figure 3.10. Electricity Generation by Source in Finland



PV = photovoltaics, TWh = terawatt hour.
Source: IEA (2020).

Finland is operating four reactors, and nuclear energy covered 35% of the electricity supply in 2019 (Figure 3.10). Olkiluoto-3, a large-scale European pressurised water reactor (EPR) is under construction, but this project faces serious delays. Another NPP is being planned in Hanhikivi, which is to adopt the Russian design VVER.

(2) Discussion on SMR development

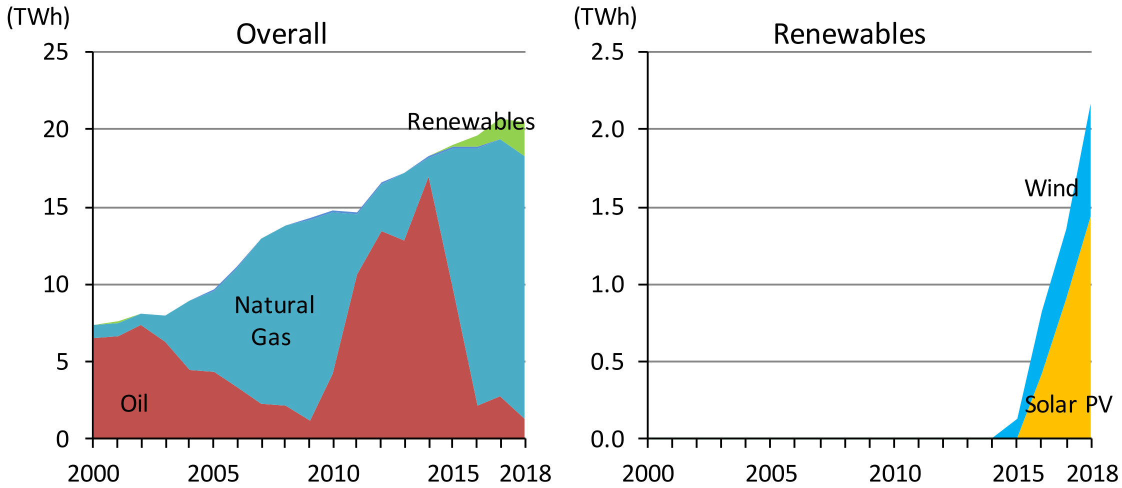
The Finnish Radiation and Nuclear Safety Authority (STUK, 2020) has published a report discussing issues related to licensing SMRs, which says: 'The current licensing procedure and safety requirements are mainly created for large, electricity generating, water-cooled reactors', and 'the needs for regulatory amendments with regard to small modular reactors must be investigated'. As for district heating, the report says: 'a plant producing heat must be located relatively close to habitation. The size of the precautionary action zone and the emergency planning zone must be considered according to need on the basis of the risk caused to the surroundings of the plant'.

In February 2020, VTT Technical Research Centre in Finland announced the launch of a project to develop an SMR for district heating. They are studying the potential use of SMRs for both district heating and electricity generation. District heating is used widely in Finland but is fuelled predominantly by coal, which is to be phased out by 2029.

2.7. Jordan

(1) Nuclear energy policy

Figure 3.11. Electricity Generation by Source in Jordan



PV = photovoltaics, TWh = terawatt hour.
Source: IEA (2020).

Jordan currently has no commercial NPPs, and the country is heavily dependent on fossil fuels (Figure 3.11). The country imports around 95% of its energy consumption, and energy independence is an important issue. In 2007, the Jordon Atomic Energy Commission (JAEC) and Jordan Nuclear Regulatory Commission were established to deploy nuclear power generation in the country. At first, they were aiming to import two 1,000 MW reactors from the export subsidiary of Rosatom. However, in 2018, JAEC cancelled the plan because of the project cost and difficulty in securing funds. Jordan is now trying to deploy SMRs.

(2) Discussion on SMR development

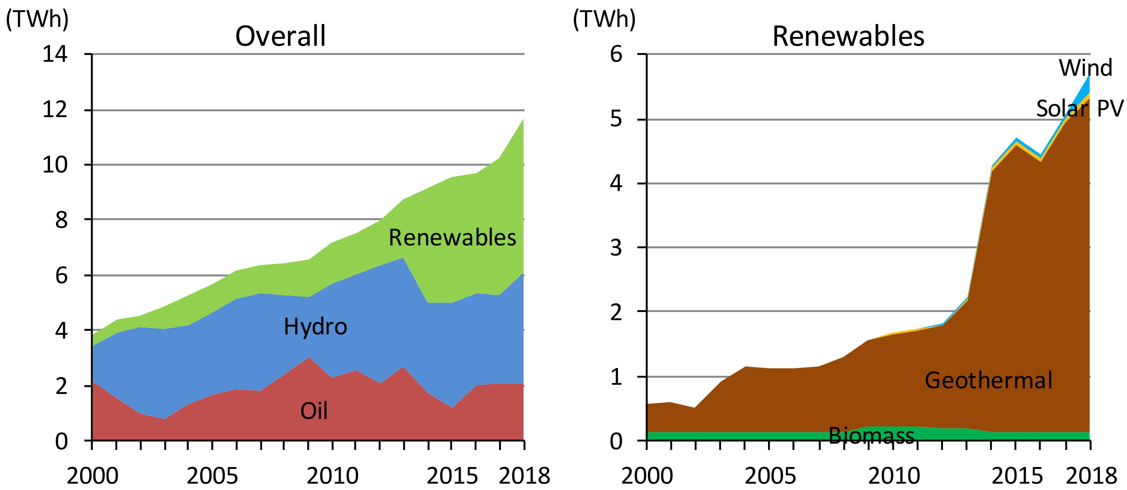
In March 2017, Jordan and Saudi Arabia signed agreements on cooperation in uranium exploration and for carrying out a feasibility study into the construction of two SMRs in Jordan. In November 2017, Rolls-Royce signed an MoU with the state-owned JAEC to conduct a technical feasibility study for the construction of SMRs of Rolls-Royce in the Middle Eastern country.

In November 2017, the JAEC signed an MoU with X-energy to assess the US company’s SMR. They will look at the potential deployment of X-energy’s Xe-100 high temperature gas-cooled pebble bed modular reactor in Jordan, and in January 2019, a joint feasibility study on the deployment of NuScale’s SMR in Jordan will be carried out through an MoU signed between NuScale Power and JAEC.

2.8. Kenya

(1) Nuclear energy policy

Figure 3.12. Electricity Generation by Source in Kenya



PV = photovoltaics, TWh = terawatt hour.
Source: IEA (2020).

Kenya currently has no NPPs, and deploys a lot of hydro and geothermal power generation (Figure 3.12). However, the country has planned to use nuclear energy as an alternative source that is stable, efficient, and reliable. In 2010, the Kenyan Ministry of Energy established a nuclear electricity project committee, subsequently transformed into the Kenya Nuclear Electricity Board in 2012. In 2019, the Energy Act was established, which transformed the Kenya Nuclear Electricity Board into the Nuclear Power and Energy Agency (NuPEA) to expand its mandate to include promoting and implementing Kenya's Nuclear Power Programme, carrying out R&D, and capacity building in the energy and petroleum sectors. In November 2020, NuPEA published its 5-year Strategic Plan 2020–2024 in order to incorporate the new mandate as well as take stock of its achievements to date.

Kenya plans to build a 1,000 MW NPP at a cost of US$5 billion. At first, they planned to complete the first construction by 2027. However, the plan faces some challenges now and it is estimated that the project will spill over into 2030. Some of the reasons are the long compliance procedures before setting up, higher costs compared to renewable energy, and the problem of radioactive waste disposal.

(2) Discussion on SMR development

NuPEA reported an initial case study of Kenya's SMR reactor technology assessment in July 2019. It concluded that most SMRs are 'first-of-a-kind' (FOAK) technology and are still in the early stages of development (conceptual and design stages). It also referred to the insufficiency of data, and with more vendor information the study could be updated.

In the Strategic Plan 2020–2024, SMRs were mentioned a few times. According to analysis through the Political, Economic, Socio-cultural, Technological, Ecological and Legal (PESTEL) model, enhancing knowledge of different reactor technologies, such as SMRs, is useful in becoming technically competitive. Additionally, according to analysis through Strengths, Weaknesses, Opportunities, and Threats (SWOT) models, the adoption of SMRs technology was mentioned as a strategic response.

3. Brief Summary

In this chapter, trends in the development of SMRs and the potential for their deployment were described through case studies. As for the leading countries (the US, the UK, and Canada), the governments are not only securing huge budgets but are also providing attractive business environments for private companies who want to develop SMRs. The regulatory bodies of these countries are also trying to prepare flexible and predictable regulatory schemes. As for the emerging countries mentioned in this chapter, they are considering the deployment of SMRs for their future energy mix, and they have begun discussions with SMR vendors.