Retrofitting Coal Power in the Philippines Using Korean SMR—Feasibility Evaluation

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1. Introduction

Reducing carbon emissions to mitigate global warming requires both the decommissioning of fossil fuels in the energy mix as well as the propagation of low-carbon electricity sources like renewables and nuclear. One way to pursue both goals is by replacing coal boilers in existing coal power plants with a nuclear heat source like small modular reactors (SMRs)—known as "repowering" or "retrofit decarbonization". This ensures that assets in the coal sector do not entirely go to waste during the green energy transition.

Such a strategy has been proposed in countries like China, most notably in a study by Xu et al. [1], which evaluates existing Chinese coal-fired power plants and outlines a strategy to retrofit them with High Temperature gas-cooled Reactor—Pebble-Bed Module (HTR-PM) units, an SMR design domestically developed in China. Similar proposals have also been explored by studies in Poland, showing that nuclear repowering of coal plants with SMRs is the most attractive option for retrofitting the coal power sector [2,3].

The current study proposes to conduct a similar profile of coal plants in the Philippines. The Philippine government has recently signaled a renewed interest in nuclear power due to its increasing energy needs and its continued reliance on fossil fuels. Pursuant to this goal, it has sought potential partnerships with leading countries in nuclear like South Korea. Nuclear repowering of its coal plants using Korean SMR designs is a possible strategy for the Philippines, the technical feasibility of which is evaluated in this study.

2. Methods and Results

This section details the evaluation of coal-fired power plants in the Philippines for retrofit decarbonization. It also explores different SMR designs of Korean origin that can be considered for use in repowering. A potential strategy for nuclear retrofit decarbonization in the Philippines is then formulated.

2.1. Profiling coal power plants in the Philippines

A list of existing coal power plants in the Philippines was obtained from the Philippine Department of Energy (DOE) and contains information such as the installed capacity, number of units, location, and date of commission for each plant [4].

There are 56 coal-fired power generation units in the Philippines as of November 2022. Out of these 56, 36 were of the circulating fluidized bed (CFB) subtype, with the rest either pulverized subcritical coal units (18) or supercritical (2). The sizes of the units have a wide range, with the smallest having an installed capacity of 15 MW to the largest with 725 MW. The ages of the units vary widely, with the oldest unit having been in operation for 40 years, while a majority of units are less than 10 years old.

A set of initial criteria to evaluate the potential suitability of each unit for repowering is formulated. The two initial criteria for consideration are (1) age, and (2) size.

For age, a cut-off of 20 years is recommended to ensure that existing equipment has significant remaining service life after retrofit. As seen in Table I, 44 out of 56 coal-fired power generation units are qualified for retrofitting based on the age criterion.

Table I: Age of coal-fired power generation units

Age	Number of units
Less than 20 years	44
More than 20 years	12
Total	**56**

For size, appropriateness depends on the capacity of the SMR that will be used for repowering, but generally, units smaller than 50 MW are too difficult to retrofit. Table II shows a classification of all 56 units into different size categories; only four units are disqualified by having capacities less than 50 MW. Combining the age and size criteria yields a total of 43 out of 56 units as potential candidates for repowering, which comprise 8 GW out of the total 12 GW of coal capacity.

Table II: Capacity of coal-fired power generation units

Capacity	Number of units
Less than 50 MW	4
Small (<200 MW)	36
Medium (200–400 MW)	9
Large (>400 MW)	7
Total	**56**

Other criteria that need to be considered include (3) location, and (4) steam parameters.

Ideally, the coal plant should be located near the coast for easier access to the sea for cooling purposes. Due to the archipelagic geography of the Philippines, all but two out of the 56 coal units in the country are located in close proximity to a coastline, which reduces the number of candidates from 43 to 42.

The steam temperature and pressure in the coal power plant steam cycle should be noted so the steam parameters of the SMR design will match. The majority of units are CFB, the typical steam parameters of which are approximately 540°C and 17 MPa. For subcritical units, steam is typically below 550°C and below 22 MPa, while for supercritical units, temperature is around 565°C and pressure is around 24 MPa.

2.2. Evaluating Korean SMR designs

A list of SMR designs developed in the Republic of Korea is provided by Choi as of 2021 [5]. Among the SMRs in the list, those designed to generate electricity using steam generators were selected as potential candidates for repowering.

Table III: Korean SMR designs and steam parameters

SMR	**Capacity**	**Temperature (°C)**	**Pressure (MPa)**
SMART	364 MWth/ 120 MWe	284	3.5
BANDI-60S	200 MWth/ 60 MWe	270-290	6.0
REX-10	10 MWth	198.3	1.5
PGSFR	392 MWth/ 150 MWe	471.2	17.8
i-SMR	540 MWth/ 180 MWe	284	3.5

The two main criteria that the SMR design must match with the coal-fired power generation unit are (1) the capacity of the reactor (with the possibility of using multiple SMR units to replace larger coal-fired units), and (2) the steam parameters (e.g., operating pressure and temperature). Table III shows the capacities and steam characteristics of five Korean SMR designs.

According to these criteria, the most suitable design to use for repowering coal units in the Philippines among those considered is the PGSFR, a sodium-cooled fast reactor design developed by KAERI. Although nuclear reactors tend to produce steam at lower temperatures and pressures compared to coal plants, the PGSFR results in the highest steam temperature and pressure among the five candidates, much closer to the steam conditions of coal units. However, the pressure remains too low for supercritical units, so it can only repower CFB or subcritical coal units. It has a capacity of 150 MWe, which also precludes the repowering of coal units with capacities significantly smaller than 150 MW.

2.3. Formulating a Philippine repowering strategy

After conducting a profile of coal-fired power generation units, an initial list of 42 candidates for repowering was determined based on the criteria of age, size, and location. Then, upon considering five Korean SMR designs and evaluating them based on capacity and steam parameters, the most suitable design for repowering coal units in the Philippines among the five candidate SMRs was determined to be the PGSFR. Based on its steam pressure, repowering supercritical coal units was deemed unfeasible; meanwhile, units with capacities lower than 135 MW were also deemed too small for the 150-MW PGSFR. After considering these criteria, the initial list of 42 candidates was narrowed down to 28 candidates, comprising 6 GW out of a total 12 GW coal capacity in the country.

It must be noted that among the 28 candidates that can be feasibly repowered using the PGSFR, 13 are in the Luzon grid (total capacity: 3.7 GW), 4 are in Visayas (625 MW), and 11 are in Mindanao (1.6 GW).

It is also important to note that all 28 feasible candidates are 10 years old or younger. This makes the timeline for a repowering strategy more flexible, since the oldest candidates will remain viable for repowering even 10 years from now.

As such, one feasible strategy to pursue is choosing one coal unit as a demonstration project. This is to increase confidence of stakeholders and the public in repowering as a viable option for decarbonization, which can lead to more willingness for further repowering of the remaining candidates.

Among the 28 units that can be repowered, one potential candidate for a demonstration project is Therma South, Inc. (TSI) in Davao City, Mindanao. TSI is composed of two 150-MW CFB units, commissioned in 2015 and 2016. It is suitable for initial repowering for three reasons: age, capacity, and location. The two units are among the oldest among all 28 candidates, which means they are more likely to be decommissioned sooner than other candidates. The 150-MW capacity of each unit is also a perfect match for the 150-MW PGSFR that will potentially be used for repowering. And TSI is located in the southernmost part of the country, where the population is smaller and urbanization is still in its earlier stages. Repowering could be welcomed as a sign of green progress leading to a path of development different from that in the more populous north, associated with “dirty” fossil fuels. Commissioning a nuclear project may also be more acceptable in an area that is less populated and far from the economic centers in Luzon.

An alternative candidate for a demonstration project is Palm Concepcion Power Corporation (PCPC) in Iloilo, Visayas. PCPC was commissioned in 2016, has a 135-MW capacity, and is likewise located in a province away from Luzon.

A three-phase strategy for a nationwide repowering of coal plants in the Philippines is hereafter formulated and proposed. However, although this paper considers the PGSFR as the most suitable candidate SMR to repower Philippine coal units among a list of five, it should be noted that before the three-phase strategy is implemented, other designs, such as molten salt reactor (MSR) designs being developed in Korea and abroad, should also be further examined and considered for repowering feasibility. The start of the three-phase strategy implementation will highly depend on the development timeframe of the SMR design, whether it is the PGSFR or another design. For the purposes of this study, it is assumed that the PGSFR will be fully developed for deployment by the year 2030. (KAERI aims to construct a functional prototype by 2028.)

The first phase of a national repowering strategy will be to complete the demonstration project, either at TSI or PCPC or both, to show the feasibility of repowering. This will likely have to be done with substantial participation of and cooperation with Korean partners, as the technology that will be used is of Korean design. This can also be seen as a part of South Korea's commitment to promote the use of clean energy, including nuclear, and the phase-out of coal globally. This phase is expected to take between three to five years due to the novel nature of the project.

The second phase of the strategy will be to repower the remaining units in Visayas and Mindanao (15 in total, including TSI and PCPC) as well as the units in Luzon that are further from the National Capital Region (5 units in Bataan and Batangas provinces). This can be done with some Korean involvement for local capacity-building. This phase is expected to take between eight to 10 years due to the number of units to be repowered.

The third and final phase will be to repower the remaining 8 units in Bataan, Luzon, which are closer to the capital and comprise a total capacity of 2.7 MW. This will be done with maximal utilization of local capacity through relevant technology transfer. This phase is expected to take another five years, making the total expected time frame for the three-phase strategy between 16 and 20 years. If the plan can commence in 2030, then complete nuclear repowering can be expected by 2050. It is also important that, alongside the three-phase repowering strategy, the remaining coal units deemed unfit for repowering will be decommissioned and no new coal units will be commissioned.

Although specific costs and savings have not been calculated yet for the PGSFR, retrofit decarbonization using SMRs has been estimated to save around 1/3 of the cost compared to a greenfield project in China [1] or around 28-35% in Poland [2]. Assuming the same estimated savings and an average cost of 3000 USD/kW for a greenfield project, the three-phase repowering strategy involving 28 coal units could save up to USD 6 billion in upfront costs. With 6 GW of coal electricity generation replaced with nuclear generation, around 27,400 kilotons CO_2-eq of emissions could be avoided annually (around 19% of total emissions in the Philippines in 2021).

3. Conclusions

In this study, a profile of all 56 coal-fired power generation units in the Philippines was made. Based on the criteria of age, size, and location, an initial list of 42 candidates was determined for potential repowering. Among five Korean SMR designs, the PGSFR was deemed most appropriate for repowering Philippine coal units based on its capacity and steam parameters. Out of the 42 initial candidates for repowering, 28 units were found to be suitable for retrofitting with the PGSFR, comprising 6 GW of the total 12-GW coal capacity in the Philippines. Two candidates (TSI in Mindanao and PCPC in Visayas) were chosen as potential demonstration projects. A three-phase strategy was proposed for national nuclear repowering of coal units, which is estimated to take between 16 to 20 years to complete. When concluded, nuclear repowering may save around USD 6 billion in total upfront costs and avoid approximately 27,400 kilotons CO_2-eq of annual emissions. The results and proposals of this study could be used as a basis for a national plan to reduce the carbon emissions of the Philippines, improve public acceptance of nuclear energy, and undergo capacity-building for a nuclear energy program as part of the country's climate obligations.

4. Recommendations

The current study considered the technical suitability of Korean SMR designs for possible repowering of Philippine coal power plants on the basis of capacity and steam parameters. A more complete version of this study would consider various aspects of feasibility, including regulation and licensing, public acceptance, siting requirements, seismic conditions, existing assets, and economic cost and benefits. Future studies may also explore other SMR designs currently under investigation such as high temperature gas cooled reactors or MSRs.

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