Assessment of Heat-only SMR Deployment Capacity for District Heating Based on Heat Demand Profiles and LCOH

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1. Introduction

According to the International Energy Agency (IEA), in 2024, heat consumption represented nearly half of global total final energy consumption, while the associated carbon dioxide emissions accounted for approximately 37% of global energy-related CO_2 emissions [1]. Industrial process heat and space heating and hot water supply in buildings constitute major components of global heat demand, and a significant portion of current heat supply still relies on fossil fuels such as natural gas, coal, and oil. Therefore, alongside the decarbonization of the power sector, securing reliable low-carbon heat sources for industrial and building applications is one of the key challenges in achieving Net-Zero.

District energy systems supply heat, or both heat and electricity, to multiple users collectively from centralized energy production facilities, such as combined heat and power (CHP) plants, heat-only boilers, and waste-to-energy facilities, instead of installing individual heat supply systems in buildings or industrial complexes [2]. However, in Korea, the heat sources for district energy systems still rely heavily on fossil fuels such as LNG. Therefore, a low-carbon baseload heat source is needed that can replace heat production from these existing facilities while maintaining the reliability and stability of the current heat supply network.

A heat-only Small Modular Reactor (SMR) can be considered as an option for decarbonizing district heating systems. This study focuses on the LDR-50, which has a rated thermal output of 50 MWth per unit [3]. Because district heating demand varies substantially by season and region, increasing the installed reactor capacity can increase the share of nuclear heat supply, while reducing reactor utilization during periods of low demand due to load reduction. To ensure efficient reactor operation, the installed capacity should be evaluated by considering both regional heat demand characteristics and reactor utilization rates.

In this study, hourly heat supply data from multiple branches of the Korea District Heating Corporation (KDHC) are analyzed by incrementally adding LDR-50 units. For each capacity configuration, the utilization rates of both the entire reactor fleet and the additional unit are evaluated, together with the fraction of district heating demand supplied by nuclear heat. In addition, the Levelized Cost of Heat (LCOH) of the entire reactor fleet is calculated using the estimated capacity factor and the LDR-50 cost model. The LCOH is used as a screening indicator to quantify how the declining utilization of additional units increases the heat production cost and to identify the point at which further capacity additions become increasingly unfavorable. The results are used to assess branch-specific differences in the technical utilization and economic implications of additional LDR-50 deployment.

2. Methods and Materials

2.1 District heating demand data

To evaluate the potential for replacing fossil fuel-based heat generation with low-carbon heat sources, this study selected branches of the Korea District Heating Corporation (KDHC) that primarily operate LNG-based combined heat and power (CHP) plants as their own heat sources. The feasibility of the LDR-50 was evaluated based on hourly heat supply data for each branch. Figure 1 presents the heat supply profile of the Hwaseong branch as a representative case. District heating demand exhibits pronounced seasonal variations, increasing in winter and decreasing in summer, along with daily fluctuations [4].

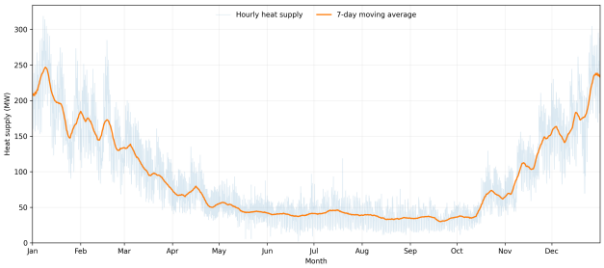


Fig. 1. Hourly Heat Supply – Hwaseong Branch [4]

Before simplifying the hourly heat supply into daily average values, the capability of the existing thermal storage tanks to mitigate intraday demand fluctuations was examined. For each branch, the required storage capacity and maximum charging and discharging rates needed to maintain a constant daily average heat output were compared with the observed operating range of the existing thermal storage system. At the Pangyo branch, which represented the most restrictive case, the

maximum required storage capacity was approximately 778 MW, lower than the observed stored-heat variation range of 947.7 MWh, while the maximum required discharging rate of approximately 103.5 MW remained below the observed maximum of 112.8 MW. Because the same criteria were satisfied at the other branches, the existing thermal storage tanks were assumed to absorb most intraday demand fluctuations. Accordingly, the daily average heat supply was used to construct the load-duration curve for each branch and to evaluate the long-term utilization and nuclear heat fraction of the LDR-50 [4–6].

2.2 LDR-50

The LDR-50 is a heat-only small modular reactor designed for district heating, originally developed by VTT Technical Research Centre of Finland and currently being commercialized by Steady Energy [3]. Based on light water reactor, it is designed to produce heat under relatively mild operating conditions of approximately 150°C and below 10 bar, substantially lower than those of conventional reactors. Each reactor has a thermal output of 50 MWth and supplies the generated heat to a district heating network through an intermediate heat transfer system, without the use of turbines or generators. The design also incorporates natural circulation and passive safety systems to simplify the overall system, with the primary objective of providing reliable, low-carbon heat near urban areas. Table 1 summarizes the cost model adopted for the LDR-50, including the assumptions for CAPEX, OPEX and other economic parameters [7].

Table 1. Economic assumptions for the LDR-50

Parameter	Value
Heat capacity (MW)	50
CAPEX ($/kW)	1755
OPEX ($/MW)	7.4
Investment cost (M$)	87.8
FOM (% of CAPEX)	3
Economic lifetime (years)	20
Discount rate (%)	7

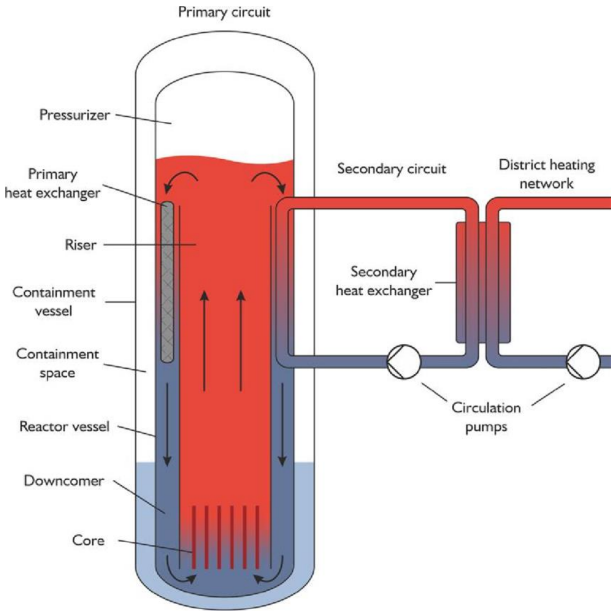


Fig. 2. Schematic configuration of the LDR-50 [8]

2.3 LDR-50 Installed Capacity and Utilization Rate

Based on the daily average heat demand at each branch, LDR-50 units were added in 50 MWth units to evaluate the operating characteristics at different installed capacities. The reactors were assumed to serve as baseload heat sources and supply district heating demand with priority, while any residual demand exceeding the installed reactor capacity was assumed to be met by existing heat sources. Byun and Yim [9] demonstrated that individually adjusting the power of selected reactor units can provide more efficient load-following operation than simultaneously reducing the power of all units. Based on this finding, the present study assumes a sequential load-following strategy in which operating units are maintained near full power while the output of additional units is reduced first as heat demand decreases.

When N reactor units are installed, the total rated thermal capacity is $50 \times N$ MWth. Under each demand condition, the total heat supplied by the reactors was calculated as the smaller of the district heating demand and the total installed reactor capacity. Using this heat supply, the capacity factor (CF) of the entire reactor fleet was calculated as follows.

$$CF_{Fleet} = \frac{E_{LDR}}{P_{rated} T}$$

E_{LDR} is the total heat supplied by the LDR-50 units during the analysis period, P_{rated} is the total installed LDR-50 thermal capacity, and T is the total duration of the analysis. For N LDR-50 units, $P_{rated} = 50N$ MW_{th}.

Under the sequential load-following strategy, the heat supplied by each 50 MWth unit is calculated separately. The capacity factor of the i-th unit was calculated as follows.

$$CF_i = \frac{E_i}{50T}$$

E_i is the total heat supplied by the i-th 50 MWth capacity block during the analysis period. This metric is

used to evaluate how the utilization of each additional reactor unit changes as the installed nuclear capacity increases.

The nuclear heat fraction is defined as a fraction of the total district-heating demand supplied by the LDR-50 units.

$$f_{LDR} = \frac{E_{LDR}}{E_{demand}}$$

E_{demand} is the total annual district-heating demand.

By comparing the fleet capacity factor, unit specific capacity factors, and nuclear heat fraction for different numbers of installed LDR-50 units, the trade-off between reactor utilization and nuclear heat supply is evaluated.

To evaluate the effect of declining reactor utilization on the economics of additional units, the Levelized Cost of Heat (LCOH) of the LDR-50 was calculated. The LCOH for each LDR-50 unit was determined as follows.

$$CRF = \frac{r(1+r)^n}{(1+r)^n - 1}$$

$$LCOH = \frac{C_{Capex} \times CRF + C_{FOM}}{E_{annuel}} + C_{OPEX}$$

As the fleet capacity factor decreases with increasing installed reactor capacity, the annual heat production per unit of installed capacity declines, causing the capital and fixed operating costs of the reactor fleet to be distributed over a smaller amount of heat generation and thereby increasing the fleet LCOH. Accordingly, comparison of fleet LCOHs for different installed-capacity configurations enables a quantitative assessment of the economic impact of declining reactor utilization and supports the identification of an appropriate LDR-50 deployment capacity.

In this study, the LCOH was used not as an absolute criterion for direct economic comparison with existing CHP systems, but rather as a screening metric to assess the increase in heat production cost resulting from the reduced utilization of additional LDR-50 units.

3. Results and Discussions

Figure 3 shows the load duration curves based on the daily average heat demand at each branch. The thermal output levels corresponding to the installation of one to four LDR-50 units are also indicated, based on the rated thermal output of approximately 50 MWth per unit.

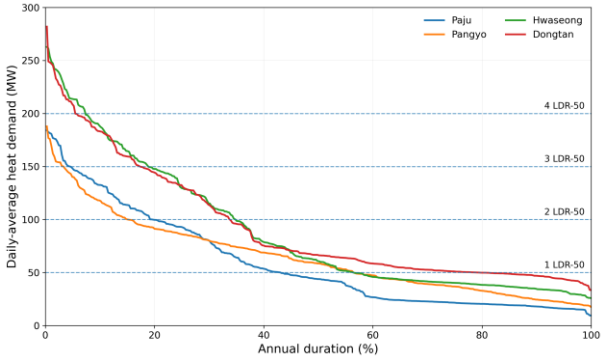


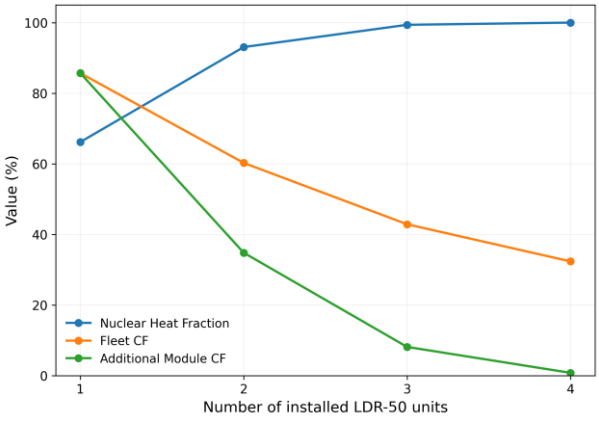
Fig. 3. Load duration curves of selected district-heating branches with LDR-50 capacity

Figure 4 shows the nuclear heat fraction, fleet capacity factor (fleet CF), and capacity factor of the added unit (additional unit CF) as the number of installed LDR-50 units increases at each branch. Across all branches, the nuclear heat fraction increased with increasing reactor capacity, whereas both the fleet CF and the additional unit CF showed a decreasing trend.

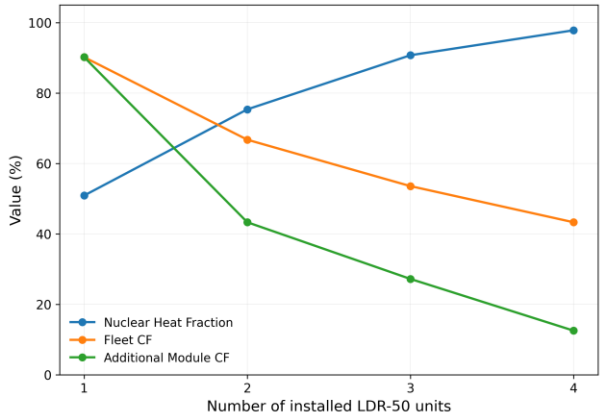
The differences between Pangyo and Paju illustrate the importance of the heat demand distribution. Although their annual heat demand is similar, Pangyo maintains relatively high heat demand even during low-demand periods. Consequently, the CF of the first LDR-50 unit was 85.7% at Pangyo, higher than 73.0% observed at Paju. This difference can be attributed to Pangyo's relatively high baseload heat demand, partly associated with summer district cooling demand.

In contrast, the CFs of additional units varied depending on the distribution of heat demand in the medium- and high-demand ranges at each branch. For example, the CF of the third unit was 8.2% at Pangyo and 11.8% at Paju, with Paju showing the higher value. This is because the utilization of the first unit is strongly influenced by the level of demand during low-demand periods, whereas the utilization of subsequent units is determined primarily by the cumulative duration for which heat demand exceeds the capacity threshold corresponding to each unit.

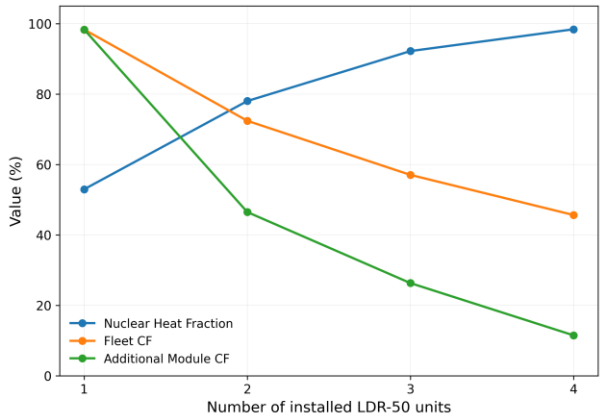
In the case of Dongtan, the relatively high heat demand maintained during low-demand periods resulted in a high CF for the first unit, whereas the CFs of subsequent units varied depending on the distribution of demand in the medium- and high-demand ranges. Therefore, the appropriate installed capacity of the LDR-50 cannot be determined solely based on annual total heat demand or peak heat demand; rather, the compatibility between the LDR-50 capacity and the heat demand distribution at each branch is an important consideration.



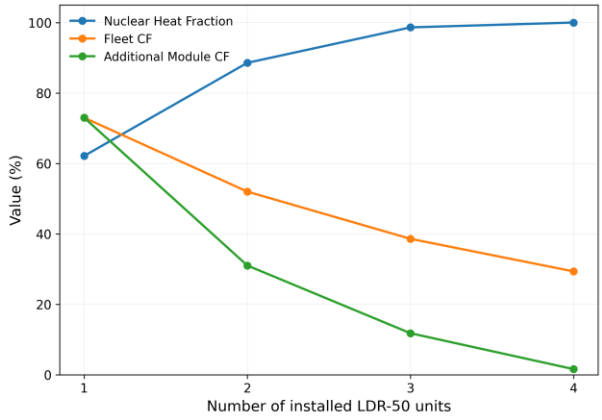
(a)



(b)



(c)



(d)

Fig. 4. Nuclear heat fraction, fleet capacity factor, and additional-unit capacity factor according to the number of installed LDR-50 units: (a) Pangyo, (b) Hwaseong, (c) Dongtan, and (d) Paju.

Table 2 presents the fleet LCOH for each branch according to the number of installed LDR-50 units. Although the same reactor cost assumptions were applied, the LCOH differed among branches because the fleet capacity factor was determined by the branch-specific heat demand distribution. As the installed capacity increased, the LCOH increased due to the declining fleet utilization, with the rate of increase varying by branch. These results indicate that the economic performance of LDR-50 deployment is influenced not only by the installed capacity but also by the compatibility between the reactor unit size and the local heat demand profile.

Based on the trade-off between the nuclear heat fraction and fleet LCOH, two LDR-50 units were identified as a reasonable capacity for Pangyo and Paju, whereas three units were more suitable for Hwaseong and Dongtan. Beyond these capacities, the additional increase in nuclear heat supply became relatively small compared with the increase in fleet LCOH.

Table 2. LDR-50 fleet LCOH by branch and installed capacity ($/MWth)

Branch	1 unit	2 units	3 units	4 units
Pangyo	36.5	48.7	65.5	84.2
Hwaseong	35.0	44.7	53.8	64.9
Dongtan	32.8	41.8	51.1	62.0
Paju	41.5	55.3	72.0	92.1

4. Summary and Conclusions

This study evaluated the potential of the LDR-50 heat-only SMR to selected KDHC district heating branches based on actual heat supply profiles. Existing thermal storage was assumed to mitigate daily demand fluctuations, and load duration curves based on daily average heat demand were used to evaluate the fleet capacity factor, additional-unit capacity factor, and nuclear heat fraction for different numbers of installed LDR-50 units.

The results showed that reactor utilization is strongly affected by the specific heat demand distribution rather than by annual heat demand alone. Although additional units increased the nuclear heat fraction, their utilization decreased, resulting in a higher fleet LCOH. Therefore, the matching between the fixed 50 MWth unit size and the local heat demand profile is important for determining an appropriate deployment capacity.

Considering the trade-off between nuclear heat fraction and fleet LCOH, approximately two LDR-50 units were identified as a reasonable capacity for Pangyo and Paju, and three units for Hwaseong and Dongtan. Further assessment considering alternative low-carbon heat costs is required to determine the economically optimal capacity.

ACKNOWLEDGEMENT

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