Nuclear Science and Technology Symposium - SYP2022
Helsinki, Finland, 1-2 November 2022

Investments in Nuclear Heating in Helsinki Metropolitan Area During Volatile Energy Markets

Esa Pursiheimo*, Tomi J. Lindroos, Ville Tulkki
VTT Technical Research Centre of Finland
FI-02044 VTT, Finland
esa.pursiheimo@vtt.fi, tomi.j.lindroos@vtt.fi, ville.tulkki@vtt.fi

ABSTRACT

The commitment to the decarbonisation of the district heating (DH) system in Helsinki Metropolitan area requires investments in carbon neutral DH capacity in cities of Helsinki, Espoo and Vantaa, and poses an opportunity for small modular reactor (SMR) based DH production. In this study, investments in SMR heat-only units and SMR combined heat and power (CHP) units are examined under varying natural gas and electricity market price scenarios. Energy system optimisation model for Metropolitan area is used in order to obtain investment levels and total annual costs for comparison purposes. The results of investment analysis indicate that SMR CHP units become profitable when annual average electricity market price reaches level of 70 €/MWh. The annual average production costs of district heating (€/MWh) vary significantly depending on used price and investment scenarios. In the case of SMR CHP investments, the annual average DH production cost varies up to 24 €/MWh depending on price scenario, whereas only 5 €/MWh with heat only reactors. The results indicate that investments in SMR CHP units provide flexibility and cost benefits under high electricity prices, but SMR heat-only units provide a more stable option for the DH system.

1 INTRODUCTION

The metropolitan area (cities of Helsinki, Espoo and Vantaa) is facing the challenge of decarbonisation of the district heating system. The imminent national coal ban [1] effectively removes a large share of DH production capacity by year 2029, especially in Helsinki and Espoo. Therefore, new investments should be considered in each city to maintain cost-effective and carbon-neutral DH system.

Värri and Syri [2] examine the cost-efficiency of SMR heat-only boiler and SMR CHP plant in the Helsinki DH system with several SMR-based scenarios concerning emission, fuel and electricity market prices. Their scenario-based findings indicate that SMRs seem suitable for the Helsinki DH system. Furthermore, SMR CHP plant appears to be a cost-efficient solution with higher electricity prices.

Lindroos et al. [3] examine the feasibility of investments in SMR units in the Helsinki DH system. In this study hourly optimisation model is used to find internal rates of return (IRR) for SMR investments by varying several model parameters. The SMR heat-only units have IRR values in range of 7-20%, whereas SMR CHP units have better profitability merely with electricity market prices above average level of 50 €/MWh.

Pursiheimo et al. [4] use optimisation model of Helsinki Metropolitan area in order to compare investments in SMRs and large air heat pumps in decarbonisation scenarios representing year 2030. The results indicate that the SMR-based investments provide 4-8 €/MWh lower levelised cost of energy in terms of DH when compared to air heat pumps. Furthermore, this study indicates that SMR CHP unit investments materialise merely in the scenarios with electricity market average prices of 60 €/MWh.

The prices of electricity and fuels for DH production have increased significantly during recent year due to the geopolitical situation in Europe and increasing demand. Therefore, in our study, we intend to use the Helsinki Metropolitan model basis from [4] and find how dramatically increasing electricity market prices affect the profitability of SMR heat-only unit and SMR CHP unit investments. Also, we analyse how these SMR investments affect the DH system in multiple energy price situations.

2 METHODS

2.1 Backbone optimisation framework

In our study, we use the Helsinki Metropolitan area DH system model introduced in [4]. This model is based on the Backbone energy system optimisation model developed by VTT (open source model framework is available in [5] and documented in detail in [6]). The model parameters for DH system and DH production technologies used in our model are listed in detail in [4]. The basic structure of the DH system model used in our analysis is illustrated in Figure 1.

Backbone energy system model can be run in two different optimisation modes: (1) the investment model uses hourly data from sample weeks from analysed year and finds optimal investments for the DH system, whereas (2) the scheduling model optimises the entire year with fixed production capacity values. We use the investment model to find the optimal investment plan and use the scheduling model to find the optimal hourly operation, and most importantly the annual operation costs, of that investment plan during the analysed year. It should be noted that in our analysis, the term *total annual costs* includes operative system costs, fixed costs, and annualised investment costs for new capacity.

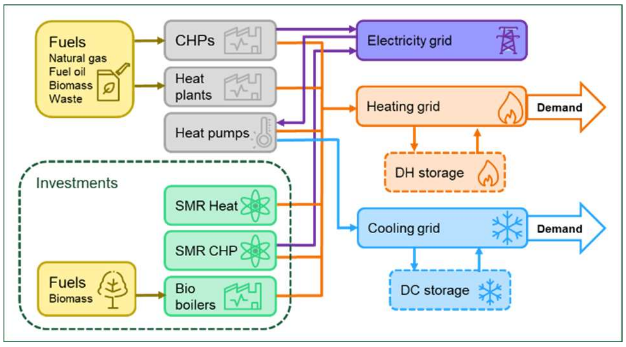

Figure 1. The simplified structure of the DH system in the Backbone energy system model.

2.2 Scenarios

The energy system scenario we are testing the SMR investments in, is representing the estimated situation for year 2030 in terms of Helsinki Metropolitan DH system. The national coal ban is effective, all the natural gas fired CHP units (except Vuosaari A unit in Helsinki) and boilers are active, there are some data-centre based heat pump units assumed to be operational in Helsinki and Espoo, and emission permit price is 100 €/ton (see Table 1 in [4] for assumed existing production capacity). In the investment model analysis, discount rate of 10% and investment period of 20 years is used.

The scenarios analysed in this study are based on varied natural gas price and electricity market price. According to [7] natural gas prices have increased during recent years from level of 30 €/MWh to 100 €/MWh and Nordic electricity market price has risen from level below 40 €/MWh to above 100 €/MWh. Therefore, we construct scenarios with two gas price levels (50 and 100 €/MWh) and seven electricity price average levels (40-100 €/MWh) combined resulting with 14 different price scenarios. The hourly electricity price is based on the year 2017 data (see Figure 3c in [4]) and scaled to match the average price level.

The first phase of our analysis is to run the investment model with all the price scenarios and examine how investments develop. The second phase is to select the investments from the extreme price cases, listed in Table 1, and to run the schedule model for these four cases with each of the four price scenarios, resulting with combination of 16 separate cases. Hereby, we can examine how the investments based on a specific price scenario manage under different price scenario in terms of total annual costs.

Table 1. Identification of the investment and price cases used in the analysis (resulting with 16 different combination scenarios).

Investment case / price case	Gas price	Electricity average price
Case 1	50 €/MWh	40 €/MWh
Case 2	50 €/MWh	100 €/MWh
Case 3	100 €/MWh	40 €/MWh
Case 4	100 €/MWh	100 €/MWh

3 RESULTS

The effect of electricity market prices and gas prices on the SMR investment levels can be observed in Figure 2 (each SMR unit reactor has 200 MW steam production capacity). It is evident that investment in SMR CHP units start to materialise when average electricity price reaches 70 €/MWh and with prices above 90 €/MWh the SMR CHP investments dominate the DH system, since SMR CHP unit can flexibly produce DH and electricity (see Table 5 in [4] for details). The higher gas prices increase the investment level by one SMR unit in nearly all electricity price scenarios since gas-fired CHP units and boilers are even less cost-efficient under high fuel and emission prices.

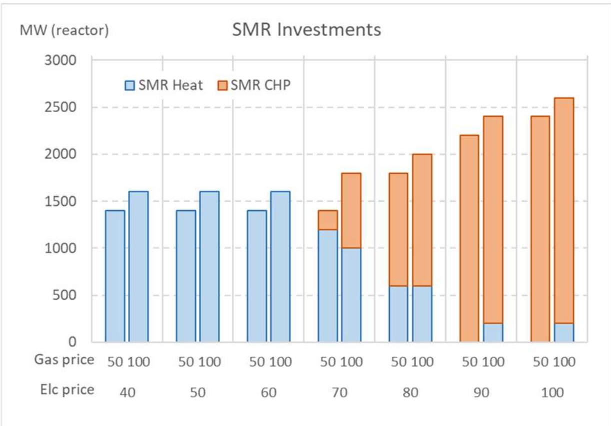

Figure 2. Investments in SMR Heat-only and SMR CHP units (200 MW steam production capacity in each unit) in scenarios with varying natural gas prices (50/100 €/MWh) and Nordic electricity market prices (40-100 €/MWh)

When investments from cases 1-4 are applied (by using the scheduling model) to all these cases separately, the total costs from these 16 scenario combinations are illustrated in Figure 3. It is evident that total annual costs vary significantly more in the cases with SMR CHP investments since electricity prices affect the cost-efficiency of CHP units. In the case of SMR heat-only units, the average annual total cost is significantly less volatile subject to electricity prices. It is important to note that in the energy system model profits from electricity sales decrease the total annual system costs. The variation in terms of annual average DH production cost (including the annualised investment costs) is approximately 24 €/MWh in the investment cases 2 and 4, and merely around 5 €/MWh in the investment cases 1 and 3. These production cost differences are calculated by using the total cost values of Figure 3 and total annual DH demand (11 TWh) of the Metropolitan area. The effect of high natural gas price is somewhat marginal on operational costs, but one extra SMR unit increases fixed costs.

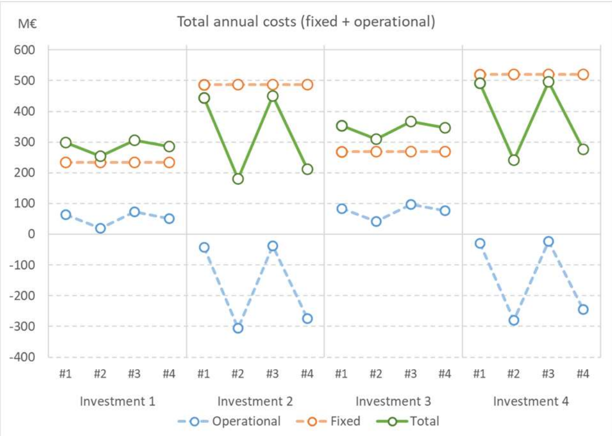

Figure 3. The total annual costs (including annualised investment costs for new capacity and operational costs) in all the 16 scenario combinations consisting of investments results (Investment 1-4) and price scenarios (#1-4).

The utilisation rates of selected production technologies of the DH system for cases 1 and 4 are listed in Table 2 (note: in this table investment scenario matches the price scenario). It is evident that SMR CHP is operated in full load to benefit from the high electricity prices (and flexible DH production), whereas SMR heat units have to somewhat adapt to the varying DH load. Utilisation rate of heat pumps, superseded by SMR units, collapse with high electricity prices, whereas biomass-based units are operated with moderate rate due to the stable and low biomass price. The gas-fired units, including the CHP units, have negligible utilisation rates.

In all the combination scenarios of Figure 3, the utilisation rate values of SMR heat units range from 55% to 90% with average rate of 66%. It should be noted that SMR heat units are invested in each of the DH model areas (Helsinki 1, Helsinki 2, Espoo and Vantaa) and SMR-based DH production must adapt to varying seasonal DH demand in each model area. Furthermore, the SMR heat units cannot operate in terms of DH and electricity production as flexibly as SMR CHP units, which have average utilisation rate of 98%.

Table 2. Utilisation rates of selected technology types in the cases 1 and 4 (note: here the investment scenario matches the price scenario).

Technology	Case 1	Case 4
SMR Heat	72 %	61 %
SMR CHP	-	99 %
Heat Pumps	28 %	3 %
Bio CHP	12 %	48 %
Bio Heat	10 %	28 %

4 CONCLUSIONS

In this study we have examined the investments of SMR units in the DH system of the Helsinki Metropolitan area under varying energy prices. The results indicate that investments in SMR CHP units in require at least annual average electricity market price of 70 €/MWh to be cost-efficient (see Figure 2). The price of natural gas does not affect this threshold; however, the high gas price increases the number of invested units. When applying the varying energy prices to investments obtained from a specific price scenario, the total annual cost comparison reveals that the DH system with SMR heat-only units is somewhat stable to price fluctuations, whereas varying electricity prices seem to affect the cost-efficiency of the SMR CHP units significantly (see Figure 3).

Few issues concerning the energy system analysis should be discussed here. Firstly, the hourly time series of electricity prices are scaled from the 2017 data, since there are not yet available actual data concerning electricity prices of average level of 100 €/MWh, and therefore, high profits and high utilisation rates of SMR CHP units might not materialise with actual price data that could have higher variability. Secondly, in the investment case 4, there are 12 units of SMR CHP which adds up to 600 MW of new power generation capacity. From the power generation and energy market point of view, an insertion of new capacity of this scale would most likely decrease the market price for Finnish region, and therefore affect the cost-efficiency of these CHP units.

Finally, one of the main obstacles for SMR based district heating is the lack of available commercial technology, which in turn creates uncertainties in creating streamlined regulatory approach and results in project risks. Most of the electricity producing SMRs that are envisioned to be constructed in near future could be fitted with CHP-capable turbines, but the reactors have rather high powers, in order of 1000 MW thermal capacity, which make them difficult to locate near communities. Lack of district heating focused SMR design has prompted several concept development projects, including VTT's LDR-50 [8], where the plant would house several 50 MW reactor units with output heat in 80 – 120 C temperature range. The aim of the LDR-50 project would be to initiate the demonstration project well within this decade.

ACKNOWLEDGEMENTS

The authors of this paper gratefully acknowledge the public financing of Business Finland for the "EcoSMR" project (9277/31/2019).

REFERENCES

[1] Ministry of Economic Affairs and Employment, *Finland's Integrated Energy and Climate Plan*. 2019. [Online]. Available: http://julkaisut.valtioneuvosto.fi/handle/10024/161977

[2] K. Värri and S. Syri, "The possible role of modular nuclear reactors in district heating: Case Helsinki region," *Energies*, vol. 12, no. 11, pp. 1–24, 2019, doi: 10.3390/en12112195.

[3] T. J. Lindroos, E. Pursiheimo, V. Sahlberg, and V. Tulkki, "A techno-economic assessment of NuScale and DHR-400 reactors in a district heating and cooling grid," *Energy Sources, Part B Econ. Plan. Policy*, vol. 14, no. 1, pp. 13–24, 2019, doi: 10.1080/15567249.2019.1595223.

[4] E. Pursiheimo, T. J. Lindroos, D. Sundell, M. Rämä, and V. Tulkki, "Optimal investment analysis for heat pumps and nuclear heat in decarbonised Helsinki metropolitan district heating system," *Energy Storage Sav.*, vol. 1, no. 2, pp. 80–92, 2022, doi: 10.1016/j.enss.2022.03.001.

[5] J. Kiviluoma, E. Rinne, T. Rasku, and N. Helistö, "Backbone—An Adaptable Energy System Model—GitLab Repository," 2018. https://gitlab.vtt.fi/backbone/backbone (accessed Feb. 14, 2022).

[6] N. Helistö, J. Kiviluoma, J. Ikäheimo, T. Rasku, E. Rinne, C. O'Dwyer, R. Li, *et al.*, "Backbone—An adaptable energy systems modelling framework," *Energies*, vol. 12, no. 17, pp. 1–34, 2019, doi: 10.3390/en12173388.

[7] Statistics Finland, "Energy Statistics," 2021. https://www.tilastokeskus.fi/til/ehi/tau_en.html (accessed Nov. 30, 2021).

[8] J. Leppänen, S. Hillberg, V. Hovi, R. Komu, J. Kurki, U. Lauranto, A. Oinonen, *et al.*, "A Finnish District Heating Reactor: Background And General Overview," *Proc. 28th Int. Conf. Nucl. Eng. ICONE-28, August 4-6, 2021, Virtual Conf. USA*, 2021.