Nuclear Science and Technology Symposium - SYP2019
Helsinki, Finland, 30-31 October 2019

The Possible Role of Modular Nuclear Reactors in District Heating – Case Helsinki Region

Konsta Värri[1], Sanna Syri[2]
[1]Fortum, [1,2]Aalto University
[1]Keilalahdentie 2-4, 02150 Espoo, Finland, [2] Otakaari 4. PL 14100, Finland
[1]konsta.varri@fortum.com, [2]sanna.syri@aalto.fi

ABSTRACT

To answer the challenges presented by climate change, all aspects of our energy systems to carry out a rapid transition towards decarbonisation. This is especially true for the European heating sector that still relies heavily on fossil fuels. District heating systems have been traditionally praised for their efficiency but replacing old fossil fuel based CHP plants is an ongoing challenge, and also the sustainability of biomass as a large-scale option can be considered questionable. Small modular nuclear reactors are one of the potential sources of future CO2-free district heat production. Their technical aspects seem promising but there is still significant amount of uncertainty around both their costs and deployability. The scenario modelling assesses the investment in 300 MWdh of new district heating capacity in the Helsinki Metropolitan area in 2030 either as a CHP plant or as a heat-only boiler. The results indicate that a modular nuclear heat-only boiler could be profitable, while profitable investment in a modular nuclear CHP plant relies heavily on future electricity market price levels.

1 INTRODUCTION

Alongside most Nordic countries, Finland has set ambitious climate goals. Most recently, the government introduced legislation to ban the use of coal for energy production by 2029 [1]. The government level goals are also further fortified by the decisions of individual cities as the latest strategy of Helsinki, for example, includes the goal of achieving carbon neutrality by 2035 [2]. However, district heating (DH) in Finland still relies heavily on fossil fuels and peat. The cities in the Metropolitan area, Helsinki, Espoo and Vantaa, are most likely trying to fill the hole left by the eventual decommissioning of fossil fuel fired plants with biomass, but recent motions put forward in multiple city councils have called for an evaluation of the potential of small modular reactors (SMR) as a source of district heating. This paper, based on the article by the same authors [3], attempts to look into under which assumptions SMRs would be a valid choice for energy production in the chosen market beyond the year 2030. SMRs have been brought up in DH discussions mainly for their ability to provide CO2 free energy at a scale smaller than traditional nuclear power plants (NPP), but the new plant designs can also provide increased safety through passive systems, possibilities for reduced costs and higher quality fabrication through factory based manufacturing and other possible advantages [4]. While these advantages are significant, there are still a number of issues to be solved before large scale deployment can be considered including licensing considerations and emergency planning zone sizes. These are considered solvable issues in this study, as the focus is on the techno-economical assessment

2 MATERIALS AND METHODS

2.1 Modular Nuclear Plant Considered in the Study

The plant considered as a representative SMR here is the NuScale SMR, a 160 MWt, 50 MWe integral pressurized water reactor (IPWR) design. The choice of SMR was primarily motivated by the availability of public data and the plant considered here for DH production features 2 to 3 modules either as a heat-only boiler (HOB) or as a combined heat and power (CHP) plant [5].

2.2 Market and Investment Analysis

The market and investment analysis is performed primarily using two separate models: The DH system analysis model and the investment model. The basic evaluation of district heating systems is performed using an hourly model that based on the plant data, capacity available and the cost of electricity, runs a script to fulfil the assigned heat demand at the lowest cost possible hour at a time over a single year. The model is fairly limited as it considers production forms a single block instead of multiple plants and ignores issues such as start-up costs and minimum loads but is used here for basic evaluation of full load hours (FLH) and production costs.

The investment model is divided further into two separate models provided by Fortum to evaluate the levelized costs of heat and electricity (LCOH/LCOE) and the net present values (NPV) and internal rates of return (IRR) for HOB and CHP plants. The first investment model calculates the data for a HOB plant whereas the second model evaluates the additional investment from HOB to a CHP plant. The model is built around the principle that a new plant is first and foremost built to produce a certain amount of heat.

3 ENERGY SYSTEM DATA AND CONSIDERATIONS

3.1 Plant Data

The basic data for heat only plants is presented in Appendix 1. While the HOB data is presented for all of the options, only pellet and gas fired HOBs are considered as an investment in their own right as the rest function as the basis for the additional CHP investment. [6,7] As a point of comparison, heat pumps, electrical boilers and wind turbines are also considered as alternatives to the large-scale plants.

The SMR is considered as both a CHP plant and a HOB. The data on the NuScale SMR used in this thesis is mostly based on data from NuScale itself while utilizing some of the same assumptions as VTT and the British Techno-Economic Assessments in their SMR studies. The data given by NuScale is for a full 12 module plant, so the price for a single module was presumed to be 1/12th of the full plant price referred up 30%. The HOB plants costs were further modified by removing the turbine island and balance of plant from the cost summary while assuming that the CHP would cost the same as a normal plant. As presumable for a technology that has yet to been applied, these cost evaluations include high levels of uncertainty. [8-10].

The cost of capital is a significant factor and a source of uncertainty for the SMR investment and was presumed at a level of 8%. For other technologies, presumed base values of 5% WACC for HOBs and 6.5% for CHP are used.

3.2 Fuel, Electricity and ETS Price Trends

The main price developments for fuels and electricity are shown in Figure 1. The CO2 price is presumed to act according to the EU reference scenario [11]. The gate fee for municipal solid waste was determined to remain at a level of 30 €/MWh. The nuclear fuel price was also determined partly through internal discussions at Fortum and a conservative fuel price estimate of 2.05 €/MWh was used [12,13,11,5].

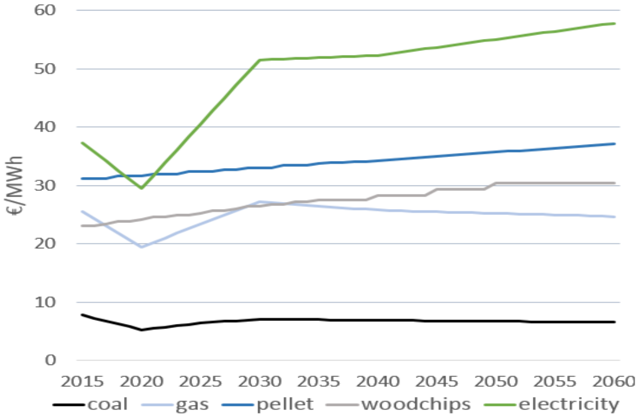

Figure 1. Development of fuel and electricity pricing[12,13].

3.3 The System

The Helsinki Metropolitan area scenario is built around the hypothetical base concept that the DH networks of Helsinki, Espoo and Vantaa would be more fully integrated by 2030. The DH production mix was evaluated based on the NETP16 scenarios and the results can be seen in Table 1. These are, once again, rough approximations but used here to gain a basic idea of the potential development of the heating markets [12].

Table 1. The presumed DH production mix in the Helsinki Metropolitan area in 2030

	Capacity (MW)
Gas HOB	2500
Gas CHP	1000
Pellet HOB	400
Woodchip CHP	500
Waste CHP	150
Electrical Boilers	50
Heat pumps	200

Based on the current heat price and estimated levels of network costs and taxes, the realized heat price of around 47.5 €/MWh was used for the plants. The tax rates used in the scenario mainly presume that the current levels of taxation would continue. The fuel tax for gas in CHP use is 13.7 €/MWh and 19.9 €/MWh for HOBs. The same values for coal are 18.2 €/MWh and 28.8 €/MWh. Electricity tax applied to its use for powering heat pumps and electrical boilers is presumed to stay at the level of 22.53 €/MWh while the transmissions costs are expected to stay around 30 €/MWh. The corporate tax rate is presumed to stay at 20% after 2015

4 RESULTS

The addition of 300 MW of SMR heat production into the production mix is presented in Figure 2. Unsurprisingly, the primary change caused by the addition of SMR is the decreasing role of gas. Cost wise, the addition of an SMR plant mostly brings the marginal cost down during the low demand hours as during the 3000 highest cost hours, the addition of either of the SMR options brings the marginal cost down just 6% in 2030 on average but the average cost would be brought down 23% with an SMR HOB and 29% with an SMR CHP plant.

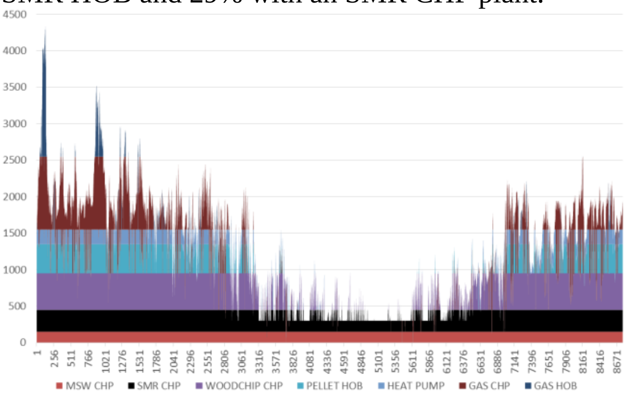

Figure 2. The modelled district heat production distribution with SMR CHP in 2030 in MW

Based on the presumed full load hours gained from the modelling, the investment evaluation was performed. The results of these are presented in Figures 3-4. Generally, the IRRs and NPVs for heat production here seem high while the additional investments in CHP do not seem profitable. If taken as full investments, the CHP plants do still return positive IRRs

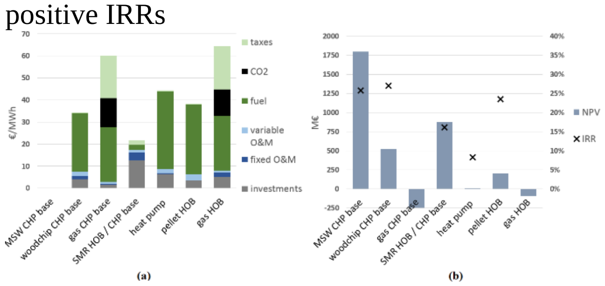

Figure 3. The LCOH breakdown (a) and the NPV and IRR (b) of HOBs and the HOB bases for CHP plants

Based on these, the SMRs seem viable, but there is a high amount of uncertainty in the SMR data and running a sensitivity analysis provides some further understanding on this. The truly significant factors are the full load hours, price achieved from the sales of the production and the cost of capital. Especially the final one becomes an important factor and will most likely become one of the most critical factors in the decision to invest in a new plant.

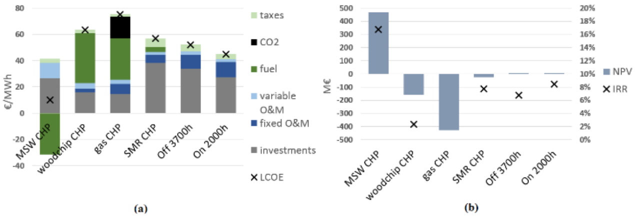

Figure 4. The LCOE breakdown (a) and the NPV and IRR (b) of the additional CHP investments considered with wind power values for reference

5 DISCUSSION AND CONCLUSIONS

As the scenario analysis contains a fair amount of uncertainty, the most important takeaways from it are rather general ideas. The SMR HOB and CHP both have potential as baseload plants. This is especially true when considering which plants they primarily run against. While biomass and especially waste might seem like attractive options, both should be looked at through the lens of fuel supply and its sustainability. If considering the fuel sourcing for both and additionally the siting for biomass, both must be considered quite limited in their capacity for expansion. In this case, the question starts to move away from "What is the cheapest way to produce heat sustainably?" towards "What options for sustainable heat production are there left?"

It is still too early to answer if SMRs would be a valid answer to that. Nevertheless, the initial results gained here do seem promising for any DH network with a large enough base heat demand that cannot be directly supplied alone by MSW incineration plants and where stringent CO_2 emission reduction targets are pursued. The SMR technology itself seems suitable for district heating. The small scale means that a single module can fit into a small DH network. At the same time, the modular nature of SMRs also means that the plants can be built for a variety of production configurations. At the moment, producing only heat seems like the better choice from the return on investment point of view, but this will rely heavily on the future development of both the electricity and heating markets. If the financing costs can be kept down and generating the full baseload by MSW and/or biomass is not possible or sustainable, SMRs could be a recommendable future option for sustainable heat production. This should also be kept in mind in the development of national legislation as currently, Finnish nuclear licensing legislation is aimed only at individual large nuclear generation units.

REFERENCES

[1] Ministery of Economic Affairs and Employment. Minister Tiilikainen: Finland to ban coal in 2029 – incentives package for faster phase-out. Available online (accessed on 9.5.2018).

[2] City Of Helsinki. Climate Protection. Available online (accessed on 4.1.2018)

[3] Värri, K & Syri, S 2019. The possible role of modular nuclear reactors in district heating : Case Helsinki region. Energies, vol. 12, no. 11, 2195 . Available online (accessed on 2.9.2019)

[4] World Nuclear Association. Small Nuclear Power Reactors. Available online (accessed on 13.12.2017)

[5] IAEA. NuScale Power Modular and Scalable Reactor, 2013.

[6] Energinet.dk, Danish Energy Agency. Technology Data for Energy Plants August 2016 - Update June, and November 2017, 2017

[7] Energinet.dk, Danish Energy Agency. Technology Data for Energy Plants - Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion, 2015.

[8] Surina, J. NuScale Plant Market Competitiveness & Financeability, 2015. Available online (accessed on 23.5.2019).

[9] Tulkki, V. Pursiheimo, E. Lindroos, T.J. District heat with Small Modular Reactors (SMR), 2017. Available online (accessed on 24.4.2018).

[10] Energy Technologies Institute. DECC Small Modular Reactor Techno-Economic Assessment - Project 2 Report. Technical report, Energy Technologies Institute, 2016. Available online (accessed on 24.4.2018)

[11] Capros, P. De Vita, A. Tasios, N. Siskos, P.; Kannavou, et al. EU Reference Scenario 2016- Energy, transport and GHG emissions Trends to 2050; EUROPEAN COMMISSION Directorate - General for Energy, Directorate - General for Climate Action and Directorate - General for Mobility and Transport, 2016.

[12] International Energy Agency / Nordic Energy Research. Nordic Energy Technology Perspectives 2016; IEA, 2016.

[13] Ea Energy Analyses. Analysis of biomass prices - Future Danish prices for straw, wood chips and wood pellets "Final Report", 2013. Available online (accessed on 11.4.2018)

APPENDIX 1.

Table 2. Basic data for plants used in this study[5,6].

HOB	**MSW**	**Woodchip**	**Pellet**	**Natural Gas**	**NuScale SMR**	**Heat Pump**	**Electrical Boiler**
heat capacity (MW_{dh})	300	300	300	300	300	20	20
efficiency$_{(dh)}$ (%)	97.6	108	108	104	93.8	380	99
lifetime (a)	20	20	20	25	60	25	25
capex (€/MW_{dh})	1 595 000[1]	500 000	250 000	90 000[1]	1 506 667	590 000	60 000
variable O&M (€/MWh_{dh})	5.4	1.851[1]	2.7	1	1.26	1.7	0.5
fixed O&M (€/MW_{dh}/a)	53 000	11 600[1]	0	1 900	30 000	2 000	1 020
CHP	**MSW**	**Woodchip**		**Natural Gas**	**NuScale SMR**	**Offshore wind**	**Onshore Wind**
heat capacity (MW_{dh})	300	300		300	300	0	0
power capacity (MW_e)	110	145		391	90	12	4
total efficiency (%)	97	95		90[2]	81,3	100	100
lifetime (a)	20	30		25	60	30	30
capex (€/MW_e)	7 000 000	3 000 000[1]		800 000	9 408 750	1 990 000	910 000
variable O&M (€/MW_e)	45,15	8,06[1]		4,20	6,33	2,70	2,30
fixed O&M (€/MW_e/a)	0	45 556[1]		27 800	150 000	37 800	22 300

[1] Adjusted based on internal discussions and public plant and other data.