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Prospects of electricity and heat-only SMRs in the Baltic Region

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ABSTRACT

In the recent years, small modular reactors (SMRs) for power and heat generation have gained high interest due to promise of carbon-free generation, design flexibility, low cost, and high safety features. In this study, electricity and heat-only SMRs are modelled in the Estonian, Latvian and Lithuanian energy systems at 2030. The results indicate that heat-only installations could replace fossil-based district heating generation cost-effectively in the Estonian and Latvian capitals. Meanwhile, electricity SMRs in the Baltic region seem profitable only under high price assumptions.

1 INTRODUCTION

The Baltic countries, Estonia (EST), Latvia (LVA) and Lithuania (LTU), have ambitious green transition targets including emission reductions and improving energy security by reducing energy import dependency. Small modular reactors (SMRs) offer a potential source for carbon-free electricity and district heat (DH) generation, with high safety features and potentially lower capital costs compared to traditional nuclear power plants (NPPs).

In previous studies, we have modelled a '2030 reference' scenario for the Baltic countries that includes current policies and investment decisions up to 2030 [1]. In this study, we add either electricity or heat-only SMRs to the '2030 reference' scenario and study their impacts. We investigate an American NuScale SMR design for electricity generation in each Baltic country, and the Finnish LDR-50 design for heat-only production in each Baltic capital (Tallinn, Riga, Vilnius).

The aim of this study is to assess the operational and financial prospects of SMRs in the Baltic region in 2030.

2 ELECTRICITY AND DISTRICT HEATING IN THE BALTICS

The key data of electricity production and district heating in the Baltic countries is collected in Table 1 and Figure 1 to provide an overview of the Baltic power and heat systems. All the countries have strong connections for import and export of electricity. Especially Lithuania has been heavily dependent on importing electricity since the closure of the Ignalina NPP in 2009. Latvia and Lithuania produce major share of electricity with renewable energy sources along with natural gas, while Estonia still relies heavily on shale oil -based fuels.

Table 1. Key data of electricity and DH in the three Baltic countries. Data compiled from [2–8].

	EST	LVA	LTU
Electricity			
Prod/imp/exp (TWh)	7.29/7.33 /4.70 (2021)	5.61/4.67 /2.89 (2020)	5.52/1 1.26/3. 35 (2020)
Installed thermal/ VRE capacity (MW_e)	2182/324 (2020)	2245/182 5 (2020)	1742/9 67 (2020)
District heat			
Production (TWh)	4.5 (2017)	7.51 (2020)	8.98 (2018)
Network length (km)	1455	2000	2885
Part of DH with CHP	~50% (2017)	71% (2018)	41% (2018)
Heating degree days (avg. 2017–2021)	4176	3806	3807

District heating serves roughly 60% of the population in the countries with their heat distribution networks initially established during the time under the Soviet Union [9]. Although parts of the DH networks have been replaced with modern pre-insulated piping, especially in Lithuania, major parts of the networks still use old, so-called, secondgeneration piping with significant heat losses. A common development in all the three countries during the last decade or two has been the shift from the use of fossil fuels (mainly natural gas) to biofuels in the DH production. The shift has been especially drastic in Lithuania where biofuels and municipal waste formed 67.5% of the DH production in 2018 while in the beginning of the millennium the share was only 2% [2]. Capital regions are the largest consumers of DH (e.g., Tallinn consumes 38.8% of DH in Estonia).

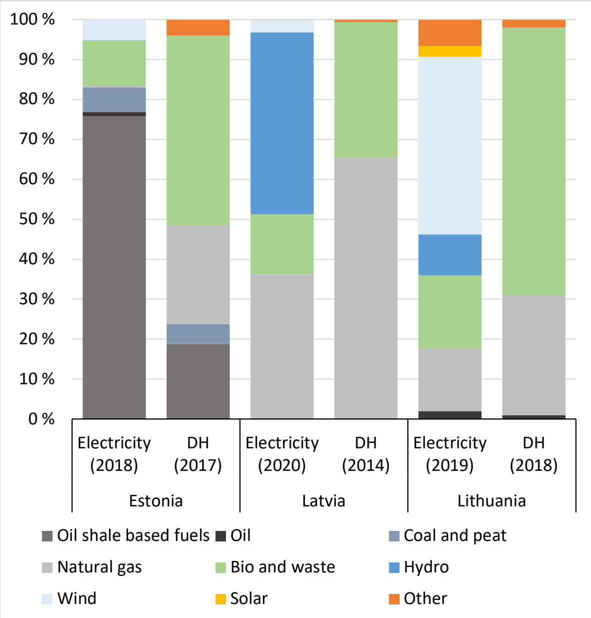

Figure 1. Electricity and DH production by fuels. Data from [2][4][6][10].

3 MODELLING SMRs IN THE BALTICS

The energy systems of the Baltics are modelled with the Baltic Backbone energy system model. The Baltic Backbone is built with open-source Backbone modelling framework. The used data and assumptions have been documented in [1], and the model and used data can be downloaded from [11]. The Baltic Backbone is designed to model the near- and medium-term energy system development in the Baltics. It includes a detailed description of the electricity and DH production, including all generation units. Additionally, the DH grid is spatially split between capital regions and the rest of the country (Figure 2). End-use energy demands in industry, buildings and transport are included as demand time series.

The model operates on hourly detail and minimizes the operation costs by optimizing the use of production units, storages, and transmission connections to neighbouring countries. The approach is similar to the operation of electricity markets. The annual operational results include costs, energy balances, emissions, renewable energy shares, and other policy relevant indicators.

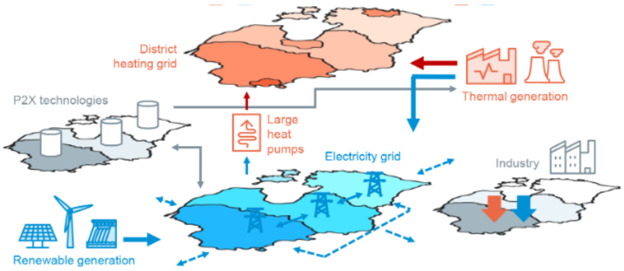

Figure 2: Simplified structure of the Baltic Backbone. Figure adapted from [1].

The modelled electricity SMRs are based on the NuScale concept. NuScale offers plants with 4, 6, or 12 SMR modules that each have 77 MW_{e_gross} of electrical capacity [12]. According to NuScale, the net electrical power of each unit would be approx. 5% below the gross electrical power [13], and the total investment costs would be around 3400 USD/kW_{e_gross} (3300 EUR/kW_{e_net}). We model several scenarios where 4 to 12 NuScale modules would be built to one of the Baltic capital regions (3 x 5 scenarios).

The modelled heat-only SMRs are based on the ‘LDR-50’, a low-pressure technology designed to provide district heating [14]. Designing a reactor specifically for DH has certain additional advantages: small unit size with almost 100% efficiency, no need for a turbine cycle, and the operating temperature can be reached at a low pressure level (below 10 bar compared to ~150 bar in pressurised water reactor).

The optimal capacity level for the heat-only reactors depends on the heat consumption in the grid, the type and the capacity of existing grid-connected units. For each Baltic capital, we model heat-only SMR capacities from 2x to 6x summer demand. There are no official estimates of the ‘LDR-50’ costs, but we study the acceptable ranges by varying the investment cost from 800 EUR/kW_{th} to 1600 EUR/kW_{th}.

4 RESULTS

Adding electricity SMR capacity to the Baltic system mostly replaces imported electricity in the modelled 2030 scenarios (Figure 3). Despite the large planned wind power investments, the Baltic region turns into an electricity net importer in the ‘2030 reference’ scenario. This is mainly due to phase-out and reduced operation hours of fossil fuel -units.

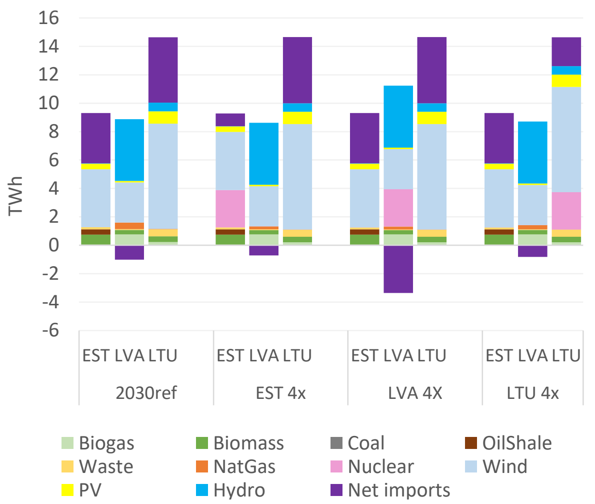

Figure 3: Electricity supply in the Baltic countries in the '2030 reference' and the 'NuScale4-module' scenarios

The addition of electricity SMRs reduced the Baltic modelled CO_2 emissions (-80 ktCO_2 between '2030 reference' and 'Nuscale 4-module' scenarios), increased total domestic electricity generation (+2.3 TWh) and slightly total increased renewable DH share (+0.5%), but reduced the total share of renewable electricity (-8.5%). Most of the impacts occurred in the country of installation but due to active electricity trade within the region and with third parties, the Baltic level results were similar regardless of the investing country.

With default assumptions, the investment in electricity SMRs in the Baltic region showed only low profitability, leading to internal rates of return (IRR) around 5% (Figure 4).

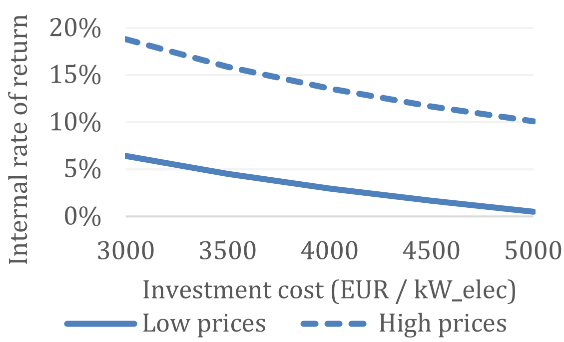

Figure 4: Internal rate of return in the 'NuScale 4-module' scenarios as a function of investment cost. Low prices are the reference case and high prices from 2022 price levels.

However, the profitability calculation is sensitive to price assumptions. The current geopolitical situation has had a dramatic impact on fuel and electricity prices, which may return to normal levels by 2030 or remain closer to current levels. When assuming 2022 price levels for electricity and natural gas, the IRR of the investment rises above 10%.

The addition of heat-only SMRs to the Baltic capitals' DH grids serves as heat baseload, replacing primarily natural gas and secondarily biomass and large heat pumps (Figure 5). Heat-only SMRs have a lower marginal operation cost and are operated before all other unit types in the Baltic capital grids, except waste incinerators, which need to continuously process waste. In Tallinn and Vilnius, there is less room for new SMR heat installations due to existing waste incinerators.

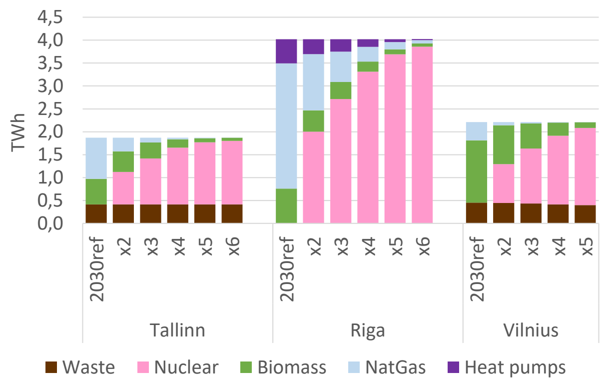

Figure 5: DH supply in Baltic capitals in the '2030 reference' scenario and in the 'LDR-50' scenarios

The introduction of heat-only SMRs has a larger impact on the modelled CO_2 emissions thanthe electricity SMRs, because there remainsa larger amount of fossil fuels in DH systems. The reduction between '2030 reference' and '4x summer demand' scenario ranges from -60 ktCO_2 in Vilnius to -200 ktCO_2 in Tallinn and up to -510 ktCO_2 in Riga. The emission reductions in Vilnius are considerably smaller as the existing heat capacity is already mostly fossil-free. The introduction of SMRs reduces the Baltic total share of renewable heat slightly (between -1.8 to -6.0% depending on country of installation).

The investment in heat-only SMRs shows the best profitability in Riga and Tallinn (Figure 6). With capacity up to 4x summer demand, the IRR with reference price assumptions is around 10%, and with 2022 price level assumptions, up to 20–30%. The financial performance of investments in Vilnius seems poorer, and remains around 10% IRR even in the high price case.

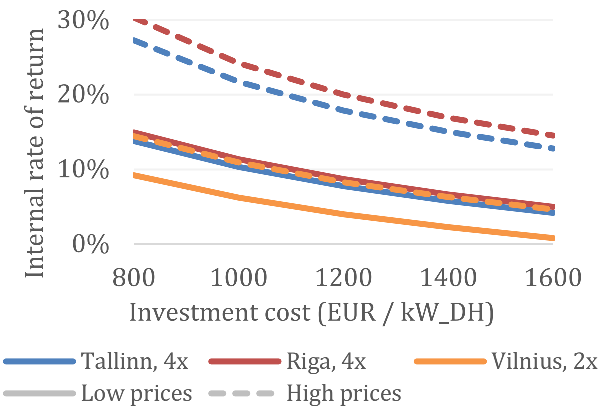

Figure 6: Internal rate of return in selected 'LDR-50' scenarios as a function of investment cost.

5 CONCLUSIONS

Based on the modelling results, an investment of 100-400 MW in heat-only SMR capacity in the Estonian or Latvian capital region could cost-effectively reduce heat-related emissions and reduce fossil-dependency in district heating generation. SMRs appear less feasible in the Vilnius, due to high share of renewable and waste DH.

Electricity SMRs show lower profitability in the Baltic countries. The electricity SMRs could increase the domestic share of electricity and reduce net electrical imports, but the planned high deployment of wind power narrow the opportunities of nuclear units that have high investment costs and long lifetimes. Increasing fuel and electricity prices may enhance the prospects of SMRs, but lack of existing reference installations and regulatory barriers will remain issues in the near-future for both heat and electricity units.

ACKNOWLEDGEMENTS

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