TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING

TECHNO-ECONOMIC ANALYSIS OF NUCLEAR DISCTRICT HEATING IN ESTONIA

TUUMAENERGIA TEHNILIS-MAJANDUSLIK SOBIVUSANALÜÜS EESTI KAUGKÜTTEVÕRKU

MASTER THESIS

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DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING

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3. Econimics of building nuclear district heating system in Estonia

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PREFACE

This thesis represents end of my academical studies and would not have been possible without support and guidance from my thesis supervisor and Eduard Latõšov and consultant Marti Jeltsov. I extend my gratitude to those who helped and gave me initiation to complete this work in timely manner.

The inception the thesis topic was initiated by taking an optional course of nuclear energy introduction during my first semester where nuclear solutions and different technologies were discussed and shown on the slideshow. I’d also like to thank Fermi Energia who invited me to visit to Finland to see Olkiluoto nuclear reactor, which gave me more oversight of how the operation of the nuclear reactor is done and what kind of technologies are used over there.

Main goal of this thesis is to explain different possible reactor technologies and how nuclear reactor could be used in Estonian district heating system to create CO2 free district heating systems according to other countries experience and available information from online sources.

LIST OF ABBREVIATIONS AND SYMBOLS

BWR - boiling water reactor.

kWh - Kilowatt hour.

MWh - Megawatt hour.

MWth – Megawatt hour thermal.

KWth - Kilowatt hour thermal.

SMR - Small Modular reactor.

HWR - Heavy water reactor.

MSR - Molten salt reactor.

LFMR - Liquid fluoride molten salt reactor.

HTGR - High-temperature gas-cooled reactor.

GMFR - Gas-cooled fast reactor.

CEA - Alternative Energies and Atomic Energy Commission.

CGN - China General Nuclear.

CNEA - Comision Nacional de Energía Atómica.

CNEC - China Nuclear Engineering Corporation.

CNNC - China National Nuclear Corporation.

KAERI - Korea Atomic Energy Research Institute.

PWR - Pressurized water reactor. If not specified, all of the reactors are land-based.

RITM-200 - Nuclear-powered icebreakers.

SWOT - analysis is a method for identifying and analyzing internal strengths and weaknesses and external opportunities and threats that shape current and future operations and help develop strategic goals.

ALWRs - Advanced light-water reactors.

SPIC - Chinese State Power Investment Corporation Limited (Nuclear energy producer).

ROI - Return on investment.

RBMK - Reaktor Bolshoy Moshchnosti Kanalny.

EGP - Channel-type Reactor.

MMR - Micro modular reactor.

VAT - Value added tax.

VTT - Technical Research Centre of Finland Ltd, a state-owned and controlled non-profit limited liability company.

NRC - Nuclear Regulatory Commission.

1 INTRODUCTION

Small nuclear reactor or small and medium-sized reactor (SMR) technology has been lauded for its numerous advantages over traditional nuclear power plants. SMRs are nuclear reactors that are made up of smaller, modular components, allowing them to be built in factories and transported to their intended sites. These reactors offer an advanced, cost-effective, and safe solution to the energy needs of today and the future.

SMRs are more efficient than traditional nuclear power plants, as they produce less waste and require less land area for installation. This is due to their small size, which allows them to be built in factories and shipped to the site of deployment. This reduces the cost of constructing and maintaining the plant, allowing SMRs to be cheaper to operate than traditional nuclear power plants.

SMRs are also safer than traditional nuclear power plants. The small size of SMRs allows them to operate at lower power density, reducing the risk of a nuclear meltdown. Additionally, SMRs are designed with built-in safety features, such as redundant and passive cooling systems, which protect against catastrophic failure. These safety features are designed to ensure that any potential accident is contained and does not cause any harm to the public.

Moreover, some (e.g. high temperature designs) SMRs are more efficient than traditional nuclear power plants, as they can generate a more power output per given core size. This efficiency allows SMRs to generate more electricity from a smaller amount of fuel, reducing the cost of electricity production. Additionally, SMRs can rapidly adjust their power output, which allows them to easily meet changing energy demands.

Finally, SMRs provide a cleaner source of electricity than traditional nuclear power plants, as they produce significantly less radioactive waste and carbon emissions. This allows them to provide a more sustainable source of energy, as they can reduce the amount of pollution and greenhouse gases released into the atmosphere.

Overall, SMRs provide an efficient, cost-effective, and safe solution to ever changing and difficult to balance electrical grid. Some SMRs can generate more electricity from a smaller amount of fuel, reduce the amount of radioactive waste and carbon emissions released into the atmosphere, and offer enhanced safety features to protect against catastrophic failure. For these reasons, SMRs offer a promising solution for meeting the energy needs of the future.

This thesis aims to explore possibilities and feasibilities of using SMR technology for co-producing district heating in addition to power. Due to ever-increasing CO2 prices and the effects of climate change, it is known that CO2 emissions need to drop in the upcoming decade. Nuclear district heating has proven to be a good option in many countries which have already experience operating nuclear reactor in district heating grid, promising a reliable heat supply while minimizing carbon emissions in nearby countries. In this thesis, data is collected from different countries and studies and analysed where experiences and technical solutions are brought out.

This study also addresses the economic feasibility of implementing a nuclear district heating system in the Rakvere and Kunda regions of Estonia.

First, we will examine the overall energy use pattern in the existing district heating infrastructure, considering both Rakvere and Kunda, which are the closest district heating grids to the Letipea area, which is one of potential locations for nuclear power production in Estonia (figure 7). This study identifies price trends that make electricity a more economically attractive option and what price should be electricity price difference to have where it is more beneficial to produce electricity or heat district heating.

This study provides valuable insight into the balance between district heating and power generation and is important for making informed decisions on whether to provide district heating, as it is a large investment that will take years to break even.

This thesis also investigates the intricate details of pipeline construction, including pipeline length, costs, and associated financial implications. We conduct a thorough financial analysis that considers acquisition costs, sales projections, and long-term maintenance considerations. These financial insights serve as a compass for understanding the economic development of implementing nuclear district heating systems. In a broader context, this study conducts a SWOT analysis of the core technology of small modular reactors (SMRs).

Through examining nuclear district heating in Rakvere and Kunda, we aim to provide actionable insights for stakeholders, policymakers, and investors regarding the type of technical solutions are used worldwide and how many countries currently implement district heating systems. Understanding economic conditions, price trends, and technical considerations will contribute valuable knowledge to the ongoing debate about sustainable energy practices in Estonia. This thesis may even propose an economic possibility to install small modular nuclear reactors close to bigger cities like Tallinn, Tartu, and Pärnu to provide more heat. With this information, it would be easier to determine the benefits of nuclear-powered district heating.

2 OVERVIEW OF SMALL-SCALE NUCLEAR TECHNOLOGIES

2.1 Definition of small modular reactor

SMRs are considered a new milestone in nuclear energy technology, although the first SMR nuclear power generators were developed for the military in the early 1960s based on the need to obtain a larger non fuelling range on ships, where most nuclear reactor designs were limited to aircraft carriers or submarines. The most widely used technology at the time was light water reactors (LWRs). To this day, SMR reactors are not widely used, with the first SMR being put into operation in Russia in May 2020 on a marine vessel Akademik Lomonossov that provides energy for a sub-arctic city using two 35 MWe reactors.[1]

Today, SMRs operate in the range of 10 MWe to 300 MWe. Reactors below 10 MWe, known as micro modular reactors (MMRs), are usually reserved for research or very remote locations without grid access relying mainly on diesel or gas generators. However, SMRs can also be adapted to many existing larger-scale nuclear reactor designs, as is the case in many countries (see Table 2.1).

2.2 Advantages of SMR technology

The benefits of small modular reactors are being observed all over the world. Each nuclear power country is currently planning or developing its own SMR technology (see Table 2.1).

SMR technologies are beneficial in that they can be deployed to a country where the existing power grid does not handle high-capacity nuclear reactors. Technology with such power range is suitable for Estonia, where, due to its lower capacity, the grid cannot sustain a traditional large nuclear power plant without changing out all of its high-voltage lines, investing heavily in grid distribution and compromising grid stability.

Proposed SMR designs are smaller and are, therefore, simpler and safer. This gives them a bigger cost advantage and makes them safer to operate overall, as it is possible to operate the critical parts of the reactor with natural circulation, gravity, and self-pressurization. This could reduce or eliminate the need to operate the plants in an isolated exclusion zone. SMR technologies have large potential to introduce a new way to heat our cities with a clean, reliable nuclear energy source.

2.3 Different SMR technologies

According to the Nuclear Energy Agency, SMR technologies can be grouped into five different subgroups. Currently, the SMR reactors in development or in the planning stages mostly use the technologies from existing nuclear reactors that are downsized due to regulations. It is also more reliable and safer to use known and tested technologies due to the wide experience with operating existing reactors that are similarly downsized to build SMR technology [2].

- **Single Unit LWR-SMR** – Light water reactor complex with a single reactor unit that is below 300 MWe.
- **Multi-Module LWR-SMR** – Multi module light water reactor complex where one of the modules does not exceed 300 MWe.
- **Mobile SMR** – Mobile small modular reactor—mainly used on nuclear-powered aircraft carriers, floating reactors, submarines.
- **GEN IV SMR** - New generation of small modular reactor designs currently under development.
- **Micro Modular Reactor (MMR)** – Small modular reactors up to 10 MWe—mostly in remote areas or for research purposes.

Each of the different groups of SMR reactor designs has its own use. The major difference and requirement on developing SMR technology is risk-informed or performance-based licensing to leverage their smaller size and safety benefits when compared to the mostly large power reactors licensed and used worldwide mostly so far.

At present, at least 72 SMR concepts are under various stages of development, 40% increase from 2018 [3]. Table 2.1 provides a representative sample of SMRs under development at the international level, with about half of the design concepts listed based on LWR technology and the other half on Gen IV concepts (more exotic coolants and fuels). While the term "SMR" has been adopted around the world to refer to all small reactor designs, significant differences remain across the major types of SMRs, especially in the degree of design modularization [2].

Table 2.1 SMR designs under development globally [3].

Design	Net output per module (MWe)	Number of modules (if applicable)	Type	Designer	Country	Status
Single unit LWR-SMRs						
CAREM	30	1	PWR	CNEA	Argentina	Under construction
SMART	100	1	PWR	KAERI	Korea	Certified design
ACP100	125	1	PWR	CNNC	China	Construction began in 2019
SMR-160	160	1	PWR	Holtec International	United States	Conceptual design
BWRX-300	300 OKBM Afrikantov	1	BWR	GE Hitachi	United States-Japan	First topical reports submitted to the US NRC and to the CNSC as part of the licensing process
CANDU SMR	300	1	PHWR	SNC-Lavalin	Canada	Conceptual design
UK SMR	450	1	PWR	Rolls Roye	United Kingdom	Conceptual design
Multi-module LWR-SMRs						
NuScale	50	12	PWR	NuScale Power	United States	Certified design. US NRC design approval received in August 2020
RITM-200	50	2	PWR	OKBM Afrikantov	Russia	Land-based nuclear power plant – conceptual design
Nuward	170	2 to 4	PWR	CEA/EDF/Naval Group/ TechnicAtome	France	Conceptual design
Mobile SMRs						
ACPR50S	60	1	Floating PWR	CGN	China	Under construction
KLT-40S	35	2	Floating PWR	OKBM Afrikantov	Russia	Commercial operation

Gen IV SMRs						
Xe-100	80	1 to 4	HTGR	X-energy LLC	United States	Conceptual design
ARC-100	100	1	LMFR	Advanced Reactor Concepts LLC	Canada	Conceptual design
KP-FHR	140	1	MSR	Kairos Power	United States	Pre-conceptual design
IMSR	190	1	MSR	Terrestrial Energy	Canada	Basic design
HTR-PM	210	2	HTGR	China Huaneng/CNEC/ Tsinghua University	China	Under construction
EM2	265	1	GMFR	General Atomics	United States	Conceptual design
v	300	1	MSR	Moltex Energy	United Kingdom	Pre-conceptual design
Natrium	345	1	SFR	Terrapower/GE Hitachi	United States	Conceptual design
Westinghouse Lead Fast Reactor	450	1	LMFR	Westinghouse	United States	Conceptual design
MMRs						
eVinci	0.2-5	1	Heat pipe reactor	Westinghouse	United States	Basic design
Aurora	2	1	LMFR	Oklo	United States	License application submitted to the US NRC
U-Battery	4	1	HTGR	Urenco and partners	United Kingdom	Basic design
MMR	05-Oct	1	HTGR	USNC	United States	Basic design

2.4 Economics of small modular reactors

Due to limited experience in running SMR plants (especially the modern designs), the capital costs, operation, maintenance, and fuel costs are uncertain. There are some indicators that adapted regulations will allow for lower kWh installation costs. Moreover, due to its smaller size, the equipment can be standardized, which would make mass production easier. The optimization of supply chains and larger orders will also come into play and could bring the building costs down. As there are many nations currently developing SMR technologies, there will be increased competition among SMR-producing companies. As shown in Table 1, around 26 reactor designs are currently being developed [5].

2.5 Investment Costs

As mentioned before, the investment costs to build one and start mass production of SMRs are yet unknown. Faster manufacturing time and adapted regulatory needs due to safer operation could bring the costs to a more feasible range.

Even if the first unit's financing terms (such as the cost of capital) are the same, the financing terms for subsequent units could be eased by the first unit's successful construction and operation. A more effective way to manage the financial risk involved with capital-intensive, long-term projects is through a gradual increase in capacity [5].

According to current estimations, the per kWe investment cost for SMRs might decrease compared to ALWRs (Advanced LWRs) due to possible savings from optimized supply chains and lower finance costs. Of course, a lot will depend on the series' size, the factory's ability to manufacture the modules and other issues that will be covered in greater detail in the following chapter.

2.6 Operation and maintenance costs

All expenses related to operation, maintenance, administration, materials, supplies, licenses, and employee wages are included among O&M costs. According to the NEA/IEA (2015), the O&M component for ALWRs is generally in the range of USD 10–20/MWh [6].

The fixed component of O&M expenses, such as the cost of security, is unaffected by the size of the facility. The O&M cost per MWh for SMRs may be greater than for ALWRs if ALWR O&M expenses were scaled down to SMR power levels. However, O&M costs per MWh for multi-unit facilities with many SMR units are anticipated to decline with improvements in regulatory requirements [7].

Nonetheless, many SMRs propose cutting-edge approaches to plant management, such as using a single control room for multiple reactors or replacing reactors rather than refuelling them locally (for example, for floating nuclear power plants; see the Russian case study below). If these approaches are approved by regulators, they could result in lower O&M costs. For instance, utilities running a fleet of SMRs might optimize manpower and do refuelling/maintenance work on individual SMR units one at a time, lowering replacement power prices, as opposed to recruiting teams from outside once every one-to-two years to refill and perform maintenance work for an ALWR [7].

2.7 Fuel costs

It is difficult to estimate the fuel consumption of the innovative (non-LWR based) SMRs, especially as the design of many has not yet been finalized. The fuel cost per MWh may be higher for integrated light water SMRs than for advanced LWRs [7].

3 OVERVIEW OF NUCLEAR CO-GENERATION

Nuclear power plants in their nature are thermal power plants that generate heat. In most cases, this heat is converted into electricity and delivered to consumers. However, nuclear energy is also used in many places around the world in so-called co-generation mode delivering heat and electricity at the same time. According to the Atomic Energy Agency, about 43 of such areas are in Russia and Eastern Europe. Combined heat and power are more useful for smaller-population towns using small and medium-sized reactors. Developing SMR nuclear plants could possibly increase this trend as these plants are expected to be safer and smaller in size, closer to population centres and, thus, more efficient with co-generation [8].

However, the nuclear power plant does not need to be near a city for co-generation, as insulated pipelines are able to transport the heating water up to 200km with minimal losses. All depends on the factor of local fuel price and how affordable it is to build it. The world’s longest insulated pipeline, located in Rajasthan, India, spans 670 km. [8] and has been in operation since 2011 which demonstrates that it is possible to build district heating pipe that is hundreds of kilometres long.

Consideration of co-generation of central heating system and electricity from nuclear powerplant is an old and solved issue, as first of them were deployed and tested back in the 1960s.

From their beginnings in the 1960s, there has not been any mention of contamination in nuclear central heating systems, as they are adequately designed and safely operated, the reactor cooling and district heating coolant loops are simply separated by heat exchangers. From about 500 reactor-years of operational experience, no incidents, including radioactive contamination have ever been reported for any of the heat supplying reactors. Radioactive contamination of the district heating networks or of the products obtained by the industrial processes has been avoided by taking adequate design precautions [9].

Nuclear power plants that deploy lower temperature reactor designs are specifically intending to use them for district heating purposes rather than for electrical generation.

China has three low-temperature reactor designs specifically intended for district heating rather than power. CGN uses the NHR-200 (200 MWt) at Daqing city, CNNC uses the DHR-400 Yanlong (400 MWt), and SPIC uses the 200 MWt LandStar-I, which delivers hot water at 110°C with convection circulation through a heat exchanger. Ten units are planned in northeastern China, with the first under construction in Jiamusi and

Daqing in Heilongjiang province. The two units at Jiamusi will provide steam to a biomass plant in summer.

Russia’s low-temperature reactor, the AST-500, is proposed for several sites and has been specifically designed for district heating rather than power (500 MWt). The 2 x KLT40 floating nuclear power plant at Pevek also produces district heat [10].

Finnish LDR 50 nuclear district heating reactor is currently under development at VTT since 2020. It is designed to work around 150 °C and below 10 bar. Due to it being simplified reactor the standards and lower working pressure than district heating systems, it is safe to operate. Lower pressure in the reactor means, that when there’s a leak in the reactor – district heating water will not be contaminated. One reactor is supposed to produce 50MWt and many modules can be installed in one complex. Benefits, of installing district heating nuclear reactor are, that they require less frequent refueling and heat exchanger loop can be installed on condensation side which is tested around the world, where nuclear energy is used in district heating systems. With small modifications to the system, it will be possible to generate low pressure steam for industrial use as well. [11]

3.1 Examples of nuclear district heating

The technical viability of using nuclear heat for the supply of hot water and steam for district heating has been demonstrated both in dedicated nuclear heating plants and in heat and power cogeneration plants. Extracted steam from high and/or low-pressure turbines is fed to heat exchangers to produce hot water/steam, which is delivered to consumers. Extracted steam from low-pressure turbines (LPT) is usually reserved for the base heat load, while steam from high-pressure turbines (HPT) is used, as needed, to meet the peak heat demand.

Depending on the transportation distance and the number of end users, there are usually several pumping stations between the heating source and end users. Heat transport pipelines are installed either above or underground and are well insulated to minimize heat loss. Glass wool or rock wool are often used for insulation.

In commercial-scale heating networks, the transportation distances are usually less than 10 km in most cases, between 3 km and 6 km. The longest delivery distance known to the IAEA is 24 km in Slovakia. A typical schematic diagram of a nuclear district heating network is shown in Fig. 2. The design precautions to prevent the transfer of radioactivity into the district heating grid network have proven to be effective throughout many years of safe and reliable operation. These design features include one or more barriers to radioactive substances in the form of a leak-tight intermediate heat transfer loop at a pressure higher than that of the steam extracted from the turbine cycle of the nuclear plant). These loops are continuously monitored, and isolation devices are provided to separate potentially contaminated areas. District heating systems require a backup heat source when the main heat source is unavailable. Therefore, at least two nuclear power units or a combination of nuclear and fossil-fired units are used for district heating grids [12].

Table 3.1 Currently or historically used nuclear district heating and reactors with technical data. [13]

Country	Plant	Location	Start of Operation	Start of reactors	Reactor type	MWe	Heat output MW	Temperature at inlet (feed/return)
Bulgaria	Kozloduy-5,6	Kozloduy	1987	1991	PWR/WWER	2x953	2x20	150/70
Hungary	Paks-2,3,4	Paks	1983	1987	PWR/WWER	3x433	3x30	130/70
Russia	Bilibino1-4	Bilibino	1974	1981	RBMK/EGP	4x12	4x19	150/70
Russia	Novovoronezh-3,4	Novovovoronezh	1972	1973	PWR/WWER	2x385	2x33	130/70
Russia	Balakovo1-4	Balakovo	1986	1993	PWR/WWER	4x950	4x200	130/70
Russia	Kailin-1,2	Udomlya	1985	1987	PWR/WWER	2x950	2x80	130/70
Russia	Kola-1-4	Apatit	1973	1984	PWR/WWER	4x410	4x25	-
Russia	Beloyarsk-3	Zarechny	1981	1981	LMFR/BN-600	560	170	130/70
Russia	Leningrad 1-4	St. Petersburg	1974	1981	RBMK	4x925	4x25	130/70
Russia	Kursk-1	Kursk	1977	1977	RBMK	3x925	128	130/70
Russia	Kursk 2-4	Kursk	1979	1986	RBMK	3x925	3x175	130/70
Russia	Desnogorsk-1,2	Desnogork	1983	1990	RBMK	2x410	2x173	130/70
Slovakia	Bohunice-3,4	Trnava	1985	1987	PWR/WWER	2x365	2x240	150/70
Switzerland	Beznau-1	Dottingen	1969	1971	PWR	365	2x80	128/50
Switzerland	Beznau-2	Dottingen	1983	1984	PWR	357	2x80	128/50
Ukraine	Rovno 1	Rovno	1981	1982	PWR/WWER	950	2x58	130/70
Ukraine	Rovno 2	Rovno	1982	1982	PWR/WWER	2x950	233	130/70
Ukraine	South Ukraine ,1.2	Yozhnoukrainsk	1983	1985	PWR/WWER	950	2x151	150/70
Ukraine	South Ukraine ,3	Yozhnoukrainsk	1989	1976	PWR/WWER	950	232	150/70
Romania	Cernavoda-1	Cernavoda	1996	1996	HWR/Candu-6	660	47	150/70

Pipe sizing as seen in table 1 is unusually higher than today's district heating standards. One of the reasons, is that the nuclear plants have been further away from population centers and to transport enough of heat to the district heating system, higher temperature is used. Considering the use of SMRs, proximity to population centres and lower temperature district heating systems nowadays the pipeline to heat exchanger plant can stay similar with high temperature transportation to keep the costs of building the pipeline down.

3.2 DH districts that are running on nuclear energy

Here are written some examples of nuclear district heating systems that are currently heating and running worldwide.

The Balakovo Nuclear power plant was built in 1986, and its district heating connection was finalized in 1993. The town is located 12 km from the plant, with an annual heating requirement of 1 000 MW Peak power per year. The plant currently has an output of 4 000 MW electrical output [14].

The Rostov Nuclear power plant, whose first VVER reactor was built in 1981. District heating was connected to the plant in 1983. The town is located 13 km from the plant, with a heat requirement of over 1000 MW_{th} per year [15].

The Tatarsk Nuclear power plant, whose first VVER reactor was built in 1989. District heating was connected to the plant in 1994. The town is located 40 km from the plant, with a heat requirement of over 2 000 MW_{th} per year [15].

Paks in Hungary employs four WWER-440 reactors, which are currently providing electricity and heat to the town of Paks.

Beznau Nuclear power plant, which was implemented in 1983 and commissioned in 1984. Since then, the district heat extraction system has operated effectively. Today, the system includes a 35-kilometer main network and an 85-kilometer local network, along with a six-kilometre expansion in 1994 with pipelines for distribution along with the three networks that were added subsequently after system was implemented. Approximately 2 160 private, small, and large users of Refuna district heating currently are getting their homes heated by nuclear district heating. Heating is provided by the Beznau plant to houses, industries, and farms at a total of 141 000 MW_{th} per year.

There have been many nuclear district plants in the world that have been connected to new or existing nuclear power plants (Table 1) There are even heating grids today for district heating systems, where the pipeline is longer. The longest pipeline in Europe that provides district heat is in the Netherlands, running 46 km long and generating heat from the port of Rotterdam to the South Holland region. Even longer pipelines have been implemented in the for-oil transportation, which requires heating circuits.

3.3 Overview of previous nuclear district heating calculations by the Loviisa nuclear powerplant operator

Loviisa is an excellent observation where a pipeline was planned to heat the Helsinki metropolitan area. Fortum investigated the feasibility of cogenerating district heat for the metropolitan region in 2009 when applying for the construction of a new nuclear power plant unit (Loviisa 3) on Finland's southern coast with a capacity of 2 800-4 600 MWt.

The primary alternative was a cogeneration plant intended for producing significant amounts of district heat for the Helsinki metropolitan region, which is located about 75 km to the west of the Loviisa location. The Loviisa 3 unit's capacity to generate district heat was assumed to be in the range of 1 000 MWt from the outset [16].

Depending on how cold the winter is, the district heat consumption in the Helsinki metropolitan region ranges from 10 to 11 TWh annually. In general, the region's district heat consumption ranges from a minimum of about 400 MW in the summer to a peak demand of 3 000–3 500 MWt in the winter. With more consumption data seen in table 3. Ideally, the Loviisa 3 unit would meet a sizeable amount of the Helsinki metropolitan area's baseload district heat requirements. For 62% of the year, the Helsinki metropolitan area's district heat usage exceeds 1 000 MWt [16]. Graph with demand is shown on figure 3.3.

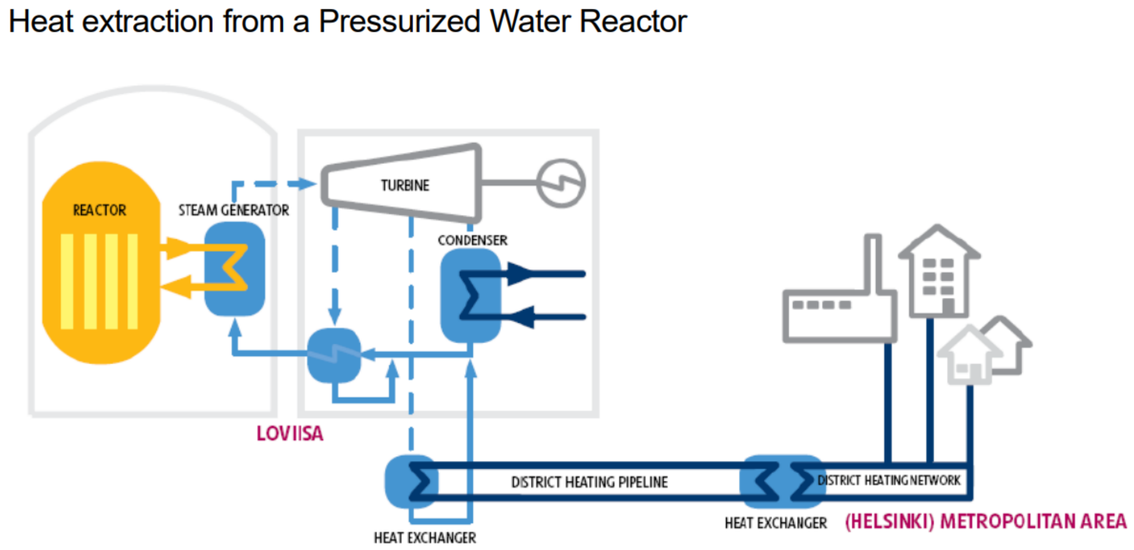


Figure 3.1 Illustration of nuclear district heating connections with Pressurized water reactor[17].

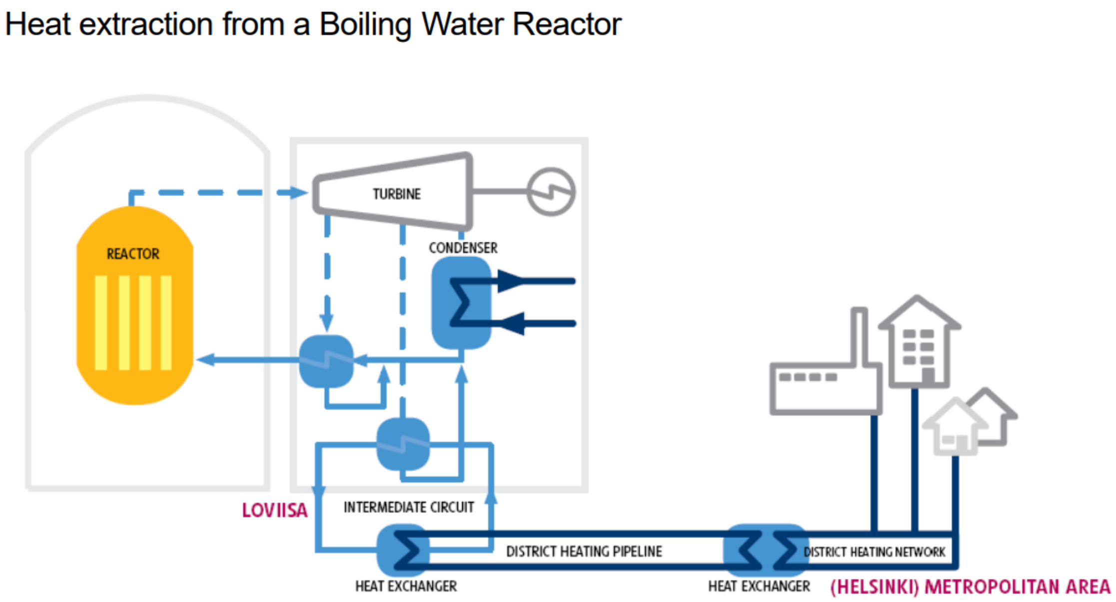


Figure 3.2 Illustration of nuclear district heating connections with boiling water reactor

[18].

Basis of Loviisa 3 CHP option

It is technically viable to implement combined heat and power generation in both PWR and BWR reactors. The district heating water is not in contact with the radioactivity of the reactor circuit, regardless of the reactor type. To effectively limit the transmission of radioactivity to the district heat transport system, both plant types have two physical barriers. Additionally, pressure differences over at least one barrier are planned so that, in the event of a heat exchanger tube rupture, the leakage will always be in the direction of the turbine plant activities [16].

Benefits of using nuclear energy in district heating would bring many ecological and economical benefits to nation, for example following:

- Replace fossil fuels in 11-12 TWh per year if energy is generated from a modern large nuclear power instead of currently used coal.
- Reduce carbon dioxide emissions up to 4 million tons annually.
- Reduce the heat discharge to the Gulf of Finland.
- Net electrical power loss of approx. 1/6 of the thermal power generated.

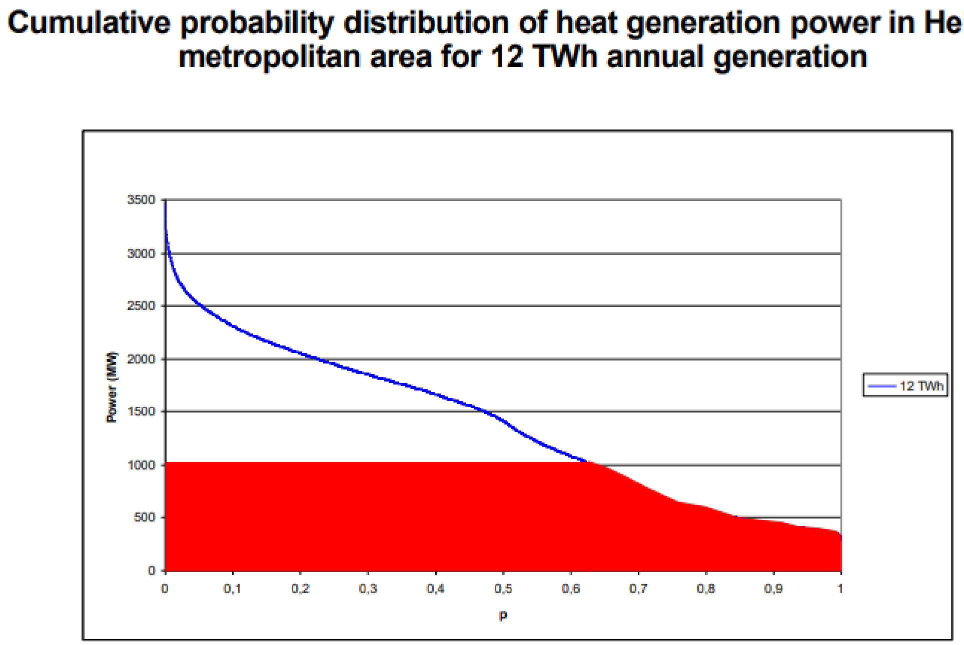


Figure 3.3 Helsinki metropolitan heating demand graph [17]

District heating consumption in the Helsinki metropolitan area is shown in table 3.2 according to the needs of different metropolitans which is possible to connect to district nuclear heating.

Table 3.2 Different metropolitan areas heating needs[17]

Town	District heat consumption (GWh/y)	District heat operator
Helsinki	7500	Helsingin Energia
Espoo	2500	Fortum
Vantaa	2000	Vantaan Energy OY (40% owned by Helsingin Energia)

Possible route for district heating pipeline

Fortum had another plan as well how to transfer heat – with barges. But due to slow transport and small capacity only pipeline transport was feasible in long run.

Figure 3.4 Proposed district heating pipeline route [17].

Technical data for the pipeline [17]

- Distance 75 km
- 2x 1200 mm pipes, PN 25 Bar $Q=4\text{-}5m^3/s$
- 4-7 pumping stations

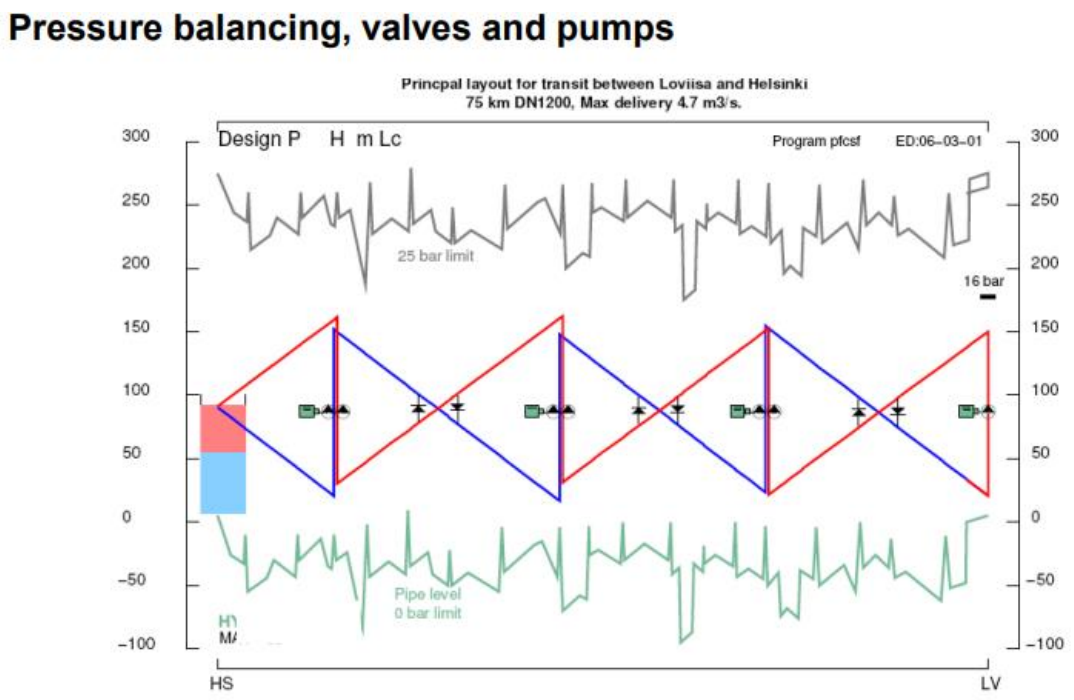


Figure 3.5 Pumping station needs and pressures. [17]

The above graph shows how the pump stations need to be located and how to balance the pressure in the pipeline. Additional sub-pumping stations will be needed.

3.3.1 Possible heat transfer options

Two different pipeline systems were examined to provide the metropolitan region with district heating water. The district heat transport system pipelines are installed in a tunnel dug out of the bedrock in the tunnel option. The district heat transport system pipelines are installed in a ditch that has been dug out of the earth in the ditch alternative, apart from the beginning and end [16].

- Tunnelling in a rock formation with following aspects.
    - Cross section 30 m^2,
    - Stable conditions,
    - Positive maintenance aspects.

Figure 3.6 Example how the pipeline would have been installed with tunnelling technique [17].

This kind of installation ensures that the temperature of the tunnel is constant, and it is easily accessible every day of the year. Although this kind of installation makes it expensive due to the need to tunnel a lot of rock it was not proven to be efficient to install like that.

Near-surface installation

Near-surface installation for district heating pipelines offers a cost-effective alternative to underground tunnels by lowering building costs due to not needing to excavate through granite and bedrock. Unlike the deep underground installations discussed above, near-surface installation is easier to build and could be carried out using cheaper labour.

However, this installation method comes with its own set of problems, particularly with respect to the potential environmental impact on the surrounding ecosystem. The near-surface placement may disturb natural habitats and landscapes or even people who do not allow construction on their property. One person could jeopardize the entire project, as the pipeline may extend through numerous properties.

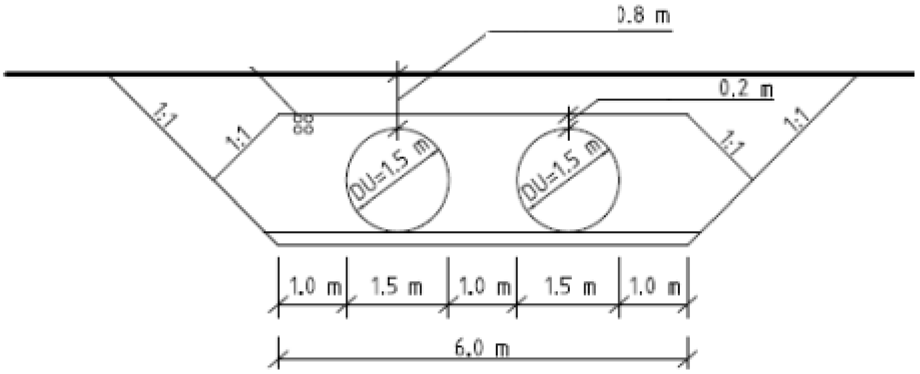


Figure 3.7 Cross-section of the underground piping [17].

3.2.3 Economic considerations

In this economic considerations, there are many benefits and problems with economical evaluation that needs to be addressed before investing that big of an amount to the new pipeline.

- Value of the lost power production:
    - 1/6 of electrical power generation.
- Investment to modify turbines and heat exchangers.
- Heat transport system:
    - investment costs,
    - operating costs.
- System costs related to the heat distribution network.
- Modifications to the heat network
- Need for a heat accumulator.
- Reserve heating plants in case of the unavailability of a nuclear heat supply [17].

Table 3.3 Graph technical data [18].

Line parameters		
Transported heat power	1507	MW
Length line	120	km
Inner diameter pipes	1600	mm
Forward temperature	115	°c
Return temperature	55	°c
Soil temperature	5	°c
Insulator thermal conductivity	0.05	W/m.k
Insulator thickness	300	mm
Hydraulic Section	2	m^2
mass flow	5.9	l/s
Heat losses forward line	13	MW
Heat losses return line	5.9	MW
heat losses total	8.9	MW
Heat losses	1.25%	
flow rate	3.12	m/s
maximum pressure	20	bar
friction coefficient	0.018	
pressure head loss	0.5	bar/km
number of piping stations	6	
pumping power required	50	MWe

Table 3.4 cost evaluation for 120km MHT line [18].

Economics		
Maximum transported power	1507	MW
Length of line	120	km
Total investment cost	2 120	M€
discount rate	8%	M€
Cost of producing 1 MWth with 50€/MWh electricity	11	EUR/MW_{ht}
amortization period	30	years
Heat sold	9	TWh/y
Total operating cost	34	m€/y
cost of heat transport	25	€/MWh
benefits	408	M€/y
return on investment	5	Years

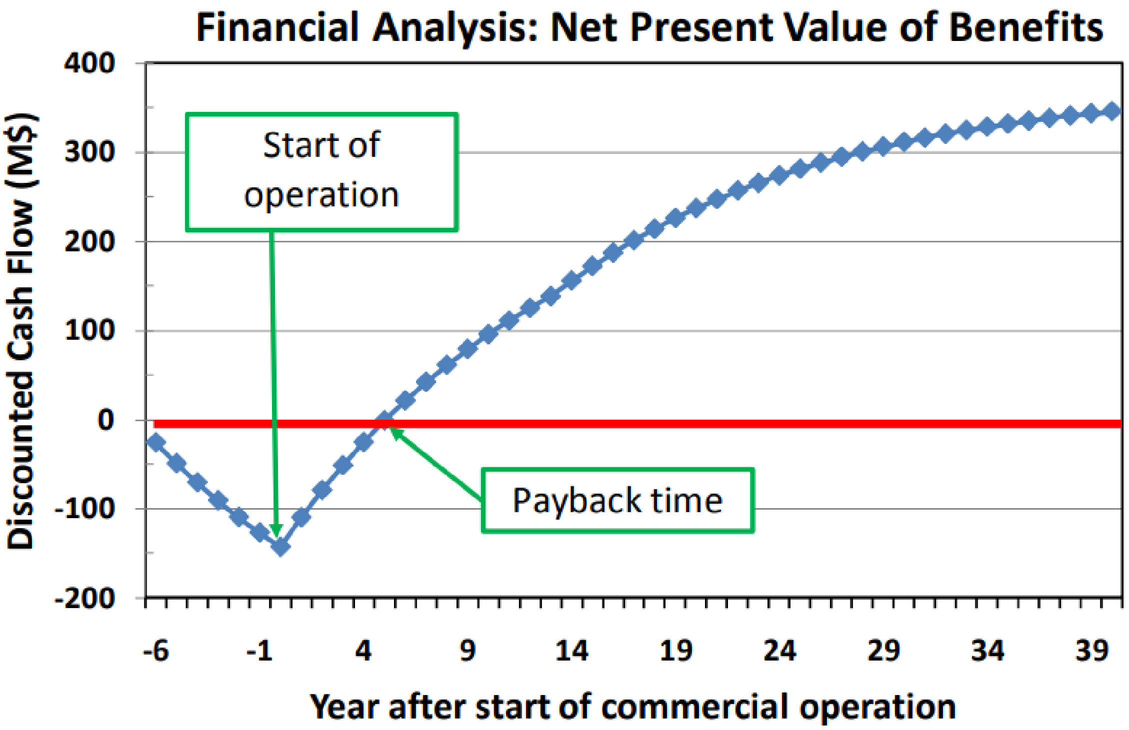


Figure 3.8 Financial analysis of project payback time [18]

The above graph shows a rough evaluation for economical payback time done by CEA France [17].

From an economic view, the project is very profitable and also would reduce a significant amount of emissions from the air. Approximately 6% of total Finnish emissions would be reduced from this single pipeline project [17].

Based on the Fortum [17] and CEA France studies, it is safe to say that considering the current energy crisis and carbon footprint 2050 goals, the project should be reintroduced. Calculating the new feasibility of the project could be very beneficial for the district heating client.

Currently from looking this study having an payback time of 4 years with lifespan of 30 years or more this project would been beneficial to build at that time.

3.3.2 Case study conclusion

The significant proportion of district-heated buildings in the Finnish energy grid makes nuclear cogeneration a good fit. The Loviisa units that are now in operation are rather close to the city, which would allow the district heat that they produce to be used in the existing district heating system network [16].

The metropolitan area's traditional district heat production can be replaced with district heat production at the nuclear power station. The typical annual demand for district heat in the metro region is 10 TWh, which would ensure a peak nuclear cogeneration use of over 6,000 hours [16].

The cost of capital and the evolution of the energy markets have a significant impact on the viability of nuclear cogeneration. Any new investment choice is risky due to the substantial percentage of renewable energy and low-cost hydropower in the Nordic market, particularly for projects with high investment costs and lengthy building timeframes in the nuclear power sector [16].

This study analysed how would be the best way to heat Helsinki and its metropolitan area and how could it benefit. If looking back at the year when this study was done and how has been the market for heat and electricity been, it is certain to say – that this project would have been beneficial in economic and technical aspects as currently Finland is still using fossil fuels to heat that area and a lot of it was imported from Russia. With this project being done the import of fossil fuels would have been drastically lower in this year.

4 OVERVIEW OF ESTONIAN DISTRICT HEATING SYSTEMS

Estonia is among the top 10 countries in the world that use centralized heating systems. Over 60% of Estonia's population already get their home heated by district heating systems.

The heat energy demand is expected to decrease year over year in the coming years and will stabilize in 10-20 years due to people renovating their homes and making them more energy efficient. As of 2020, only public buildings with an energy mark can be built [9], and the increase in ventilation systems with heat exchangers has made heating more efficient. Analyses show that in some parts of the district heating sector, the drop in consumption can be up to 35% [20].

REKK2030 is a government initiative designed to decrease Estonian greenhouse gases by 70% by 2030 and by 80% by 2050. In 1990, Estonian greenhouse gases reached 40.4 mln tonnes CO2ekv, which had decreased to 20.9 mln tonnes CO2ekv by 2017. By 2030, the REKK2030 initiative aims to decrease gas emissions to 10.7 – 12.5 mln t CO2ekv [21].

The main source of pollution in Estonia, which can be easily changed, is large power production, or so-called fossil-based district heating and electrical generation. REKK2030 aims to develop efficient co-generation, wind parks (including offshore parks), and district heating. Synchronizing into the central European electrical grid will also be beneficial, as more connections would be made available.

The most noticeable benefits of district heating are reliability, safety, and consistency. It is very user-friendly, as all features are built-in, and no fuel purchase or servicing is required. Due to advanced systems, district heating is stable 24/7 and due to higher burning volumes, central heating systems can achieve better efficiency and better follow environmental standards.

However, there are also problems with district heating, as highlighted in 2022. If the only main fuel is natural fossil gas, which is mostly imported from Russia, the price of central heating can vary significantly. As of December 2022, natural gas was 240 euros per MWh. Due to companies' inputs being energy in form of natural gas, they also need to add OPEX and CAPEX costs for the end client, the price for natural gas-based district heating systems were up to 300 EUR/MWh for client with VAT tax added. As gas used to cost 25 EUR per MWH, the price hike was 400-500%.

Heat pumps are an alternative for district heating and a good solution for sparsely populated areas where it is too expensive to build district heating pipelines. However, in most cities, heat pumps violate regulations, as they ruin the facade of the buildings.

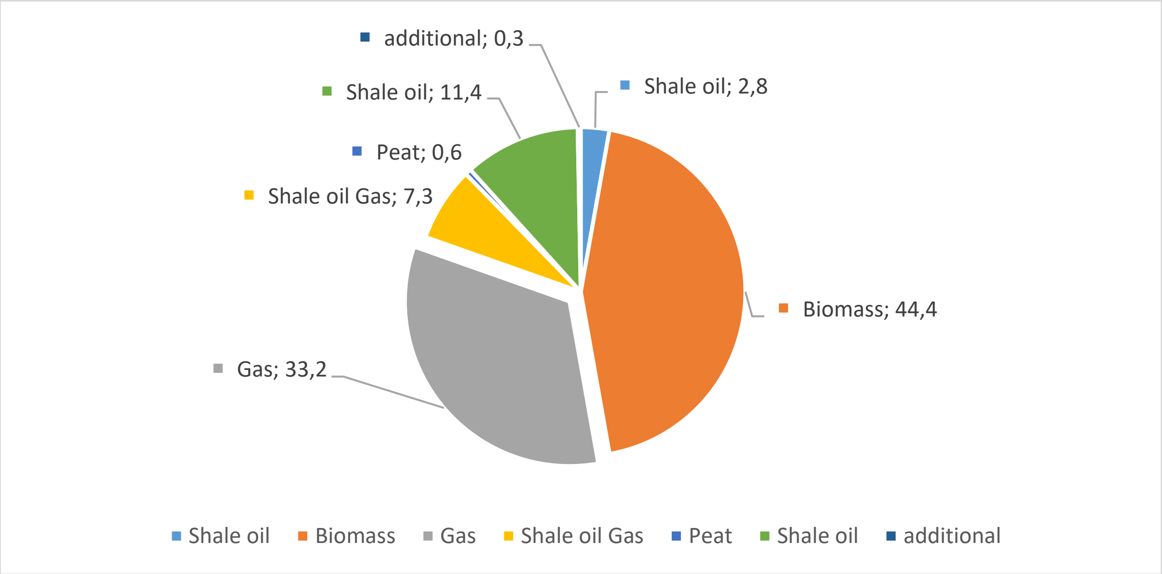


Figure 4.1 Estonian energy balance [22].

Currently – there are 4.6 TWh of energy used in district heating all over Estonia. With today's gas prices – the oil shale oil and oil shale use are rapidly increasing which is concern for climate goals in 2030. As they are the most polluting options for district heating that are currently used by Estonian district heating companies.

Table 4.1 % of Estonian energy needs per month in district heating.

Month	**Consumption % of year**
January	17.6
February	16.1
March	15.5
April	10.5
May	0.9
June	0
July	0
August	0
September	0
October	10.1
November	13
December	16.3

The above graph displays the % of yearly usage of district heating [22].

Existing heat grids

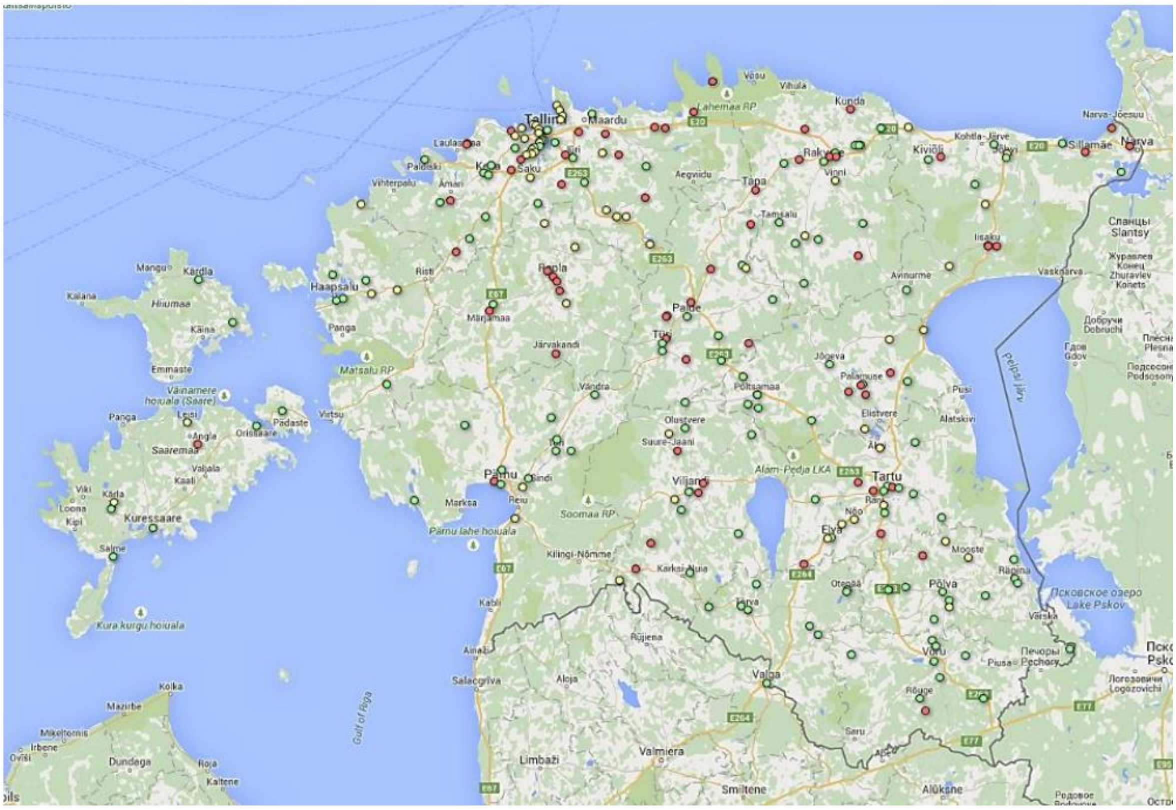


Figure 4.2 Existing Estonian district heating areas [22].

Table 4.2 Pipeline lengths of Estonian district heating with consumption data [22].

County	District heating by county	Length of pipeline (km)	GWh	Average consumption MWh/m
Tallinn	20	444.35	1784.8	4.2
Ida-Viru maakond	18	258.77	993.7	2.8
Tartu maakond	17	176.164	510.9	2.1
Harju maakond (v.a. Tallinn)	39	121.787	297.5	2.6
Pamu maakond	13	80.282	212.6	2.4
Jarva maakond	23	71.993	170.2	2.2
Laane-Viru maakond	22	62.536	143.4	2.2
Viljandi maakond	17	24.007	119.5	3.3
Saare maakond	8	40.913	773	1.9
Voru maakond	9	37.839	69.9	1.8
Valga maakond	9	19.991	64.6	2.2
Põlva maakond	15	27.152	2.1	2.4
Rapla maakond	10	32.405	0.2	1.5
Jõgeva maakond	17	26.477	47.1	2.1
Hiiu maakond	2	6.054	8.5	3.4
Eesti	239	1430.72	4602.4	25

Table 4.2 shows that a total of 4.60 TWh is being produced yearly which is an average yearly consumption of energy in Estonian district heating grids.

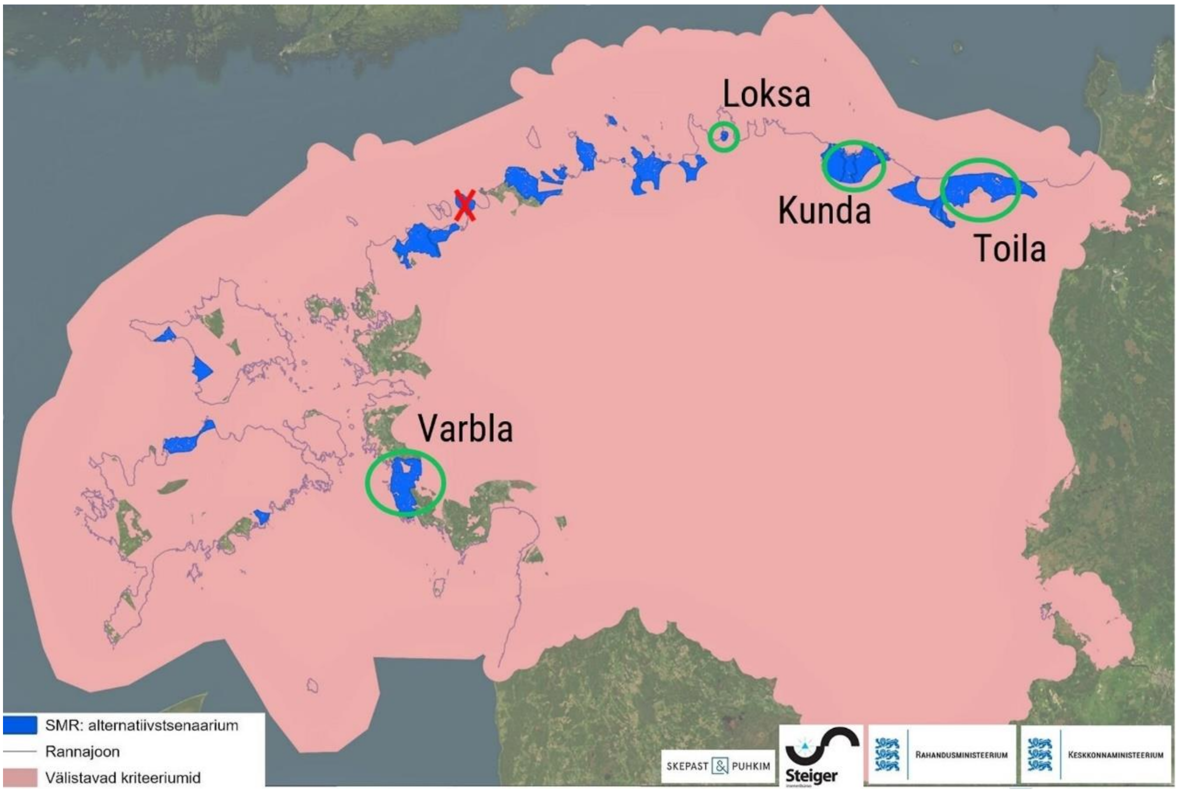


Figure 4.3 Study by Ministry of Climate showing where the potential SMR plant would be built [23].

Ministry of Climate introduced an analysis that identifies areas in Estonia where it is theoretically possible to build a nuclear power plant in the future based on various scenarios and criteria. A socio-economic analysis conducted during Kliimaministeerium report found that the construction of a nuclear power plant is likely to have the strongest positive impact in four areas [23].

In this work we focus on the Kunda location considering its close proximity to Rakvere and the Näpi DH networks with having suitable existing district heating systems already built and working.

5 POINTS TO ADDRESS WHEN BUILDING A NUCLEAR DISTRICT HEATING NETWORK

5.1 Locations, regulations, and other considerations

Choosing the best grid areas is essential for putting nuclear district heating into practice. The best locations are those that have both a high population density and a high heating demand. Therefore, it is critical to evaluate the regulatory environments, infrastructure availability, and energy demand of these areas.

Regulations and safety: When using nuclear energy, safety is of most important. Nuclear district heating systems must be designed, built, and operated under the strict supervision of regulatory bodies to guarantee the highest levels of safety. Additionally important are public acceptance and the communication of safety precautions.

Advances in technology could make nuclear district heating more practical, particularly in the fields of materials science and reactor technology. Future development of this application may be significantly influenced by research into next-generation reactors that provide better safety, efficiency, and waste management.

Economic viability: It is needed to calculate viability and prospects of the nuclear district heating industry. The viability and competitiveness of nuclear district heating projects must be assessed considering factors including upfront investment costs, ongoing costs, and the price of alternative heating sources (such as natural gas or renewables).

Impact on the environment: Nuclear energy is frequently hailed as a low-carbon energy source. To understand its overall environmental impact and contribution to achieving climate goals, however, the entire life cycle of nuclear district heating, including uranium mining, reactor construction, and waste management, should be assessed.

Public Perception: A project involving nuclear energy must succeed in order for the public to have a positive perception of it. Gaining public support for nuclear district heating depends on providing clear information about its advantages, safety precautions, and waste management techniques.

5.2 Suitable reactor types and implementation limits

Small nuclear reactors (SMRs) are intended to be more adaptable and smaller than conventional large-scale reactors. Due to their compact size, modular construction, and conceivably lower initial capital costs, they may be well-suited for district heating applications. SMRs can deliver the required heat output for neighbourhood heating networks, and their scalability enables better matching of reactor size to heat demand.

High-Temperature Reactors compared to conventional reactors, operate at higher temperatures. Because of this quality, they are suitable for producing both high-temperature heat for industrial processes and district heating as well as electricity. Their capacity to generate heat at higher temperatures may help district heating networks' heat transfer systems operate more effectively.

CANDU (Canada Deuterium Uranium) Pressurized heavy-water reactors are renowned for their ability to utilize a variety of fuels, including thorium and natural uranium. Because of their adaptability and capacity to burn a variety of fuels, CANDU reactors may be used for district heating applications.

Challenges and Limitation of implementing a nuclear power plant can vary between country to country, each country is in charge on their own regulatory needs.

Regulatory Obstacles: Navigating the approval process for nuclear district heating projects can be difficult due to the complex and strict regulatory framework for nuclear energy.

Public Acceptance: Nuclear projects are frequently met with public scepticism and concern about safety, waste management, and the environment. Therefore, it is essential to develop public support and trust.

Cost: Design, construction, and regulatory compliance expenses for nuclear reactors, even those that are smaller, like SMRs, can be very high up front. Considerations like financial availability and economic viability are crucial.

Waste Management: Safe and effective disposal of nuclear waste, both low-level and high-level, is still a major concern. To ensure the long-term viability of nuclear district heating, appropriate disposal techniques are required.

Heat Distribution Infrastructure: To efficiently distribute heat to end users, nuclear district heating requires a well-developed heat distribution infrastructure. It must be possible to integrate nuclear heat into the local heating system.

Technical difficulties: One technical difficulty is ensuring the dependability, safety, and effectiveness of the heat exchange systems that transfer heat from the reactor to the district heating network.

In conclusion, the selection of reactors for district heating is influenced by several variables, including heat output, scalability, safety features, the regulatory environment, and economic considerations. The possibility of using small modular reactors and high-temperature reactors as a source of heat for district heating networks has been investigated. For nuclear district heating projects to be implemented successfully, however, issues with regulations, public perception, cost, waste management, and technical aspects must be carefully addressed.

Exploring different nuclear reactors and given aspects there are benefits in each one of them. SMRs offer adaptability and scalability, suitable for producing heat to local networks due to smaller size. High-Temperature Reactors excel in providing both high-temperature steam for industry which is beneficial for the plant and area, and it will help bring more jobs to area. CANDU reactors stand out for their fuel versatility.

However, implementation faces challenges: navigating complex regulations, addressing public concerns, managing high upfront costs, and ensuring effective waste disposal. Technical problems, including reliable heat exchange systems, must be overcome. Success requires careful consideration of regulatory, economic, public perception, waste management, and technical factors.

6 THE LETIPEA (KUNDA PARISH) TEST SITE FOR DISTRICT HEATING

6.1 BWRX-300 technology

While there are no modern modular nuclear reactor designs used in currently operating commercial power plants there are designs that share similarities with existing nuclear technology, and the initial nuclear plant projects are currently in progress. The associated technology licensing and environmental assessments are also underway by the government and Fermi Energia AS, the company developing an SMR project in Estonia, selected GE Hitachi's SMR reactor design for implementation in Estonia.

GE Hitachi's tenth-generation boiling water reactor, the BWRX-300, represents the latest advancement in the design of boiling water reactors. The technologies used in this reactor have a proven track record of reliability in previous reactor generations, with the most recent innovations having received licensing approval from the United States' Nuclear Regulatory Commission (NRC). This small modular reactor is capable of a 300MWe and utilizes natural circulation water cooling, eliminating the need for pumps to ensure reactor safety. It incorporates passive safety systems that maintain the reactor in a safe state under all circumstances without the need for human intervention [24].

The first reactor of its kind is scheduled for construction by Ontario Power Generation—a Canadian energy company from 2024 to 2025, with commercial operation expected to commence in 2027-2028 [24].

Key Features: The area and the BWRX-300 plant itself are compact, occupying a land area of 170 x 280 meters. The grid connection switchyard, cooling tower, office, parking lot, warehouse, and other essential auxiliary buildings are situated within this space. The estimated size of the emergency planning zone is approximately 8 hectares.

Cost-effective: In comparison to traditional nuclear power plants, the BWRX-300 uses 90% less concrete. Furthermore, the construction volume per unit of electricity produced (MW) is reduced by 50%. The straightforward design and the proven performance of earlier boiling water reactors make the BWRX-300 approximately 60% more cost-effective than other small reactors. The estimated cost for one reactor is 1 billion euros [24].

Safety: Passive safety systems minimize the risk of accidents resulting from the loss of cooling water. Reactor steam condensation and cooling systems based on the laws of nature ensure reactor safety without the need for human intervention, even in the unlikely event of a severe accident, for at least one week. In such a scenario, the addition of cooling water can be accomplished using a conventional water pump or a fire truck pump. There are also four water reservoirs available for cooling the reactor.

In Canada, Ontario Power Generation is embarking on the construction of the first reactor of its kind, with current plans to start building in 2025 and start producing electricity in 2029. Canadian project construction and start of commercial operation provides an opportunity for Estonia to monitor and evaluate the process and prepare for similar construction in Estonia in the future [25].

Key elements of the BWRX-300

Table 6.1 BWRX-300 technical parameters [24].

Reactor type	BWR – boiling water reactor
Electric power output	300 MWe
Thermal power output	870 MWth
Coolant	H2O
Neutron moderator	H2O
Designed lifespan	60 years (extendable)
Capacity factor	95%
Ability to regulate power	50-100% daily, 0.5% per minute
Fuel cycle	12-24 months
Fuel type	UO2
Fuel enrichment (average)	3,4%
Emergency fuel	Not needed
Estimated probability of nuclear damage	Less than 10^7 per reactor year
Construction time (Nth reactor)	26 months
Construction cost (Nth reactor), estimated	1 billion euros for the plant's first reactor; construction costs will lower with the next reactors
Cost of electricity generation (estimated)	50-60 €/MWh

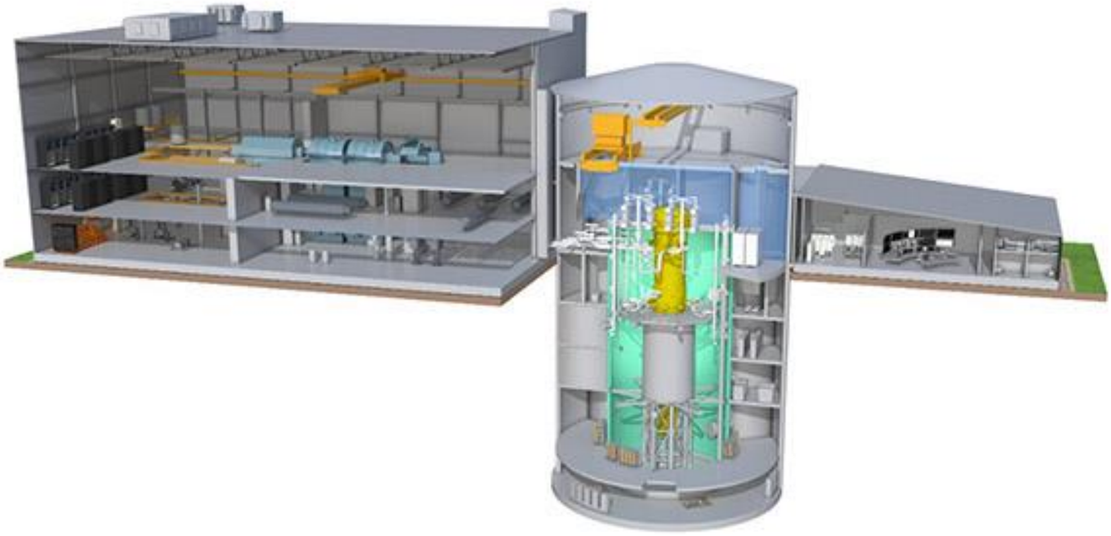


Figure 6.1 Picture of planned unit for GE Hitachi BWRX-300 [26].

6.2 Turbine for district heating

The chosen turbine configuration for this district heating project is a controlled extraction machine with specific technical parameters that allow it to extract heat in certain parameters. Difference between turbines with extractions and condensation turbine is that, the condensation turbine is mainly chosen for a plants, where there is no need for steam in industrial setup or heating the district heating grid. Benefits, of having extraction turbine is that it is possible to sell industrial steam with lower parameters than reactor is producing in nearby facilities or used by district heating system.

With the intention to extract more steam in the future, it is assumed to extract 80 t/h at 6 bar atmospheres system and 50 t/h at 1.2 bar, which will allow to heat Rakvere and nearby districts all year round.

Table 6.2 Turbine technical data for extractions

Steam input	**800 t/h; 315C; 28 bar**
I Extraction	80 t/h; 6 bara
II Extraction	50 t/h; 1.2 bara
Condenser max	880 t/h
Condenser summer	25/35 °c
Condenser winter	10/20 °c
	3000 rpm
Possible Turbine producers	SIEMENS/SKODA/GE
800 t/h; I 80 t/h; II 50 t/h Winter	294,800 kW
800 t/h; I 25 t/h; II 40 t/h Summer	299 825 kW
Min Power	50,472 kW

Table 6.3 Turbine configuration

Configuration	
Extraction	Controlled extraction machine
Turbine	Axial
Reductor	1500 rpm
Generator	10.5 kV / 1500 rpm
Generator	310 000 kW
Oil system for Turbo	Inside reducer
Oil pump 1, prim	On the shaft
Oil pump 2, backup	Electrical motor pump
Oil pump 3, emergency	DC motor backup
Oil coolers	2 x 100%
Oil cleaning	2 x 100% filters
Oil system control	Separate
Oil pumps	3 x 100%
Oil coolers	3 x 100%
Condenser	Titanium heat exchanger
Condenser pumps	3 x 100% condenser pumps
Condenser cleaning system	Automatic ball cleaning

6.3 Cooling towers

Cooling towers are crucial for district heating system balance due to sudden stoppages of district heating system due to some leak or pumping problem, which may cause need to cool the reactors. Due to that there has to be reserve in the cooling towers to have capacity to cool district heating water in case of emergency.

Cooling towers are specialized heat exchangers designed to remove excess heat from industrial processes or power generation facilities by transferring it to the atmosphere through the process of evaporation. This is the easiest way to remove excess heat that cannot be turned into electricity anymore.

Key components of cooling towers:

- Water circulation system – As there is always some water evaporation, there is always a need to add additional water into the system.
- Distribution system – Pumps pump the water inside the tower where it is sprayed by small nozzles to create a fog inside the system.
- Airflow – By spraying water into the system, ventilators pull outside air in from the bottom sides, which will create a cooling effect.
- Cooling – Water is collected from the basin, recirculated in the turbine condenser heat exchanger, heated up again, and sent to a new cycle.

Table 6.4 Cooling towers data [27].

Configuration	10 x 50 MW + 2 standby
Normal working conditions	500 MW
Summer graph	35/25°C
Winter graph	35/25°C
DT for water	10 °C
DT wet bulb temperature	3 °C
Water circulation	30 000m^3/h
Water consumption due to evaporation	1100 m^3/h
Motor location	Outside of the tower
Vent V, Hz	400V, 50Hz
Vent rpm	1500 rpm
Ventilator control	Direct drive
Ventilator rpm	136 rpm
Average electrical consumption per tower	300 kW/tower
Installed electrical capacity total	3 600 kW

10 cooling towers have been chosen for cooling the excess waste heat as they can be economically transported to the site from the manufacturer, and it is easier and more efficient to control the needs and loads of the heat balance by turning the required sections on and off automatically.

6.4 Pipeline for district heating clients

The Rakvere–Kunda railway section is a nearly 20-kilometer-long broad-gauge industrial railway that was opened on November 26, 1896. The railway was constructed to deliver goods to the Kunda cement factory, established in 1870. In the 1930s, passenger trains were also in operation on the railway. Including branch lines, the total length of the railway is now 37 km and is owned by AS Kunda Trans. Currently, it is mainly used for cargo transport. On average, the width of the railway area is 32 meters and the railway is located more on one side, leaving 24 meters of free space on the other side to theoretically build a district heating pipeline.

Figure 6.2 Map from Maa-amet [28].

In this scheme, there are districts and consumers that could be connected to the grid.

Table 6.5 Table of consumptions on this specific grid.

	Yearly GWH	Maximum peak demand (MW)	Diameter of grid (mm)	length of grid (meters)
Rakvere DH	82.4	18	500	27151
Kunda DH	15	7	250	665
Sõmeru and Näpi DH	6	2	150	2245

These are current high energy areas, where already existing working district heating system has been built.

4291888

Kitsenduse objektid ja mõjualad

Raudtee kaitsevöönd

Väline ID: 4291888
Nimi:
Kattuv pindala: m2
Omanik: Raudteeliiklusregister
Täpsusklass:
Asukoht:
Seisund: Kehtiv
Liik: Raudtee kaitsevöönd
Õigusliku kehtivuse kpv:
Õiguslik alus:
- Ehitusseadustik §70
- Ehitusseadustik §73
- Planeerimisseadus §75
Maksusoodustus: 0%
Möödistaja: Eesti Põhikaart
Möödistuse kpv: 09.01.2015

Figure 6.3 Limitation map from Maa-amet [29].

According to the above map, this leaves plenty of space to build the pipeline next to the railway in theory. Due to restrictions for building next to railways, a special permit must be obtained from the owner of the railway, and a technical inspection must be performed by Estonian Technical Regulations Agency.

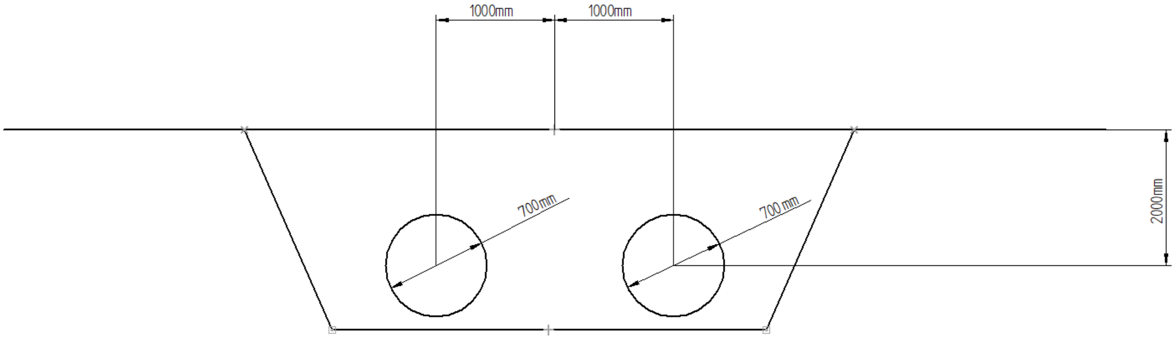


Figure 6.4 Schematics for pipe installation.

Pipes will be buried into the ground and located next to the railways, as this will make them easier to access due to their crossing less populated areas. This will also make the building process smoother, as agreement will only need to be obtained from one landowner.

6.5 Substations and pumping stations

As nuclear district heating is involved in the project, there are strict requirements in place for monitoring the water. To do so, substations must be located between the reactor and district heating. In the cities where the plan is to heat district heating water, there will be heat exchangers and radiation monitoring. To keep the loop safe. higher pressure is needed on the client side.

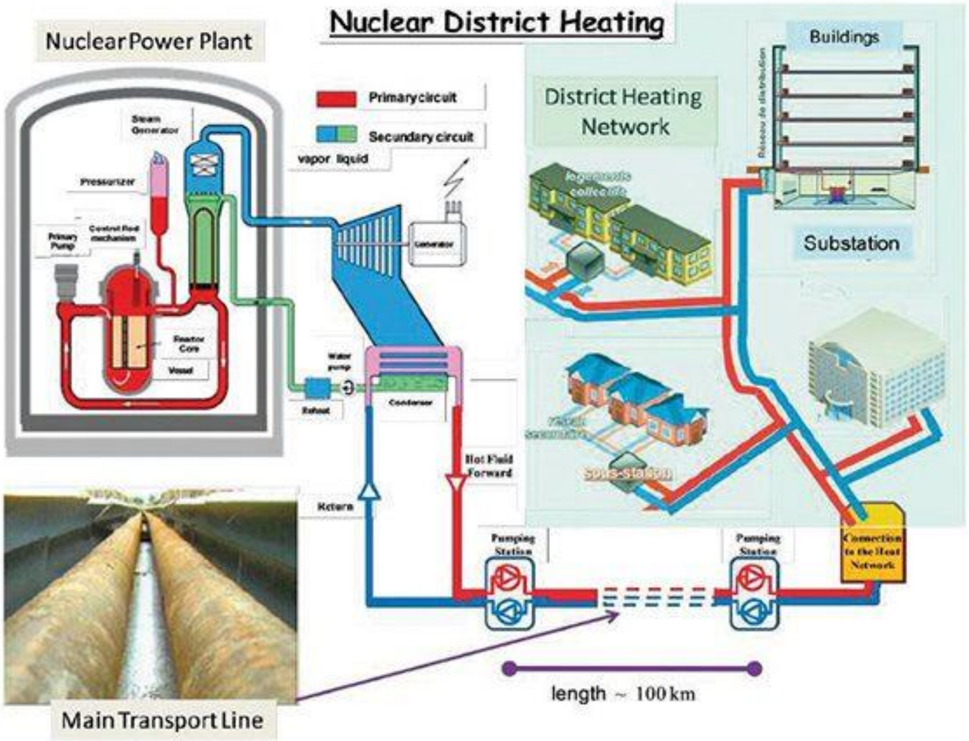


Figure 6.5 Nuclear powerplant schematic for district heating loop [30].

This kind of loop of substations and heat exchangers will provide safety by ensuring that radioactive water does not reach homeowners.

6.6 Potential of building the pipeline

The focus of this work is on carefully evaluating the feasibility of the proposed pipeline infrastructure. Maintaining a consistent temperature of 100/60°C in the pipeline project throughout the entire year is assumed. Before integrating this district heating network, a crucial part of the design is the inclusion of substations. Each of these substations has its own dedicated heat exchanger and temperature regulation system specifically designed to match the temperature needs of each parish district covered by the system.

There are two important reasons for this approach. First, it helps prevent the accidental mixing of the pipeline water with the water used for central heating. This is a concern because there could be leaks from household heating systems, and this precaution ensures the purity and integrity of the pipeline water. Second, the comprehensive substation framework is essential to protecting household heat exchangers. Many of these heat exchangers might be old and may not have received proper maintenance and pressure testing. By preventing the pipeline water from mixing with domestic heating water, we reduce the risk of increasing the hardness level in the pipeline. This is crucial in preventing corrosion that could damage the heat exchangers in the small modular reactor (SMR) plant.

1. **Total Energy Requirement for DH Users:** An intricate analysis has been done to know the power generation, which is needed for the energy demands of the district heating (DH) users, culminating in a formidable sum of 103.4 MW.

2. **Heat Disparities Across the Pipeline:** There is an 85-meter height difference between the source and the clients.

3. **Maximum Peak Demand of DH Users:** It is imperative to ascertain the zenith of energy demand that the DH users might potentially manifest. This demand peaks at 30 MW during -25 °C weather.

4. **Diameter Selection for Potential Business-to-Business (B2B) Client Connections:** An intricate facet of the design involves the choice of diameters, which is tailored to accommodate potential connections with business-to-business (B2B) clients, rendering the infrastructure versatile and accommodating to future expansion.

5. **Underground Placement of the Pipeline:** The entirety of the pipeline infrastructure is planned to be positioned underground, helping to minimize noticeability among the public and to keep it safe from cars or vandalization. The pipeline route is planned to run alongside old train tracks that are not often used currently. This makes it possible to minimize the area where the pipeline intersects with people’s private land, as the majority of the land where the pipeline will run through is governmentally owned.

Table 6.6 Heat consumption of Rakvere, Kunda, Sõmeru, Näpi DH [31].

Rakvere, Kunda, Sõmeru, Näpi DH		
Annual heat consumption in DH network	82 000	MWh
Share of hot tap water	30%	%
Heat for hot tap water	21 400	MWh
Heat for heating and ventilation	80 400	MWh
Losses in DH network	17%	
Total heat production	103 400	MWh

Calculations for annual DH usage and losses in district heating. As shown, the annual heat consumption in DH network will be 103.4 GWh yearly. With losses of 17% in DH, the plant must supply 84.2 GWh of energy each year.

Table 6.7 Inputs for outside temperature.

Inputs for temperature-dependent heat load calculation		
Base temp	15	°C
Design outside temp	-21	°C
Degree hours	87039.4	°C-hours
Constant	0.57905	

Data for calculating the temperatures of hourly graphs is shown in Figure 6.6.

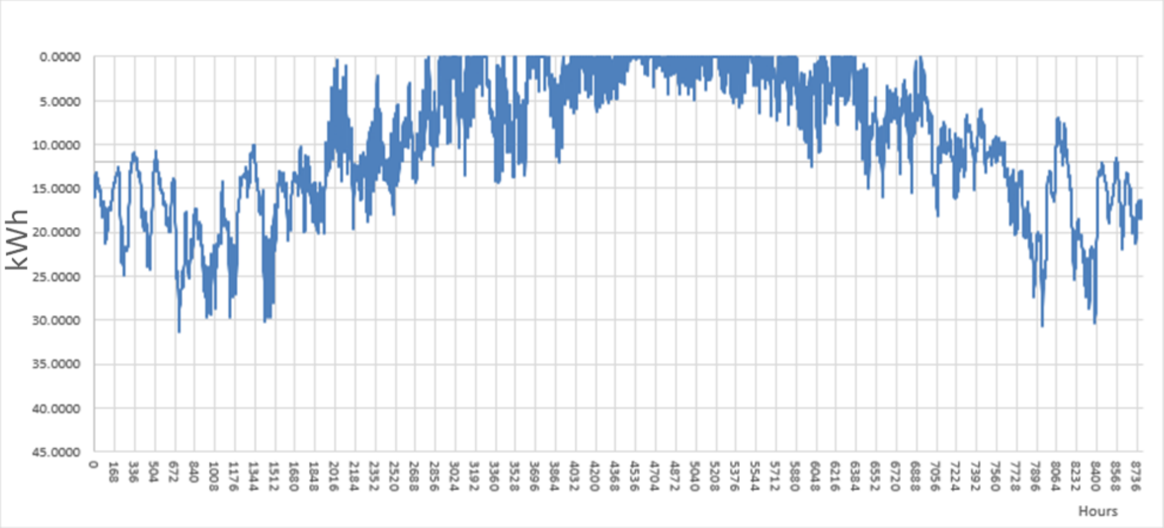


Figure 6.6 Temperatures when district heating is turned on in households in temperature difference.

Peak consumption according to an hourly scale where it is shown, what kind of energy needs are at what temperature at what time of the year.

Table 6.8 Assumed B2B client demand of energy per year.

	Yearly GWh	Maximum peak demand (MW)	Diameter of grid (mm)	Length of grid (meters)
HKScan B2B	35	5	400	0
Kevili B2B	35	10	400	0
Golden Field Factory B2B	100	30	500	0

Here are the business-to-business clients who could be potential customers of the pipeline for heating during summer and non-peak times.

HKScan mainly produces food, meaning that it will demand heat all year around. Though it is not possible to supply production steam, it may be to supply general heating so that the company can use their own boilers to run process steam.

Kevili and Golden Field Factory are both agricultural companies that produce animal feed, so their peak demand is during summer months, a time of year when the peak is typically smaller for district heating.

In thesis feasibility those numbers are not calculated into but stated, that adding additional big clients to the heating system will increase the feasibility of the project.

6.7 Technical calculation of the pipeline and pumping needs

For this thesis, the friction of the pipeline is calculated under the assumption that there is one supplier in the main branch and, thus, energy moves only in one direction in the system. All the energy is moving from the Letipea DH system to Kunda and Rakvere. As the system will not be feeding the Kunda or Letipea system from the Rakvere system, the process of the calculations is simplified, which helps the system to be more accurate.

To calculate the needed pumping energy, the pipeline's hydraulic friction factor, the length of the pipeline, its internal diameter, the density of the heat carrier, and the velocity of the medium must be known/estimated. To pump the water to all the clients, the pumps needs to pump over the pressure resistance, which can be calculated using the following formula:

$$\Delta P = \Delta P_l + \Delta P_k \text{ ; (Pa)} \tag{6.1}$$

The Weisbach-Darcy formula is used to calculate out Δ P_l on different sections of pipeline:

$$\Delta \mathrm{Pl} = \lambda * \frac{\mathrm{l}}{\mathrm{d}} * \frac{\rho * W^2}{2} \text{ ; (Pa)} \tag{6.2}$$

Formula definition:
λ – hydraulic friction factor
l – length of the pipeline, (m)
d – internal diameter of the pipeline, (m)
ρ – density of the heat-carrier, (kg/m^3)
W – velocity of the heat-carrier (m/s)

Hydraulic friction is calculated using Reynold's number (Re), which is determined by the choice of the pipeline. Most of the time, the hydraulic friction factor is provided by the supplier who supplies the pipes.

$$\mathrm{Re} = \frac{\mathrm{W*d}}{\mathrm{v}} \tag{6.3}$$

Formula definition:
W – velocity of the heat carrier, (m/s)
V – Kinematic viscosity of the liquid, (m^2/s)
d – internal diameter of the pipeline (m)

To calculate a hydraulically smooth system, Murin formula is used:

$$\lambda_{s}=\frac{1{,}01}{(lgRe)^{2.5}} \tag{6.3}$$

With help of the Weisbach formula, we can calculate the local resistances:

$$\Delta P_m = \xi * \frac{\rho * W^2}{2}; (Pa) \tag{6.4}$$

Formula definition:
ξ – resistance of calculated pipe section

This formula is used in calculations since a rectilinear pipeline is assumed, which means that our pipeline has very few bends and L turns. This is due to the fact that the pipeline is designed to flow by old train railways, which are as straight as possible.

For that the following length needs to be estimated:

$$l_{ekv=} \frac{\xi \mathrm{d}}{\lambda} \ (m) \tag{6.5}$$

providing enough information to calculate the total resistance of the pipeline:

$$\Delta \mathrm{P} = \Delta P_1 + \Delta P_m = \Delta P_1 * \left(1 + \frac{\Delta P_m}{\Delta P_l}\right) = R_l * l * (1 + \alpha) = R_l * (l + l_{ekv}); (Pa) \tag{6.6}$$

where:

ɑ – pressure losses resistance by length
R_l – Pressure drop per meter; length of the pipeline (Pa/m)

In this thesis, as simplified formula is used and the calculations are performed for a hydraulically smooth system. As the system is not yet built, there is the advantage of defining the pipeline that will later be designed and built according to performance and calculations made with modern knowledge and machinery.

6.8 Pump selection

The most efficient pump is chosen based on its operating point. Flow speed needs to be corresponding to head loss, which is correlated to the height difference of the system and pressure friction from the pipeline and overcome pressure from calculations so the water can flow to the end clients and retain required pressure. Pumps transport the water to districts where there are heat exchangers and from there, local pumps continue transporting the water to clients. This is to ensure that there are sufficient barriers to eliminate the risk of contamination reaching the households should the water become contaminated on the supply side.

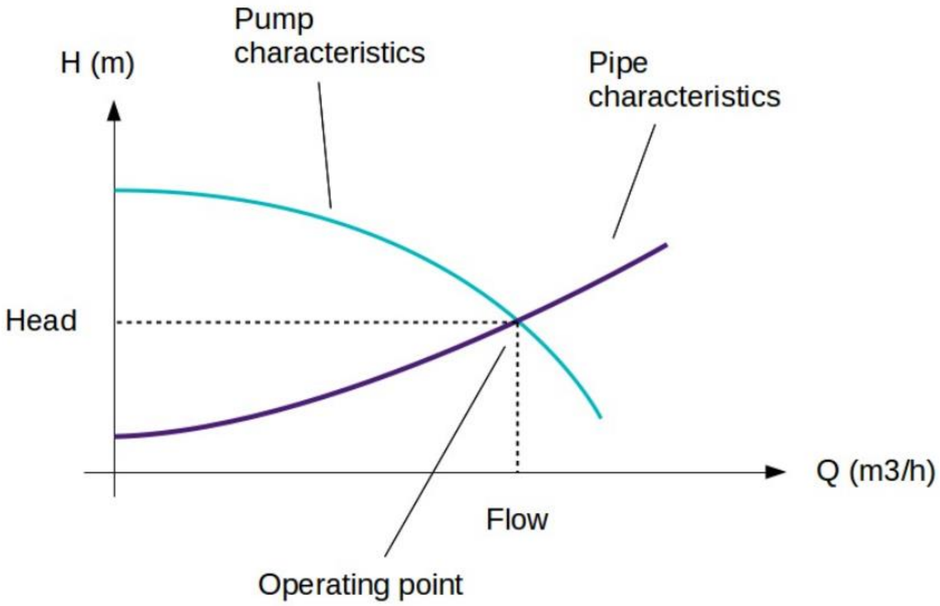
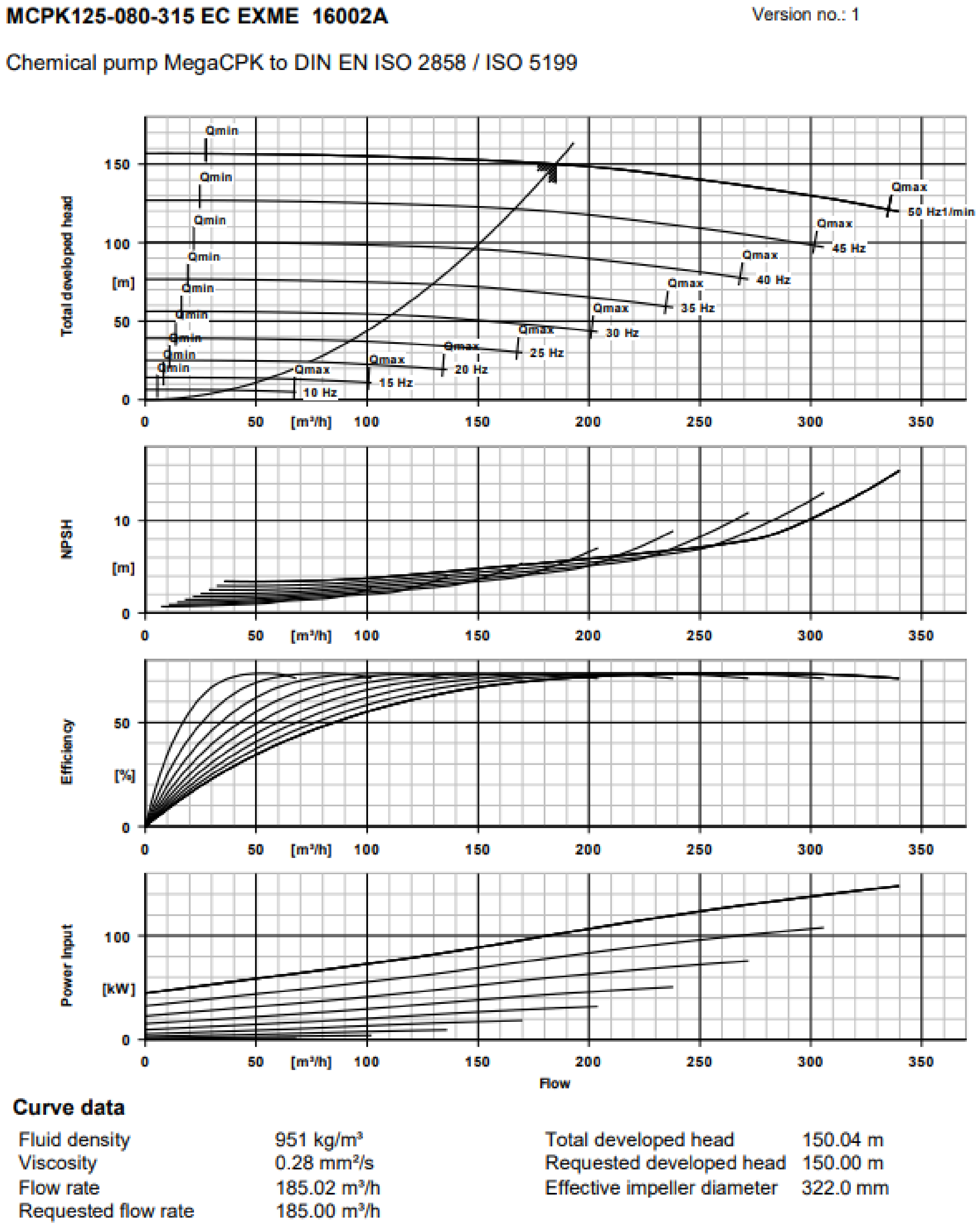


Figure 6.7 Pump selection graph [32].



MCPK125-080-315 EC EXME 16002A Version no.: 1

Chemical pump MegaCPK to DIN EN ISO 2858 / ISO 5199

Curve data

Fluid density	951 kg/m³	Total developed head	150.04 m
Viscosity	0.28 mm²/s	Requested developed head	150.00 m
Flow rate	185.02 m³/h	Effective impeller diameter	322.0 mm
Requested flow rate	185.00 m³/h		

Figure 6.8 Pump characteristics [33].

According to the graph, the most efficient pump operates at 185 m^3/h. Thus, we elected to install four pumps at our site. Each pump gives the capacity to transfer 185 m^3/h of water in 100/60 °C graph 10 MW of transfer possibilities, which amounts to up to 40 MW of heat from the SMR nuclear power plant.

Choosing four working pumps for our district heating grid also has the benefits of being able to switch pumps on or off based on need which will increase the efficiency of the system overall.

6.9 Heat losses on the pipeline

To calculate the amount of heat lost when passing through the underground network, we must determine the coefficient of the insulation of the pipeline, the medium, and the outside temperature. Using these data points, we can calculate the total heat loss of the pipeline.

For this thesis, we will use insulated cylinder or pipe heat loss calculations to simply the calculations.

Conductive heat loss through an insulated cylinder or pipe can be expressed as:

$$Q = \frac{2\pi L(ti - to)}{\frac{ln\left(\frac{ro}{ri}\right)}{k} + \frac{\ln\left(\frac{rs}{ro}\right)}{ks}} \qquad (6.7)$$

where:

Q - Heat loss in watts (W).
L - Length of the pipe in meters (m).
ti - Inside temperature of the pipe in degrees Celsius (°C).
to - Outside temperature of the pipe in degrees Celsius (°C).
ro: - Outer radius of the pipe in meters (m).
ri - Inner radius of the pipe in meters (m).
rs - Outer radius of the insulation (if applicable) in meters (m).
k - Thermal conductivity of the pipe material in watts per meter-kelvin (W/m·K).
ks - Thermal conductivity of the insulation material in watts per meter-kelvin (W/m·K).

This equation may be applicable in cases where the simplifying assumptions of convective heat transfer on both sides of the pipe are used.

$$Q=(hi1+ho1)2\pi L(ti-to) \qquad (6.8)$$

where:

Q - Heat loss in watts (W).
L - Length of the pipe in meters (m).
ti - Inside temperature of the pipe in degrees Celsius (°C).
to - Outside temperature of the pipe in degrees Celsius (°C).
hi - Inside convective heat transfer coefficient in watts per square meter-kelvin (W/m²·K).

ho - Outside convective heat transfer coefficient in watts per square meter-kelvin (W/m²·K)

The convective heat transfer coefficients hi and ho are calculated using the Dittus-Boelter equation, which is determined using a table's fluid properties, where they are marked as fluid velocity (m/s), and the pipe's internal and external characteristics.

The Dittus-Boelter equation is:

$$\mathrm{Nu}=0.023*\mathrm{Re}^{0.8} * Pr^{0.3} \tag{6.9}$$

Where:

Nu - Nusselt number
Re - Reynolds number, which depends on the fluid velocity and pipe dimensions
Pr - Prandtl number, a property of the fluid

6.10 Calculations for heat losses in the pipeline

To calculate the heat loss in the pipeline, insulated cylinder formula is used. This allows us to determine the level of heat loss using premeasured parameters.

Table 6.9 Line parameters for Letipea-Rakvere DH line.

Line parameters		
Transported heat power	40	MW
Length line	27+27	km
Inner diameter pipes	400	mm
Forward temperature	115	°c
Return temperature	55	°c
Soil temperature	5	°c
Insulator thermal conductivity	0.04	W/m·K
Insulator thickness	300	mm
Hydraulic section	0.25	m^2
Mass flow	4	l/s
Heat loss forward line	0.95	MW
Heat loss return line	0.43	MW
Total heat loss	1.38	MW
Heat loss forward line	2.38%	
Heat loss return line	1.08%	
Flow rate	3.12	m/s
Maximum pressure	16	bar
Friction coefficient	0.018	
Pressure head loss	0.38	bar/km
Pumping power required	0,355	MW

6.11 Feasibility

Feasibility is calculated on base of data collected in this thesis and here and find out the suitable price range so the project is feasible and in how many years it would be feasible. This is done by comparing the electrical price for district heating price and OPEX and CAPEX costs of the pipeline. Heating District heating with nuclear power plant means, that there will be less electricity generation. Here it is written out at what price ranges is it more feasible to generate electricity or when it is more feasible to heat district heating network. District heating price for the end client is divided into two points. Transportation costs for the heating to reach the end client and production cost which is associated with generating heat instead of electricity for the district heating system.

Total Energy Usage:

The annual amount of energy used in Rakvere and Kunda DH is around 103 400 MWh. If there will be possibility to connect B2B clients to district heating system who have high energy needs then that solution will make the feasibility twice as short possibly. As we do not know the plans of the business-to-business sector, will they need energy and for how long they have planned to use the district heating energy so we will only calculate feasibility for district heating clients.

Total electricity generation loss for district heating

Assuming the use of modern turbines with 27% efficiency instead of 103,400 MWh of district heating, it is possible to generate 27 918 MWh of electricity instead of selling district heating energy.

With price models following it can be seen how much the plant make from the nuclear plant if it decides to sell electricity instead of heat to district heating.

Table 6.10 Possible revenue by generating electricity instead of heat.

Electrical price	**Sum (t. EUR)**
25	697.95
35	977.13
50	1395.9
65	1814.67
75	2093.85
90	2512.62
100	2791.8

This graph compares the electric output from generating electricity instead of district heating.

Table 6.11 Revenue by generating district heating instead of electricity.

Heat output price	Sum (t. EUR)
10	1540
15	2310
20	3080
30	4620
40	6160
50	7700
60	9240

This graph shows how much does generate selling district heating for what price point for water heating. Transport cost must be adjusted accordingly.

By comparing the two graphs, we can see that the average electricity has to be more than 75 EUR/MWh so that clients can get energy cost at feasible price of the district heat for 20+20 = 40 EUR/MWh, which would make it more feasible to sell a district heating system.

Table 6.12 Revenue comparison by DH price and electricity price.

avg. El. Price (EUR/MWh)	Dh price (EUR/MWh)	Dh revenue (t. EUR)	El. Revenue (t. EUR)
10	10	1034	279.18
15	15	1551	418.77
20	20	2068	558.36
30	30	3102	837.54
40	30	3102	1116.72
50	30	3102	1395.9
60	30	3102	1675.08
70	30	3102	1954.26
80	30	3102	2233.44
90	30	3102	2512.62
100	30	3102	2791.8
110	30	3102	3070.98
120	30	3102	3350.16
130	30	3102	3629.34
140	30	3102	3908.52
150	30	3102	4187.7
160	30	3102	4466.88
170	30	3102	4746.06
180	30	3102	5025.24

The above graph demonstrates the point when electricity production becomes more financially beneficial than supplying the district heating network. Specifically, when the district heating network price for heating the water is set capped at 30 EUR/MWh with an additional 20 EUR/MWh for water transportation, the graph reveals that generating electricity becomes a more viable option when the average electricity price surpasses 110 EUR/MW$_{he}$. For end users, the district heating end price will be 50 EUR/MWh without tax.

Table 6.13 Average electrical price from 2020 to 2023 (EUR/MWh). [34]

	2020	**2021**	**2022**	**2023**
December	45,49	202,65	263,45	
November	40,99	116,78	218,99	113,12
October	37,62	105,61	174,29	87,37
September	39,60	122,40	228,93	113,46
August	40,90	87,03	361,35	94,38
July	30,10	83,78	233,21	79,56
June	37,77	71,68	173,83	92,08
May	25,02	48,42	151,37	65,56
April	23,69	43,60	100,66	65,89
March	24,02	43,55	151,23	87,18
February	28,11	59,15	104,63	113,12
January	30,82	53,55	141,74	99,27

In the last years, the average price for electricity was 89.60 EUR/MWh on average. This means that currently, the district heating would have generated more profit by selling to district heating than by generating electricity. However, the months where the electricity has higher tend to be colder months as there is more need for electricity and due to heat pumps and other electric heating in homes where district heating is not an option.

Annual Maintenance Costs

This calculation is done for amortization and upkeep cost analysis. In this thesis it is calculated that each year the maintenance costs increase 3% for 30 years.

Annual maintenance costs= 83250×1.05^{30}=359.8t € yearly upkeep cost at the end of 30 years of pipeline operation.

Table 6.14 Annual maintenance costs.

Years	Sum (t. EUR)
1	87.4
5	106.3
10	135.6
15	173.1
20	220.9
25	281.9
30	359.8

Pipeline OPEX and CAPEX costs with IRR.

Table 6.15 Pipeline CAPEX costs

CAPEX		
Project design cost	(t. EUR)	300
Pipeline cost	(t. EUR)	16 650
Pumping station	(t. EUR)	400
Construction	(t. EUR)	1 000
Project leading costs	(t. EUR)	360
Engineering calculations and permits	(t. EUR)	120
CAPEX buffer	(t. EUR)	1 883
Total Capex cost	(t. EUR)	20 713

Capex costs are given approximately numbers, of how much would given pipeline cost to build. Due to many variations there is added 1 883 thousand EUR as an CAPPEX buffer. In this thesis only 1 pumping station is being built as with this pipeline it is not needed, to build two. Construction cost in CAPEX calculations is meant for any bridge, road or civilian structure rebuild cost when it is necessary to build through or under an road.

Table 6.16 OPEX Cost

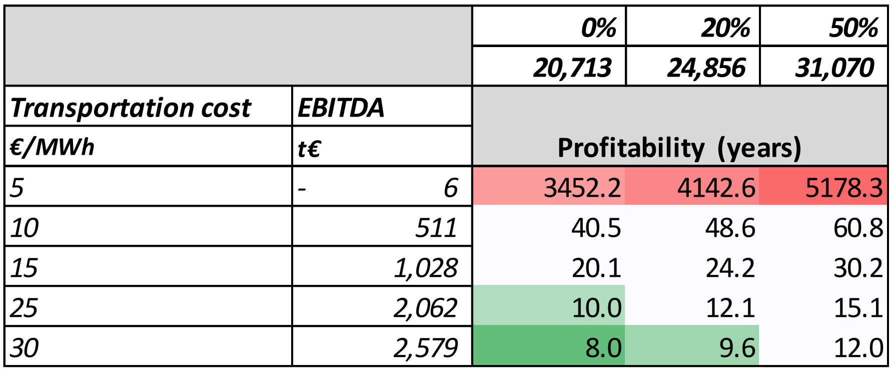
OPEX		
Sub contracting maintenance cost	(t. EUR)	100
Fix OPEX	(t. EUR)	247
Workforce costs	(t. EUR)	197
Service costs	(t. EUR)	50
Pumping electricity cost 40 EUR/MWh	(t. EUR)	175
Total OPEX	(t. EUR)	769

OPEX costs in table 6.16 are meant for yearly operation costs that are needed for upkeep of the pipeline to keep the heat running. Fix OPEX cost is directly made costs of changing valves and equipment incase of breakdown or when the equipment lifecycle is ended. Service cost is meant for all kind of inspections done by third party. In Estonia – That would be Tehnilise järelvalve amet and Inspecta, who do routinely control on pressure vessels around Estonia and possibly to inspect the heat exchangers in the future to avoid radioactive water to be inside district heating water.

Table 6.17 Revenue and economic data

Yearly revenue	(t. EUR)	2 068
Total transported energy	MWh/a	103 400
Heat transmission cost	€/MWh	20
EBITDA	(t. EUR)	1 546
Feasibility	years	13.4
IRR	%	3.57%
ROE	%	1.87%

In table 6.17 it is calculated out that After 13,4 years of operation, the pipeline becomes economically viable with IRR of 3.57% if the initial construction cost is 20,713 MEUR in case the heat transmission cost will be 20 EUR per MWh. 20 EUR per MWh is the cost – that is needed in case third party investor decides to invest in the pipeline and operates it as a middle man to sell heat to local municipalities . For the client – the given amount will be added for the producers production costs that are shown in table 6.11



		0%	***20%***	***50%***
		20,713	***24,856***	***31,070***
Transportation cost	***EBITDA***	**Profitability (years)**		
€/MWh	***t€***			
5	*- 6*	3452.2	4142.6	5178.3
10	*511*	40.5	48.6	60.8
15	*1,028*	20.1	24.2	30.2
25	*2,062*	10.0	12.1	15.1
30	*2,579*	8.0	9.6	12.0

Figure 6.9 Profitability of the district project on different price levels and CAPEX costs.

In figure 6.9 it is modelled different transportation costs of the heating water with different CAPEX costs. As it is seen, the project can be profitable if the price is more than 10€ per MWh. Below given price point, the pipeline feasibility will be higher than the lifecycle of given pipeline and it would not be economically feasible project and would generate negative revenue.

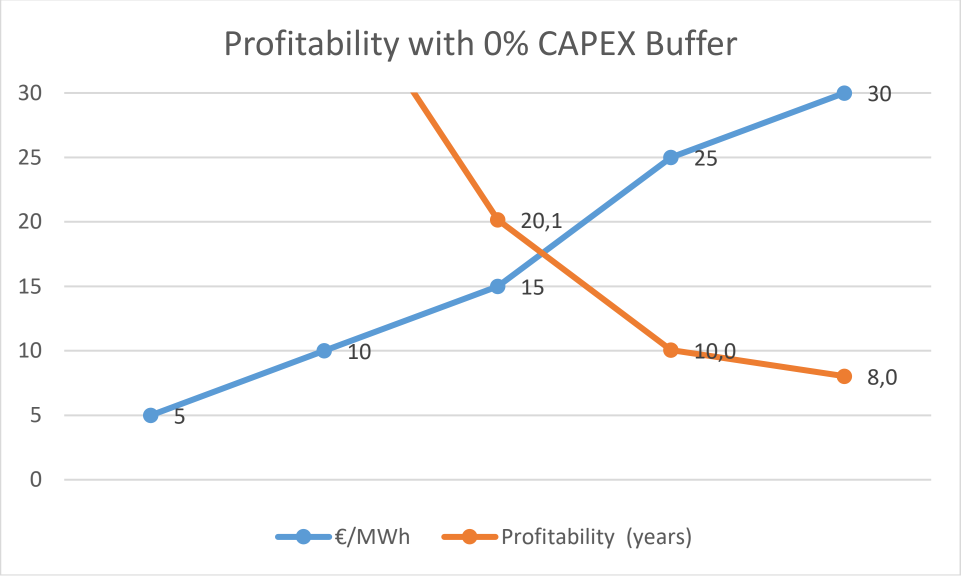


Figure 6.10 Profitability with 0% CAPEX buffer.

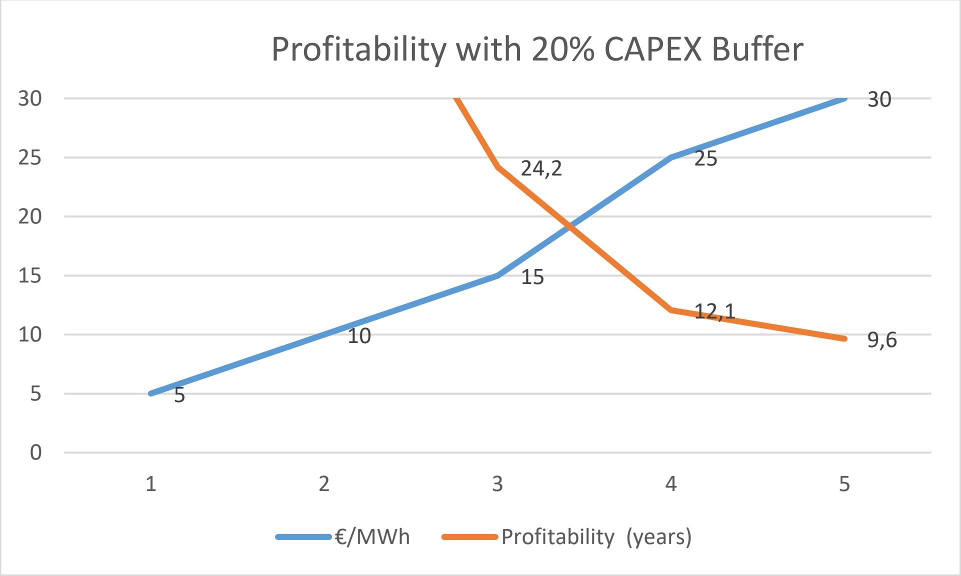


Figure 6.11 Profitability with 20% CAPEX buffer.

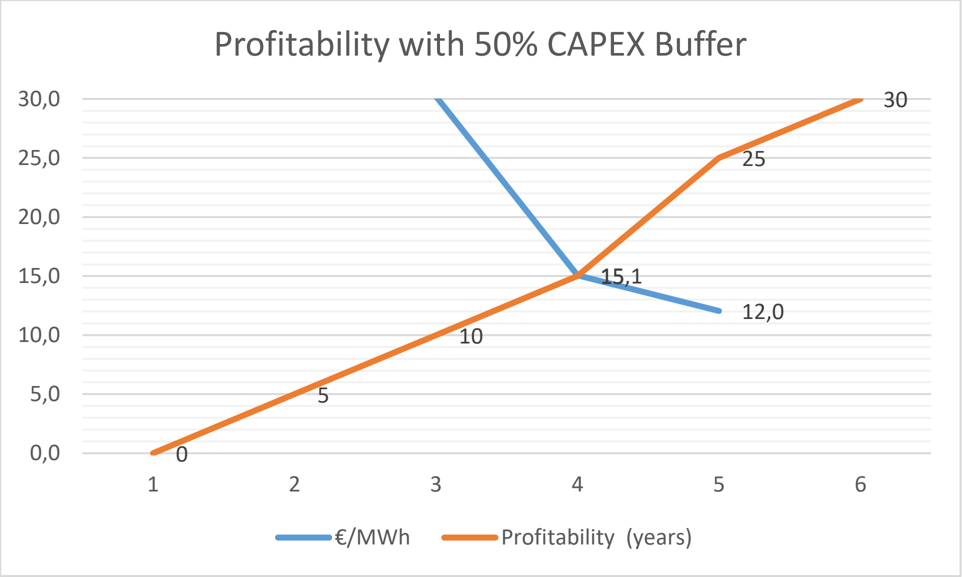


Figure 6.12 Profitability with 50% CAPEX buffer.

With 0% CAPEX buffer the profitability will be following as shown on graph. For it to be feasible with given CAPEX and OPEX numbers of transportation costs need to be at least 7.8 EUR/MWh for this project to break even on the lifespan of 30 years of designed lifecycle of the project on 0% CAPEX buffer. By adding 20% CAPEX buffer to the project the minimum transportation cost to be feasible will increase to 9 EUR/MWh transportation costs and by adding 50% CAPEX Buffer it will increase to 11 EUR/MWh.

6.12 Swot analysis

SWOT analysis has been carried out to bring out all the problems and threats that have to be accounted for when planning to build a nuclear reactor. The strengths of SMR nuclear technology are their high performance and cost-effectiveness, coupled with an impeccable protection and safety record and less deaths around the world. [25] However, like with many energy sources, there are also downsides to nuclear energy, including the significant extended lead time required for operationalization and the advance funding required to build and operate the plant. In this SWOT analysis it is written what are the main strengths, weaknesses, threats, and opportunities of building an SMR technology in Estonia.

Table 6.188 SWOT analysis.

Strengths	**Weaknesses**
SMR nuclear technologies are highly efficient and have a low cost of operation.	SMR nuclear technologies require a long lead time before they can be operational.
Their safety record is excellent, and they have a low risk of radioactive leakage.	There is a lack of public acceptance of SMR nuclear technologies due to safety concerns and perceived risks.
SMR nuclear technologies are relatively easy to transport and deploy.	SMR nuclear technologies require a large up-front investment.
SMR nuclear technologies do not require large amounts of land to be constructed.	SMR nuclear technologies can be difficult to regulate due to their small size.
Opportunities	**Threats**
SMR nuclear technologies provide an opportunity for countries to reduce their dependence on fossil fuels.	SMR nuclear technologies face strong opposition from environmental groups.
SMR nuclear technologies can provide an alternative energy source for remote areas that lack access to traditional energy sources.	SMR nuclear technologies pose a potential risk of radioactive leakage and people are afraid of nuclear disasters
SMR nuclear technologies can help reduce carbon emissions and contribute to a healthier environment.	Nuclear technologies may be vulnerable to terrorist attacks.
SMR nuclear technologies can be used in a variety of applications including electricity generation and desalination.	SMR nuclear technologies can be difficult to regulate due to their small size.

CONCLUSION

In conclusion, a comprehensive analysis of the feasibility of nuclear district heating systems focusing on the Rakvere and Kunda district heating plants has provided valuable insights into the economic viability and potential benefits of such a system.

An examination of the total energy consumption of different users at different temperature ranges reveals that this project can be profitable. If business-to-business clientele were to also connect to the grid, the heating needs would be doubled, which means twice as short payback time as planned with only district heating option.

A comparison of district heating and electricity generation considering pricing models and revenue potential shows the cost of district heating compared to the cost of electrical price. If the production price is lower than the revenue from the district heating system, the system will be beneficial in that it will provide a stable income for grid operator and nuclear power plant for years.

The typical lifespan of pre-insulated pipes is approximately 30 years, and this project is expected to become economically viable on certain price points. Nowadays, the higher-quality pipeline materials may outlast the 30 year mark. Which will increase the projects profitability after the project has paid itself back from fees.

The study provides valuable insight for stakeholders, policy makers, and investors operating in the sustainable energy sector regarding the use of nuclear power in district heating systems as an alternative CO2-free energy source.

SUMMARY

This thesis explored the economic viability of nuclear district heating systems in Rakvere, Kunda, and close by villages that use district heating, with a focus on total energy usage, electricity generation, pricing models, pipeline construction, and financial analysis.

The annual energy consumption of Rakvere and Kunda district heating is 103 400 MWh which may increase to approximately 200 000 MWh when including additional B2B clients in the future. The feasibility analysis concentrates on district heating clients due to uncertainties in the business-to-business sector.

Assuming a modern turbine with 27% efficiency, the study finds a loss of 27 918 MWh in electricity generation for district heating. Comparative price models reveal that electricity generation becomes more profitable when the average price exceeds 75 EUR/MWh, with a critical threshold at 110 EUR/MWh.

The planned pipeline for district heating would be around 27,000 meters, with a cost of 616.6 euros per meter, resulting in a total construction cost of 16,650,000 euros.

Initial costs, including pipeline construction and equipment, amount to 20,713 MEUR. Revenue, based on a 20 EUR/MWh transport fee, reaches 2 MEUR annually.

An analysis of pipeline feasibility shows that, with a 20 EUR/MWh transport fee, the pipeline becomes economically viable after 12 years. Reducing the transport cost to 10 euros per MWh extends the feasibility to 25 years, aligning with the expected lifespan of pre-insulated pipes. If the pipeline serves B2B clients, the feasibility will drop by half which depends on the B2B energy needs.

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