Project “Wood energy and Cleantech”

Case Study of Elva Heat Sector

Environmental and Economic Aspects

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INTRODUCTION

This paper is an analysis of environmental and economic aspects prepared within conducting a case study as part of the project "Wood Energy and Cleantech" working package "Technology and Production" coordinated by the Estonian University of Life Sciences. The project "Wood Energy and Cleantech" is a project of developing the usage of clean wood energy in the Central Baltic Sea region. This case study looks at the district heating system of the town of Elva, focusing foremost on wood burning boiler plants and using wood chips. Source data used for preparing the report was largely derived from other reports and sources prepared during the "Wood Energy and Cleantech" project.

Pursuant to the source task given by the project coordinators, the report consists of two parts:

1. **Environmental aspects of Elva wood burning boiler plants;**
2. **Cost-benefit analyses of future scenarios.**

The first part of the report (analysis of environmental impacts) was prepared by Hendrikson & Ko with the participation of the following experts:

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The second part (cost-benefit analyses) was prepared by the following experts:

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PART 1. ENVIRONMENTAL ASPECTS OF ELVA WOOD BURNING BOILER PLANTS

INTRODUCTION

So far, Estonia has reduced greenhouse gas emissions by more than 50% compared to 1990, the percentage of renewable energy sources in the total energy consumption was 18% in 2005 [1]. Pursuant to Directive 2009/28/EU on the promotion of the use of energy from renewable sources [2] (hereinafter referred to as Directive of Renewable Energy), Estonia is obliged to increase the percentage of renewable energy sources in total energy consumption to 25% by 2020 in comparison to the reference year 2005.

The objective of the Development Plan for Enhancing the Use of Biomass and Bioenergy [3] is to create comfortable circumstances for producing local biomass and bioenergy to reduce Estonia's dependence on imported resources and fossil fuels and reduce the pressure on nature. The objective of the development plan is to reduce Estonia's dependence on imported energy resources and expand the use of biomass as raw material for energy, which also conforms to the objective of the National Energy Development Plan [4] to ensure constant energy supply by diversifying energy sources and more even distribution in energy balance.

The Development Plan for Enhancing the Usage of Biomass and Bioenergy [3] states that implementing biomass in the production of energy and materials brings about, among other things, direct positive effects on the environment:

- helps reduce pollution pressure on the environment, especially the environmental load of energy sector;
- helps distribute energy production;
- helps ensure the upkeep of agricultural and forest land.

The use of biofuels in Estonia is still low, but interest in its use is constantly growing [1].
According to the Ministry of Economic Affairs and Communications, examinations regarding environmental impact have not been conducted for biofuels and the production of its raw material. Liquid biofuel is currently not being produced in Estonia, and so far, other agricultural activity isn't more substantial in terms of environment than usual.

Pursuant to the source task of "Wood Energy and Cleantech" project, this chapter focuses foremost on the environmental aspects of using wood chips as fuel in Elva boiler plants and analyses aspects associated with establishing a combined heat and power plant operating on local biofuel.

This report does not describe all environmental impacts of wood burning boiler plants but focuses foremost on exhaust gases and emission of carbon dioxide associated with boiler plants as the most important environmental impact of burning fuels, pursuant to the project's source task. Calculations of emissions were conducted in the practical part both for existing circumstances and compared scenarios. The report also looks at opportunities of handling ash in the Estonian practice.

1 CONNECTION WITH RELEVANT ENERGY DEVELOPMENT DOCUMENTS

This chapter looks at important strategic documents associated with the paper's source task (generating heat in wood burning boiler plants, expediency of CHP plant operating on local biomass).

1.1 Development documents of the European Union

Green Paper on Energy Efficiency or Doing More with Less [6] of the Commission of the European Communities brings up the importance of promoting distributed generation and co-generation of electricity and heat. The three main objectives of the Green Paper are competitiveness, sustainability, and security of supply. Improving energy efficiency thus means using the best available technology in order to consume less, either in the end stage of consumption or energy production phase. Chapter 2.3 „Electricity generation" states the following:

> ***Promotion of distributed generation.*** *The biggest waste in the electricity supply chain (generation – transmission, distribution – supply) is the unused heat which escapes in the form of vapour, mostly by heating the water needed for cooling in the generation process. The supply chain is still largely characterised by central generation of electricity in large power plants, followed by costly transport of the electricity to final consumers via cables. This transport generates further losses, mainly in distribution. Thus centralised generation has advantages in the shape of economies of scale, but also wastes energy.*
>
> *The current investment needs in electricity generation could be used to Europe's advantage if it was to use the opportunity to facilitate a shift in electricity generation away from the big power stations to cleaner and more efficient distributed and on-site generation. Distributed generation is normally much closer to useful outlets also for the heat which is lost in conventional generation, so increasing heat recovery opportunities, which dramatically improves fuel efficiency. This change will be a gradual process which can be facilitated at national level by using the right incentives for industry.*
>
> *The second electricity Directive, 2003/54/EC, already contains an incentive for Member States and national regulatory authorities to promote distributed generation by taking account of its benefits for the transmission and distribution networks in the form of long-term avoided investment costs. Furthermore, Member States are obliged to ensure that authorisation procedures for this type of generation take account of its small-scale nature and therefore potentially limited impact. Streamlining and reduction of the regulatory load of authorisation procedures for distributed generation is therefore required: national authorities, regulators, and local and regional authorities need to make this happen. The Commission will see to it that the measures provided for by the*

Directive are enforced. In any event, to conform to the community rules on freedom of establishment and of provision of services, authorisation procedures for energy production must be based on objective and non-discriminatory criteria, made known in advance to the undertakings concerned, so as to ensure that the discretionary power of the national authorities shall not be used in an arbitrary fashion The nature and scope of public service obligations to be imposed by a system of administrative authorisations must be made clear in advance to such undertakings. In cases where the number of available permits for a particular activity is subject to a limit, the validity of the permit must not exceed the time necessary to write off the investment and to allow for equitable payback on the capital. Furthermore, any person affected by a restrictive measure based on such derogation must have the opportunity to enter an appeal.

Co-generation also offers a substantial potential gain in efficiency. To date, only around 13% of the electricity consumed in the EU is generated using this technology. The Member States have to implement the Directive promoting the use of high-efficiency co-generation by February 2006. They should ensure that the best possible use is made of this technology. In addition, they could stimulate further progress in developing co-generation technologies not only in respect of energy efficiency and fuel flexibility but also with the aim of reducing construction costs. Member States could equally further explore and develop co-generation technologies which can increase the use of renewable sources.

Most Member States of the EU-25 have district heating systems, and especially in the new ones in Central Europe with transition economies, this is a very common means of providing heat, especially to households. District heating, if managed well, can be environmentally friendly. It is estimated that even just those district heating and co-generation facilities, including industrial applications, already existing, may save 3-4 % in primary energy use as compared with separate production.

However, the main problem to be solved is how to finance the upgrading of old systems. To this end, the financial institutions such as the European Investment Bank need to be further mobilised to enable financing for energy efficiency measures in district heating.

Biomass Action Plan [7] foresees methods to enhance the development of energy from wood, waste, and agricultural products. This way, Europe can reduce its dependence on fossil fuels, limit greenhouse gas emissions, and enliven economic activity in rural areas.

Directive 2004/8/EC of the European Parliament and of the Council [8] on the promotion of co-generation of energy is currently being transpositioned by the Republic of the Government along with an amendment motion to the Electricity Market Act. The main objective of the directive is the promotion of efficient co-generation. Co-generation reference values are being prepared pursuant to the directive.

Pursuant to **Directive 2001/77/EC** passed in 2001 [9] on the promotion of the use of electricity from renewable energy sources on the internal electricity market, in 2010, 22% of domestic gross consumption of electricity must be covered by electricity from renewable energy sources. The directive decrees generating 5.1% of electricity from renewable energy sources by 2010 and 7.5% by 2015 as an objective to Estonia to achieve.

1.2 Estonian development documents

Sustainable development strategy **Sustainable Estonia 21** [10] is a development strategy for the Estonian state and society until the year 2030. Long-term development goals are the viability of the Estonian cultural space (maintaining national traditions), growth of welfare, coherent (without acute social conflicts) society, and ecological balance.

The strategy generally supports the growth of the share of the use of energy based on renewable natural resources, but also sees the danger in the growth of pressure on the nature and biological diversity. Fossil or irrecoverable natural resources should be used with a principle that the exploitation of these is ensured until the time they can be replaced with some other, for example renewable, resource.

The objective of **Estonian Environmental Strategy 2030** [11] is to define the long-term development trends for maintaining a good status of the natural environment, while keeping in mind the links between the environment, economic and social spheres, and overall impact on the natural environment and people.

In 2030, environmentally sustainable technologies and various raw materials, which can be supplied from nearby locations, will be used, in parallel, for production of energy. Stable energy supply will be ensured, alternatives for raw materials currently used for energy production will exist, new technologies will be applied, and oil shale will be used in a more efficient manner and with less waste (considering current technologies, wind, sun, and water cannot cover the energy need of Estonia). It will be possible to easily switch from one energy producer (source) to another. Micro-energy concepts and autonomous ecological houses will be widespread, with the little necessary energy being produced on the basis of renewable sources. Among developed countries, Estonia will stand out by the smallest energy consumption per unit produced. The load of the oil shale industry, both power and oil industry, on the environment will be minimal and its side effects will have been eliminated.

In energy, the goal is to produce energy in an amount that meets the consumption needs in Estonia and to develop diverse and sustainable production technologies based on different sources of energy, which do not impose a significant burden on the environment and which enable electricity to be produced for export.

The aim of the development is to advance the energy industry that meets the consumption needs of Estonia and is based on different energy sources. The production technologies that encumber the environment less are preferred, but may also use fossil energy sources. Provided that production technologies characterised by small environmental burden are developed and applied under an optimal production regime, electricity can also be produced for exports. Slowing down and stabilising the consumption of energy, while ensuring that the needs of people are met, i.e. ensuring the preservation of the volume of primary energy while consumption grows.

Estonian Development Plan for the Electricity Sector 2005-2015 [12] describes the state's electricity sector mission by mentioning:

- current state of electricity sector;
- predicted electricity consumption in 10 years;
- volume and structure of production and transmission capacities necessary for ensuring electricity supply until 2015;
- goals of electricity sector development, incl. development aims of renewable energy and co-generation;
- limits and undertakings affecting the development of energy sector;
- general principles of the regulation of electricity market and pricing electricity.

Electricity production has been the biggest exploiter of water and mineral natural resources and cause of waste in Estonia in the last decades. Burning fossil fuels (oil shale, fuel oil, and natural gas) in generating electricity and heat produces the largest share of Estonian greenhouse gas emission, particulates emitted in air, and organic compounds in air.

The strategic objective of Estonian development plan for the electricity sector until the year 2015 is to ensure the optimal functioning and development of Estonian electricity system and responsive long-term electricity supply to consumers for the lowest prices possible in the conditions of market economy. All requirements of reliability and supply and environment are complied with thereat. Pursuant to the criticality of the strategic objective, the following goals important to the Estonian state in developing the electricity sector must be complied with:

- Ensure the operational security and immunity of the Estonian power system and the security of consumer supply at least at the level of 2005 and complete modernisation of the power network in approximately every thirty years in the transmission network and in approximately every forty years in the distribution network.
- Ensure the existence of local generating power to cover the domestic electricity consumption needs.
- Develop technologies which use energy resources, including co-generation of heat and power, more efficiently.
- Stimulate sustainable electricity consumption.
- Establish new interconnections with the power systems of the EU neighbouring states and enhance international cooperation.
- Ensure that the know-how is available in the field of power engineering, ensuring efficient technology development and transfer of technology, research, and innovation in the state.

Development Plan 2007-2013 for Enhancing the Use of Biomass and Bioenergy [13]

The development plan mentions the following:

The deployment of biomass in the production of energy and materials:
- o helps ensure a reliable supply of energy;
- o reduces dependence on imported energy and its price fluctuations;
- o creates new market outputs for agricultural produce, making it possible to earn an alternative or additional income as compensation for decreasing direct aid;
- o helps reduce pollution pressure on the environment, especially the environmental load of the energy sector;
- o helps ensure the growth or stability of the gross domestic product;
- o has a positive impact on trade balance;
- o makes it possible to create new jobs or retain the existing ones (especially in rural areas);
- o diversifies the nomenclature of agricultural produce and energy resources;
- o helps disperse energy production;
- o helps ensure the upkeep of agricultural and forest land.

The use of biomass to produce energy will develop until the year 2013 as follows:
- o owing to measures and aid implemented in the Rural Development Plan 2007-2013, the availability of biomass (mainly cutting waste and unconventional biomass) will increase considerably;
- o owing to support measures foreseen in the Electricity Market Act and the measures of the National Strategy 2007-2013 for the Use of Structural Instruments, the price of energy produced from unconventional biomass resources will become more competitive as compared to other energy products;
- o the proportion of biomass for producing energy will increase to 3% of national gross consumption;
- o the proportion of biomass for producing heat will increase;
- o the competitiveness of combined heat and power microplants has increased compared to other ways of energy production, owing to the relevant research and development activities in Estonia and in the European Union;
- o consumers are thoroughly informed of the advantages of using domestic renewable resources in block heating.

National Strategy 2007-2013 for the Use of Structural Instruments [14] states that the energy-intensity of the Estonian gross domestic product and the relatively low efficiency of using primary energy show a great potential for a more effective energy recovery. The state should therefore pay greater attention to controlling the growth of energy consumption, as well as to the increase in efficiency and energy conservation from the part of end consumers. In connection to the existence of support schemes for the development of renewable energy and a more efficient electricity production in electricity sector, and with the obligation to invest in the development of energy infrastructure in case of coordinated energy prices, the limited resources can be directed mainly at actions supporting and enhancing the development of the energy sector.

The structure of Estonian production capacity will be made more rational to cover peak load and reduce the concentration of electricity production. For this there will be support for the generation of combined heat and power capacities in areas with heat load, as well as for the construction of production equipment using renewable energy sources to produce electricity, and of peak load capacities.

In order to increase the proportion of renewable energy sources in heat production, ensure heat supply for heat consumers and do it for as low prices as possible, and use energy resources in a sustainable way, support will be provided for the renovation of smaller district heating networks and the construction of power stations or switching them to renewable energy sources.

In the framework of measure 1.1.3 "Investments in bioenergy production" of the **Estonian Rural Development Plan 2007-2013** [15], investments that are directed at the production of biomass and bioenergy in agricultural enterprises are supported.

In the framework of measure 1.2 “Giving added value to agricultural and forestry produce” of the Rural Development Plan, support is provided for investments into obtaining and implementing processing techniques, equipment, and technologies, the aim of which is to produce biofuels from agricultural produce, non-wood forestry produce, and the production waste of industry that processes agricultural and non-wood forestry produce.

In the framework of measure 1.6 “Development of new products, processing techniques, and technologies in the agricultural and food sector and forestry sector” of the Rural Development Plan, applied research and product development related to bioenergy crops and biofuels is supported.

In the framework of measure 1.5 "Improvement of the economic value of forests and giving added value to forestry produce" of the Rural Development Plan, support is provided for investments by micro-enterprises of the industry processing forestry produce into tangible and intangible assets in order to obtain and deploy new products, processing techniques and technologies (including investments in the production of bioenergy), with a view to ensuring

a more extensive supply and use of forestry produce, the production of innovative high-quality forestry products and yield with a higher added value (including bioenergy products), energy saving, and environment-friendly management.

In the framework of measure 2.7 “Establishment of energy coppices” of the Rural Development Plan, the growing of an energy coppice will be supported to foster increasing the volumes of bioenergy raw material, ensure a good condition of the environment, and contribute to alleviating climate change. The aid will cover a part of the costs of creating an energy coppice.

In conclusion based on above-mentioned references, we can mention the following trends in energy policy:

- using renewable fuels;
- using local fuels;
- co-generation (effective production of energy);
- distributed generation (effective distribution of energy).

Establishing a CHP plant operating on local biomass would conform to all the main trends in energy policy. Boiler plant that produces only heat is not the most effective solution, given the future trends. Generating heat from renewable fuels also reduces the use of fossil fuels, i.e. producing electricity from oil shale in Estonia.

2 METHODOLOGICAL BASES FOR CALCULATING CARBON EMISSION

2.1 Carbon footprint and calculating the emission of greenhouse gases

One method to represent the total environmental impact of a product or activity is to calculate its **ecological footprint**. Ecological footprint is a standard measure that relates the ecological effect of human activity quantitatively to ecological resources available to human consumption. Equivalent biologically productive land (in hectares) capable of regenerating the natural resources a human population consumes and assimilating associated waste is calculated for material and energy flows of a state or some other unit.

The most suitable value for describing the effect of human activity on the environment (especially on climate changes) when burning fuels is **carbon footprint** - the total set of greenhouse gas (methane, nitrous oxide, etc.) emissions caused by a person, organisation, or some other unit or that arises during the life cycle of a product or service [16].

Carbon footprint is calculated using the relative measure of global warming potential (GWP) for different greenhouse gases that characterises the relative effect of greenhouse gases on global warming. The value of global warming potential can be used to convert various greenhouse gas emissions into CO2 emission equivalent, add these, and find the total carbon footprint. Different values of global warming potential are valid for different time periods, but carbon footprint is usually calculated using the 100-year global warming potential GWP100 [17].
Global warming potential values have constantly been supplemented over time, and manuals prepared at different times contain different values for global warming potential. Here, values from Directive 2009/28/EC on Renewable Energy [2][1] have been referred to:
CO_2: 1
N_2O: 296
CH_4: 23.

The manual 2006 IPCC Guidelines for National Greenhouse Gas Inventories [18]prepared by the United Nations Intergovernmental Panel on Climate Change is used to calculate different greenhouse gas emission in coordination with the United Nations Framework Convention on Climate Change.

> United Nations Framework Convention on Climate Change is an international contract prepared at the Conference on Environment and Development (UNCED), informally known as Earth Summit, on 3-4 June, 1992, in Rio de Janeiro, with the aim to develop global cooperation in stabilising and reducing anthropogenic emission of greenhouse gases

[1] more detailed overview of the directive on Renewable Energy is given in chapter 3.2

that cause climate changes; the main objective is to avoid anthropogenic climate changes [19].

United Nations Intergovernmental Panel on Climate Change) is an organisation reporting on climate changes whose aim is to assess risks caused by climate changes. According to IPCC fourth assessment report, global greenhouse gas emissions must be reduced by 50% compared to 1990 in order to avoid dangerous climate changes: both industrial and developing countries should reduce emissions to achieve the goal [19].

Characteristic of biofuels: Biofuels are usually considered fuels with a neutral carbon balance - when burning, biomass emits the same amount of CO2 in the atmosphere that was bound with it, and sustainable use of bioenergy does not therefore bring about the net growth of quantity of greenhouse gas CO2 [20]. Pursuant to Estonian legislation, CO2 arising from burning biofuels is also calculated as zero [21].

Pursuant to above-mentioned instruction materials, greenhouse gas inventories and predictions are prepared in practice, incl. national (e.g. reports submitted to the European Commission) and as part of various projects (incl. e.g. Fuel Switch projects of boiler plants).

2.2 Directive on renewable energy and life cycle of fuels

Although biofuels are considered fuels with a neutral carbon balance, the total impact of using fuel still significantly depends on how biofuel is produced and transported. These aspects are taken into consideration in the **product life cycle** - the life cycle of a product or a service from cradle to the grave, so to speak, that consists of successive and related stages of a product system. Life cycle consists of mining and producing raw material necessary for producing the product, packaging, distributing to consumers, using, and removing from consumption, i.e. waste management. Life cycle also includes transport between stages. [16]

Among newer international agreements, Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources [2] (hereinafter referred to as Directive on Renewable Energy) that also takes the life cycle of biofuels into account regulates the controlling of environmental impact of biofuels. The directive implements the **Sustainability criteria for biofuels and liquid biofuels, it also gives** instructions (methodology) on how Member States must assess potential benefit of replacing fossil fuels with biofuels for the environment (incl. reduction of greenhouse gas emission).
According to the directive, reducing greenhouse gas emissions is one of the main reasons for promoting the use of biofuels.

Specifically, the Directive on Renewable Energy looks at biofuels only used in transport and liquid biofuels used in other sectors. In order to fill that gap and also regulate the use of solid biofuels (incl. wood chips perused in this report), the European Commission has prepared a supplementary report that, among other things, presents requirements for the use of solid biofuels in terms of environment-friendliness [22].

Article 22 of the Directive on Renewable Energy obliges Member States to submit a report to the European Commission on progress in the promotion and use of energy from renewable sources by 31 December 2011, and every two years thereafter. Estonia submitted the respective report in 2011 [23].

Pursuant to the Directive on Renewable Energy [2] and the report of the European Commission that supports it [22], **life cycle analysis** is a suitable means to assess the advantages of bioenergy compared to fossil energy. The total volume of emitted greenhouse gases depends on several different stages and activities, incl. growing bioenergy cultures (e.g. NH3 emission due to fertilising), changes in land use, processing of raw material (burning fossil fuels during processing), transport (e.g. NOx, CO, PM emissions), used technology when burning fuels, etc.

The report of the European Commission also states that there is no one and only life cycle analysis methodology for conducting relevant life cycle analyses. The choice of methods for conducting a life cycle analysis affects assessment results [22]. Thus, the Member State should follow the methodology described in the Directive on Renewable Energy and the report of the European Commission that supports it when finding the positive effect of reducing greenhouse gases with bioenergy, so that the results would be comparable to other states.

According to the requirements of the Directive on Renewable Energy, Estonia has also assessed the reduction of greenhouse gas emissions as a result of using renewable energy in the report submitted to the European Commission in 2011 [23]. It is admitted in the report that the presented data regarding the reduction of greenhouse gas emission has been calculated based on simplified methodology, consider only direct CO2 emission, and are thus approximate assessments.

The report also shows that the detailed calculation of the reduction of greenhouse gas emission due to using renewable energy pursuant to the instructions of Directive 2009/28/EC (Directive on Renewable Energy) has not yet been conducted. **So far, there are also no examinations conducted in Estonia that are necessary for developing an assessment method that would consider the entire (or partial) product life cycle in Estonian conditions** [23].

At the moment, there is no methodology for Estonian conditions that would enable calculating the entire carbon footprint of the product life cycle of biofuels (incl. wood chips).

Because of that, this paper looks at the environmental impact of wood chips and carbon emissions on two different methodological bases:

- Chapter 4 conducts a calculation of pollutant emissions from fuel burning process that conforms to the greenhouse gas inventory methodology common in practice;
- Chapter 5 looks at the life cycle of wood chips, due to the lack of calculation methodology, it looks at stages that are quantitatively likely to have a larger impact.

3 BURNING WOOD CHIPS IN BOILER PLANTS

This chapter looks at pollutants arising from wood burning boiler plants, while presenting

- source inventory of emissions - base situation of residue in Elva heat sector (see chapter 4.3), and
- comparison of different scenarios in terms of emissions (see chapter 4.4).

3.1 Short description of significant pollutants

This chapter lists and describes the more important pollutants that arise from burning biomass. Concentration of pollutants in fume is not standardised in Estonia for combustion plants of 50 MW_{th} input power. It is, however, limited for CHP plants operating on biofuel (depending on heat capacity) in some European countries. Data is taken from the paper "Basic information regarding decentralised CHP plants based on biomass combustion in selected IEA partner countries final report" [24].

Emission of sulphur dioxide (SO_2) depends on the content of sulphur in fuel. Concentration of sulphur in wood fuel is modest, approx. 0.02-0.05% (approx. twice as much in herbaceous biomass). Wood fuel-operated plant doesn't therefore require a sulphur removal system. SO_2 emission in fumes is standardised 300 mg/Nm^3, 10-20 mg/MJ as a comparison for fuel oil 140 mg/Nm^3.

The negative effect of SO_2 manifests foremost on respiratory tracks, concurrence with other pollutants has also been detected. Environmental damage is reflected in acid rains.

Nitric oxides (NOx) are a mix of nitrogen dioxide (NO_2) and nitrogen oxide (NO). Most first generate NO that oxidises further due to ozone and becomes NO_2. NOx emerges during combustion when air nitrogen oxidises, to a smaller extent also from nitrogen in fuel. Primary methods, i.e. boiler's operating mode settings that do not cause high emissions are used to reduce NOx emission. One primary method is to keep the combustion temperature at a sufficiently low level <900^{o}C. However, when the combustion temperature is lowered too far, there is a danger of unburned fuel residue (VOC, CO, soot). NOx emission can also be reduced with combustion technological methods (recirculation of fumes). Regulation options of combustion mode therefore depend on the construction of a specific boiler. NOx emission in fumes is standardised in the range 200-300 mg/Nm^3.

NOx negative effect manifests on respiratory tracks, body's resistance. It is also included among greenhouse gases.

Carbon monoxide (CO) and volatile organic compound (VOC) emission depends on the combustion mode. The lower the combustion temperature and shorter the fuel remains in the combustion zone, the more compounds emerge from incomplete combustion. In modern plants, the CO emission in fumes is standardised in the range 250-625 mg/Nm^3 and VOC (TOC) 50 mg/Nm^3.

CO prevents oxygen transport, because it binds itself with blood cells tighter than oxygen. Especially central nervous system and cardiovascular system are damaged. Attention capability and reaction speed slows and sense of light and time deteriorates.

Particulates (PM) are a mixture of different fractions of ash, the most dangerous of which are fine ash fractions, i.e. particulates with a diameter less than 10 and 2.5 microns. Several cleaning installations are used for reducing PM. Highly effective electric filter (>99%) or dry filter system (so-called industrial filter with 99.8% efficiency) are common. Small boiler plants use cyclones that can also be used as a pre-cleaner in more complex cleaning installations. The cyclones' flaw is their low cleaning efficiency of fine particulates (<10 microns). Electric filter and industrial filter, on the other hand, clean fine dust most effectively and can clean particulates with a dimension of 0.01 microns. Fine dust is considered to be the most dangerous fraction among particulates, because these particulates get stuck in lungs and may cause illnesses. PM emission in fumes is standardised in the range 40-265 mg/Nm^3.

Fine dust particulates that have an aerodynamic dimension of less than 10 microns and cause lung diseases are dangerous to health. Researches have revealed that fine dust may be a factor in cardiovascular and respiratory diseases. Particles of other pollutants (heavy metals, PAH, etc.) agglomerate with particulates in fumes.

Emission of heavy metals is reduced together with cleaning particulates. Exceptions are mercury and selenium that evaporate and therefore the efficiency of cleaning them with particulate cleaning installations is low. Electric filter cleans mercury with 50% efficiency. Main emission of these metals takes place during combustion, it is not of concern with wood. Usually, 98% of heavy metals are contained in ash.

Heavy metals, particularly in above standard quantities, cause significant weakening of immune system, irritation, and depression and by causing free radicals elicit the destruction of cell membrane. Heavy metals get into organism through respiratory track and food chain. Co-existence of several heavy metals may increase their toxic effect further.

When lead vapours or dust (heavy metal with the highest emission factor value, in this case) get into the organism, they deposit in the bones and liver, stop several enzymes, and may cause anaemia. They also damage central nervous system, hinder liver and kidney functions. Lead also reaches the placenta through embryonic (foetal) blood circulation, causing fixation and underweight in infants. Lead also damages male reproductive system.

3.2 Methodology of calculating pollutant emissions

Pollutant emissions are calculated according to the Minister of the Environment's 02.08.2004 regulation no. 99 "Procedure for determining pollutant emissions released into ambient air from combustion plants and determination methods" [25].

Pollutant emissions are defined computationally as follows:

Fuel consumption is converted in heat units B_1 (GJ)

$$\mathbf{B_1 = B \cdot Q^r,}$$

where B - fuel consumption in a reference period (t);
Q^r - lower calorific value of fuel (MJ/kg).

Pollutant's emission factor value is derived - q_i

Emission factor value has been chosen for a heat energy device with a capacity below 10 MW that operates on wood fuel and is equipped with a cyclone. Also for oil boiler with a capacity below 10 MW.

Respective pollutant emission M_I (t) is calculated using the following formula:

$$\mathbf{M_I = 10^{-6} \cdot B_1 \cdot q_I,}$$

where B_1 – fuel consumption in a reference period (GJ);
q_I – emission factor of pollutant i (g/GJ).

Current values of emissions released from pollutants M (g/s)

Current emission value M (g/s) is calculated for every relevant pollutant according to methodology, pursuant to the capacity of combustion plant:

$$\mathbf{M = 10^{-3} \cdot P \cdot q,}$$

where P is heat capacity of combustion plant (MW)
q is emission factor of relevant pollutant (g/GJ).

Calculating the emission of sulphur dioxide

Emission of sulphur dioxide Mso_2 (t) is calculated depending on the sulphur content in fuel in the event of solid and liquid fuel.

$$\mathbf{Mso_2 = 0{,}02 \cdot B \cdot S^r \cdot (1 - n),}$$

where B - fuel consumption (t);
S^r – sulphur content in fuel's consumption substance (mass %);

n – relative quantity of sulphur emerging from sulphur cleaning installations or binding with ash in a combustion plant that is calculated only in the event of oil shale.

Sulphur content is 0.8% in this case.

Finding current emission of sulphur dioxide

Current emission of sulphur dioxide $M_p so_2$ (g/s) is calculated in the event of burning solid and liquid fuel, pursuant to sulphur content in fuel.

$$\mathbf{M_p so_2} = \frac{\mathbf{20 \cdot P \cdot S^r \cdot (1 - n)}}{\mathbf{Q^r{}_I}},$$

where P - current heat capacity of combustion plant (MW);
S^r – sulphur content (%);
n – relative quantity of sulphur emerging from sulphur cleaning installations or binding with ash in a combustion plant;
$Q^r{}_I$ – lower calorific value of fuel (MJ/kg).

Calculating CO_2

Pursuant to the Minister of the Environment's 16.07.2004 regulation no. 94 "Methods for determining the emission of carbon dioxide released into ambient air" [21], the emission of carbon dioxide is derived as follows:

$$\mathbf{Mc = 10^{-3} \cdot B_1 \cdot q_c \cdot Kc},$$

where Mc - emission of carbon in gigagrams (GgC)
B_1 – fuel consumption (TJ);
q_c – emission factor of carbon (tC/TJ);
Kc – oxidised part of carbon.

$$\mathbf{Mco} = \mathbf{Mc} \cdot \frac{44}{12},$$

where Mco – CO_2 emission ($GgCO_2$);
Mc - emission of carbon in gigagrams (GgC).

In the event of shale-derived oil q_c = 21.1 (tC/TJ), Kc = 0.99.

CO_2 emerging from burning biofuels is considered zero pursuant to mentioned regulation.

3.3 Emissions of existing pollutants

3.3.1 Source data

Elva district heating is based on three boiler plants: Nooruse and Kirde boiler plants and Haigla boiler plant. The analysis of fume cleaners only looks at Nooruse and Kirde boiler plants at this point. To describe the emissions of these boiler plants, the paper uses the projects of permitted emission level (PEL) of their ambient air pollution permission, prepared by OÜ Märja Monte respectively in 2008 and 2006. The reason for preparing both PEL projects was the modernisation of heating installations, i.e. installing a new wood boiler. Data regarding the production is taken from energy production development scenarios of the case study of this project [26].

Nooruse boiler plant

supplies heat energy to consumers in the centre of the town of Elva. Working time 5496 h/y, this means that the boiler plant is not operational during the summertime period of warmth.

The main boiler is fully automatic Justsen JU-MMV 22 with grid hearth, designed for burning wood chips, sawdust, and shredded wood waste, with a moisture content up to 55%. According to primary energy, the boiler's heat capacity is 3.75 MW_{th} (efficiency 80%). Lately, the main fuel is primarily wood chips (>90%), the moisture content of which is 50% on average and lower calorific value is 10.2 MJ/kh, i.e. 2.83 MWh/t, which corresponds to the 40% moisture content.

Peak boiler is oil boiler Basoe SIS 133 that burns shale-derived oil. According to primary energy, the boiler's heat capacity is 5 MW_{th} (efficiency 90%). Sulphur content of shale-derived oil is up to 0.8% and lower calorific value is 38.9 MJ/kg, i.e. 10.81 MWh/t.

Total output of wood boiler (basis for scenario I) on average is 10411 MWh/y, i.e. 37588 GJ/y, which gives the primary energy quantity of 46985 GJ/y in the event of 80% efficiency. Quantity of wood chips is 4998 t/y (calorific value 9.4 MJ/kg).

Total output of peak boiler on average is 172.4 MWh/y, i.e. 620 GJ/y, which gives the primary energy quantity of 690 GJ/y in the event of 90% efficiency. Quantity of shale-derived oil is 18 t/y (calorific value 39 MJ/kg).

Fumes are released through a chimney with a height of 45 m and entrance diameter of 1.2 m. Volumetric flow of released fumes is 2.82 Nm^3/s; volumetric flow is 4.68 m^3/s at temperature 180 ^oC.

Kirde boiler plant

supplies Kirde district's objects in Elva. Working time 5496 h/y, this means that the boiler plant is not operational during the summertime period of warmth.

The main boiler is fully automatic HKRSV 1300 with grid hearth, designed for burning wood chips, sawdust, and shredded wood waste, with moisture content up to 55%. According to primary energy, the boiler's heat capacity is 1.63 MW_{th} (efficiency 80%). Lately, the main fuel is primarily wood chips (>90%), the quantity of which is up to 5000 t/y, moisture content is 50% on average, and lower calorific value is 10.2 MJ/kh, i.e. 2.83 MWh/t, which corresponds to the 40% moisture content.

Peak boiler is oil boiler BRFV 1500 that burns shale-derived oil. According to primary energy, the boiler's heat capacity is 1.88 MW_{th} (efficiency 80%). Quantity of shale-derived oil is up to 60 t/y, sulphur content is up to 0.8% and lower calorific value is 38.9 MJ/kg, i.e. 10.81 MWh/t.

Total output of wood boiler on average is 3378 MWh/y, i.e. 12161 GJ/y, which gives the primary energy quantity of 15201 GJ/y in the event of 80% efficiency. Quantity of wood chips is 1617 t/y (calorific value 9.4 MJ/kg).

Total output of peak boiler on average is 100.4 MWh/y, i.e. 361 GJ/y, which gives the primary energy quantity of 451 GJ/y in the event of 80% efficiency. Quantity of shale-derived oil is 11.6 t/y (calorific value 39 MJ/kg).

Fumes are released through a chimney with a height of 43 m and entrance diameter of 1.2 m. Volumetric flow of released fumes is 1.2 Nm^3/s; volumetric flow is 2.0 m^3/s at temperature 180°C.

3.3.2 Pollutant emissions from existing boiler plants

Table 1. Pollutant emissions when burning wood chips at Nooruse boiler plant (46985 GJ/y)

pollutant	emission factor (g/GJ)	emission (g/s)	emission (t/y)
NO_x	100	0.375	4.699
Particulates (PM SUM)	240	0.900	11.276
CO	1000	3.750	46.985
SO_2	10	0.038	0.470
VOC COM	48	0.180	2.225
CO_2	-	-	-*
Heavy metals	112.8 mg/GJ	0.4 mg/s	5 kg/y

* - CO_2 emission released when burning biofuels is considered zero

Table 2. Pollutant emissions when burning shale-derived oil at peak load at Nooruse boiler plant (690 GJ/y)

pollutant	emission factor (g/GJ)	emission (g/s)	emission (t/y)
NO_x	150	0.750	0.104
Particulates (PM SUM)	100	0.500	0.069
CO	100	0.500	0.069
SO_2	-	2.057	0.283

VOC COM	1.1	0.006	0.001
CO_2	-	-	52.849
Heavy metals	396.7 mg/GJ	2 mg/s	0.3 kg/y

Table 3. Pollutant emissions when burning wood chips at Kirde boiler plant (15201 GJ/y)

pollutant	**emission factor (g/GJ)**	**emission (g/s)**	**emission (t/y)**
NO_x	100	0.163	1.520
Particulates (PM SUM)	240	0.390	3.648
CO	1000	1.630	15.201
SO_2	10	0.016	0.152
VOC COM	48	0.078	0.730
CO_2	-	-	-*
Heavy metals	112.8 mg/GJ	0.2 mg/s	2 kg/y

* - CO_2 emission released when burning biofuels is considered zero

Table 4. Pollutant emissions when burning shale-derived oil at peak load at Kirde boiler plant (451 GJ/y)

pollutant	**emission factor (g/GJ)**	**emission (g/s)**	**emission (t/y)**
NO_x	150	0.281	0.068
Particulates (PM SUM)	100	0.188	0.045
CO	100	0.188	0.045
SO_2	-	0.771	0.186
VOC COM	1.1	0.002	0.000
CO_2	-	-	30.790
Heavy metals	396.7 mg/GJ	0.75 mg/s	0.2 kg/y

3.3.3 Dissipation calculation of pollutants

Table 5 presents values of maximum pollution levels in the vicinity of Nooruse and Kirde boiler plants, derived as a result of dissipation calculation of pollutants (data from projects of permitted emission level (PEL) of ambient air prepared by OÜ Märja Monte).

Table 5. Maximum values of pollution level of pollutants µg/m^3

CAS-code	Pollutant	SPV_1	C *µg/m^3 Nooruse bp*	C *µg/m^3 Kirde bp*
10102-44-0	NO_2	200	13	10
PM SUM	Particulates	500	49	39
630-08-0	CO	10000*	50	41
7446-09-5	SO_2	350	25	18
VOC COM	VOC (aliphatic hydrocarbons)	5000	2	2

SPV_1 – average of one hour

* - average limit value of 8 hours

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As a result of dissipation calculation of pollutants, the near-surface concentrations of all pollutants were below 10% of hourly average value of pollution level (SPV1) that may arise in the air layer near the surface (up to 2 m). This shows that dissipation conditions for pollutants are good (this is foremost due to the noteworthy height of chimneys) and there is no negative environmental impact on the ambient air in the vicinity.

Emissions of pollutants are calculated in reference, should all the heat energy be produced only from shale-derived oil in existing oil boilers.

3.4 Comparison of scenarios

During the comparison of scenarios, pollutant emissions were compared in the event of the following scenarios:

- **Scenario I – using wood chips** according to existing situation and the continuation of it;
- **Heating on the basis of shale-derived oil** - hypothetical situation, where existing district heating network is serviced by boiler plants operating on fossil fuels. Information on energy consumption is taken from scenario I, the fuel is more specifically shale-derived oil if the optimal choice is amongst fossil fuels.
- **Scenario II** – change of technology, alternative heat energy device is a **combined heat and power (CHP) plant operating on local biofuel**.

Comparison of scenarios was conducted both for the base year and for the year 2025. Source data for calculation of emissions was taken from the case study report of this project [26].

3.4.1 Scenario I - existing situation

Base situation

Pursuant to above-mentioned tables 1-4, summary pollutant emissions have been found for both boiler plants and all boilers:

Table 6. Total pollutant emissions in the event of scenario I base

pollutant	emission (t/y)
NO_x	6.391
Particulates (PM SUM)	15.038
CO	62.3
SO_2	1.091
VOC COM	2.956
CO_2	83.639
Heavy metals	7.5 kg/y

Prediction for 2025

Table 7. Pollutant emissions when burning wood chips at Nooruse boiler plant 26553 GJ/y

pollutant	emission factor (g/GJ)	emission (g/s)	emission (t/y)
NO_x	100	0.375	2.665
Particulates (PM SUM)	240	0.900	6.373
CO	1000	3.750	26.553
SO_2	10	0.038	0.266
VOC COM	48	0.180	1.275
CO_2	-	-	-*
Heavy metals	112.8 mg/GJ	0.4 mg/s	3 kg/y

*** - CO_2 emission released when burning biofuels is considered zero**

Table 8. Pollutant emissions when burning shale-derived oil at peak load at Nooruse boiler plant 472 GJ/y

pollutant	emission factor (g/GJ)	emission (g/s)	emission (t/y)
NO_x	150	0.750	0.071
Particulates (PM SUM)	100	0.500	0.047
CO	100	0.500	0.047
SO_2	-	2.057	0.194
VOC COM	1.1	0.006	0.001
CO_2	-	-	36.152
Heavy metals	396.7 mg/GJ	2 mg/s	0.2 kg/y

Table 9. Pollutant emissions when burning wood chips at Kirde boiler plant 8616 GJ/y

pollutant	emission factor (g/GJ)	emission (g/s)	emission (t/y)
NO_x	100	0.163	0.862
Particulates (PM SUM)	240	0.390	2.069
CO	1000	1.630	8.616
SO_2	10	0.016	0.086
VOC COM	48	0.078	0.414
CO_2	-	-	-*
Heavy metals	112.8 mg/GJ	0.2 mg/s	1 kg/y

*** - CO_2 emission released when burning biofuels is considered zero**

Table 10. Pollutant emissions when burning shale-derived oil at peak load at Kirde boiler plant 306 GJ/y

pollutant	emission factor (g/GJ)	emission (g/s)	emission (t/y)
NO_x	150	0.281	0.046
Particulates (PM SUM)	100	0.188	0.031
CO	100	0.188	0.031
SO_2	-	0.771	0.125
VOC COM	1.1	0.002	0.000
CO_2	-	-	23.438
Heavy metals	396.7 mg/GJ	0.75 mg/s	0.1 kg/y

Table 11. Total pollutant emissions in the event of scenario I (2025)

pollutant	emission (t/y)
NO_x	3.644
Particulates (PM SUM)	8.52
CO	35.247
SO_2	0.671
VOC COM	1.69
CO_2	59.59
Heavy metals	4.3 kg/y

3.4.2 Heating on the basis of shale-derived oil

Pursuant to source data for scenario I, summary pollutant emissions have been found for an event that the boiler plants are heated with shale-derived oil.

Base situation

Table 12. Pollutant emissions in the event of burning only shale-derived oil at Nooruse boiler plant 46985+690=47675 GJ/y GJ/y

pollutant	emission factor (g/GJ)	emission (g/s)	emission (t/y)
NO_x	150	0.750	7.151
Particulates (PM SUM)	100	0.500	4.768
CO	100	0.500	4.768
SO_2	-	2.057	19.552
VOC COM	1.1	0.006	0.052
CO_2	-	-	3652
Heavy metals	396.7 mg/GJ	2 mg/s	19 kg/y

Table 13. Pollutant emissions when burning shale-derived oil at peak load at Kirde boiler plant 15201+451=15652 GJ/y

pollutant	emission factor (g/GJ)	emission (g/s)	emission (t/y)
NO_x	150	0.281	2.348
Particulates (PM SUM)	100	0.188	1.565
CO	100	0.188	1.565
SO_2	-	0.771	6.416
VOC COM	1.1	0.002	0.017
CO_2	-	-	1199
Heavy metals	396.7 mg/GJ	0.75 mg/s	6 kg/y

Table 14. Total pollutant emission in the event of scenario I, if only shale-derived oil is used for heating

pollutant	emission (t/y)
NO_x	9.499
Particulates (PM SUM)	6.333
CO	6.333
SO_2	25.968
VOC COM	0,069
CO_2	4851
Heavy metals	25 kg/y

Prediction for 2025

Table 15. Pollutant emissions in the event of burning only shale-derived oil at Nooruse boiler plant 26553+472=27025 GJ/y

pollutant	emission factor (g/GJ)	emission (g/s)	emission (t/y)
NO_x	150	0.750	4.054
Particulates (PM SUM)	100	0.500	2.703
CO	100	0.500	2.703
SO_2	-	2.057	11.088
VOC COM	1.1	0.006	0.030
CO_2	-	-	2070
Heavy metals	396.7 mg/GJ	2 mg/s	10.7 kg/y

Table 16. Pollutant emissions when burning shale-derived oil at peak load at Kirde boiler plant 8616+306=8922 GJ/y

pollutant	emission factor (g/GJ)	emission (g/s)	emission (t/y)
NO_x	150	0.281	1.338
Particulates (PM SUM)	100	0.188	0.892
CO	100	0.188	0.892
SO_2	-	0.771	3.664
VOC COM	1.1	0.002	0.010

CO_2	-	-	683
Heavy metals	396.7 mg/GJ	0.75 mg/s	3.5 kg/y

Table 17. Total pollutant emission in the event of scenario I, if only shale-derived oil is used for heating (2025)

pollutant	emission (t/y)
NO_x	5.392
Particulates (PM SUM)	3.595
CO	3.595
SO_2	14.752
VOC COM	0.04
CO_2	2753
Heavy metals	14.2 kg/y

3.4.3 Scenario II - alternative heat energy device

Alternative heat energy device can be a combined heat and power (CHP) plant operating on local biofuel. CHP plant's heat capacity, i.e. using produced heat, sets certain limitations to the choice of technological solution. Electric capacity of the plant is usually 1/3 of heat capacity.

Initial selection was Turboden TD 10 device, whose electricity production is based on organic Rankine cycle (ORC). In the event of conventional Rankine circulation process, vapour generated in the steam boiler expands to the pressure required by heat consumer in the turbine connected to electricity generator. Advantages of this system are considered to be the option to use various fuels, relatively long service life, fairly low production costs, and option to apply it with high capacities. In the event of ORC, heat conductor is thermal oil instead of water, which ensures a smoother movement of turbine and increases its service life.

ORC has high overall efficiency. 97% of energy inserted in thermal oil is converted into electricity (19%) and heat energy (78%), with a loss of only 3%.

The device also has another characteristic - option to use the cleaner or fume condenser.

Fume cleaner cools down the temperature of released fumes below dew point and gets the heat of water vapour chemically accrued during fuel combustion or heat used to vaporise water in the fuel back as condensation heat. The additional function of fume cleaner is connected to ambient air protection - it also works as an additional device that cleans fumes from volatile particles.

More important factors that affect the choice of cleaner capacity are the humidity of fuel and temperature of returned district heating water. If we presume the humidity of fuel to be 50% and returned water temperature 60 ^{o}C, then the cleaner capacity would make about 15% of boiler heat capacity.

The higher the humidity of fuel, the more additional heat can be accrued with fume cleaner. Fume cleaner increases the heat efficiency of biofuel boiler plant. It reduces fuel consumption necessary for producing the required quantity of heat. Installing a fume cleaner is suitable for boiler plants that use humid fuel, and it is economically and environmentally beneficial.

This case study and calculations do not take the use of fume cleaner into consideration.

Turboden TD 10 heat energy device has 1.0 MW_e electric capacity, 4.095 MW_t heat capacity, and 88% general efficiency, which gives heat energy of 5.8 MW_{th} according to primary energy. Heat consumption is 2244 kg/h, whereas calorific value is 2.6 kWh/kg, i.e. 9.36 MJ/kg.

Technological description of a standard solution

CHP plant's building is divided in three larger parts - fuel storage, boiler plant, and ORC or turbine facility.

The technological cycle begins with receiving wood chips in the fuel storage. Mobile floor of the warehouse transports fuel to the conveyor room's transport belt and from there to the pre-hearth located in the boiler room. Ash produced during combustion falls on dishes underneath the pre-hearth through hearth grid which transport ash to a closed container.

Fumes released in the hearth pass the boiler and other after-combustion surfaces and move to the chimney after passing a fume cleaning device (cyclone + fume condenser).

Heat conductor in the boiler is thermal oil (unlike the traditional solution where the heat conductor is water). Thermal oil is heated to about 300 degrees in the boiler. It is circulated with oil circulation pumps. At the same time, it goes through the boiler (oil heats up) and heat exchanger (oil transfers its heat to silicone oil), it is a closed cycle. As a result, silicone oil vaporises on the other side of the heat exchanger, and vapour is directed into a turbine that operates the generator. After the turbine, vapour is directed into a cleaner where it condenses, transferring its heat to district heating water. Silicone oil condensate is again pumped into the heat exchanger where it vaporises, and the entire cycle repeats once more. It is a closed cycle.

Heat transferred to district heating water is pumped into the district heating network where it is given to the heating system of buildings. It is a closed cycle.

Question regarding the use of heat outside the heating period remains unsolved. One option could be, for example, producing cool air that could be used to supply predominantly spacious objects such as factories, shopping centres, and public buildings. This paper does not analyse this opportunity further.

Source data

Pursuant to the base data for scenario II, the primary energy requirement of CHP plant is 76510 GJ/y in the event of 88% efficiency. Quantity of wood chips is 8139 t/y (calorific value 9.4 MJ/kg).

Kirde wood boiler with primary energy requirement of 1702 GJ/y in the event of 88% efficiency helps to cover peak load. Quantity of wood chips is 181 t/y (calorific value 9.4 MJ/kg).

Kirde oil boiler with primary energy requirement of 289 GJ/y in the event of 88% efficiency is also added. Quantity of shale-derived oil is 7.4 t/y (calorific value 39 MJ/kg).

The surest way to calculate pollutant emissions is to base it on emissions guaranteed by the producer, usually mg/Nm^3 (quantity in exhaust gases) or mg/MJ (quantity in relation to input energy). In this case, however, such information was not available, and the assessment of emissions had to be based on values presented in literary sources. Emissions of a device with a cleaner are taken from paper "Expert assessment of the cost, technical solution, and operational expenditures of boiler plants'" [27].

In this case, however, the use of a cleaner is not presumed, which means that general standards should be used. Because similar devices are installed the most in Austria, this paper uses Austrian emission standards for wood boilers with an automatic feeder for calculations regarding CHP plants. Estonian standards consider older technologies (incl. use of multi-cyclone) and are therefore not the best for newer CHP plant technology.

Table 18. Pollutant emission factors when burning wood fuels

pollutant	emission factor (g/GJ)		
	Estonian standard (emission factor with multi-cyclone)	Emissions of a device with cleaner	Austrian standard
Nitrogen oxide	100	100	150
Particulates	240	38	60
Carbon oxide	1200	1200	500
Sulphur dioxide	10	8	-
VOC	48	48	40*
Heavy metals mg/GJ	112.8	22.56	-

* - OGC – compounds containing organic gaseous carbon. Austrian standards do not state the VOC emission factor value, therefore calculations here use the Estonian methodology.

Using a fume condenser helps to significantly reduce the emissions of particulates and heavy metals, SO_2 emission reduces slightly (thanks to binding with ash). Mentioned pollutants have a local effect and help to improve environmental conditions in the immediate vicinity of the pollution source. Globally, the usefulness of the cleaner is reflected in increasing the efficiency of energy production, +15% in this case.

If we compare Estonian and Austrian emission factor values, we notice a vast difference in terms of CO. Therefore, Austria presumes more effective fuel combustion in wood boilers, and this presumption can also be extended to Turboden boilers.

Pollutant emissions - base situation

Pursuant to source data for scenario II, summary pollutant emissions have been found for a CHP plant:

Table 19. Pollutant emissions when burning wood chips at a CHP plant 76510 GJ/y

pollutant	**emission factor (g/GJ)**	**emission (g/s)**	**emission (t/y)**
NO_x	150	0.870	11.477
Particulates (PM SUM)	60	0.348	4.591
CO	500	2.900	38.255
SO_2	10	0.058	0.765
VOC COM	40*	0.232	3.060
CO_2	-	-	-*
Heavy metals	112.8 mg/GJ	0.6 mg/s	8.6 kg/y

* - CO_2 emission released when burning biofuels is considered zero

Table 20. Pollutant emissions when burning wood chips at peak load at Kirde boiler plant 1702 GJ/y

pollutant	**emission factor (g/GJ)**	**emission (g/s)**	**emission (t/y)**
NO_x	100	0.163	0.170
Particulates (PM SUM)	240	0.390	0.408
CO	1000	1.630	1.702
SO_2	10	0.016	0.017
VOC COM	48	0.078	0.082
CO_2	-	-	-*
Heavy metals	112.8 mg/GJ	0.2 mg/s	0.2 kg/y

* - CO_2 emission released when burning biofuels is considered zero

Table 21. Pollutant emissions when burning shale-derived oil at peak load at Kirde boiler plant 289 GJ/y

pollutant	emission factor (g/GJ)	emission (g/s)	emission (t/y)
NO_x	150	0.281	0.043
Particulates (PM SUM)	100	0.188	0.029
CO	100	0.188	0.029
SO_2	-	0.771	0.118
VOC COM	1.1	0.002	0.000
CO_2	-	-	22.135
Heavy metals	396.7 mg/GJ	0.75 mg/s	0.4 kg/y

Table 22. Total pollutant emissions in the event of scenario II base

pollutant	emission (t/y)
NO_x	11.69
Particulates (PM SUM)	5.028
CO	39.986
SO_2	0.9
VOC COM	3.142
CO_2	22.135
Heavy metals	9.2 kg/y

Pollutant emissions - prediction for 2025

Pursuant to source data for scenario II, summary pollutant emissions have been found for a CHP plant:

Table 23. Pollutant emissions when burning wood chips at a CHP plant 56267 GJ/y

pollutant	emission factor (g/GJ)	emission (g/s)	emission (t/y)
NO_x	150	0.870	8.440
Particulates (PM SUM)	60	0.348	3.376
CO	500	2.900	28.134
SO_2	10	0.058	0.563
VOC COM	40*	0.232	2.251
CO_2	-	-	-*
Heavy metals	112.8 mg/GJ	0.6 mg/s	6.3 kg/y

* - CO_2 emission released when burning biofuels is considered zero

Table 24. Pollutant emissions when burning shale-derived oil at peak load at Kirde boiler plant 216 GJ/y

pollutant	emission factor (g/GJ)	emission (g/s)	emission (t/y)
NO_x	150	0.281	0.032
Particulates (PM SUM)	100	0.188	0.022
CO	100	0.188	0.022
SO_2	-	0.771	0.088
VOC COM	1.1	0.002	0.000
CO_2	-	-	16.544
Heavy metals	396.7 mg/GJ	0.75 mg/s	0.1 kg/y

Table 25. Total pollutant emissions in the event of scenario II (2025)

pollutant	emission (t/y)
NO_x	8.472
Particulates (PM SUM)	3.398
CO	28.156
SO_2	0.651
VOC COM	2.251
CO_2	16.544
Heavy metals	6.4 kg/y

3.4.4 Comparison of pollutant emissions

Summarising the results presented above, the comparison of pollutant emissions in the event of different scenarios is given below.

Table 26. Comparison of pollutant emissions in the event of scenario I and II base situation

	Scenario I		Scenario II
POLLUTANT	Emission (t/y) in the event of SHALE-DERIVED OIL	Emission (t/y) in the event of WOOD CHIPS	Emission (t/y) in the event of WOOD CHIPS
NO_x	9.499	6.391	**11.69**
Particulates (PM SUM)	6.333	**15.038**	5.028
CO	6.333	**62.3**	39.986
SO_2	**25.968**	1.091	0.9
VOC COM	0.069	2.956	**3.142**
CO_2	**4851**	83.639	22.135
Heavy metals	**25**	7.5 kg/a	9.2 kg/y

Table 27. Comparison of pollutant emissions in the event of scenario I and II (2025)

	Scenario I		Scenario II
POLLUTANT	Emission (t/y) in the event of SHALE-DERIVED OIL	Emission (t/y) in the event of WOOD CHIPS	Emission (t/y) in the event of WOOD CHIPS
NO_x	5.392	3.644	**8.472**
Particulates (PM SUM)	3.595	**8.52**	3.398
CO	3.595	**35.247**	28.156
SO_2	**14.752**	0.671	0.651
VOC COM	0.04	1.69	**2.251**
CO_2	**2753**	59.59	16.544
Heavy metals	**14.2**	4.3 kg/a	6.4 kg/y

Maximum emissions in comparison of three versions are given in bold.

Oil fuel brings about significantly higher SO_2, CO_2, heavy metal emissions. Scenario I brings about significantly higher PM and CO emissions. Scenario II causes somewhat higher NOx and VOC emission, but CO_2 emissions decreases significantly.

There are no differences of principle between the base situation and year 2025, emissions of all pollutants are smaller in 2025, due to the decrease of heat consumption.

3.4.5 Comparison of carbon emission

Emissions of various pollutants from combustion process in boiler plants are calculated in previous chapters. As chapter 3.1 explained, the impact of human activity when burning fuel on environment on a global scale is reflected in the **carbon footprint** or the total emission of carbon dioxide and other greenhouse gases (methane, nitrous oxide, etc.).

In this case (in combustion process) no other greenhouse gases besides carbon dioxide emerge, which is why the carbon footprint of boiler plants is characterised by CO_2 emission. If we look at carbon emission in a global scale, however, we must take into consideration that in the event of scenario II (CHP plant), electricity is also generated as a by-product (which is not produced in the event of other perused scenarios) when producing the same amount of heat. We should therefore take the reduction of carbon emission at the expense of electricity into account when calculating global carbon emission (same amount of electricity "is not produced elsewhere").

The reduction of global carbon emission in the event of CHP plant is then equal to carbon emission released during electricity production in a central power plant, and it can be calculated by multiplying the quantity of produced electricity by carbon emission factor.

Pursuant to the report submitted to the European Commission in 2011 by the Ministry of Economic Affairs and Communications [5]:

> *"Large percentage of electricity in Estonia is produced from oil shale (85% in 2010), which releases a lot of carbon when burnt - emission factor as carbon dioxide 99.4 t CO_2/TJ_{fuel}. Because efficiency of producing electricity from oil shale is low, the average emission factor for electricity produced from oil shale is very high – 1085 kg CO_2/MWh_e. About 94% of all CO_2 emission in producing electricity is released from oil shale. Emission factors for oil shale are determined as weighted averages, considering two combustion methods being used - dust combustion and combustion in circulating fluidised bed. Because the relative importance of other fuels in producing electricity is fairly small, the general emission factor is also high - 980 kg CO_2/MWh_e, when taking only fossil fuels into account, the average is 1066 kg CO_2/MWh_e."*

Pursuant to the above-mentioned emission factor (980 *kg CO_2/MWh_e*)[2], carbon emission conservation at the expense of electricity produced at the CHP plant was calculated in this paper and added to the comparison of scenarios.

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[2] However, it must be admitted that there currently isn't an accurate and uniform carbon emission factor value for Estonian conditions. Electricity base line calculations have previously been conducted by the Stockholm Environment Institute Tallinn, but there have been changes in the production of electricity and relevant calculations that take later developments into account are non-existent. For example, instruction materials prepared by the Covenant of Mayors of the European Commission give Estonia an electricity production standard coefficient of 0.908 (t CO2/MWhe) [29] This paper uses the emission factor value taken from the above-mentioned report of the Ministry of Economic Affairs and Communications.

Table 28 presents CO_2 emissions released in Elva boiler plants (taken from calculations conducted earlier - tables 36 and 37) and CO_2 emission conservation at the expense of producing electricity.

Table 28. Carbon emission in the event of different scenarios and reduction of global carbon emission in the event of scenario II

		Heating with shale-derived oil	Heating with wood chips Scen. I	Heating with wood chips Scenario II			
				Carbon emission from boiler plant	Produced electricity	Carbon emission **conservation** from produced electricity	TOTAL carbon emission **conservation**
Basis	t CO2 / y	**4851**	**84**	22	3700 (MWh/y)	-3626	**-3604**
	kg CO2 / MWh	352	6	2	3700 (MWh/y)	-259	-257
2025	t CO2 / y	**2753**	**60**	17	2700 (MWh/y)	-2646	**-2629**
	kg CO2 / MWh	293	6	2	2700 (MWh/y)	-270	-268

Results of the comparison show that transition from shale-derived oil to wood chips brings about a significant decrease of carbon emission from the boiler plant. But almost the same reduction of additional carbon emission is in this case brought about by the transition to a CHP plant (compared to the existing wood chip boilers), this at the expense of produced electricity.

4 LIFE CYCLE OF BIOFUELS

4.1 Typical carbon footprint values of biofuels

If we consider the total life cycle of fuel when assessing environmental impact, we must admit that the production (e.g. NH3 emission due to fertilisation, burning fossil fuels when processing biofuels, etc.) and transport (e.g. NOx, CO, PM emission) of biofuels may constitute a significant part of total environmental impact of biofuels. The relative importance of respective stage is larger, when the production process of a fuel is more complex and energy-intensive or distances to be transported are longer.

The effect of changes to the land use in cultivating raw material for bioenergy should also be taken into account when assessing the environmental impact of a total life cycle. For example, examinations conducted by the Environment Agency of the United Kingdom [30] show that in some cases the carbon footprint of the life cycle of biofuel on established grassland may be larger than that of fossil fuels.

As explained in chapter 3.2, so far there is no methodology for Estonian conditions to calculate the total carbon footprint of the life cycle of biofuels (incl. wood chips) in detail, as stipulated in the Directive on Renewable Energy.

Article 22, section 2 of the Directive on Renewable Energy states that "In estimating net greenhouse gas emission saving from the use of biofuels, the Member State may, for the purpose of the reports referred to in paragraph 1, use the typical values given in part A and part B of Annex V." "Typical value" is defined as an estimate of the representative greenhouse gas emission saving for a particular biofuel production pathway [2].

Therefore, typical values taken from the directive can thus be used to assess the carbon footprint of the life cycle of biofuels.

Typical life cycle greenhouse gas emission values for solid biofuels for different fuels based on biomass are given in the report prepared for supplementing the Directive on Renewable Energy by the European Commission [22]. Greenhouse gas emission arising from the use of fuels is represented in CO2-equivalent grams per fuel megajoule (gCO2eq/MJ). All typical values presented in the report are given in Annex 1. The following table shows the typical values of relevant fuels in consideration of the objectives of this paper:

Table 29. Typical greenhouse gas emission of chosen biofuels according to the Directive on Renewable Energy.

Type of fuel	Typical greenhouse gas emission (gCO2eq/MJ)	Reduction of greenhouse gas emission in comparison to fossil fuels
Wood chips from forest residues (from European forests)	1	96-98%
Wood chips from energy coppice (European plantations)	3	
Wood briquettes or pellets from forest residues (European forests) - using natural gas as process fuel	30	58-72%

According to typical values, the report of the European Commission concludes that if forestry or agricultural residues are used to produce solid biofuels, the reduction of greenhouse gasses is usually over 80% in comparison to fossil fuels [22]. The case study perused in this paper conforms to these general conditions.

4.2 About the life cycle of wood chips on the example of Elva

4.2.1 About the life cycle of wood chips in Estonian conditions

Overview of the production and consumption of wood chips in Estonia is presented in the 2011 report "Overview of the Estonian Bioenergy Market in 2010" [31] commissioned by the Ministry of Economic Affairs and Communications. Pursuant to the report: raw materials used for wood chips are loggings, firewood, firewood from cleaning, etc. The same report also states that Statistics Estonia has not gathered data in Estonia regarding the raw material of wood chips, i.e. there is no data according to raw material types about production volumes of wood chips in Estonia.
Therefore, there are currently no source data to accurately describe the production stage of wood chips in Estonia as a whole.

Treatment and usage options of ash arising from burning wood chips are looked at in a more detailed manner in chapter 6 of this report.

As explained in chapter 3.2, so far there is no methodology for Estonian conditions to calculate the total carbon footprint of the life cycle of biofuels (incl. wood chips) in detail, as stipulated in the Directive on Renewable Energy.

We can presume that because wood chips used in Estonia are local raw material and because wood chips does not require significant processing before using as fuel, the carbon footprint of using wood chips as fuel in Estonian conditions is not high (i.e. ensures the significant reduction of greenhouse gas emission compared to fossil fuels in the contexts of the

Directive on Renewable Energy), but the respective assessments cannot be presently proved with numbers.

In light of the Directive on Renewable Energy, the further research topic in Estonia should be gathering source data and classifying it in terms of raw material of wood chips and the use of these and developing a methodology for detailed calculation of the carbon footprint of the entire life cycle of biofuels.

4.2.2 About the life cycle of wood chips in Elva case study

Since there does not exist a complete methodology for calculating the carbon footprint of the entire life cycle of wood chips in Estonian conditions, this case study quantitatively assessed processes that likely used more fossil fuels in order to give an assessment of the effects of the life cycle. Perused processes are:

- producing wood chips;
- transporting wood chips to the boiler plant.

When comparing the results with CO2 quantities arising from the combustion process described in chapter 4, we can give an approximate assessment of the carbon footprint of the entire life cycle of wood chips in Elva case study conditions.

Overview of the origin of wood chips on the example of Elva

Wood chips burned in Elva boiler plants are sourced from suppliers. The following companies supply boiler plants with wood chips during the period from 1 October, 2011 to 31 May, 2012:

- Selmet Invest OÜ;
- AS Reinsalu Auto;
- OÜ Latesto.

Interviews[3] were conducted with representatives of these suppliers as part of this case study in order to gather necessary data to give an assessment of the environmental impact during the production and transport stage of wood chips.

According to the interviews, the production and transport of wood chips is described in short as follows:

[3] Time of interviews: Selmet Invest OÜ - 21.02.2012; OÜ Latesto – 21.02.2012; AS Reinsalu Auto – 23.02.2012

Producing wood chips

Main sources for wood chips supplied to Elva are the following:

- invaluable wood from logging, coppice and loggings from forestry companies. Supplier chops forestry residues on location with a chipping machine.
- Invaluable forest and coppice from farmers. Growing coppice and invaluable wood is first cut with a cutter, then transported out of the coppice with vehicles and chopped on location with a chipping machine.
- Residue from sawmills (sawing surfaces, log residues, etc.) - chopped with a chipping machine by the supplier, if necessary.
- Wood residue from Otepää plywood industry - comes to the supplier finished.
- Wood chips do not generally require additional processing (in addition to the above-mentioned).

Transporting wood chips

- Transport distance of wood chips from the production site to Elva boiler plant is on average 50-70 km. Supplier considered the maximum distance for expedient transport of wood chips to be 100-120 km.
- Majority of wood chips transported to Elva are from Southern Estonia. To a smaller extent they are also transported from Northern Latvia, but transport distances are within the same range (70-100 km) in this case also.
- If possible (and usually), produced wood chips are transported directly to the contracting entity (boiler plant). That is, intermediate depositing of wood chips can usually be avoided. In the event that the wood chips transported to Elva boiler plants are brought from an intermediate depot, it does not cause a significant increase of distance during transport - suppliers' warehouses are also located in Southern Estonia.
- Trailers with a holding capacity of 80-90 m^3 load are used for transport.

According to interviews, we can say that technologies with a higher than usual environmental impact are not used to produce wood chips used in Elva boiler plants and transport distances for wood chips are not long. Changes in land use for gathering wood chips are also non-existent, it is rather using residues from other industry sectors (forestry, timber industry).

Illustrative calculations for two separately perused stages are presented subsequently. Because there is no complete methodology for Estonian conditions, the calculation should be considered approximate estimates where used presumptions are taken from sources with different origins (sources are referred to in the calculations) and may depend on several circumstances. It is not expected to significantly distort the general conclusion of the calculations, however.

Carbon emission during the production of wood chips

According to interviews with suppliers of wood chips burned in Elva boiler plants, the following approximate motor oil quantities can be used as a basis for the calculations:

- Fuel consumption for chopping wood 0.6-0.7 l of fuel per 1 m^3 wood chips.
- In the event that growing wood is chopped, fuel consumption for transporting wood out of the coppice, with an approximate magnitude of 0.3--0.5 l of fuel per 1 m^3 wood chips, can be added to it. Fuel used for cutting growing wood is minimal compared to the aforementioned magnitudes (~10 times smaller).

Summarising the aforementioned, we consider the approximate fuel consumption for producing wood to be **1 l of fuel per 1 m^3 wood chips**.

Calculations are made according to diesel fuel.
Pursuant to the manual of the UN Intergovernmental Panel on Climate Change [18] (hereinafter 2006 IPCC), the following source data has been taken for calculating carbon emission:

- Emission factors for vehicles operating on terrain in the forestry sector:
  - 74100 kg CO_2 / TJ
  - 4.15 kg CH_4 / TJ
  - 28.6 kg N_2O /TJ
- Energy value of diesel fuel (NCV): 43 TJ / Gg

Estimated density of diesel fuel: 0.845 kg/l.

Pursuant to the Directive 2009/28/EC of the European Parliament and of the Council [2], CH_4 and N_2O quantities are converted to the CO_2-equivalent, using the following GWP values:

- CO_2: 1
- N_2O: 296
- CH_4: 23.

<u>The following emissions have been calculated on the basis of the listed source data:</u>

- 2.69 kg CO_2 / l;
- 0.0002 kg CH_4 / l, converted to CO_2-equivalent 0.003 kg CO_2 / l;
- 0.001 kg N_2O / l, converted to CO_2-equivalent 0.03 kg CO_2 / l;

By adding up the three above-mentioned greenhouse gas emissions, we find that the entire CO_2 emission when producing wood chips is **3 kg CO_2 per 1 litre of burned motor fuel.**

Therefore, approximately **3 kg CO_2** is released when producing 1m^3 of wood chips (chopping) in this example.

Carbon emission during the transport of wood chips

The following presumptions have been made for calculating motor fuel consumption during the transport of wood chips, according to interviews:

- Transport distance of wood chips to Elva boiler plant is on average 50-70 km. Taking into account that the vehicle has to drive the route both ways to transport wood chips and any other potential additional distances, the total distance travelled is estimated to be **150 km** for one load.
- On the estimation of the suppliers, trailer fits 65-90 m^3 of wood chips, in calculations the average is **75 m^3** load.
- Vehicle fuel consumption for transporting wood chips is 45-40 l of fuel per 100 km. Here, calculations consider **fuel consumption of 40 l of fuel per 100 km.**

Summarising the above-mentioned presumptions, we can calculate that in the event of Elva's example **0.8 l of fuel is required for transporting 1 m^3 of wood chips to the boiler plant.**

Calculations are made according to diesel fuel.
Pursuant to 2006 IPCC [18], the following source data is taken for calculating carbon emission:

- Emission factors during highway transport:
  - 74100 kg CO_2 / TJ
  - 3,9 kg CH_4 / TJ
  - 3.9 kg N_2O /TJ
- Energy value of diesel fuel (NCV): 43 TJ / Gg

Estimated density of diesel fuel: 0.845 kg/l.

Pursuant to the Directive 2009/28/EC of the European Parliament and of the Council [2], CH4 and N2O quantities are converted to the CO2-equivalent, using the following GWP values:

- CO_2: 1
- N_2O: 296
- CH_4: 23.

<u>The following emissions have been calculated on the basis of the listed source data:</u>

- 2,69 kg CO_2 / l;
- 0.0001 kg CH_4 / l, converted to CO_2-equivalent 0.003 kg CO_2 / l;
- 0.0001 kg N_2O / l, converted to CO_2-equivalent 0.,04 kg CO_2 / l.

Because emissions of other greenhouse gases are nearly non-existent compared to CO_2 emission, the entire CO_2 emission during transport of wood chips is also **2.7 kg CO_2 / l**.

Considering the fuel consumption derived above, we can assess that approximately **2.2 kg of CO_2** is released during the transport of 1 $m^3$of wood chips to the boiler point on the example of Elva.

Conclusions

Summarising the stages analysed above, an estimated **5.2 kg of CO_2** in total is released during producing (3 kg CO_2) and transporting (2.2 kg CO_2) 1 m^3 of wood chips.

Considering that the average calorific value of wood chips in this paper is 0.65 MWh/m^3 [26], we can assess that an estimated **8 kg of CO_2** is released during the production and transport of wood chips necessary for producing 1 MWh of energy.

If we compare this to the CO_2 emissions emerging from combustion processes a the boiler plant (see table 28), we can mention the following conclusions:

- Carbon emission released during the production and transport of wood chips is in the same magnitude as carbon emission from peak boilers if the primary fuel is wood chips.
- In comparison to the situation where boiler plants only operate on fossil fuels, carbon emission released during the production and transport of wood chips is only approximately a few per cent.
- CO_2 emissions released during the production and transport of wood chips also only constitute a few per cent of the reduction of CO_2 emission achieved by changing the technology or fuel burnt in boiler plants.

We can therefore conclude that the production and transport stage of wood chips in Elva boiler plants only constitute a small part of the total carbon footprint of Elva heat sector.

5 DEPOSITING AND USING ASH

5.1 Overview of wood ash

According to the list of waste imposed pursuant to the Waste Act, ash arising from burning biomass is classified with waste code 10 01 03 - fly ash from peat and untreated wood and 10 01 01 - bottom ash, slag, and boiler dust. While fly ash has a separate code for wood and peat, bottom ash, slag, and boiler dust is not distinctively identified (excl. oil, heavy fuel oil, and oil shale). Pursuant to that, the only statistic indicators that can be differentiated in the state waste handling statistics are those of fly ash produced when burning biomass. Waste statistics also show waste codes 10 01 15 and 10 01 17 that are non-dangerous bottom ash from co-incineration and non-dangerous fly ash from co-incineration respectively. These fuels are waste (which are not looked at in a more detailed manner in the paper based on the example of AS Elva Soojus because these are a different type of waste in terms of their composition and handling options) emerging from co-incineration of biomass and fossil fuels (e.g. coal, oil shale, etc.).

Table 30. Production of fly ash from peat and untreated wood (waste code 10 01 03) and bottom ash, slag, and boiler dust (waste code 10 01 01) from burning fuels (excl. oil, heavy fuel oil, and oil shale) and the handing of those (pursuant to waste handling annual reviews prepared by the Estonian Environment Information Centre).

	Type of waste	Production, t	Recycling, t	Depositing in landfills, t	Unspecified handling, t	Residue at the end of the year, t
2010	10 01 03	11088	11016	-	72	-
	10 01 01	4595	813	696	57	3590
2009	10 01 03	7818	4348	1447	2022	-
	10 01 01	4005	2303	883	552	589

Pursuant to the presented information (handed to the waste handler), AS Elva Soojus Nooruse boiler plant produced 48.11 t of ash in 2009, 58.02 t of ash in 2010, and 94.16 t of ash in 2011. It is a mix of fly and bottom ash that is gathered in the same filling hopper. Ash is handed to Ragn-Sells AS (information regarding what the company does with ash (whether they take it to a landfill or processes and recycles) is not available), pursuant to the contract. Records are not kept for ash quantities in the Kirde boiler plant, where it's given to a local farmer for handling. Pursuant to the quantity of wood chips in Kirde boiler plant and ash production factor indicators for Nooruse boiler plant, we can assess the quantity of ash produced in Kirde boiler plant to be 25-35 t of ash per year. The quantity of ash produced in AS Elva Soojus boiler plants is marginal (in magnitude of 1%) compared to the quantity of ash produced from burning peat and wood in Estonia (see table 30).

Composition of wood ash depends on various circumstances, including wood used in the combustion plant (whether it's clean wood or processed wood residue), type of tree, proportion of wood bark in the fuel, etc. Chemical composition of wood ash produced in different combustion plants is thus fairly variable. One important factor for the generation of the chemical composition of ash is combustion technology, particularly combustion temperature (i.e. whether combustion takes place at a low temperature - for example furnaces at home - or high temperature - large boiler plants) and whether fly and bottom ash are separated for handling. Wood ash primarily consists of phosphorus, calcium, magnesium, and potassium; nitrogen content in wood ash is minimal because it flies gaseous in the combustion process [32]. Mineral compounds in ash are primarily oxides, hydroxides, silicates, and carbonates. Description of the average composition of wood ash pursuant to wood ash data in the database of the Swedish University of Agricultural Sciences is presented in table 31.

Table 31. Average chemical composition of wood ash in the Wood Ash Database of the Swedish University of Agricultural Sciences (SLU) [33].

Element	**Unit**	**Fly ash**	**Bottom ash**
Ca	g/kg	202.6	130.39
K	g/kg	59.51	43.88
Mg	g/kg	20.23	15.39
Mn	g/kg	10.47	6.97
Fe	g/kg	26.02	13.37
Na	g/kg	9.34	9.72
Al	g/kg	29.00	26.24
S	g/kg	15.56	0.55
P	g/kg	13.74	9.04
Hg	mg/kg	1.3	0.07
Cd	mg/kg	23.47	1.91
As	mg/kg	30.41	7.17
Cr	mg/kg	82.91	75.73
Ni	mg/kg	49.12	30.33
Pb	mg/kg	182.62	40.85
Cu	mg/kg	146.34	87.6
Zn	mg/kg	4402.84	508,79

Heavy metal content in fly and bottom ash differs significantly, because some metals vaporise at high temperatures, followed by their condensation away from the combustion zone as temperature lowers, as a result of which the content of heavy metals is significantly higher in fly ash than in bottom ash. Some metals may result in a reverse situation. Very high zinc content in wood fly ash shown in the table is significant. For example, based on literary sources, Pitman [34] has presented that zinc content in fly ash of wood boiler plants is in the range between 40-700 mg/kg. Environmentally dangerous organic compounds are not present in ash produced by burning untreated wood. Despite the significant PCB load in 1950-1970s, these compounds have not accumulated in wood, and traces of PCB have not been detected in the ash of boiler plants burning untreated wood, according to literature [34]. PAH can be represented by less toxic compounds (e.g. naphthalene), the probability of these may be higher with inefficient combustion when large amounts of unburnt carbon can also be found in ash. Dioxin and furan content in ash is small, and their leaching out of ash is unlikely due to the absorbent properties of ash [34].

As previously described, the chemical and physical properties of ash produced in different combustion plants may vary significantly, which is why it is impossible to characterise the properties of ash in detail without the results of specific chemical analyses. Analyses have not been conducted on the chemical composition or physical properties of ash in Elva boiler plants (ash samples have been gathered for analyses, but the results have not reached Elva), so the composition of ashes given in table 31 should be used as a guide of principle.

5.2 Handling options for ash

Using biomass as fuel in boiler plants or CHP plants has been considered an important development trend at a national level, and developing and promoting it has been imposed in several development documents of this sector. However, we can assess that the question of handling ash has not been given much attention to in this sector. Examinations or materials regarding the use of biomass generally consider using ash as a fertiliser in forestry or liming fields to be a solution for handling ash, using it as a filler or in road construction has also been proposed as an option, but specific instruction materials have not been prepared. There are also estimations that wood ash should be recycled in forests and straw ash in agricultural lands, but peat ash has not been considered suitable for fertilising forest and field produce due to its composition [35]. The issues of handling ash produced by burning biomass have not been treated in the state waste management plan either, however, and because this type of waste is a production waste, attention has not been paid (predominantly) in the waste management plans of local governments either. The general trend of handling and developing the handling of production waste that ash also falls under is increasing recycling and reducing disposal (incl. disposing in landfills).

Pursuant to the information regarding handling ash presented by AS Elva Soojus, it should be mentioned that the produced ash is waste that must be handled according to the Waste Act. Pursuant to the Waste Act, waste producer or person transferring waste must verify that the receiver of waste has a waste permit or integrated environmental permit that permits handling transferred waste. In the event that waste permit or integrated environmental permit is not required for handling transferred waste, the transferor of waste must verify that the receiver of waste is competent to handle waste and has relevant technical and environmental protection equipment.

Various areas of using ash in terms of both legislation and practical application aspect have been described subsequently. Areas to be treated are: depositing in landfills, recycling as filler, using as lime on fields, (re)using in forestry.

5.2.1 Transferring to the waste handler

In heat producer's viewpoint, transferring produced ash to the waste handler is often the most available and comfortable, but possibly also most expensive, option. The company often loses track of further ash handling after transferring it to the waste handler. Waste handlers currently use primarily two practices for handling ash from biomass: depositing ash in landfills or recycling it with different options.

Ash of biomass belongs amongst non-hazardous waste, and it can be deposited in non-hazardous waste landfill. The closest non-hazardous waste landfill to Elva is the Torma landfill in Torma rural municipality, Jõgevamaa, approx. 85 km from Elva. Other operating non-hazardous waste landfills are Jõelähtme, Uikla, Väätsa, and Paikuse, but these are even further from Elva. The cost of depositing ash in the landfill includes transport cost for waste and landfill operator's reception price (which also includes pollution charges). Deposition reception price for ash, as for other non-hazardous waste, in Torma landfill is 50.58 €/t (including VAT). Other landfills have the same magnitude of prices. Transport cost for taking ash to the landfill will be added, which can be found based on the following indicators: price of transport contracted from waste handler approx. 1.2 €/km (including VAT), transport distance 180 km, according to the scheme applied in AS Elva Soojus, waste handler removes 5 t of ash at a time. According to these presumptions, the cost of transporting ash to Torma landfill and depositing it there is approx. 94 €/t. Pursuant to given unit costs and ash quantity produced in Elva boiler plants in 2011 (estimated to be 125 t, actual quantity is not available), yearly cost of ash handling is in the magnitude of 12 000 €. The cost of transferring ash to the landfill largely depends on transport cost, however, which in turn depends on the applied logistic scheme. If handling is reorganised in a way that, for example, 10 t of ash is transported at a time, the price of handling ash would be approx. 72 €/t based on transport, 62 €/t for a 20 ton load (yearly cost of ash handling would then be 9000 or 7800 € respectively). Actual sums spent on handling ash by AS Elva Soojus are not available.

In addition to direct depositing, waste handlers are trying to find potential recycling options for the ash of biomass. According to state waste statistics, majority of wood and peat fly ash is recycled. Ash is largely recycled in landfills and waste centres where it is used for interim covering, if possible, and other similar specific and technical objectives. By analysing waste permits of various waste handling companies in the information system of environmental permits, we can conclude that many companies have the right to recycle ash, and recycling is conducted with the help of various recycling activities (multiplicity of activities may also be due to malfunctions in the system, as ash is sometimes classified as an organic substance, for example). Besides using ash as lime fertiliser (looked at later in the paper), its main recycling method is adding it to the compost generated by composting biodegradable waste (for example, companies Velo AV OÜ, Bilkker OÜ, Ragn Sells). The cost of such recycling options, however, largely depends on the specific handler, and reception prices of different recyclers cannot be expressed uniformly. Specific waste handlers also often handle ash from a specific company. Recycling ash as waste requires the recycler to have a waste permit.

Transferring ash to a waste handler to be handled is usually the easiest and less problematic, but often also the most expensive, solution for a waste producer. The cost of depositing ash in landfills largely depends on the logistics of waste transport.

5.2.2 Recycling ash as filler

In previous years, calling ash an inert waste and using it as filler, for example, was a fairly common practice. It was largely possible because the nature of inert waste was not uniformly standardised. By the time of preparing this paper, requirements for using non-hazardous waste as filler in road construction, planning, filling, and repairing sites have been specified. Requirements have been stipulated in the Minister of the Environment's 21. 04. 2004 regulation no. 21 „Requirements for recycling or removing from production site for a specific type and quantity of non-hazardous waste that does not require waste permit for handling" §4[1] [36]. This paragraph imposes requirements for the concentration of hazardous substances (also organic carbon in the event of ash) in fillers, leaching of pollutants, and specific recycling techniques, these requirements were entered into force in 2011.

The most important issue regarding ash are leaching indicators, particularly the total value of dissolved solids (TDS). Analyses of the solutions of ash samples available to the authors of the paper from different Estonian boiler plants that burn biomass show results where indicator exceed the limit value of total quantity of dissolved substance given in the aforementioned regulation by almost an entire magnitude (which is to be expected, because using ash as a fertiliser would not be possible otherwise). Excessive (i.e. above limit value) alkalinity of the solution may also set the limit. In principle, we can assess that there shouldn't be any problems with heavy metal concentration of ash and leaching heavy metals, either. Pursuant to data presented in literature [34] and various analyses of ash from Estonian boiler plants that burn biomass available to the authors of this paper, heavy metal concentrations in ash predominantly remain below limit values (imposed with the Minister of the Environment's 11.08.2010 regulation no. 38 "Limit values of dangerous substances in the soil" [37]). Generally, problems with the leaching of heavy metals are not anticipated either, the heavy metal concentration in ash solution has remained well below limit values in the leachate analyses of ash samples available to the authors of the paper. Unlike for other waste, the total quantity of unburnt organic carbon has also been limited for ashes. This parameter is usually not examined in analyses of ashes, due to which data is relatively sparse. The concentration of unburnt organic carbon in ash largely depends on the combustion conditions and technology and may therefore vary significantly. According to the regulation, total content of organic carbon (TOC) in ash may not exceed 30 g/kg (i.e. 3%). Based on literary sources, Pitman [34] has argued that the concentration of unburnt carbon in wood boiler plants in Eastern USA is usually in the range of 7-50% (average 26%), and therefore it can be presumed that conformity to the requirements of the regulation cannot be ensured in wood boiler plants.

In conclusion, we can assess based on the existing data that ash produced when burning wood does not usually conform to the conditions stipulated for waste that is permitted to use for road construction, planning, filling, and repairing sites. Anticipated problems are foremost with the total content of substance in ash solutions, but also excessively high content of unburnt carbon and excessive alkaline reaction of the solution. Processing ash (e.g. pelleting) could prove to be a solution for this problem, but relevant practice in Estonia is not known.

Pursuant to the amended requirements of the legislation, recycling wood ash as inert material as previously widely practised (for example, filling the ground) is not practically applicable any longer.

5.2.3 Using wood ash in agriculture

Soon, the primary recycling option of ash should be its use as a soil amendment or lime fertiliser in agriculture. Large part of South and South-East Estonian soils are acidic, the optimal soil reaction for the majority of cultivated produce is neutral. Soil reaction significantly affects the activity of microorganisms in soil and mobility of plant nutrients. Mobility and metabolism of plant nutrients in acidic soil is small. On the other hand, mobility and metabolism of several semi-micro and microelements, including large quantities of harmful heavy metals, is better in acidic soil [38]. Acidic soil also doesn't have good structure, calcium brought into the soil while liming enhances the generation of soil grains, removing excessive acidity of soil also activates microorganisms and earthworms [39].

When using ash as a fertiliser, it must be remembered that ash from AS Elva Soojus is waste in the current situation. This means that the person using ash as a fertiliser must have a respective waste permit. There isn't much reason to hope that potential ash users would apply for respective permits in a situation where using ash as a fertiliser is uncommon. Realistic solution would be for heat companies to apply for handling ash as a fertiliser, in this case it would no longer be waste but a product, and its use would no longer be waste handling in terms of the Waste Act.

Plant material ash as lime fertiliser has been mentioned in the Minister of Agriculture's 10.02.2009 regulation no. 19 "Nomenclature of fertilisers" [40], requirements for ash as lime fertiliser produced during the combustion of plant material have been mentioned in the minister of Agriculture's 10.03.2005 regulation no. 23 "Requirements for the composition of fertiliser by types of fertiliser" [41]. Thus, handling wood ash as lime fertiliser when performing respective requirements is realistic. Ash of some companies has also been entered in the state register of fertilisers[4] as a fertiliser. Minister of

[4] Register is located at: http://www.pma.agri.ee/index.php?id=104&sub=134&sub2=167

Agriculture's 25.07.2003 regulation no. 75 "Requirements for management works for land improvement systems" [42] includes an additional provision, which states that wood ash can be used as a soil amendment, unless it's ash from wood that has been treated with laminated timber, treated with chemical, painted with environmentally dangerous paint, or treated with oil and grease, or become stained with these.

Requirements for wood ash as fertiliser composition are stipulated in the Minister of Agriculture's 10.03.2005 regulation no. 23 "Requirements for the composition of fertiliser by types of fertiliser" [41]. Pursuant to this regulation, the neutralising capacity of ash as calcium used as lime fertiliser must be minimum 10% and humidity maximum 6% (of mass), quantity of potassium soluble in diluted hydrochloric acid must also be analysed. Permitted maximum concentrations of heavy metals are also environmentally important. Data regarding the concentration of heavy metals in wood ash produced in Estonian boiler plants are generally incomplete [43] and variable. It is therefore impossible to uniformly predict whether wood ash produced in every boiler plant conforms to valid regulations in relation to the concentration of heavy metals. Some examples on the concentration of heavy metals in the ash of different Estonian boiler plants, also permitted concentrations of lime fertilisers, are given in table 32. According to presented examples, one of wood chips fly ash and pellet ash did not conform to the requirements due to excessive potassium concentration. We can also conclude based on the literature [34] that it's mostly potassium, chromium, and lead that exceed the limit values, and based on Swedish data, excessive zinc may also occur. Therefore, the conformity of ash produced in a specific boiler plant to requirements of lime fertiliser can only be assessed according to chemical analyses of a specific ash. Ash analyses must be repeated regularly, especially when significant changes take place in used fuels. Concentration of heavy metals is usually higher in fly ash in comparison to bottom ash [34]. In the event that a specific boiler plant collects bottom and fly ash together and heavy metal concentrations in the mix still end up to too high, organising the collection and subsequent handling of fly and bottom ash separately may be an option.

Table 32. Examples of some properties of ash in Estonian boiler plants and lime fertilisers (pursuant to the Minister of Agriculture's 10.03.2005 regulation no. 23 "Requirements for the composition of fertiliser by types of fertiliser" [41])

	Wood chips fly ash	**Wood chips fly ash**	**Wood chips bottom ash**	**Sawdust pellet ash**	**Permitted concentration in lime fertilisers (mg/kg)**
Potassium (mg/kg)	1.7	13.9	0.05	4.08	3
Mercury (mg/kg)	<0.05	0.02	0.01	0.0	2
Lead (mg/kg)	12.8	7.4	<0.2	4.56	100
Nickel (mg/kg)	14	5.7	2.7	6	100
Arsenic (mg/kg)	1.1	9.2	4.2	<0.1	50
Copper (mg/kg)	14.9	68	19	35	600
Zinc (mg/kg)	470	1450	739	18.6	1500
Chromium (mg/kg)	14.5	7.7	2.5	17.8	50

Fertiliser and its producer is entered in the register of fertilisers by the Fertilisers Department of the Agricultural Board. For that, a respective application and additional data that prove the fertiliser's conformity to requirements has to be submitted. Respective instructions are available on the Agricultural Board's web page [44]. State fee (127.82 €) is required for entering the fertiliser in the register, the fertiliser producer also pays a state fee for the quantity of marketable fertiliser (0.00001 €/kg for lime fertilisers). Waste permit has to be applied for in order to define ash as waste (i.e. cessation of waste in the wording of Waste Act § 2^1).

Requirements for handling wood ash as soil amendment are stipulated in Minister of Agriculture's 25.07.2003 regulation no. 75 "Requirements for management works for land improvement systems" [42]. Pursuant to the regulation, dust soil amendment must be kept in a rainfall and wind resistant dry storage facility, if no such facility exists then isolated from the ground in a humidity-proof manner, under a water and wind resistant cover for up to 30 days. Dust soil amendment must be transported with a tank vehicle equipped with a pneumatic loading device, but wood, straw, chaff, hay, and peat ash can also be transported in closed rainfall and dust resistant container, vessel, or freight. In the event of liming with wood, straw, chaff, hay, and peat ash, the dosage of soil amendment is 2-5 t/ha (depending on lime consumption), the time and scattering technique of liming with wood ash must eliminate direct contact of wood ash with sprouting seeds, emerging young plants, or plant roots. The regulation also mentions several detailed requirements for scattering soil amendment.

Considering that, on the one hand, about 100-125 t of ash per year is generated in AS Elva Soojus boiler plants and, on the other hand, ash consumption for liming with ash is 2-5 t/ha (depending on the lime consumption of soils), the required field's surface area for scattering all the ash should be in the range of 20-60 ha. Acidic soils must be limed regularly;

depending on several factors, they need to be re-limed every 4-7 years [39]. It is generally recommended to lime with soil amendment quantities that are smaller than maximum liming standards, but do it more frequently. It must be taken into account that even though it is, in principle, possible to lime throughout the year, it is practically not possible to lime fields during the growth period of produce (excl. grasslands), which is why the peak time inevitably falls on the period following harvesting and on early spring [39]. This, however, denotes the need for establishing a wood ash storage facility.

The cost of liming fields with wood ash (as with other soil amendments) consist of the price of soil amendment, transport cost of soil amendment, and cost of scattering works. Cost of liming therefore varies, depending foremost on the transport distance and price of soil amendment, price of scattering work is essentially the same for various soil amendments. Data regarding the price of liming with wood ash is currently not available, but it is possible to give numerical indicators for liming with clinker dust, for example. According to PRIA subsidy granted in 2010 in the framework of RDP measure 1.8 "Infrastructure of agriculture and forestry", the unit cost for scattering soil amendment is 10 €/t [45]. In the event of liming with wood ash, the production cost of soil amendment is minimal (heat producer's goal should be to get rid of the ash as cheaply as possible), transport cost to fields will be added.

According to the Minister of Agriculture's 27.05.2010 regulation no. 65 "Requirements for receiving investment aid for agriculture and forestry infrastructure, the procedure of applying for the aid, and detailed procedure of proceeding the application" [46], it is possible to apply for a subsidy for liming fields, and according to § 3 s. 1 cl. 1 of the regulation, subsidised activities may also include purchasing, transporting, and scattering (liming soil) soil amendment required for liming soils on the regulating network area of land improvement system on agricultural land.

Conformity of ash produced in AS Elva Soojus boiler plants to the standards imposed on lime fertilisers (incl. heavy metal concentration in ash) has not been examined. It is not possible to assess without conducting specific chemical analyses whether ash produced in a company's boiler plants corresponds to the requirements and, thus, if it can be used on fields as lime fertiliser. If produced ash corresponds to the requirements of lime fertiliser, its cost depends directly on whether local agricultural producers are interested in (demand for) conducting liming works. The cost (or cost benefit) of scattering ash on the field cannot therefore be calculated uniformly. We can presume that the unit cost for scattering soil amendment is about 5 times smaller than the reception price in a landfill, thus the cost or (cost benefit) of using ash in agriculture will largely depend on the cost of transporting ash to the fields (foremost on the distance of fields to be limed from the production site of ash). In practice, it would probably be sensible for a heat producer to collaborate with companies conducting field liming works, who have technical equipment both for transporting and scattering lime fertiliser.

Using wood ash in agriculture as lime fertiliser can be considered the most prospective method for using ash at the moment. Using wood ash as a soil amendment presupposes the conformity of ash properties (incl. concentration of heavy metals) to the requirements of lime fertilisers and entering ash in the register of fertilisers. Applicability depends on the local agricultural producers' demand for liming works.

5.2.4 Using wood ash in forestry

For a long time already, examinations have been conducted in the Nordic countries regarding the use of ash produced from burning biomass, but in particular wood, in forestry. In the last few years, examinations have also given way to practical activities, i.e. more and more wood ash is actually recycled or disposed of in forestry. Lately, this topic has attracted more attention in Estonia too, particularly in the Estonian University of Life Sciences. The dominant view is that intensive forestry causes soil impoverishment of nutrients and acidification of soil. One solution would be to return wood ash to the forest, thus compensating plant nutrients removed from forest soils with logging waste, and ash would be utilised [32]. Wood ash has not been used in Estonia for neutralising forest soils and enriching nutrient substrate so far, thus there are no practical experiences of influencing the growth and production of forests with the use of wood ash [32].

Using wood ash as a fertiliser on forest lands has not been uniformly regulated in the Estonian legislation. Estonian Forestry Development Plan Until 2020 also states that the question of returning wood ash from producing energy to the forest has not been completely solved. Forest Act § 27 (3) prescribes that the fertilisation of forests (except the fertilisation of forest nurseries) with direct effective mineral fertilisers is prohibited due to reasons of nature conservation [47]. Pursuant to the instruction material of EGM's volunteer forest auditors [48], direct effective fertilisers are those that contain chemical substances necessary for plants, and fertilisers that influence chemical processes in the soil and thus improve nutrition conditions of trees are permitted in the forest, such as lime fertilisers. Fertilisers Act also defines wood ash as soil amendment or lime fertiliser, the objective of which is to reduce the acidity of soil. At the same time, however, researches about the use of wood ash on forest lands emphasise that returning wood ash to the forest helps to (in addition to solving the problem of ash handling) compensate the loss of nutrients arisen due to intense forestry (i.e. relatively important emphasis is on nutrients and not on changing soil's reaction). We can thus conclude that using wood ash in forestry has not been uniformly regulated in the legislation at the moment, and it is important to achieve clarity in this matter.

Using wood ash in forestry has been researched in Estonia predominantly in the Institute of Forestry and Rural Engineering of the Estonian University of Life Sciences (e.g. EIC project no. 47 "Options of using wood ash in forestry" in 2006). Results of both this project and several other researches are not uniform. Many examinations conducted both in Estonia and other countries that look at the options of using ash in fertilising forests have generally revealed positive results, but harmful effects have also been detected [32]. Considering the aforementioned, extensive use of wood ash in forestry cannot be viewed as a realistic solution for the ash problems of heat producers, at least not in short-term In long-term, it may become one option. Because fertilising forests with wood ash has not been practised in Estonia, the technological or economic aspects of this are not uniformly clear either.

In Nordic countries, fertilising with ash has moved from research level to actual practises, and fertilising requirements for wood ash have been developed, which define fertilisation standards, and also, for example, maximum permitted concentration of heavy metals in wood ash taken to forest, or maximum loads of heavy metals [49]. The cost of fertilising forests with wood ash depends on several different circumstances; scattering ash on the forest land with a tractor would cost about 14-22 €/t, plus transport cost for ash [50]. Several researches indicate that fertilising with wood ash gives more positive effect in habitations growing on peat soils where nitrogen is naturally prevalent, but have a deficiency of phosphorus and potassium [51]. In the event of other soil types, direct fertilisation may require mixing it with a component that adds nitrogen [50], which in turn would affect the economical profitability of fertilisation. Swedish researches focusing on fertilising forests with wood ash also mention that using so-called young ash as forest fertiliser may be inadvisable, because its excessive aggressiveness and alkalinity may damage the ground vegetation of the forest [50]. This can be avoided by stabilising ash, during which ash is mixed with water and allowed to harder on its own, or a hardener is added (e.g. dolomite), and ash is then pressed into granules or pellets. Stabilising ash, however, makes ash handling in forestry more expensive. The aforementioned reveals that Nordic countries haven't developed a uniform best and universal practice for fertilising the forest with wood ash either. It is therefore impossible to demonstrate the economic cost of this activity. Pursuant to the unit cost of Swedish ash scattering referred to previously, however, we can presume that this solution would be economically more affordable (predominantly due to transport cost) for AS Elva Soojus than depositing ash.

Wood ash has not been recycled in forestry in Estonia, although it is a common practice in the Nordic countries. Various legal and practical issues that require solutions appear in Estonia for using wood ash in forestry. Until then, the question must be looked at as a theoretical prospective solution.

Using wood ash in restoring spent peat fields is a topic closely related to forestry. Institute of Forestry and Rural Engineering of the Estonian University of Life Sciences has conducted researches of this topic too (e.g. EIC project no. 32 "Utilising waste produced in bioenergy for silvicultural purposes" in 2007, EIC project no. 51 "Ecological analysis of spent remainder swamps in Ahtme county to find prospective recultivation options" in 2007). The results of the researches have shown that using nutrient-rich ash helps the afforestation of milled peatlands by significantly accelerating the growth of trees and improving the balance of nutrients in peat [51]. However, these are relatively short-term researches (with a duration of up to a few vegetation periods), and it is admitted that additional examinations are necessary for determining a long-term effect. Using wood ash to restore remainder swamps is thus probably one potential option, but it is unlikely to be a permanent and long-term solution for the heat producer's (for example, AS Elva Soojus) ash handling problems.

5.2.5 Other options for use

In addition to the aforementioned, it is possible to find other, but less common and often theoretical, recycling options for wood ash. Literature has pinned its faith on using ash of biomass as raw material in industrial processes, mostly using it as an additive in the production of concrete, bricks, glass, and cement. It has been discovered, however, that using ash as raw material is very complicated, and they are likely to be theoretical solutions that have in some cases (depending on specific quality of ash, technological processes, quality requirements for products, etc.) been successfully applied in reality. Such options should, however, be looked at when specific conditions and requirements are known.

5.2.6 Summary of options for ash handling

Presently, the most common way to handle wood ash is to deposit or recycle it in landfills. Alternative for it would foremost be using it as lime fertiliser in agriculture. This presupposes that the composition of ash conforms to the requirements (foremost in terms of heavy metal concentration, see table 32) presented in the Minister of Agriculture's 10.03.2005 regulation no. 23 "Requirements for the composition of fertiliser by types of fertiliser" [41], and that the heat producer registers produced ash as a lime fertiliser in the register of fertilisers and applies for a waste permit, which changes ash from waste to product. In long-term, using ash in forestry could become applicable, especially in re-cultivating spent peatlands. Depending on specific conditions, some other recycling method may also become possible and economically reasonable (e.g. mixing it with waste water sediment and using it in restoring or re-cultivating greenery, for example). Recycling ash as waste generally requires the recycler to have a waste permit. Considering valid requirements, it is usually not possible to use wood ash as inert material to fill the ground, for example.

Table 33. Applicability of various wood ash uses

Method of use	Applicability
Depositing or recycling in a landfill	So far the most common practice among ash handling in Estonia. Comfortable but fairly expensive solution for a heat producer (AS Elva Soojus). Cost of handling is mostly due to transport cost, but also due to reception prices of a landfill.
Using as lime fertiliser in agriculture	Currently the primary alternative for depositing. Requires entering ash in the register of fertilisers. Applicability depends on the demand for liming fields. Presumably cheaper for AS Elva Soojus than deposition, mostly at the expense of transport cost.
Using in forestry	Has not been practised in Estonia to date, various legal and practical issues that need to be resolved. Common practice in the Nordic countries. Therefore, currently theoretically prospective solution.
Using for filling, arranging the ground	Previously common practise, currently not applicable due to valid requirements
Other options for handling	May become possible and economically reasonable (for example, mixing it with compost material and using in greenery, presupposes cooperation with waste handler) or theoretical (for example, using it as a material in construction material industry) alternative.

6 SUMMARY

The aim of the analyses was not to assess all environmental impacts of woodchip fuel, but to focus on air emissions from the boiler houses as the most significant environmental aspect of fuel combustion.

The impact of heat production is measured by **carbon footprint** – the amount of overall GHG emissions during the whole life cycle of heat production. Wood fuel (eg. wood chips) is considered to be carbon neutral. As a tree grows it absorbs carbon dioxide (CO_2) from the atmosphere. The same level of CO_2 is subsequently returned to the atmosphere when the processed wood is burnt. This means that burning wood fuel does not result in Greenhouse Gas (GHG) emissions. However, the overall GHG emissions during the whole life cycle are (in the worst case to a great extent) impacted by production and transportation of biofuels.

The Renewable Energy Directive (RED)[5], adopted in 2008, sets the framework for reduction of GHG emissions for (a) biofuels for transport and (b) bioliquids used in other sectors (electricity, heating and cooling). The methodology set out in RED considers also the **Life Cycle** of biofuels. In 2010 an additional Report[6] was issued by the European Commission to accompany the RED that set the requirements also for solid and gaseous biomass sources in electricity, heating and cooling.

The Directive establishes the need for each Member State to develop a set of emission factors for all biofuels that consider the whole life cycle of the biofuels applicable to the specific conditions in the member state.

However, in 2011 the Estonian Ministry of Economic Affairs and Communications has reported[7] the following:

- Detail calculations of the reduction of CO_2 according to RED methodology have not yet been carried out in Estonia.
- So far there are no necessary studies in Estonia to develop the methodology for Estonian conditions (to consider life cycle impacts).

Thus there is no suitable methodology at this point for assessment (calculations) of the exact CO_2 emissions for the full life cycle of wood chips used in Elva.

[5] DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

[6] REPORT FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling.

[7] "Eesti Vabariigi aruanne Euroopa Komisjonile taastuvatest energiaallikatest toodetud energia kasutamise ja edendamise edusammude kohta". MKM. 2011.

Taking this into account current study carried out the following analyses for the Elva case study:

- Calculation of air pollutants from current boiler plants (Kirde boiler house and Nooruse boiler house) during the fuel burning process, prognosis for different scenarios and comparison of scenarios.
- Description of the life cycle on woodchips and calculation of CO_2 emissions from some of the more significant stages of the life cycle, such as production and transport of woodchips.

The main basis for the calculations carried out were the following:

- "2006 IPCC *(Intergovernmental Panel on Climate Change)* Guidelines for National Greenhouse Gas Inventories"
- Estonian legislation (such as the 16.07.2004 regulation No 94 of Minister of the Environment "Välisõhku eralduva süsinikdioksiidi heitkoguse määramismeetod").

Calculations for the existing situation

Maximum values of different pollutants from boiler plants in the surrounding air were analyzed for the existing situation.

Table 34. Maximum values of pollutants (µg/m^3) around the boiler plants

CAS code	Pollutant	Limit Value (SPV_1)	C *µg/m^3 Nooruse boilerhouse*	C *µg/m^3 Kirde boilerhouse*
10102-44-0	NO_2	200	13	10
PM SUM	Particles	500	49	39
630-08-0	CO	10000*	50	41
7446-09-5	SO_2	350	25	18
VOC COM	VOC (Aliphatic Hydrocarbons)	5000	2	2

SPV_1 – hourly average
* - average for 8 hours

The table shows that **concentrations of all pollutants from both boiler plants are far below the limit levels and there are no adverse environmental impacts due to emissions from the Elva boiler plants**.

Comparison of scenarios

The emissions of different pollutants and CO_2 were calculated for the base situation and for the year 2025 for the following scenarios:

- Hypothetical scenario for a situation where all heat in Elva was produced from fossil fuel (shale oil).
- Scenario I – continuation of the existing situation, burning woodchips in existing boiler houses.
- Scenario II – change in technology, introduction of a woodchip-fuelled combined heat and power plant for heat production in Elva.

The results of the calculations were as follows:

Table 35. Emissions of pollutants - base year

	Scenario I		Scenario II
Pollutant	**Total emissions (t/y) SHALE OIL**	**Total emissions (t/y) WOODCHIPS**	**Total emissions (t/y)) CHP WOODCHIPS**
NO_x	9,499	6,391	**11,69**
Particles (PM SUM)	6,333	**15,038**	5,028
CO	6,333	**62,3**	39,986
SO_2	**25,968**	1,091	0,9
VOC COM	0,069	2,956	**3,142**
CO_2	**4851**	83,639	22,135
Heavy metals	**25**	7,5 kg/a	9,2 kg/a

Table 36. Emissions of pollutants – year 2025

	Scenario I		Scenario II
Pollutant	**Total emissions (t/y) SHALE OIL**	**Total emissions (t/y) WOODCHIPS**	**Total emissions (t/y) CHP WOODCHIPS**
NO_x	5,392	3,644	**8,472**
Particles (PM SUM)	3,595	**8,52**	3,398
CO	3,595	**35,247**	28,156
SO_2	**14,752**	0,671	0,651
VOC COM	0,04	1,69	**2,251**
CO_2	**2753**	59,59	16,544
Heavy metals	**14,2**	4,3 kg/a	6,4 kg/a

The results show that:

- Burning shale oil results in bigger emissions for: SO_2, CO_2 and heavy metals.
- Scenario I results in bigger emissions for: Particles and CO.
- Scenario II results in bigger emissions for: NOx and VOC, however, **CO_2 emissions are reduced remarkably**.

As electricity is also produced in case of scenario II, global CO_2 savings were calculated. In Estonia vast majority of electricity is produced from oil shale and the carbon footprint of electricity production is great. Therefore, when electricity is produced in a CHP locally, it results in remarkable CO_2 reduction globally. The results of the calculations were as follows:

Table 37. CO_2 emissions and reduction for the scenarios

		Shale oil	Wood-chips)	SCENARIO II (CHP)			
				CO2 emissions from boiler plant	Produced electricity	CO2 savings from electricity	TOTAL CO2 SAVINGS
Base	CO2 t/y	**4851**	**84**	22	3700 (MWh/a)	-3626	**-3604**
	CO2 kg/MWh	352	6	2	3700 (MWh/a)	-259	-257
2025	CO2 t/y	**2753**	**60**	17	2700 (MWh/a)	-2646	**-2629**
	CO2 kg/MWh	293	6	2	2700 (MWh/a)	-270	-268

The results for the Elva case study show that replacing fossil fuels with woodchips results in remarkable CO_2 reduction. But almost as big additional global CO_2 reduction can be achieved if switching from existing woodchip boiler houses to combined heat and power plant technology.

<u>Life cycle of woodchips</u>

The life cycle of woodchips was described for the Elva case study. The main sources of woodchips used in Elva are: forest residues, brushwood, waste from sawmills, timber processing etc. Before use in Elva boiler houses woodchips do not need energy consuming processing. Woodchips are transported to Elva from distances of 50-70 km.

Calculations of CO_2 emissions carried out showed that:

- Production of 1 m^3 of woodchips from forest residues and brushwood results in emissions of about 3 kg CO_2.
- Transportation of 1 m^3 of woodchips to Elva boiler houses results in emissions of about 3 kg CO_2.

Based on this, the production of **1MWh of heat** in Elva boiler plants results in emissions of about **8 kg CO_2** from production and transportation stages of woodchips.

When comparing this result with the CO_2 emissions from the burning process in boiler plants (see Table 4 above) it can be concluded for the Elva case study that the production and transportation stages of woodchips give a small CO_2 emission compared to the CO_2 reductions from combustion stage.

Utilization of ashes from wood boilers

Additionally the study analyzed the possibilities for the utilization of ashes from wood boilers in Estonia. Four main options were discussed.

1. Giving ash over to the waste handler is the most accessible and convenient option for the boiler plants. However, it is probably not the cheapest option for boiler plants who have to pay for transportation and a fee to hand the waste over to the waste handler. In this case the waste ash is most commonly deposited or reused in landfills by the waste handler.

2. Using as a fertilizer in agriculture is under present conditions in Estonia the most accessible alternative to depositing in landfills. It depends on the existence and area of fields that need lime, but much of the agricultural land in Southern and South-Eastern Estonia is acidic and neutral soil provides better conditions for most agricultural species. In long run it is probably cheaper to the boiler house compared to the first option, however, some requirements need to be met. The boiler house needs to acquire a waste permit as officially it is re-usage of waste. Also, the boiler plant needs to register the ash as lime fertilizer in the fertilizer registry. The composition of ash must be in accord with the requirements set in the Regulation No 23 of 10.03.2005. a. „Nõuded väetise koostisele liikide kaupa“ (most notably heavy metals may become a problem).

3. The third option, **using ash as a fertilizer in forestry** has been long studied in the Nordic Countries and as of recent been also increasingly used in practice. However, in Estonia there are neither suitable regulations nor practice for this option yet. Also it has been suggested that for Estonian conditions there has been not enough research yet in this field.

4. Reusing ash as infill (in building, landscaping etc) was previously commonly practiced in Estonia, as there were no requirements for inert waste. But the requirements were set with the regulation in 2004 and it may be assessed that most probably the ash from wood fuels does not comply with the requirements. The most probable shortcomings are as follows:

- soluble matter content exceeds limits;
- unburned carbon exceeds limits;
- alkalinity of ash water exceeds limits.

These shortcomings may be eliminated with treatment (eg pelleting) but there has been no such practice in Estonia and it probably becomes more costly for the boiler house.

Further options (such as adding to compost, usage in green landscaping) may prove possible and economically feasible but these require case-by-case analyses and co-operation with a waste handler.

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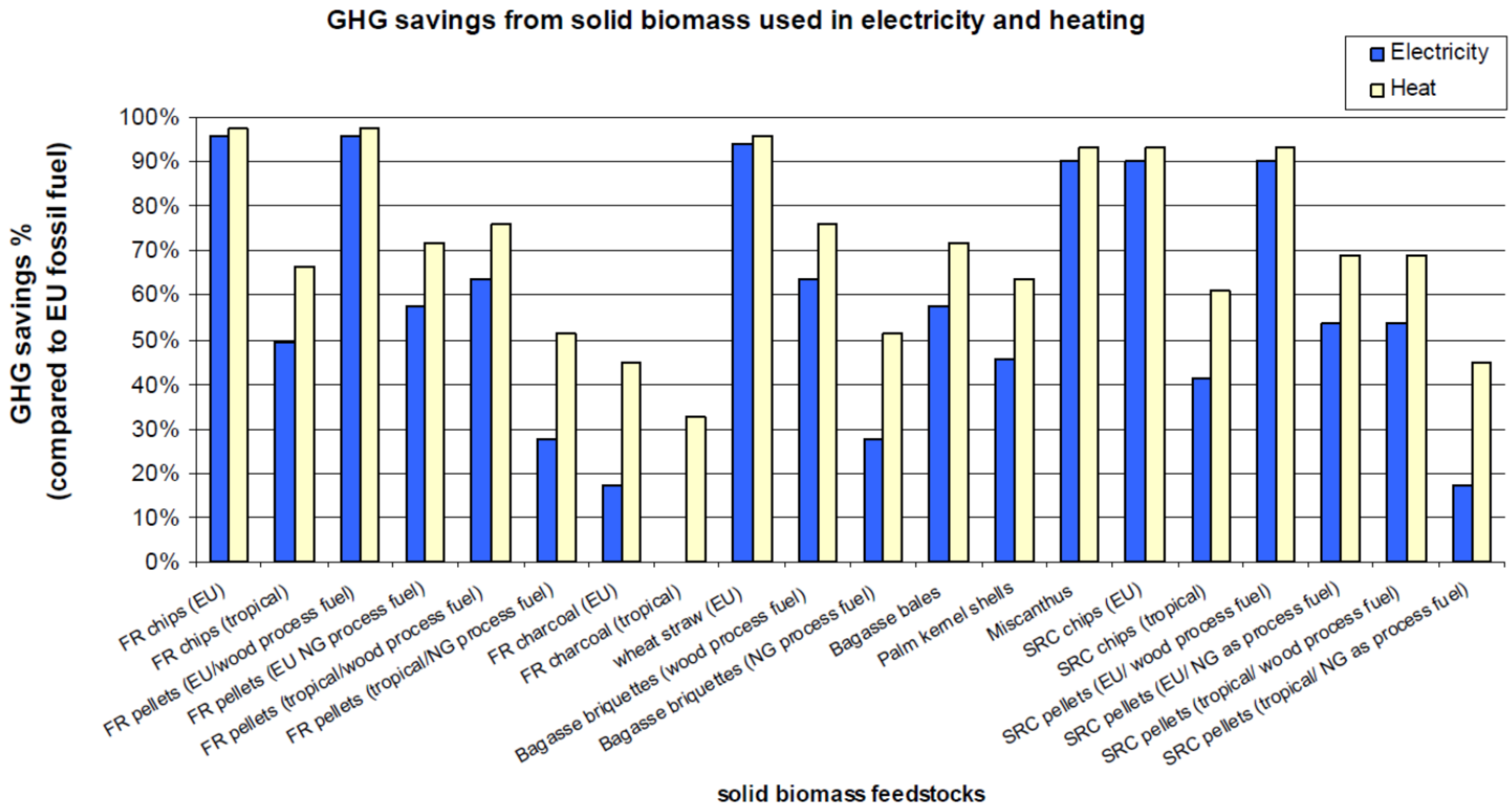
ANNEX A. TYPICAL LIFE CYCLE GREENHOUSE GAS EMISSION VALUES FOR SOLID BIOFUELS.

Source: REPORT FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling



Source: JRC 2009[18]

ANNEX II – Typical and default values for solid and gaseous biomass if produced with no net carbon emissions from land use change

Primary solid and gaseous biomass pathways	Typical greenhouse gas emissions (gCO_{2eq}/MJ)	Default greenhouse gas emissions (gCO_{2eq}/MJ)
Wood chips from forest residues (European temperate continental forest)	1	1
Wood chips from forest residues (tropical and subtropical forest)	21	25
Wood chips from short rotation forestry (European temperate continental forest)	3	4
Wood chips short rotation forestry (tropical and sub-tropical e.g. eucalyptus)	24	28
Wood briquettes or pellets from forest residues (European temperate continental forest) – using wood as process fuel	2	2
Wood briquettes or pellets from forest residues (tropical or subtropical forest) – using natural gas as process fuel	17	20
Wood briquettes or pellets from forest residues (tropical or subtropical forest) – using wood as process fuel	15	17
Wood briquettes or pellets from forest residues (European temperate continental forest) – using natural gas as process fuel	30	35
Wood briquettes or pellets from short rotation forestry (European temperate continental forest) – using wood as process fuel	4	4
Wood briquettes or pellets from short rotation forestry (European temperate continental forest) – using natural gas as process fuel	19	22
Wood briquettes or pellets from short rotation forestry (tropical and sub-tropical e.g. eucalyptus) – wood as process fuel	18	22

Wood briquettes or pellets from short rotation forestry (tropical and sub-tropical e.g. eucalyptus) – natural gas as process fuel	33	40
Charcoal from forest residues (European temperate continental forest)	34	41
Charcoal from forest residues (tropical and sub-tropical forest)	41	50
Charcoal from short rotation forestry (European temperate continental forest)	38	46
Charcoal from short rotation forestry (tropical and sub-tropical e.g. eucalyptus)	47	57
Wheat straw	2	2
Bagasse briquettes – wood as process fuel	14	17
Bagasse briquettes – natural gas as process fuel	29	35
Bagasse bales	17	20
Palm kernel	22	27
Rice husk briquettes	24	28
Miscanthus bales	6	7
Biogas from wet manure	7	8
Biogas from dry manure	6	7
Biogas from wheat and straw (wheat whole plant)	18	21
Biogas from maize as whole plant (maize as main crop)	28	34
Biogas from maize as whole plant (maize as main crop) – organic agriculture	16	19

PART 2. COST-BENEFIT ANALYSES OF FUTURE SCENARIOS

1. INTRODUCTION

1.1 Starting points of economic analysis

The objective of economic efficiency analysis of Elva combined heat and power plant operating on burning wood gas is to assess the economic perspective of producing alternatively to the current situation both for the heat producer and consumer. It is a supplement to the analysis of environmental aspects, but differs partly in terms of its starting points.

1. The bases for the environmental analysis are two potential scenarios, the so-called 0-scenario, in the event of which management continues with Nooruse and Kirde street boiler plants operating on wood chips and shale-derived oil and on the basis of district heating networks, and alternative scenario, in the event of which current devices, except peak boilers, are replaced with combined heat and power devices in one plant and town's district heating networks are joined. In the economic analysis, the alternative has been divided in three potential scenarios that have individual calculations:
    a. Scenario II, in the event of which ORC-type CHP plant is commissioned and the heating networks of Nooruse and Kirde boiler plants are joined, hospital network remains separate,
    b. Scenario III, in the event of which CHP plant is commissioned and heating networks of Nooruse, Kirde, and hospital boiler plants are joined,
    c. Scenario IV, in the event of which heating networks are not joined, but Nooruse boiler plant is replaced with a smaller ORC-type CHP plant.

   Scenarios differ from each other both in terms of source and end data - energy production capacities, quantity of energy consumed by customers, quantity of wood chips and fuel oil necessary for production, size of necessary investments. The closest to the alternative scenario of environmental analysis is scenario III of the economic analysis.
2. Environmental analysis peruses base data as at 2011 and alternatives as at 2025. Reference period of the economic analysis is the years 2011-2032, pursuant to the following circumstances:
    a. 2011 is suitable as a base year in respect to availability and comparability of data,
    b. first feasible period for making investments is 2015-2017, when some devices operating in Elva boiler plant have reached the limit of depreciation and assets of the new programme period of European Union Structural Funds have become available (which does not mean that investments can be made only with the support of structural assets),
    c. depreciation period of new devices is 15 years (6.67%) per year on average, useful life is thus 2018-2032. Calculating profitability only from period 2018-2025 is too short to make conclusions, especially given the temporal shift of making an investment in comparison to the time of conducting the analysis.

Source data for economic scenarios is taken primarily from the following sources:

1. Data regarding OÜ Elva Soojus production, sales, and costs and benefits from the cost accounting of reconstructing Elva town centre's heating utility lines prepared by OÜ Nordic Energy Group in 2009 [1], and survey sheets prepared for the same research, also from the "Development Plan of the Heat Supply in the Town of Elva" (OÜ Märja Monte) [2],
2. source data for scenarios (produced and sold heat and electricity during base year and 2025) from model calculations prepared by the contracting entity,
3. source data for investments from information "Cost-Benefit Analysis of Switching Elva Hospital Boiler Plant to Biofuel" (MTÜ Letek, 2011) [3] submitted by the contracting entity, CHP plant's documentation.

1.2 Methodology

1.2.1 Used financial indicators

The economic analysis looks at four production and consumption models (scenarios) from base year 2011 to year 2025, the period of which is extended to 2032 in analysis tables, prepared in cooperation with the contracting entity. Analysis of financial data has been prepared individually for four scenarios, without considering the comparison of increase scenario, i.e. 0-scenario, and the chosen alternative scenario. The reason for such approach is the objective of the research - focusing foremost on the feasibility of establishing CHP plants. In respect to feasibility, the following criteria are assessed herein:

1. in which event is it possible to ensure the economic sustainability of the CHP plant to be established and heating network operating on its production, and
2. which are the economic prospects of one or the other scenario.

In this case, economic comparison arises from the comparison of financial indicators of the scenarios.

Here, differences in source data in the event of scenarios also prevent developing increase scenarios - the quantity of consumers and range of heating network incorporated in the project changes depending on the chosen scenario. Assessing the development of the entire heating network of the town of Elva has not been the objective of this paper. When choosing a specific work project or scenario, it is important to conduct a new analysis that accurately describes the increase scenario, where 0-scenario and alternative scenario are based on the same source data for a planned investment in the near future (1-2 years before the start of the project).

Estimation for conducting cost-benefit calculations are based on methodology for cost-benefit analysis of investment projects sponsored by the European Union [4], [5], [6], and manuals for assessing the cost-benefit and feasibility of environmental investments for Cohesion Fund projects. Although the current European Union subsidy programme period is ending, instruction materials can be transferred to the subsequent period for preparing economic-financial analysis, if the objective is to give a cost-benefit assessment for a potential investment without considering conditions arising from specific measures. Pursuant to the instruction materials, financial and economic analysis has the following important parts that are described in this textual part of the analysis and most of which have also been given as table calculations:

- investment expenditure and residual value;
- operational revenues and consumption;
- operational expenditures;
- cash flows and profitability of investment;
- socio-economic analysis;
- sensitivity analysis;
- risk factors.

The financial and economic analysis has been prepared with nominal prices and represented without value added tax. Of long-term predictions, the analysis considers the actual growth of GDP publicised by the Ministry of Finance, prediction of changes in the consumer price index and actual price growth. Reference period comprises a 15-year period (2018-2032), as common to a project in an energy sector, which has been extended to 2011-2017 in respect to comparability. The time for making investments has been assessed to be 2015-2017.

The analysis has been prepared based on heating company's cash flows, because AS Elva Soojus, which belongs to the town, is planned to remain the owner of the infrastructure, collector of profits accruing from providing services, and maker of necessary expenditures. Increase (significant) of operational expenditures arising from conducting the project is generally not expected, because increase of cost-efficiency is aimed at.

According to the recommendations from the European Commission, the following economic performance indicators can also be determined for the given scenarios:

- present economic net asset value: it should be higher than zero in the interest of economic advisability of the project;
- proportion of benefits and costs: it should be higher than one.

Socio-economic cost benefit threshold has not been calculated herein, because only some aspects of the socio-economic analysis have been reflected - environmental impact (in the environmental part of the paper) and effect on the price of heat.

Sensitivity analysis in the classic sense has been substituted with a calculation about the prerequisites for making an investment and its effect - in the event of which subsidy sum is the investment economically profitable, which will be the price of heat for a consumer if the project is not subsidised, how does potential subsidy for renewable energy affect financial indicators. It is expedient to conduct a classic sensitivity analysis at the start of a specific project, when the necessity of investment, size, and potential financing sources and conditions are better known.

1.2.2 Macroeconomic prerequisites

The used macroeconomic prerequisite data are the Ministry of Finance's spring of 2012 prediction until the year 2016, extended until 2030. The paper also uses the prerequisites for assessing long-term sustainability of fiscal policy for the whole of EU agreed on by the Economic Policy Committee of the European Union. The average national growth of wages is taken as a basis for predicting personnel costs. The nominal growth of consumer price index is taken as a basis for predicting other costs. Predictions are available in the Ministry of Finance and European Commission [8], macroeconomic indicators on the EU Structural Funds web page [9].

2. SCENARIO I (SO-CALLED 0-SCENARIO)

2.1 Source data

0-scenario in this treatment is continuing the current practise on the basis of three existing boiler plants - combined heat and power plant operating on burning wood gas is not commissioned and district heating networks are not joined. In this case, activities mentioned in valid development plans continue - increasing heating efficiency in the existing district heating network and production of heat (foremost the reduction of heat losses in district heating network, insulating houses, increasing the efficiency of boilers). Replacing the hospital's fuel oil-operated boiler with a wood chips-based boiler is also assumed. If necessary, repair works are conducted both in the district heating network and boiler plants. Costs therefore include repairs expenditures that increase over the years.

Creating a description for the base year of the zero-scenario is based on the consumption data for 2008-2010, to which the estimated heat energy requirement of consumers joined in 2011 has been added.
The heating period was chosen to be 229 days instead of the regular 216 days by modelling heating characteristics with the help of output of May and September of different years. The heating period chosen for the year 2025 is 1 October to 30 April, considering that as the consumption of heat energy decreases, the necessity to heat buildings with the arrival of warmer weather decreases due to better use of optional heat. The estimated production of all boiler plants in 2010 is shown on the following figure.

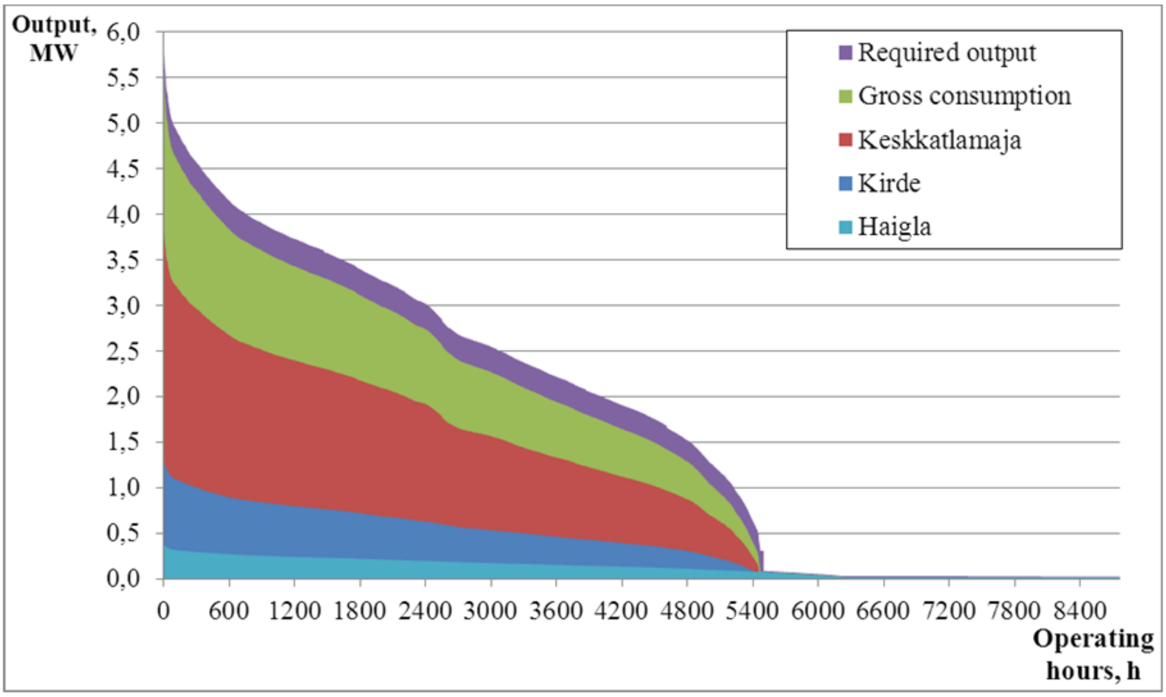


Fig. 1. Heat load duration diagram of Elva district heating system during a standardised production period

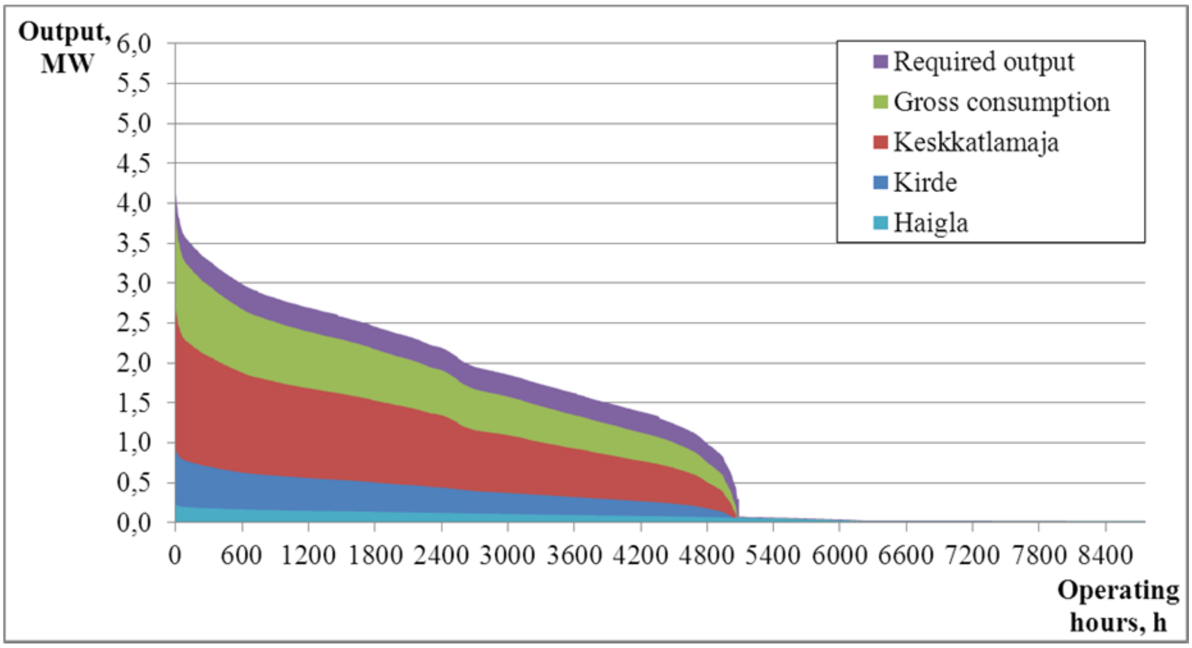


Fig. 2. Computational heat load duration diagram of Elva district heating system in 2025

This model has been used to derive the source data for 0-scenario, according to which the consumption of heat energy decreases by a total of 32% in volume from base year to year 2025, 40% in case of private consumers thereat. Reason for the decrease of heat consumption is foremost the insulation of houses and decrease of heat losses in utility lines.

Table 1. Source data for scenario I

	Unit	**Base**	**2025**
Selling heat energy to end consumers	MWh	13 803	9 390
incl. residential fund 37%	MWh	5 097	2 957
local government buildings 29%	MWh	3 942	2 287
industry and service 35%	MWh	4 764	4 146
Losses	MWh	1 559	1 455
Total	MWh	15 362	10 845
Heating period	h	5 496	5 088
Output of peak furnaces	MWh	273	186
Price of heat energy for private consumers	EUR	52.28	
Required quantity of wood chips	m^3	23 295	20 930
Required quantity of fuel oil	t	25.2	17.2
Renovating, constructing heating utility line	m		65
Cost of renovating the pipeline	EUR/m		226

2.2 Investments

In the event of 0-scenario looked at herein, the investment necessity into Elva boiler plants and heating networks is estimated conditionally. Because by the end of 2011, most investments in heating utility lines had already been made, the scenarios only consider the renovation of 65 m of utility lines (226 EUR/m according to expert assessment). The largest investment, however, is the required replacement investment due to the depreciation of existing boiler plants. The total capacity of wood chip boilers currently installed in two boiler plants is 5.3 MW. Planned 750 kW wood chip boiler for the hospital network will also add to that. Therefore, total of *ca* 6 MW of boilers in three separate boiler plants need to be installed with replacement investment. Investments must be made from 2013 (for the hospital) until 2022 (for Nooruse boiler plant), considering the 15-year depreciation period of the devices. The year of renewal for Kirde boiler plant should be 2020. In respect to simplifying the calculations, all investments of the 0-scenario have also been scheduled for the years 2015-2017.

The amount of investment has been derived from existing data for building the hospital wood chip boiler plant (*ca* 224 thousand euros, according to the prices in 2010). The cost of wood chip boilers would be approximately 1.8 million euros. Because fuel oil boilers also need to be renewed, *ca* 350 thousand euros has to be added to the investments. In the event of scenario I, the amount of investments is estimated to be 2 150 000 euros for boiler plants and 14 690 euros for utility lines, total 2 164 690 euros. Due to the conditional nature of the calculation, price changes until the year 2017 have not been taken into account. Such approach is justified with the option to invest flexibly should the current practice continue, by dividing expenditures over several years and replacing only some of the devices in boiler plants, if possible.

2.3 Operational revenues

In the event of zero-scenario, primary operational revenues are accrued from selling heat energy to consumers. Due to the decrease in heat losses as a result of renovating utility lines and supplementary insulating of buildings, production of heat reduces by an estimated 32% in 2011-2025. The decrease in producer's revenues is compensated by the rise in tariff rates. The base year estimates heat price tariff to be the currently valid 52.28 EUR/MWh for private consumer and 56.56 EUR/MWh for legal person (without VAT). The heat price tariff is going to increase equally with the consumer price index per year, on average.

Additional profits are not currently assumed in the scenario, but respective option is new consumers joining with joining fees and complementary turnover. It is likely, however, that joining fees only cover direct costs on building and starting connections. Complementary turnover is difficult to predict, because the size of Elva's population indicates a tendency of slow decrease and the expansion of district heating network in the residential area is naturally going to be fairly slow (it rather assumes respective support measures, but these options are not perused in this analysis). At the moment, it is also difficult to predict the expansion of business in Elva.

2.4 Operational expenditures

The majority of operational expenditures are due to the purchase price of fuel (wood chips for main boilers and light shale-derived oil for peak boilers). Increase in fuel prices both on the world market and for an Estonian consumer has largely already taken place during the last decade (see the table below). Because the rise in fuel prices has also hindered the development of economy on a global scale, its further price increase is limited by market demand. Steep price increase is possible in the event of major political and economic crises, but will then probably remain as a temporary jump. However, risk scenarios consider the rise of fuel prices as one of the most critical factor. Main scenarios consider the rise of fuel prices equally with the consumer price index. In the base year, the average purchase price of wood chips for AS Elva Soojus was 13.42 EUR/m^3. Further predicted price increase is represented on the following figure. Calorific value of wood chips in the calculations is 0.65 MWh/m^3, which corresponds to the current practise of Elva Soojus.

Table 2. Price of energy consumed in Estonian companies by types (Statistics Estonia [10])

	2003	2004	2005	2006	2007	2008	2009	2010
Wood chips, EUR/m³	4.15	4.35	4.47	6.20	7.29	9.97	12.40	12.53
Wood residues, EUR/m³	2.94	3.26	3.52	3.96	5.11	6.01	8.12	7.03
Electricity, EUR/MWh, incl. network fees	47,87	48,32	48,89	50,94	51,26	56,05	59,44	67,81
Heat, EUR/MWh	21,92	23,90	23,58	27,10	32,15	44,16	44,10	44,29

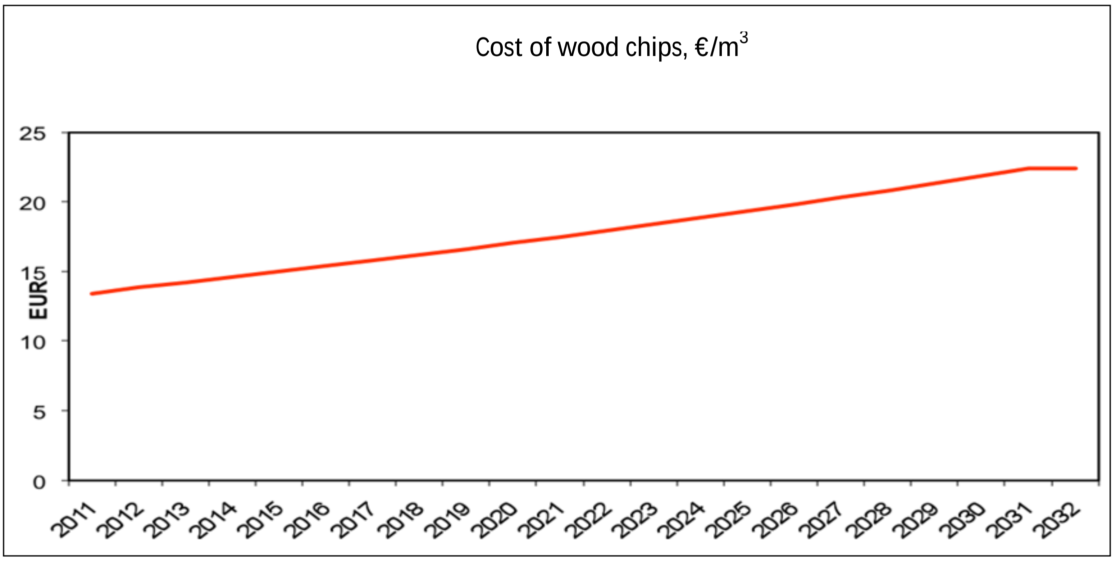


Fig. 3. Prediction of the price of wood chips for 2011-2032

Similarly to the price of wood chips, the price of fuel oil, which was 266 EUR/t for OÜ Elva Soojus in 2011, will also rise. Because using fuel oil is becoming less important in Elva year by year (only when peak capacities are required during cold winter days), its proportion in expenditures is going to be relatively small.
The growth of personnel costs is estimated pursuant to the increase of average wages; because the economic model is not changing, there probably won't be structural changes in the personnel costs.
Increase of other economic expenditures is estimated equally to the growth of consumer price index.

2.5 Consolidated data for the scenario and result of investment

2.5.1 Financial data

The following table provides the summary consolidated data for the 0-scenario.

Table 3. Consolidated data for scenario I.

	Undiscounted	Discounted
Data for zero-scenario		
Expenditure of initial investment	2 164 690	1 244 388
Operational revenue	17 356 168	7 385 213
Operational expenditure	16 564 026	6 727 091
Residue value of investment DRV	0	0
Present value of investment FNPV/C	-586 266	
Profitability rate of investment FRR/C	-	

According to currently used data, the scenario is not feasible in terms of economic sustainability. However, economically positive results are possible, if additional financial assets are used for investments or as profits from consumption, also if the amount of investment can be reduced.

2.5.2 Subsidy and tariff

According to calculations, in order to achieve positive indicators for investment (i.e. NPV > 0), it is necessary to include subsidy sum of at least 58% of the amount of investment, i.e. in this case 1 256 000 euros. In this case, it is possible to increase heat tariff equally to the increase of consumer price index over the years. If it is not possible to include a subsidy sum to the investment, additional 17% increase of heat tariff from 2018 onwards, when investments have been conducted, is required to maintain economic sustainability.

2.5.3 Effect on the consumer

Price of heat energy for a consumer in Elva is one of the cheapest in Estonia as at the base year, predominantly due to the fact that boiler plants started using relatively cheaper local fuel early on. In 2011, price of heat was 52.28 EUR/MWh for private consumer and 56.56 EUR/MWh for legal person. If it is possible to include additional assets to the renewal of Elva boiler plants, heat tariffs will change equally to the change of consumer price index over the years. In 2025, the price of heat will then be 76 EUR/MWh for private consumer and 82 EUR/MWh for business consumer. For private consumers this means a total of 46% price increase. Because at the same time, consumption of heat will reduce by an estimated 40% for private consumers, the average proportion of heating costs will become smaller in household budgets, when considering the average of 5.6% increase of wages per year. The following figure illustrates the decrease of the proportion of heating costs in comparison to income (average gross wages per year).

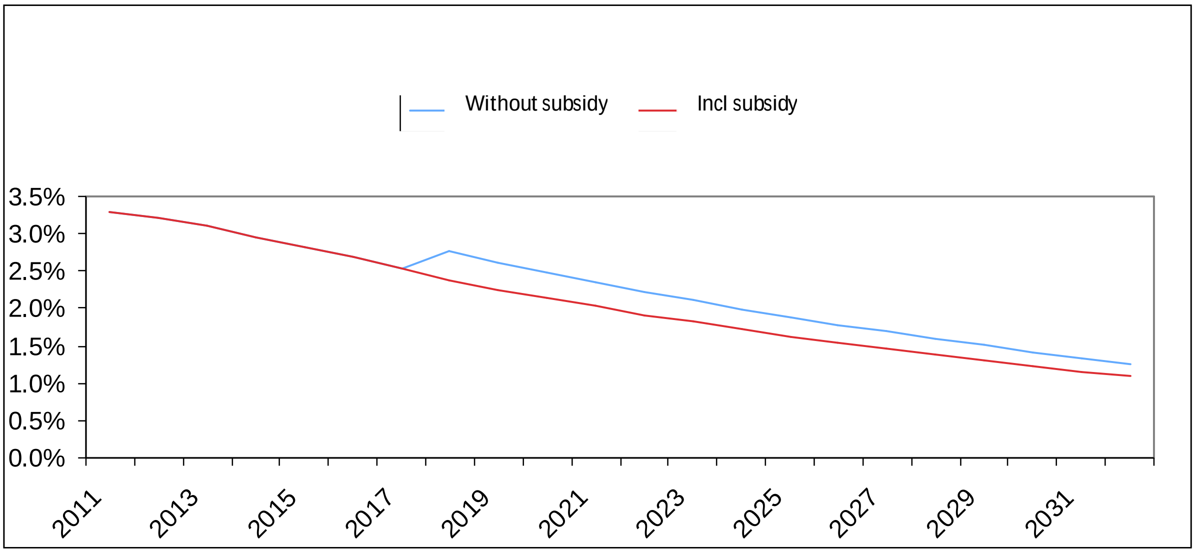


Fig. 4. Proportion of heating costs in comparison to average wages (scenario I)

In the event that investment subsidy is not available, price of heat for private consumer in 2005 is 89 EUR/MWh and for legal person 96 EUR/MWh, price increase thus 71%. Because estimated increase of wages in the same period is 115%, it means a relative decrease of the price of heat for a consumer. In both cases, however, expenditures for insulating buildings must be considered, which in the period 2011-2025 means higher utility costs for the consumer.

2.6 Source data

Alternative for the current heating system is commissioning an ORC-type CHP plant by joining the district heating networks of Nooruse and Kirde boiler plants. In the event of scenario II, the hospital boiler plant with its district heating network continues to operate separately from these. Buildings are insulated during the period 2011-2025 to increase heating efficiency. When joining district heating networks, it is possible to join other companies and houses to the network that have not been part of the district heating network so far. ORC-type CHP plant is established probably at the location of the boiler plant (central boiler plant) on Nooruse street, the oil-based boiler device will also continue operating to cover peak capacity.

Haigla boiler plant remains as a stand-alone plant and is therefore not included in the diagrams illustrating the duration of computational production capacities (Figures 5 and 6).

Creating a description for the base year is based on the consumption data for 2008-2010, to which the estimated heat energy requirement of consumers joined in 2011 and of the potential consumers has been added.

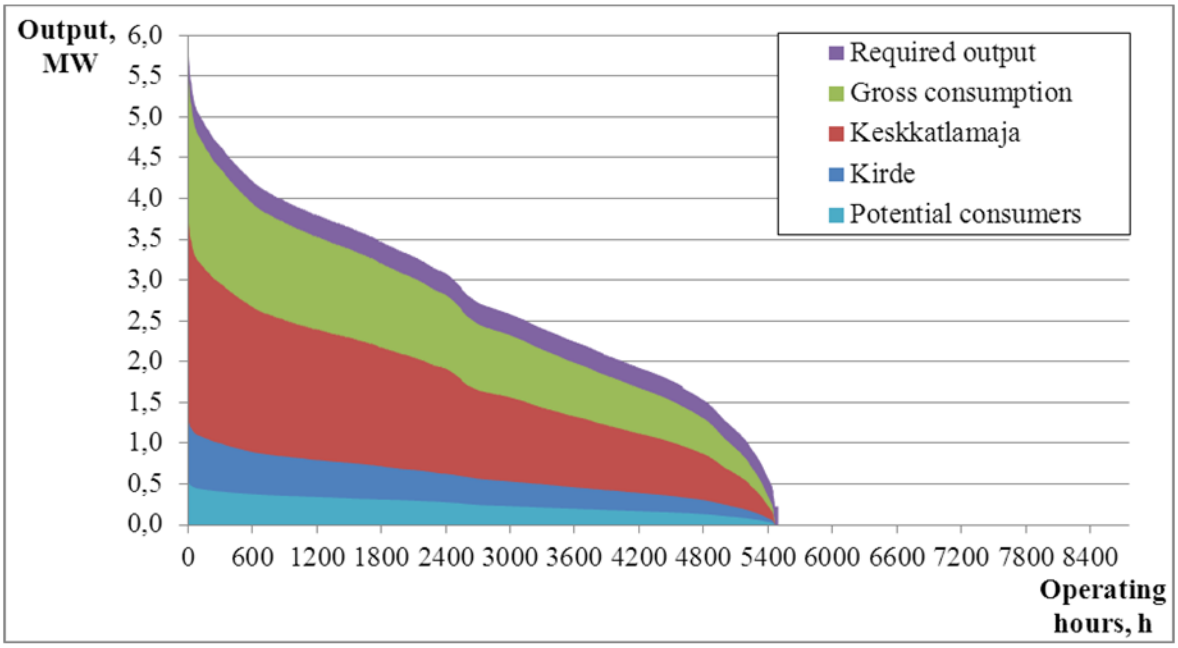


Fig. 5. Predicted heat load duration diagram in Keskkatlamaja and Kirde boiler plant's district heating networks during a standardised production period

CHP plant's heat capacity was chosen to be smaller than the maximum production requirement, insofar as the maximum production requirement will decrease to 4.29 MW according to the prediction (Figure 5.4). The circumstance that the demand for electricity will increase in the future (e.g. due to ventilation demand of renovated houses) and the production of electricity from fossil fuels will decrease or increase in price can be considered as a reason for building a larger CHP plant.

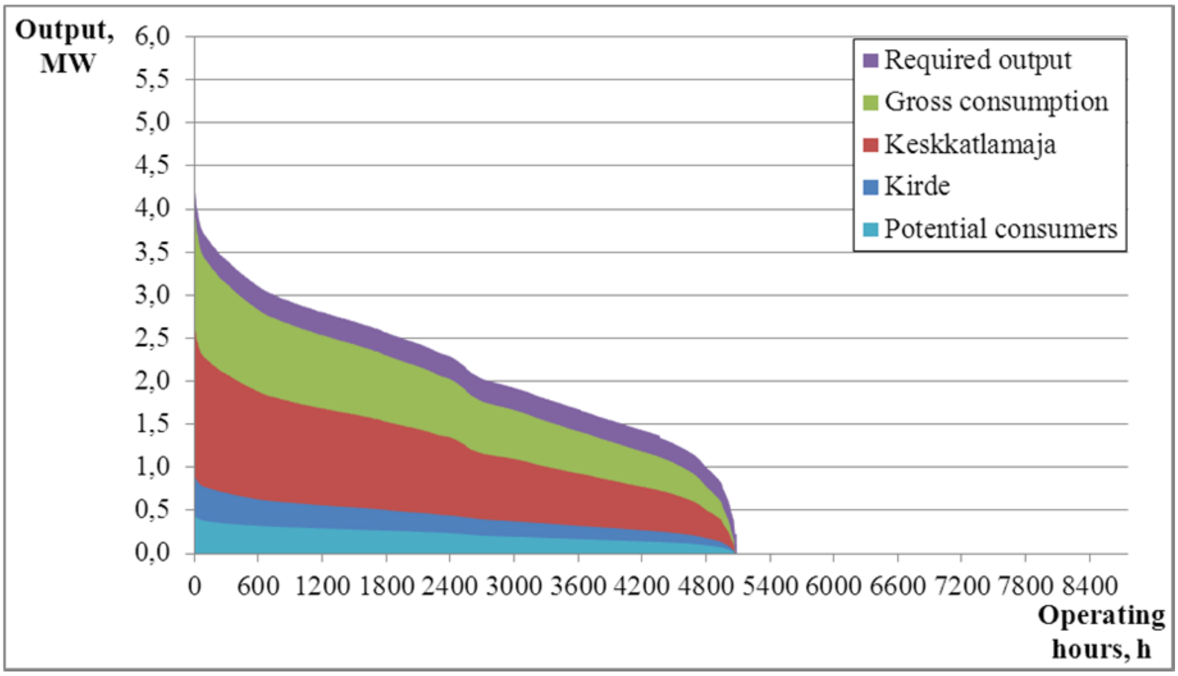


Fig. 6. Predicted heat load duration diagram in the event of scenario II in Keskkatlamaja and Kirde boiler plant's district heating networks in 2025

Insofar as the renovated Kesklinna heating pipeline was designed so that 1000 kW could potentially be joined, we presume that devices located in Kirde boiler plant will be operated during a time when load is larger than that provided. It was revealed in the calculations that 1990 h per year of pipeline's throughput is lacking at today's consumption volumes when the maximum load for a pipeline is 1000 kW. Calculation results for the future scenario are provided in Table 4.

Table 4. Source data for scenario II

	Unit	**Base**	**2025**
Selling heat energy to end consumers	MWh	14 084	9 812
incl. residential fund 37%	MWh	5 201	3 090
local government buildings 29%	MWh	1 485	2 390
industry and service 35%	MWh	513	4 332
Losses	MWh	1 414	1 308
Total	MWh	15 498	11 120
Heating period	h	5 496	5 088
Number of hours when utility line's throughput is insufficient	h	1990	451
Quantity of heat energy deficit	MWh	442	48
Number of hours when capacity of CHP plant is insufficient	h	788	58
Quantity of heat energy deficit	MWh	405	12

Quantity of produced electricity (derived according to the requirement of heat energy)	MWh	3 691	2 713
Price of heat energy for a consumer	EUR/MWh	52.28	
Sales price of electricity	EUR/MWh	40	
Required quantity of wood chips	m^3	26 833	24 130
Required quantity of fuel oil	t	5.95	4.44
Renovating, constructing heating utility line	m	1 718	
Cost of renovating the pipeline	EUR/m	226	

Presumption that the connection between heat and electric production capacity is linear and that electricity can be produced until heat capacity falls to 10% of maximum was used to calculate electricity throughput. Therefore, the scenario presumes that electricity is produced as a by-product to heat energy to receive subsidies, not the other way around. CHP plant's own consumption was derived according to the consumption capacity and duration of heating period on the data sheet.

Although CHP plant's capacity is insufficient only during 788 hours, unlike the throughput of pipeline, the system must be optimised according to the maximum throughput of the heating pipeline in this instance. Based on the presumption that the boiler located in Kirde boiler plant is not completely depreciated by the time the CHP plant is completed, part of the required energy requirement (378 MW·h) is covered with a heating generator located there. The production requirement of peak boilers operating on shale-derived oil was assessed to be 64 MW·h.

In 2025, the entire deficit heat energy quantity is covered by peak boilers. The required heat energy quantity is therefore dictated by the maximum heat throughput of a pipeline, and the required heat energy quantity is 48 MW·h.

2.7 Investment

In the event of this scenario, the planned investments are building a combined heat and power plant in 2016-2017 and joining Keskkatlamaja and Kirde boiler plant's heating (pipelines) regions. The chosen production unit is Turboden TD 10 CHP with heat production capacity of 4095 kW_h and electricity production capacity of 1000 kW_e. Depending on the time of building the CHP plant, the capacity should be inspected, however, and perhaps build one that is slightly smaller. It is initially presumed that the plant is built within 5...7 years. The circumstance that the demand for electricity will increase in the future (e.g. due to ventilation demand of renovated houses) and the production of electricity from fossil fuels will decrease or increase in price can be considered as a reason for building a slightly larger CHP plant. Estimated cost of CHP plant is $\frac{12000000}{2400} = 5000$ EUR/kW_e (ca 5 000 000 EUR) on the example of Kuressaare CHP plant. Because calculations are conditional, price increase until the year 2016 has not been taken into account. In actuality, cheaper analogous devices are also available on the market.

Building and reconstructing 1718 m of heating utility lines as an investment, incl. partially for increasing the throughput of utility lines, is necessary for joining heating networks. The cost is calculated according to the cost accounting of reconstructing Elva town centre's heating utility lines prepared by OÜ Nordic Energy Group [1]. According to this, the cost of reconstructing the utility line with the thickest, 150 mm pipes is 226 EUR/m. Precise width of pipes is currently not available, which is why the highest potential cost should be considered. Price increase of piping works and pipes by the time of making the investment is also anticipated. According to the scenario, the total cost of reconstructing the pipeline is thus 388 268 euros.

Additional investment cost for joining the district heating networks of Nooruse and Kirde boiler plants is building a high pressure pumping station, with a cost of 63 912 euros, for ensuring heating water pressure in the expanded network.

The total investment amount in the scenario is 5 452 180 euros.

2.8 Operational revenues

According to scenario II, the sources of revenue are primarily the sale of heat to private and business consumers and producing energy with efficient co-generation and selling it to AS Elering's network. Commissioning produced electricity at the location presupposes additional investments in storage and transmission systems. Due to seasonal and often daily fluctuation of the quantity of produced electricity, it is difficult to plan its local use without selling it to a network company. However, because heat is most often produced together with electricity during the high time of energy consumption, CHP plant's electricity enables covering the peak load of electricity production in the entire Elering's network.

The estimation of heat sales revenues is based on the same assumption as in the zero-scenario. This means that the quantity of sold heat decreases over the years (in this case, 28% by 2025 compared to the base year), but tariffs increase equally to the consumer price index, if subsidies are available to the investment.

Electricity sales revenues consider electricity market price without network fee. From 2013, all Estonian consumers purchase electricity for over-the-counter market price like business consumers right now. Depending on the seasons and market, price of electricity has fluctuated on the over-the-counter market, but it can be predicted in long-term that it will increase equally to the growth of consumer price index. At the beginning of 2011, electricity on the electricity market of the Nordic countries cost 40 EUR/MWh. This sum is taken as a basis for calculating the future price. The following figure presents the price of electricity prediction for 2011-2032 without considering network fees. The price of exported electricity is likely to be similar to this net price.

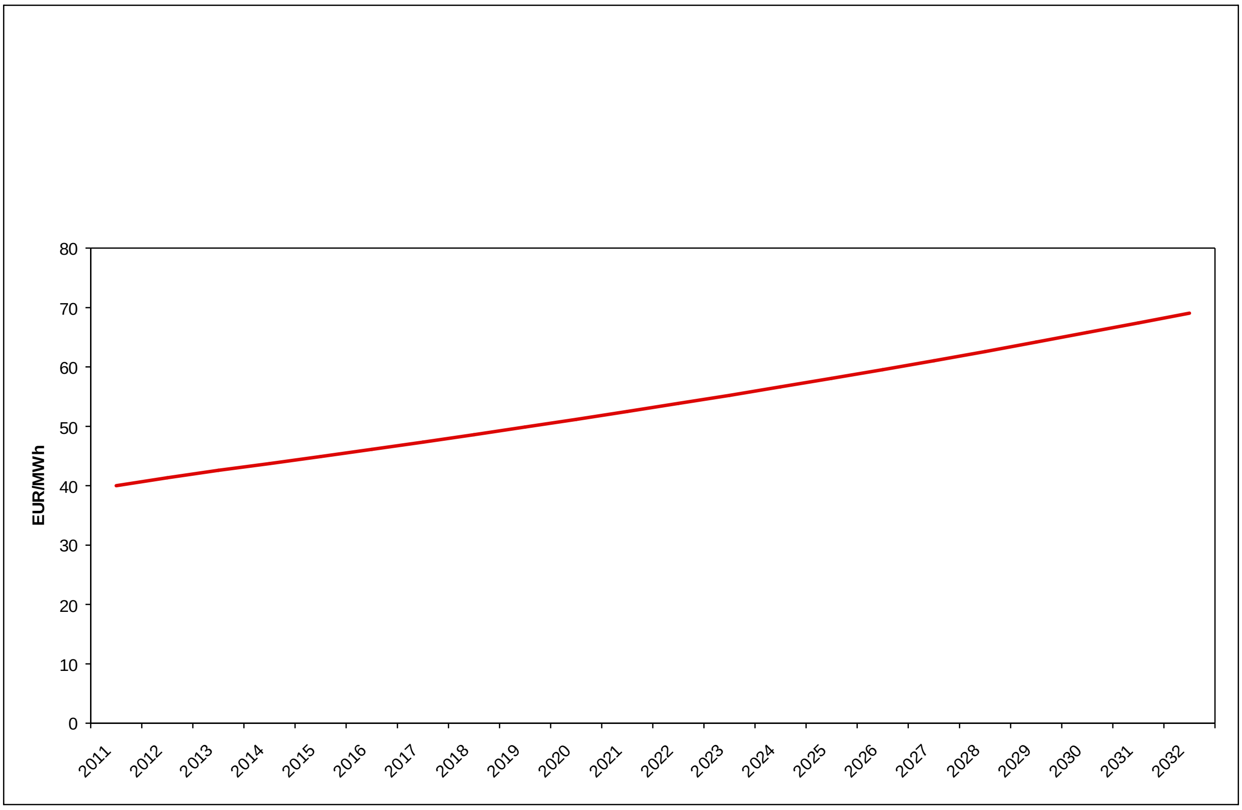


Fig. 7. Net price of electricity in 2011-2032.

Potential additional source of income are subsidies for renewable energy that are paid to electricity producers according to the energy production method and capacity of devices (http://elering.ee/taastuvenergia-toetus). Presently, the producer of heat and power with efficient co-generation receives the subsidy for renewable energy 32 EUR/MWh. Because the competition in producing renewable energy is constantly growing and Estonia is likely to achieve its strategic goals in respect to the proportion of renewable energy in energy balance by the year 2020, subsidy for renewable energy is not considered in the main scenario. This type of subsidy is likely to reduce or disappear in the event of CHP plants. Therefore, subsidy for renewable energy has been estimated as a component of sensitivity analysis that may improve the project's economic indicators.

2.9 Operational expenditures

Majority of operational expenditures are due to the purchase price of fuel (wood chips for main boilers and light shale-derived oil for peak boilers) also in the event of scenario II. Price change is estimated on the same bases as in zero-scenario. According to the scenario, the consumption of wood chips will increase by approximately 25% in 2018 due to switching to CHP plant devices. Additional quantity of wood chips is necessary for producing electricity with efficient co-generation. 78% of energy handled by the CHP plant is spent on producing heat, 19% on producing electricity, and *ca* 3% for losses.

The increase of personnel costs per employee is estimated according to the increase of average wages. At the same time, personnel requirement will decrease with joining district regions (estimated 25% from the year 2018). Other economic expenditures increase equally to the growth of consumer price index, similar 25% decrease of management costs is expected from year 2018.

2.10 Consolidated data for the scenario and result of investment

2.10.1 Financial data

The following table provides the summary consolidated data for scenario II.

Table 5. Consolidated data for scenario II

	Undiscounted	Discounted
Data for scenario II		
Expenditure of initial investment DIIC	5 452 180	3 146 413
Operational revenue DR	20 243 584	8 322 286
Operational expenditure DOC	15 767 856	6 373 738
Residue value of investment DRV	0	0
Present value of investment FNPV/C	-1 197 865	
Profitability rate of investment FRR/C	-3.66%	

Data for the scenario shows that this investment is not profitable as planned (present net asset value is negative, internal rate of return is below discount rate). Economically positive results are possible, if additional financial assets are used for investments or as profits from consumption.

2.10.2 Subsidies and tariff

Calculations on how the indicators of scenario II are affected by the potential European Union or some other fund's subsidy for the investment were conducted with the methods of sensitivity analysis. Summaries of the calculations are presented in the following table. It is revealed that the project becomes economically profitable if the amount of subsidy is at least 39% of the amount of investment. It is thus a subsidy that a company can also apply for on its own (usual amount of subsidy for a company is up to 50%). However, it is currently not possible to consider the subsidies for the following programme period of the EU funds, because the principles of dividing subsidies are not yet clear.

Table 6. Effect of investment subsidies on the financial indicators of scenario II.

BASE LEVEL	
Discounted operational revenue	8 322 286
Discounted operational revenue	6 373 738
Investments	5 452 180
Internal rate of return IRR	-3.66%
Net present value of investment NPV	-1 197 865
INVESTMENT SUBSIDY 20%	
Discounted operational revenue	8 322 286
Discounted operational revenue	6 373 738
Investments	4 361 744
Internal rate of return IRR	0.56%
Net present value of investment NPV	-568 582
change of IRR**	4.23%
change of NPV*	-52,.3%
INVESTMENT SUBSIDY 40%	
Discounted operational revenue	8 322 286
Discounted operational revenue	6 373 738
Investments	3 271 308
Internal rate of return IRR	10.94%
Net present value of investment NPV	60 700
change of IRR**	14.61%
change of NPV*	-105.07%
INVESTMENT SUBSIDY 60%	
Discounted operational revenue	8 322 286
Discounted operational revenue	6 373 738
Investments	2 180 872
Internal rate of return IRR	-
Net present value of investment NPV	689 983
change of IRR**	-
change of NPV*	-157.60%

* Percentage change
** Change of absolute value

If a subsidy of 2 126 350 euros (39%) is included in the investment, it is possible to increase heat tariff equally to the growth of consumer price index over the years. If it is not possible to include a subsidy sum to the investment, additional 34% increase of heat tariff from 2018 onwards when investments have been conducted is required to maintain economic sustainability.

If in the following years it is possible to count on subsidies for renewable energy in the current capacity (32 EUR/MWh) for electricity sold to Elering's network, the economic data for the scenario will also improve. It must be considered, however, that double subsidies are avoided on the state level, i.e. it is possible to have either investment subsidy or subsidy for renewable energy, but not both at the same time.

Table 7. Effect of subsidy for renewable energy on financial indicators.

BASE LEVEL	
Discounted operational revenue	8 322 286
Discounted operational revenue	6 373 738
Investments	5 452 180
Internal rate of return IRR	-3.66%
Net present value of investment NPV	-1 197 865
WITH SUBSIDY FOR RENEWABLE ENERGY	
Discounted operational revenue	8 762 592
Discounted operational revenue	6 373 738
Investments	5 452 180
Internal rate of return IRR	1.52%
Net present value of investment NPV	-757 559
change of IRR**	5.18%
change of NPV*	-36,.6%

2.10.3 Effect on the consumer

If it is possible to include at least 39% of additional assets to the renewal of Elva boiler plants (Nooruse and Kirde), heat tariffs will change equally to the change of consumer price index over the years. In 2025, the price of heat will then be 76 EUR/MWh for private consumer and 82 EUR/MWh for business consumer, according to the scenario. For private consumers this means a total of 46% price increase. Because at the same time, consumption of heat will reduce by an estimated 40% for private consumers, the average proportion of heating costs will become smaller in household budgets, when considering the average of 5.6% increase of wages per year. The following figure illustrates the decrease of the proportion of heating costs in comparison to income (average gross wages per year).

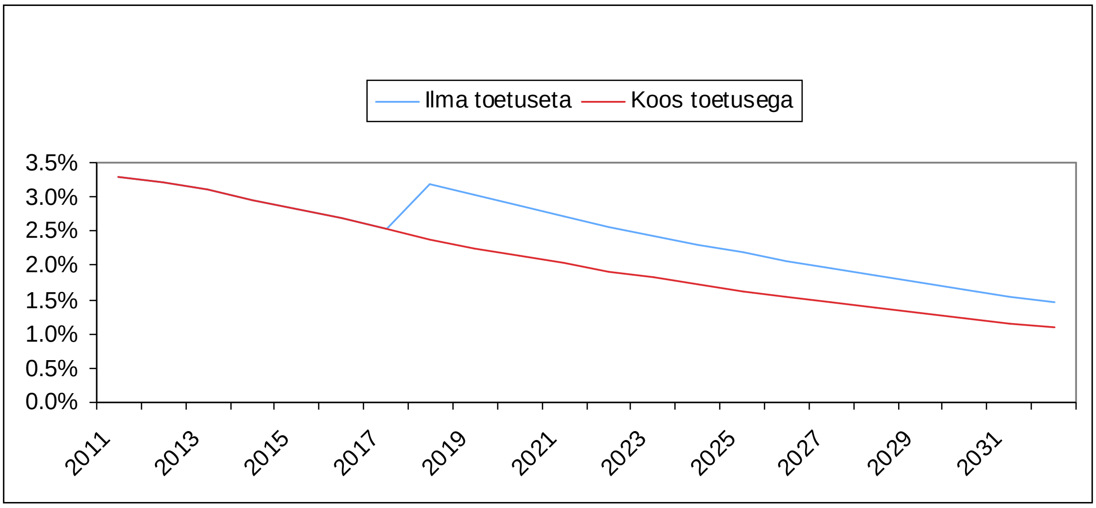


Fig. 8. Proportion of heating costs in comparison to average wages (scenario II)

In the event that investment subsidy is not available, price of heat for private consumer in 2005 is 102 EUR/MWh and for legal person 110 EUR/MWh, price increase thus 96%, according to scenario II. Because estimated increase of wages in the same period is 115%, it means a small relative decrease of the price of heat for a consumer. However, expenditures for insulating buildings must be considered, which in the period of 2011-2025 means higher utility costs for a consumer (even though part of it is for investment).

3. SCENARIO III

3.1 Source data

Scenario III means complete transformation of Elva district heating network and boiler plants by commissioning ORC-type CHP plant and joining Nooruse, Kirde, and hospital boiler plant district heating regions. This scenario has the largest investment amount and also solves the heat energy throughput limitation of an existing, already renovated utility line: *ca* 500 m additional utility line is established from Nooruse boiler plant to increase the pipeline's throughput.

Buildings will be insulated during the period of 2011-2025 to increase heating efficiency. When joining district heating regions, it is possible to join more companies and houses to the network that haven't been part of the district heating network so far in a larger volume than in the event of scenario II. ORC-type CHP plant is established probably at the location of the boiler plant (central boiler plant) on Nooruse Street, the oil-based boiler device will also continue operating to cover peak capacity.

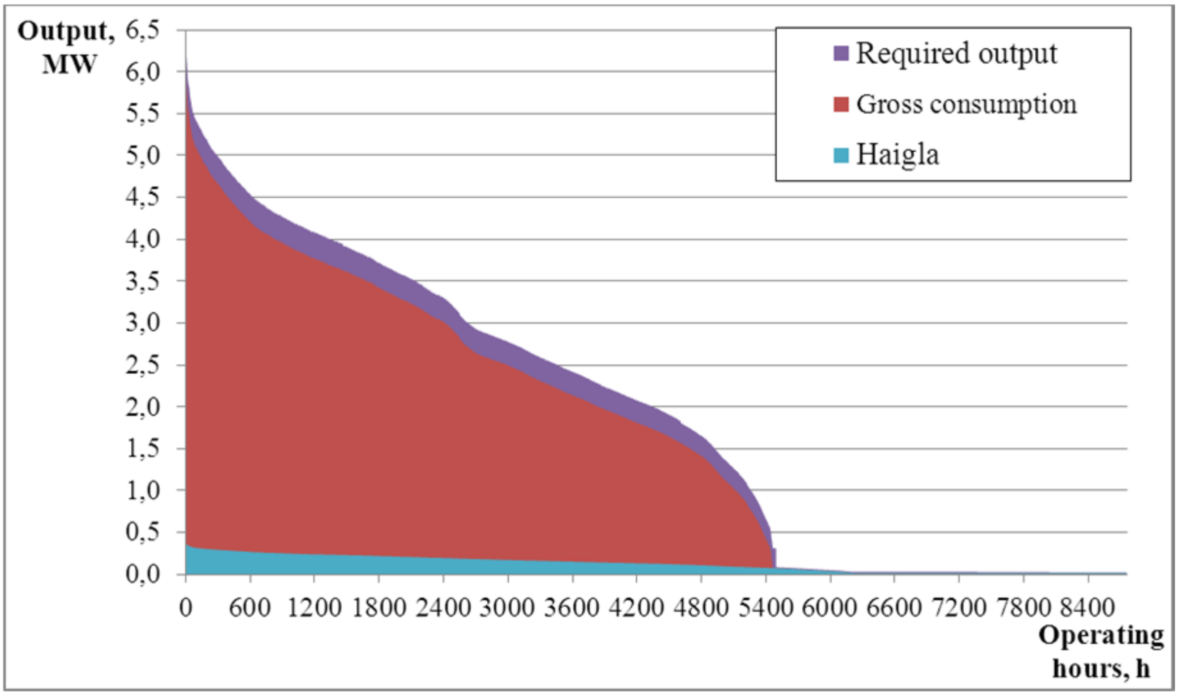


Fig. 9. Heat load duration diagram of district heating networks located in Elva during a standardised production period in the event of connecting all heating networks

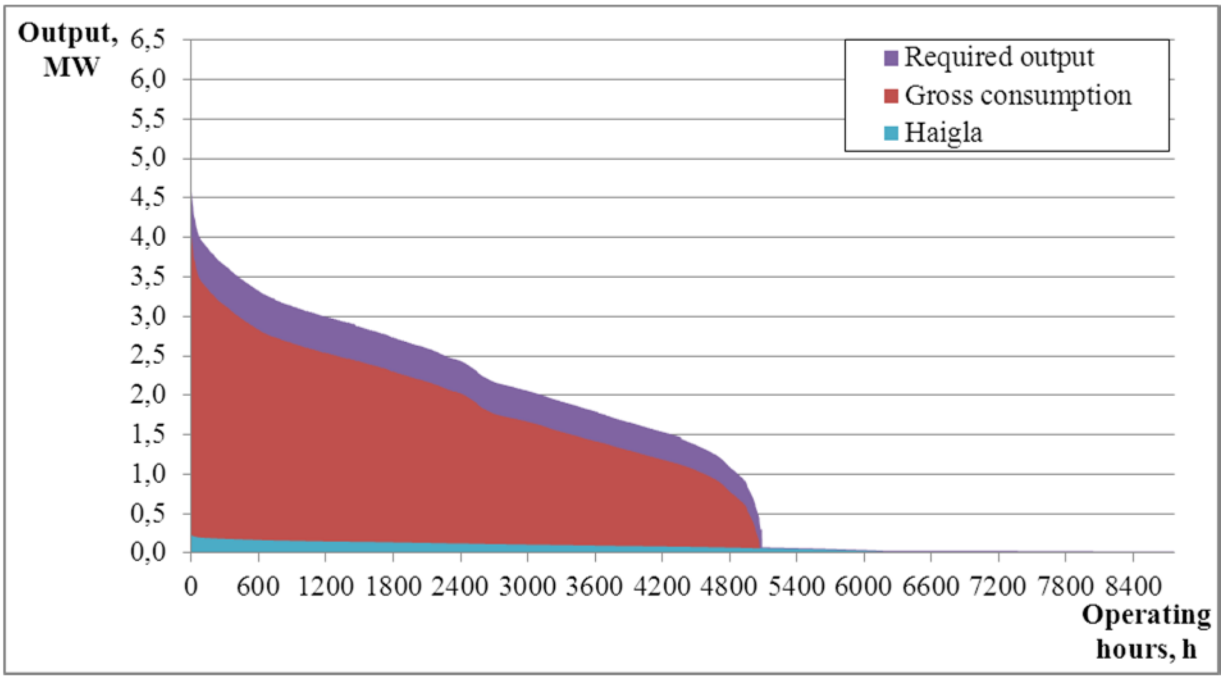


Fig. 10. Predicted heat load duration diagram of district heating networks in 2025 in the event of connecting all heating networks

Table 8. Base data for scenario III

	Unit	**Base**	**2025**
Selling heat energy to end consumers	MWh	15 176	10 524
incl. residential fund 37%	MWh	5 604	3 090
local government buildings 29%	MWh	4 334	2 390
industry and service 35%	MWh	5 238	4 332
Losses	MWh	1 605	1 499
Total	MWh	16 781	12 022
Heating period	h	5 496	5 088
Number of hours when capacity of CHP plant is insufficient	h	1 260	184
Quantity of heat energy deficit	MWh	739	16
Quantity of produced electricity (derived according to the requirement of heat energy)	MWh	3 901	2 900
Price of heat energy for a consumer	EUR/MWh	52.28	
Sales price of electricity	EUR/MWh	40	
Required quantity of wood chips	m^3	29 054	26 035
Required quantity of fuel oil	t	3.30	1.45
Renovating, constructing heating utility line	m	2 328	
Cost of renovating the pipeline	EUR/m	226	

3.2 Investment

In the event of this scenario, the planned investments are building a combined heat and power plant in 2016-2017 and joining Nooruse, Kirde, and hospital boiler plant district heating (pipelines) regions. As with scenario II, the chosen production unit is Turboden TD 10 CHP with heat production capacity of 4095 kW_h and electricity production capacity of 1000 kW_e. It is initially presumed that the plant is built within 5...7 years. The cost of CHP plant is estimated to be 5 000 000 euros.

Building and reconstructing 3228 m of heating utility lines, incl. partially for increasing the throughput of utility lines, is necessary for joining heating networks. The cost of this is estimated to be 226 EUR/m, as in scenario II. According to the scenario, the total cost of reconstructing the pipeline is thus 729 528 euros.

Additional investment cost for joining the three district heating regions is building two high pressure pumping stations, with a cost of 127 824 euros, for ensuring pressure in the heating pipeline.

The total planned investment amount for scenario III is 5 857 352 euros during 2015-2017.

3.3 Operational revenues

According to scenario III, the sources of revenue are the sale of heat to private and business consumers and producing energy with efficient co-generation and selling it to AS Elering's network, as in the previous scenario.

The estimation of heat sales revenues is based on the same assumption as in the zero-scenario. This means that the quantity of sold heat decreases over the years (in this case, 28% by 2025 compared to the base year), but tariffs increase equally to the consumer price index.

The estimation of profit from the sales of electricity has been conducted the same way as in scenario II. Subsidy for renewable energy is also potential additional revenue that is perused as a sensitivity indicator.

3.4 Operational expenditures

The majority of operational expenditures here are also due to the purchase price of fuel (wood chips for main boiler and light shale-derived oil for peak boilers). Its change is estimated on the same bases as in zero-scenario. By year 2018, there is *ca* 25% increase in the quantity of wood chips being burnt because electricity will be produced with the co-generation mode.

The increase of personnel costs per employee is estimated according to the growth of average wages. Personnel requirement will decrease upon joining district regions, estimated 25% from 2018. Other economic expenditures increase equally to the growth of consumer price index, only management costs are expected to similarly decrease by 25% from year 2018.

1.1 Consolidated data for the scenario and result of investment

3.4.1 Financial data

The following table provides the summary consolidated data for scenario III. Data shows that this investment is not profitable as planned (present net asset value is negative, internal rate of return is below discount rate). Economically positive results are possible, if additional financial assets are used for investments or as profits from consumption.

Table 9. Consolidated data for scenario III

	Undiscounted	Discounted
Data for scenario III		
Expenditure of initial investment DIIC	5 857 352	3 392 964
Operational revenue DR	21 374 071	8 804 897
Operational expenditure DOC	16 848 393	6 808 726
Residue value of investment DRV	0	0
Present value of investment FNPV/C	-1 396 793	
Profitability rate of investment FRR/C	-4,63%	

3.4.2 Subsidies and tariff

As in the previous scenario, calculations on how the indicators of scenario III are affected by the potential European Union or some other fund's subsidy for the investment were conducted with the methods of sensitivity analysis. Summaries of the calculations are presented in the following table. It is revealed that the project becomes economically profitable if the amount of subsidy is at least 42% of the amount of investment. Thus, it is here also a subsidy that a company can apply for on its own (usual amount of subsidy for a company is up to 50%). However, it is currently not possible to consider the subsidies for the following programme period of the EU funds, because the principles of dividing subsidies are not yet clear.

If subsidy sum 2 460 000 euros (42%) is included in the investment, it is possible to increase heat tariff equally to the growth of consumer price index over the years. If it is not possible to include a subsidy sum to the investment, additional 38% increase of heat tariff from 2018 onwards when investments have been conducted is required to maintain economic sustainability.

If in the following years it is possible to count on subsidies for renewable energy in the current capacity (32 EUR/MWh) for electricity sold to Elering's network, the economic data for the scenario will also improve. It must be considered here too, however, that double subsidies are avoided on the state level, i.e. it is possible to have either investment subsidy or subsidy for renewable energy, but not both at the same time.

Table 10. Effect of investment subsidies on the financial indicators for scenario III.

BASE LEVEL	
Discounted operational revenue	8 804 897
Discounted operational revenue	6 808 726
Investments	5 857 352
Internal rate of return IRR	-4.63%
Net present value of investment NPV	-1 396 793
INVESTMENT SUBSIDY 20%	
Discounted operational revenue	8 804 897
Discounted operational revenue	6 808 726
Investments	4 685 882
Internal rate of return IRR	-0.73%
Net present value of investment NPV	-718 200
change of IRR**	3.90%
change of NPV*	-48.58%
INVESTMENT SUBSIDY 40%	
Discounted operational revenue	8 804 897
Discounted operational revenue	6 808 726
Investments	3 514 411
Internal rate of return IRR	7.85%
Net present value of investment NPV	-39 607
change of IRR**	12,47%
change of NPV*	-97,16%
INVESTMENT SUBSIDY 60%	
Discounted operational revenue	8 804 897
Discounted operational revenue	6 808 726
Investments	2 342 941
Internal rate of return IRR	-
Net present value of investment NPV	638 985
change of IRR**	-
change of NPV*	-145.75%

* Percentage change
** Change of absolute value

Table 11. Effect of subsidy for renewable energy on financial indicators.

BASE LEVEL	
Discounted operational revenue	8 804 897
Discounted operational revenue	6 808 726
Investments	5 857 352
Internal rate of return IRR	-4.63%
Net present value of investment NPV	-1 396 793
WITH SUBSIDY FOR RENEWABLE ENERGY	
Discounted operational revenue	9 245 203
Discounted operational revenue	6 808 726
Investments	5 857 352
Internal rate of return IRR	0.30%
Net present value of investment NPV	-956 487
change of IRR**	4.92%
change of NPV*	-31.52%

3.4.3 Effect on the consumer

If it is possible to include at least 42% of additional assets to the renewal of Elva boiler plants, heat tariffs will change equally to the change of consumer price index over the years. In 2025, the price of heat will then be 76 EUR/MWh for private consumer and 82 EUR/MWh for business consumer, according to the scenario. For private consumers this means a total of 46% price increase. Because at the same time, consumption of heat will reduce by an estimated 40% for private consumers, the average proportion of heating costs will become smaller in household budgets, when considering the average of 5.6% increase of wages per year.

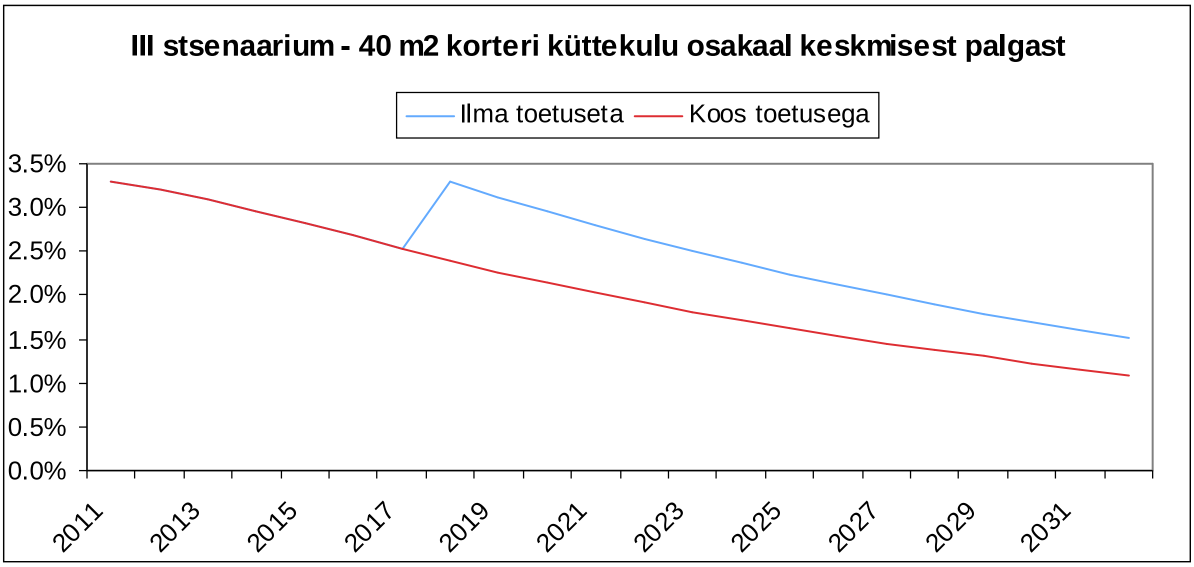


Fig. 11. Proportion of heating costs in comparison to average wages (scenario III)

In the event that investment subsidy is not available, price of heat for private consumer in 2005 is 105 EUR/MWh and for legal person 113 EUR/MWh, price increase thus 102%, according to scenario III. Because estimated increase of wages in the same period is 115%, it means a small relative decrease of the price of heat for a consumer. Considering the expenditures on insulating buildings, housing costs will significantly increase for a consumer during the period of 2011-2025, although the value of real estate will grow in the end due to investments made in insulating.

4. SCENARIO IV

4.1 Source data

Characteristic of scenario IV is the smaller amount of investments compared to scenarios II and III. ORC-type CHP plant is built only for the district heating network of central boiler plant (Nooruse St.). 65 m of heating pipeline is reconstructed at the same time.

Buildings in the central heating region are insulated during the period of 2011-2025 to increase heating efficiency. CHP plant decreases the heat losses of the boiler plant. Oil-based boiler device will also continue operating to cover peak capacity.

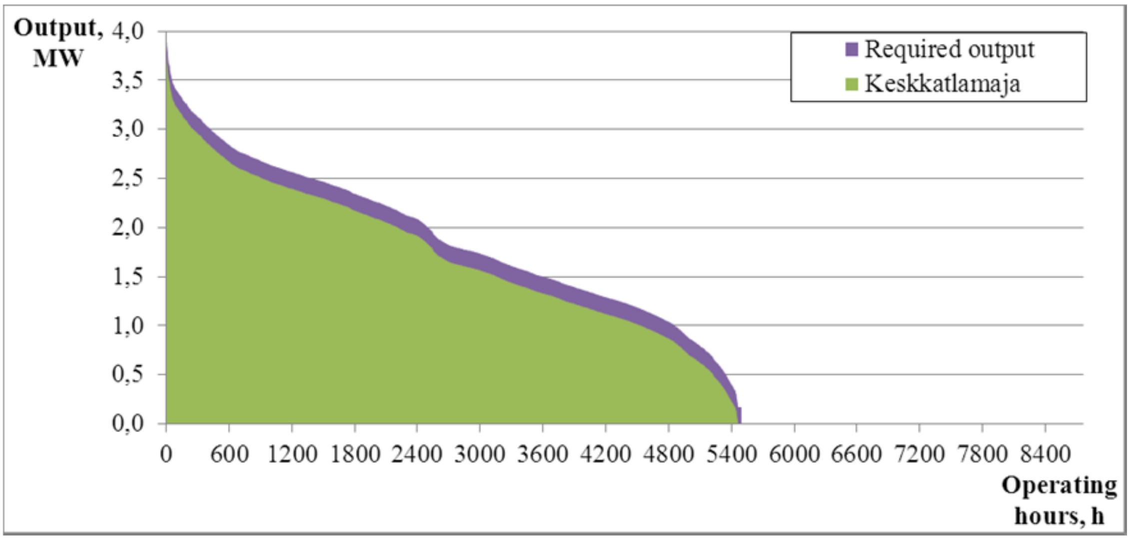


Fig. 12. Load duration diagram of CHP plan in the Keskkatlamaja district heating network during a standardised production period

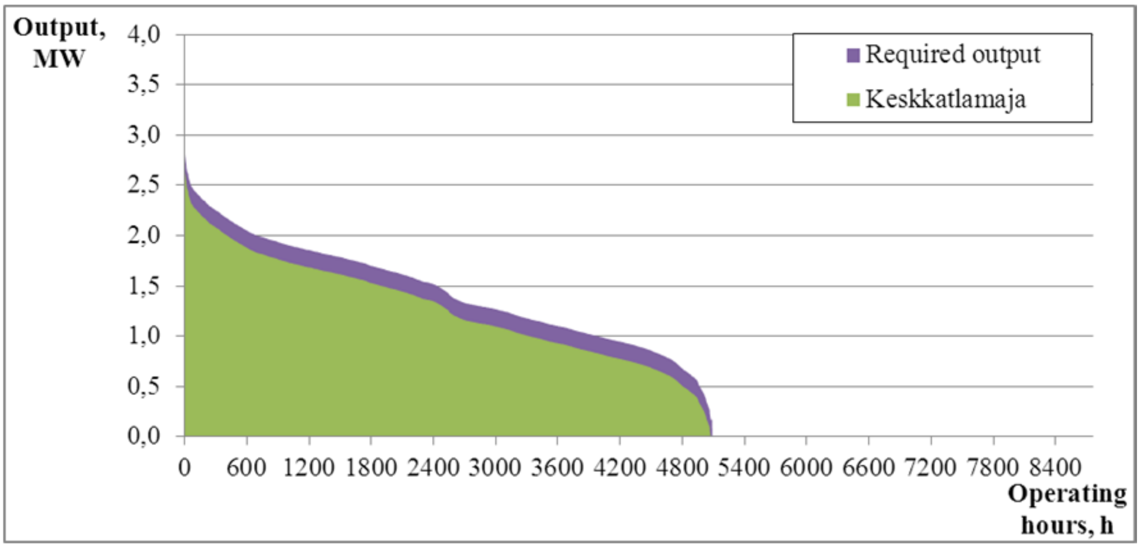


Fig. 13. Predicted heat load duration diagram of Keskkatlamaja district heating network in 2025

Table 12. Source data for scenario IV

	Unit	Base	2025
Selling heat energy to end consumers	MWh	9 502	6 490
incl. residential fund 37%	MWh	3 509	3,090
local government buildings 29%	MWh	2 714	2 390
industry and service 35%	MWh	3 280	4 332
Losses	MWh	940	870
Total	MWh	10 442	7 360
Heating period	h	5 496	5 088
Number of hours when capacity of CHP plant is insufficient	h	424	0
Quantity of heat energy deficit	MWh	79	0
Quantity of produced electricity (derived according to the requirement of heat energy)	MWh	2 520	1 795
Price of heat energy for a consumer	EUR/MWh	52.28	
Sales price of electricity	EUR/MWh	40	
Required quantity of wood chips	m^3	18 067	16 040
Required quantity of fuel oil	t	7.31	0
Renovating, constructing heating utility line	m	65	
Cost of renovating the pipeline	EUR/m	226	

4.2 Investment

In the event of scenario IV, a smaller device than previously is chosen as a CHP plant: Turboden TD 7 CHP with heat production capacity of 3 146 kW_h and electricity production capacity of 729 kW_h. The plant is estimated to be built within 5...7 years. The cost of CHP plant is 5000 EUR/kW_e (*ca* 5 000 000 EUR) on the example of Kuressaare CHP plant, total *ca* 3 645 000 euros. 65 m of utility line is also renovated. The cost of renovating the heating utility line is 29 360 euros.

The total amount of investments for scenario IV is 3 659 690 euros.

4.3 Operational revenues

According to scenario IV, the sources of revenue are the sale of heat to private and business consumers and producing energy with efficient co-generation and selling it to AS Elering's network, as in the previous scenarios. The estimation of heat sales revenues is based on the same assumption as in the zero-scenario. This means that the quantity of sold heat in the central boiler plant region decreases over the years (in this case, 29% by 2025 compared to the base year), but tariffs increase equally to the consumer price index.

The estimation of profit from the sales of electricity has been conducted the same way as in scenarios II and III.

4.4 Operational expenditures

The majority of operational expenditures here are also due to the purchase price of fuel (wood chips for main boilers and light shale-derived oil for peak boilers). Price change is estimated on the same bases as in zero-scenario.

The increase of personnel costs per employee is estimated according to the growth of average wages. Personnel requirement and management costs do not decrease in this scenario, because it covers only one district heating region. Other economic expenditures increase equally to the growth of consumer price index.

4.5 Consolidated data for the scenario and result of investment

4.5.1 Financial data

The following table provides the summary consolidated data for scenario IV.

Table 13. Consolidated data for scenario IV

	Undiscounted	Discounted
Data for scenario IV		
Expenditure of initial investment DIIC	3 659 690	2 103 009
Operational revenue DR	17 555 050	6 748 176
Operational expenditure DOC	10 895 798	4 392 922
Residue value of investment DRV	0	0
Present value of investment FNPV/C	252 245	
Profitability rate of investment FRR/C	12.43%	

Data for the scenario shows that this investment itself is profitable as planned (present net asset value is positive, internal rate of return is above discount rate). It is thus possible to consider making the investment without including subsidies.

As with previous scenarios, the tables of conducted sensitivity analysis are presented in the annex of this analysis, because the project is beneficial in the event of all subsidy sum values. At the same time, it is possible to correct the heat tariff equally to the increase of consumer price index over the years. In the event that subsidies for renewable energy are also applied for the scenario, the project's financial indicators are good enough to keep the increase of heating costs for consumers lower than the average price increase or use additional assets for some other purpose necessary for the heat company's owner.

Table 14. Effect of subsidy for renewable energy on financial indicators.

BASE LEVEL	
Discounted operational revenue	6 748 176
Discounted operational revenue	4 392 922
Investments	3 659 690
Internal rate of return IRR	12.43%
Net present value of investment NPV	252 245
WITH SUBSIDY FOR RENEWABLE ENERGY	
Discounted operational revenue	7 188 482
Discounted operational revenue	4 392 922
Investments	3 659 690
Internal rate of return IRR	19,92%
Net present value of investment NPV	692.551
change of IRR**	7.49%
change of NPV*	174.55%

4.5.2 Effect on the consumer

In the event of scenario IV, the heat tariffs change equally to the change of consumer price index over the years. In 2025, the price of heat will then be 76 EUR/MWh for private consumer and 82 EUR/MWh for business consumer, according to the scenario. For private consumers this means a total of 46% price increase. Because at the same time, consumption of heat will reduce by an estimated 40% for private consumers, the average proportion of heating costs will become smaller in household budgets, when considering the average of 5.6% increase of wages per year. The following figure illustrates the decrease of the proportion of heating costs in comparison to income (average gross wages per year).

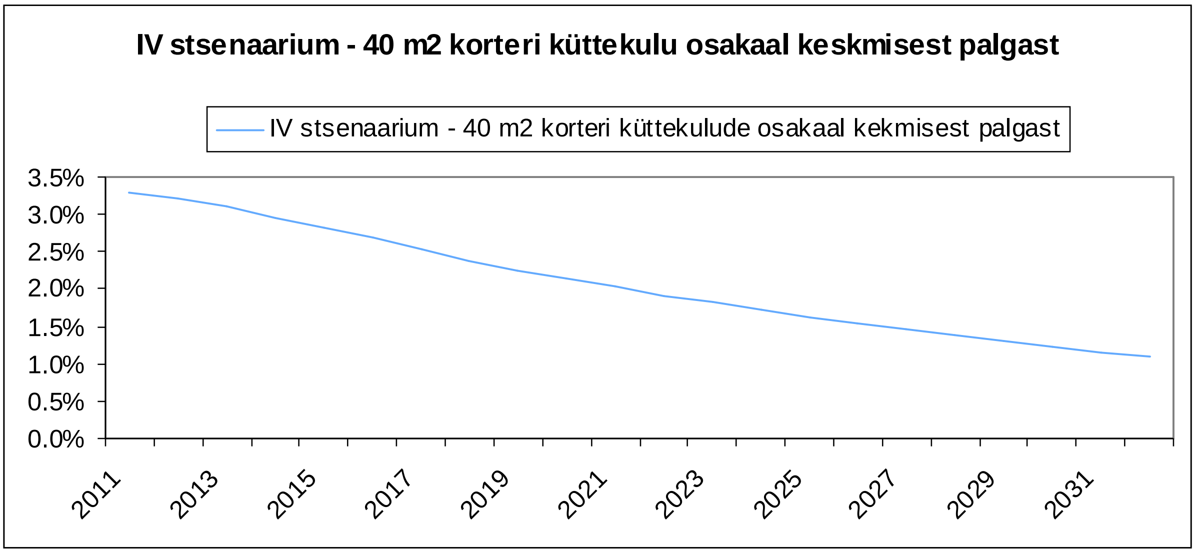


Fig. 14. Proportion of heating costs in comparison to average wages (scenario IV)

Considering the expenditures on insulating buildings, we can still predict that housing costs will increase for many consumers in the Nooruse boiler plant network, although it will beneficial for their real estate in the end.

5. MAIN CONCLUSIONS AND SUMMARY

The aim of the economic analysis was to assess if it's possible to base the heat supply of the Elva town on combined heat and power unit like practiced in some other places in Estonia and elsewhere. The other aim was to compare different scenarios to find most promising ways to go.

Current economic analysis is guided by methodology of the cost-benefit analyses of investment projects implemented by European Union. There are four main scenarios for comparison:

- the First, the so-called 0-scenario, which means the continuation of current practices. There will remain three boiler plants in Elva, with their own heating districts. The bulk of the heat is produced from wood chips, but also there are smaller oil boilers to cover peak load for heat in winter period;
- the Second scenario connects heating districts of Nooruse (Central) and Kirde boiler plants. The old boilers will be replaced by ORC-type combined heat and power unit;
- the Third Scenario connects heating districts of Nooruse, Kirde and Elva hospital boiler plants. The old three boilers will be replaced by ORC-type combined heat and power unit;
- in the Fourth scenario an existing boiler equipment in Nooruse is replaced by a smaller ORC-type combined heat and power unit, district heating networks are not consolidated.

Economic modeling has been carried out for the years 2011 - 2032, whereas the realization of investments takes place in all cases in years 2015 to 2017. Primary data for all scenarios come from mathematical models of heat production ja consumption for the years 2011 and 2025. The models take into account the scope of the heating districts and corresponding raw data (number of clients, amount of heat consumed, heat cost, scale of investment, etc.). The 0-scenario in economic analysis corresponds to the 0-scenario in environmental analysisis, scenarios II - IV are variations of scenario II in environmental analysis.

The Cost-Benefit Analysis shows, that economically the most cost-effective opportunity is establishing a high-efficiency Heat and Power Unit for existing heating district in central town of Elva, i.e. scenario IV. This scenario does not require additional investments in heating networks, while investment in equipment is significantly less than in scenarios II and III. Such a project is profitable even without European Union funding. The other scenarios would require grants or supports to ensure the sustainability of the investments.

The advantage of the 0-scenario consists in flexibility. It's the way to manage costs, while making maximum use of existing facilities and equipment. It is possible that the actual investment costs turn out to be smaller than predicted here. Also the 0-scenario brings for consumers relatively small increase of the heat costs.

At the same time, the analysis shows that all the scenarios are feasible under certain conditions, and the final choice will depend on the environmental and technological solutions.

The following is a summary table of all four scenarios with main financial indicators.

Table 5. Financial indicators of the scenarios

(EUR)	**Total**	**Discounted**
I scenario (0)		
Initial Investment	2 164 690	1 244 388
Revenues	17 356 168	7 385 213
Operating Expenses	16 564 026	6 727 091
Residual Value	0	0
Net Present Value	-586 266	
Internal Rate of Return	-	
II scenario		
Initial Investment	5 452 180	3 146 413
Revenues	20 243 584	8 322 286
Operating Expenses	15 767 856	6 373 738
Residual Value	0	0
Net Present Value	-1 197 865	
Internal Rate of Return	-3,66%	
Simple Payback Period	15	
III scenario		
Initial Investment	5 857 352	3 392 964
Revenues	21 374 071	8 804 897
Operating Expenses	16 848 393	6 808 726
Residual Value	0	0
Net Present Value	-1 396 793	
Internal Rate of Return	-4,63%	
Simple Payback Period	18	
IV scenario		
Initial Investment	3,659,690	2,103,009
Revenues	17,555,050	6,748,176
Operating Expenses	10,895,798	4,392,922
Residual Value	0	0
Net Present Value	252,245	
Internal Rate of Return	12.43%	
Simple Payback Period	6	

Key conclusions

1. By matching the scenarios it is clear that the most critical factor is the size of the investment. The Scenario IV has the highest productivity, because the minimal investment and because there is no need for additional expenditures to connect different heating districts.
2. Despite the high investment costs none of the scenarios is unachievable. The opportunity for Heat and Power Unit is to improve the economic efficiency through the sale of electricity during its working time, especially in cold seasons.
3. Using the scenario IV, the price of the heat will remain relatively low for consumers. The heating rate increases proportionally with the CPI. As the heat price is reduced, it is easier for people to find resources to cover the cost of thermal insulation of buildings. Also by the I scenario the increase of the heat price will remain relatively small compared to II and III scenario.
4. Scenarios II and III, despite the relatively good economic indicators compared to I scenario, involve higher prices for consumers. The reason is that a large part of company's revenues will come from electricity sales. The subsidy of heat price in electricity's account could be complicated by involvement of outside financial resources (bank loans or structural funds). Rather, additional revenues can be used to improve company's financial performance.
5. Pure economic analysis does not take into account the merits of the field of environmental scenarios. It's possible to calculate income from reduced environmental pollution, if there are implemented less polluting technologies. One way is to calculate the carbon emissions reduction and price calculation based on the formation of CO_2 quota at global market. Environmental arguments may determine the choice between different scenarios, if the financial indicators are as close as in this case, but such an analysis was not in the focus of the current work.
6. Analyses do not permit any fundamental conclusions about the heat production methods or effects on business and labour market in Elva region. In the long term the need for wood chips quantity in Elva is reduced. As the use of renewable fuels in other areas (such as transportation or small residential heating) increases, the market for producers of wood chips is not reduced. The fuel production and it's price depend more on world market situation than local demand. Change in the number of jobs of the project is so small that almost does not affect the local labour market.
7. The choice of the scenario has a certain influence on the regional economy through the effects of purchasing power of residents. Scenarios II or III result in higher housing costs while the investment money will move out of the area.
8. If there is one or another scenario chosen, it's necessary to carry out new economic analysis based on specific facts and terms (data of the specific heating unit, financing and funding conditions, execution terms, etc).

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