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Development Prospects of the Oil Shale Industry under Conditions of Renewable and Low-Carbon Energy Policy

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology, has not been previously submitted for doctoral or equivalent academic degree.

Svetlana Pulkkinen

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Põlevkivitööstuse arenguperspektiivid taastuvenergia ja madala süsinikuheitmega tehnoloogia arendamise poliitika tingimustes

SVETLANA PULKKINEN

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Contents

List of Publications

The present doctoral thesis is based on the following publications, which are referred to in the text by their Roman numerals I-III:

Publications in conference proceedings

I. S. Pulkkinen, "Evaluation of investments profitability in conventional power generation sector in Estonia", *12th International Conference on the European Energy Market*, Lisbon, Portugal, 19-22 May 2015, IEEE Conference Publications, DOI: 10.1109/EEM.2015.7216768.

II. S. Pulkkinen and J. Valtin, "Economic evaluation of retort gas utilization for electricity generation", *13th International Conference on the European Energy Market*, Porto, Portugal, 6-9 June 2016. IEEE Conference Publications, DOI: 10.1109/EEM.2016.7521315.

Publication in a journal

III. S. Pulkkinen and J. Valtin, "Investments in the shale oil industry under risk and uncertainty", in *Przeglad Elektrotechniczny*, NR 12/2018, DOI: 10.15199/48.2018.12.01.

The copies of the publications I-III are included in Appendix B.

During doctoral studies, the author also participated in the writing of the following manuscript, not included in the thesis:

- S. Pulkkinen and R. Attikas, "Power and frequency control principles of different European synchronous areas". 11th International Symposium "*Topical problems in the field of electrical and power engineering*", Doctoral School of Energy and Geotechnology II, Pärnu, Estonia, January 16-21, 2012: (Toim.) J. Zakis, Tallinn: Elektrijaam, pp. 200-204.

Author’s Contribution to the Publications

The author of the thesis is the main author of all the included publications. The contribution by the author to the publications was as follows:

I. Svetlana Pulkkinen was the corresponding author and wrote the manuscript. She was responsible for the literature review, data collection, calculations, and analysis.

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Introduction

There is a large potential for the development of the oil shale industry in the world. The shale oil equivalent of world oil shale proven reserves is close to 420 billion tons. It is much greater than 170 billion tons of recoverable reserves of world crude oil, even greater than 300 billion tons of its estimated resources [1]. More than 70% of these reserves are located on the territory of the United States, where under active development of the shale industry mainly tight oil and shale gas are produced. In the oil shale industry, the world leaders are Estonia, China and Brazil. Other countries with abundant reserves of oil shale, such as Jordan, Morocco and Australia, are now investigating the possibilities of oil shale utilization to produce liquid fuels [2].

Presently, the oil shale industry consists of two main branches: shale oil production and electricity generation. In addition to that, the by-products of these production processes can also be used in different fields. So, a by-product of shale oil production is a retort gas that needs to be utilized to provide constant production of the fuel. The retort gas can be utilized in a power plant to generate electricity and heat. Moreover, it can be used for the extraction of the fractions of gasoline and diesel. A by-product of oil shale combustion to generate electricity is oil shale ash. The shale ash can find use for road construction, for soil acidity neutralization in agriculture, for backfilling of mining space, as a component for cement production and as a raw material for building blocks. Oil shale is also used in the chemical and pharmaceutical industry, but not on a large scale.

Despite the possibility of a wide use of oil shale and its processing products, the industry has a substantial environmental impact. The mining of oil shale worsens ground stability and landscape properties, causes mining waste and influences the quality of ground water. The process of oil shale retorting to produce shale oil is accompanied by air pollutants, solid waste and discharged waste water. The generation of electricity and heat from oil shale causes a significant amount of shale ash, fly ash and flu gases that, in turn, contain harmful carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxide (NO_x).

The current climate and energy policy is focused on the increase of renewable and low-carbon production capacities and on the toughening of environmental requirements for emission-intensive industrial installations. In the light of these targets, the development of the oil shale industry faces a lot of challenges. Internationally-agreed climate treaties, as well as national energy programs influence directly the future state of the industry. One of the key documents that will form trends for the further development of the energy sector is the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC). It provides the framework for the future global cooperation in the field of climate change. The central aim of the Agreement is to keep the world temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to limit the temperature increase even further to 1.5 degrees Celsius. Of the 197 original signatories, 184 countries representing about 90% of global greenhouse gas emissions have ratified the Agreement to January 2019 [3].

At the level of the European Union (EU), a long-term vision for climate and energy policy is set out in the three major documents - the Strategy for a climate-neutral Europe in 2050, the Energy Roadmap 2050 and the Transport White Paper [4]. The Strategy shows how Europe can lead the way to climate neutrality by investing into realistic technologies and aligning action in the key social areas. It covers nearly all EU policies and is in line with the objective of the Paris Agreement of the UNFCCC [5]. The Energy Roadmap sets out the main routes to a sustainable and secure energy system in 2050, whereas the White Paper presents a vision for a competitive and resource efficient transport system.

To realize these long-term targets, the 2030 climate and energy framework was adopted by the European Commission in 2014. The main goals of the framework for the year 2030 are to reduce greenhouse gas emissions by at least 40% (from 1990 levels), to boost a share of renewables to at least 27% and to improve energy efficiency by at least 27%. To achieve such significant cut of greenhouse emissions, the EU Emissions Trading System (EU ETS) was reformed and strengthened [4]. The most important change made in the course of the EU ETS reform was a creation of the Market Stability Reserve (MSR). It had a great effect on the energy sector in Europe. The MSR came into operation in January 2019. The 900 million allowances back-loaded in 2014-2016 was allocated directly to the MSR rather than auctioned in 2019-2020 [6]. Thus, the MSR removed 24% of the surplus allowances from the market. The expectations of a large decrease in supply led to a drastic increase in CO_2 allowance price in 2018. The price growth amounted to more than 250% in comparison with the average allowance price in 2017. This huge increase of CO_2 allowance price was an essential growth factor for production variable costs in the oil shale industry, which is a carbon-intensive one.

Another instrument that has a significant impact on the development of the oil shale industry is the Industrial Emissions Directive (IED). It is the main EU document regulating pollutant emissions from industrial installations. The IED sets emissions limits for toxic pollutants such as SO_2, NO_x and particulate matter. In 2021, the new limits will enter into force and replace present emissions limits, which came into effect in 2016 [7]. The new emission standards will be challenging to meet especially for oil shale and coal power plants.

The major producer of electricity from oil shale is Estonia. Since Estonian oil shale power plants, the largest oil shale plants in the world, participate in trading at the Nordic power exchange, they are forced to compete with Nordic production capacities. Therefore, the development of the capacities in the Nordic region will significantly influence the oil shale-based electricity production in the future. Presently, all Nordic countries have established long-term targets to become low-carbon or clean energy societies. Norway has the most ambitious plan, according to which it should achieve climate neutrality by 2030 [8]. Sweden has planned to produce 50% of the total consumed energy from renewable sources by 2020, whereas Denmark intends to realize this target by 2030 [9], [10]. Finland, in its turn, contributes to low-carbon production development by aiming to close its coal power plants in 2029 [11]. Besides Nordic power producers, the oil shale power plants compete with Baltic production capacities, where the share of renewable energy is also continuously increasing. The growth of wind power production in the Nordic and Baltic countries was the greatest in recent years. It has more than tripled during this decade that can be seen in Figure 1. Thus, the oil shale power plants, where a significant share of variable costs is environment-related, are forced to compete with emission-free and partly subsidized renewable energy sources.

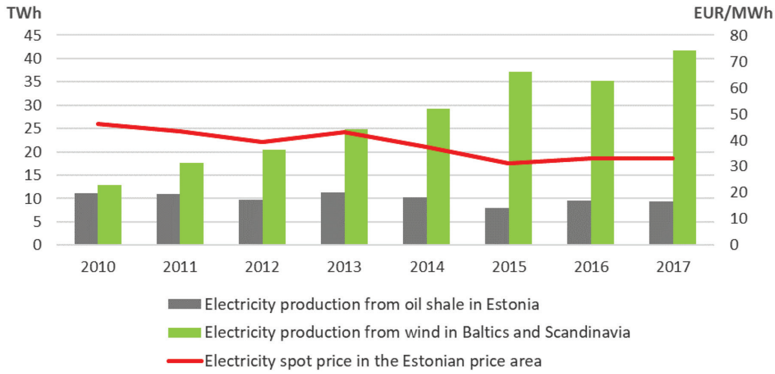

Figure 1. Electricity production from oil shale and wind in the Nordic and Baltic regions [12], [13].

As for shale oil production, it is closely related to the prices of the global crude oil market illustrated in Figure 2. In the early 21st century, soaring oil price greatly improved economics of the shale oil industry. Starting from 32 USD/bbl in 2000, crude oil price reached the highest level of 145 USD/bbl in July 2008. This price growth stimulated countries with plentiful oil shale resources to pay more attention to oil shale processing. The production of shale oil has been significantly expanded in China and the USA.

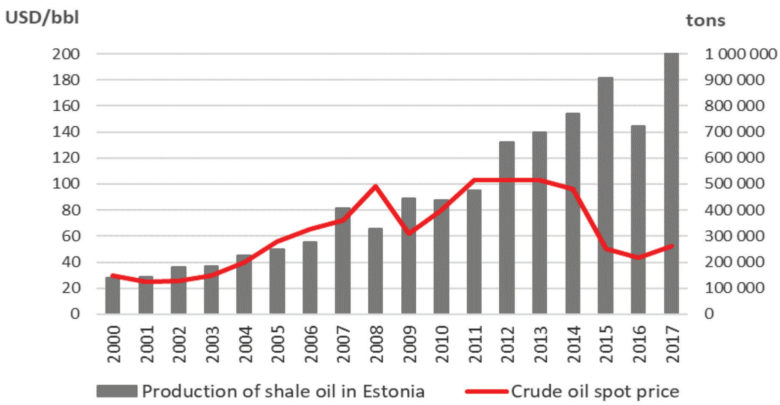

Figure 2. Relation between shale oil production and crude oil price on the example of Estonian shale oil industry [14], [15].

However, due to worldwide financial crisis followed by economic recession, the crude oil price fell dramatically, dropping to the level of 33 USD/bbl in February 2009. It has a direct impact on the development of the industry [1]. The oil price crossed the threshold of 100 USD/bbl only in 2011, then fluctuated in the range of 90-110 USD/bbl until June 2014. This period was characterized by recovering of shale oil production, but the next oil price drop in the period from June 2014 to January 2016 caused by oversupply compelled shale oil producers to revise production volumes. After fall to the lowest level of 26 USD/bbl in January 2016, the crude oil price began to rise gradually up to October 2018, when it reached the high of 80 USD/bbl [14]. The new soar of oil price was a basic reason for the consideration of possible new investments into the shale oil industry. Nevertheless, the oil price drop triggered by the expectation of the next global financial crisis in October 2018 may force shale oil producers to refuse from these plans.

The fluctuations of world oil price are caused by the law of supply and demand. The dominant factor that influences the oil supply is OPEC's production policy, as it controls 40% of crude oil extraction in the world. Political instability in the Middle East, natural disasters affecting production, storage level and production costs have also supply-side impact on oil prices. The demand of crude oil mainly depends on the world's economic situation. However, the current climate initiatives, including the Transport White Paper mentioned above, may significantly affect oil demand by promoting the use of electric vehicles in the future. Presently, nine countries have stated their intention to eliminate completely the use of internal-combustion engine cars with timeline for their phase out between 2025 and 2050. In addition to the factors listed above, the new standards that regulate the quality of liquid fuels may also influence the demand of shale oil.

Purpose of the Thesis

The main purpose of this thesis is to estimate the development prospects of the oil shale industry by analysing the economic feasibility of new investments in this field in the light of renewable and low-carbon energy policy. The analysis focused on the two main sectors of the oil shale industry – shale oil production and electricity generation. To evaluate the profitability of investments in the shale oil production sector, the potential construction of a shale oil plant was considered on the example of Estonian oil shale industry. The expansion of shale oil production capacities will lead to an increase of the generation of retort gas, a by-product of oil shale retorting process needed to be utilized to provide constant oil production. Therefore, a potential solution for the gas utilization was considered as well. Thus, the objects of the analysis are the following projects:

- potential construction of a shale oil production plant;
- potential construction of a condensing oil shale power plant to utilize retort gas for electricity generation.

Specific goals of the applicant's doctoral studies were:

- to create a cash flow model for each project considered;
- to propose an approach for forecasting the variables of the models;
- to analyse projects' cash flows obtained from the models;
- to evaluate the economic feasibility of the projects on the basis of the calculation results received by employing appraisal techniques;
- to study the projects under risk by applying sensitivity analysis and break-even analysis for pricing.

Contribution of the Thesis

The thesis includes theoretical approaches for the estimation of the economic feasibility of the investments in the oil shale industry under the conditions of renewable and low-carbon energy policy. The methodology for the risk analysis of the investment projects in this field is also proposed. The originality of the thesis consists in the theoretical and practical results.

Theoretical originality of the thesis lies in the methodological recommendations proposed to create the cash flow models of the projects and to analyse the profitability of the relevant investments. The contribution to the methodology is also in the approaches applied to calculate the break-even prices of the main products of the oil shale projects. Additionally, the principles employed to forecast the variables of the projects' cash flow models under the influence of the climate and energy policy are demonstrated.

Practical originality of the thesis includes the results obtained by applying the proposed methodological recommendations and approaches. The results are presented as the projects' models and the economic and risk appraisal criteria. The output data received from the models were the basis of the calculation of the criteria. The results can be used by investors and companies' managers to support decisions regarding furtherance of the oil shale projects or for their further analysis.

The current relevance of the thesis is related to the necessity to estimate the viability of the potential projects in the oil shale industry in the light of renewable energy-focused policy. Currently, many shale oil producers are standing on the threshold of making the decision regarding further expansion of their oil production capacities. Therefore, the thesis pays more attention to the analysis of the profitability and risks of a project in the shale oil production sector by considering the investments into possible construction of a shale oil plant. At the same time, the undertaking of this project may lead to the problem of the utilization of the retort gas produced in the plant. Thus, the thesis also discusses a possible technical solution for this problem by analyzing the economic feasibility of the construction of an oil shale power plant to produce electricity from the fuel mix of oil shale and retort gas. As was mentioned above, the results of these analyses may be used by decision-makers to estimate the profitability and risks of the investments in the oil shale industry during the planning phase of the investment projects to make a decision regarding their acceptance.

Structure of the Thesis

The current thesis consists of four main chapters, a summary chapter and three appended published papers. The thesis is mainly based on the research papers written by the author. However, it also includes additional analyses, which have not been previously published.

Chapter 1 presents the overview of the world oil shale industry, which includes the present state of the industry as well as the directions of its further development. This chapter also discusses the potential projects in the oil shale industry on the example of Estonia, which are considered in the thesis as the objects for the analysis of investment performance in this field under the conditions of the current climate and energy policy.

Chapter 2 focuses on the data and basic assumptions used to calculate the cash flows generated by the considered projects during their lifetime. The approach proposed to forecast the price of heavy fuel oil 1%, one of the key variables, is also considered. The principles applied to project future oil shale price and environmental charge rates as important input data are discussed. Additionally, this chapter presents the basic parameters of the potential projects.

Chapter 3 describes the methodology applied to appraise the economic feasibility of the investment projects in the oil shale industry. The methodology relies mainly on the principles of economic analysis, adjusting the appraisal techniques to the peculiarities of the studied projects. Besides the appraisal techniques, the methodology includes two more crucial aspects: the principles of the creation of the projects' cash flow models and the projects' analysis under risk. Approaches for the analysis of break-even pricing of the key products of the investment projects, which supplement the techniques of risk analysis, are also proposed.

Chapter 4 presents the outcomes of the current work. All the calculation results were obtained by applying the cash flow models of the projects created in Microsoft Excel. The output data of the models are the cash flows generated by the projects, on the basis of which the appraisal criteria and risk indicators were calculated. The results of the break-even analysis for pricing are also demonstrated. Moreover, the chapter presents the critical assessment of the results and discusses additional risk factors that may influence the profitability of the considered projects.

In the *Summary* chapter, the main conclusions made relying on the obtained outcomes are presented and the potential directions for the further work are addressed.

Abbreviations

BFW	boiler feed water
BOPD	barrels of oil per day
bbl	barrel
CFB	circulating fluidized bed
CO_2	carbon dioxide
DPP	discounted payback period
ESP	electrostatic precipitator
EU	European Union
EU ETS	European Union’s Emissions Trading System
EUR	euro
GHG	greenhouse gas
GWh	gigawatt hour
IEA	International Energy Agency
IED	Industrial Emissions Directive
IPCC	Intergovernmental Panel on Climate Change
IRR	internal rate of return
kg	kilogram
MEUR	million euros
MJ	megajoule
MSR	Market Stability Reserve
MW	megawatt
MWe	megawatt electrical
MWh	megawatt hour
MWt	megawatt thermal
m^3	cubic meter
Nm^3	normal cubic meter (at standard atmospheric pressure and temperature)
NOx	nitrogen oxide
NPV	net present value
NWE	Northwest Europe
O&M	operation and maintenance
OPEC	Organization of Petroleum Exporting Countries
PF	pulverized (fuel) fired
PI	profitability index
SI	sensitivity indicator
SO_2	sulphur dioxide
SV	switching value
TWh	terawatt hour
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USD	American dollar

Symbols

^0C	degree Celsius
C_{It}	cash inflow in the year t
C_n	net cash flow in the year n
C_{Ot}	cash outflow in the year t
C_t	net cash flow in the year t
D_t	depreciation in the year t
F_t	fixed cost in the year t
I_j	investment in the year j
J	total number of the project construction years
j	year of the investment
k_t	income tax rate payable in the year t
NPV_b	value of the NPV in the base case
NPV_1	value of the NPV in the sensitivity analysis
n	year, in which the present value of the cumulative cash flow produced by a project exceeds the cost of initial investment
P_{Et}	average selling price of one unit of electricity in the year t
P^*_E	break-even selling price of one unit of electricity
P_{Ot}	average selling price of one unit of shale oil in the year t
P^*_O	break-even selling price of one unit of shale oil
Q_{Et}	amount of electricity produced in the year t
Q_{Gt}	amount of retort gas produced in the year t
Q_{Ot}	amount of shale oil produced in the year t
R^2	coefficient of determination
r	discount rate
T	total number of the project operation years
t	year of the cash flow
V_t	variable cost of one unit of the production in the year t
X_b	value of the variable in the base case
X_1	value of the variable in the sensitivity analysis
x	predictor variable
y	criterion variable

1 Overview of the Oil Shale Industry

This chapter describes the present state of the world oil shale industry and provides an overview of the directions of its further development. The leading countries with the most well-established oil shale sector, the current technologies of oil shale retorting and combustion, as well as the activities of the countries with plentiful oil shale resources in the field of its possible utilization are discussed. The chapter also presents the potential projects in the oil shale industry on the example of Estonia that are considered in the thesis as the objects for the analysis of investment performance in this field under the conditions of renewable and low-carbon energy policy.

1.1 Current State of the Oil Shale Industry

The potential of the development of the oil shale industry over the world is capacious. The shale oil equivalent of world oil shale reserves amounts to more than 400 billion tons. It is 2.5 times greater than world crude oil recoverable reserves. The United States has the largest in-place shale oil equivalent reserves of oil shale, more than 300 billion tons. Besides the United States, such countries as Russia, Zaire and Brazil have also abundant reserves of oil shale [1]. Top ten countries with the largest oil shale reserves in the world are presented in Figure 3.

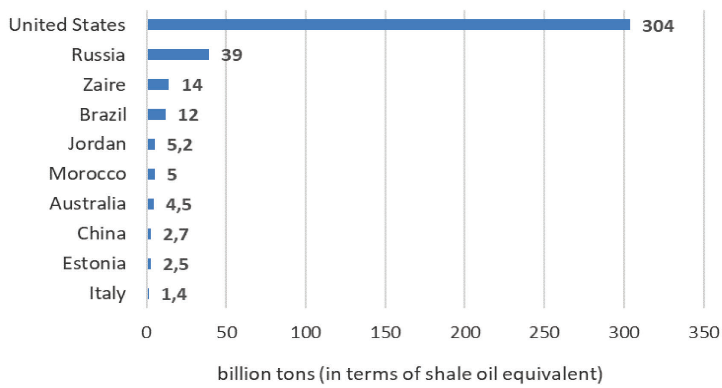

Figure 3. Top ten countries with the largest oil shale proven reserves [1].

It should be pointed out that the numbers in Figure 3 indicate proven reserves, in-situ oil shale quantity that has been proven with detailed exploration. On the basis of the estimated oil shale resources, the potential for the development of the oil shale industry in these countries would be much greater [1].

Presently, there are three countries with the most well-established oil shale industry in the world. These are Estonia, China and Brazil, the oil shale sectors of which are illustrated in Figure 4. In 2017, Estonia processed 20.5 million tons of oil shale. 68% from this amount was utilized in power plants to generate electricity and heat and 25% was used in oil shale plants to produce liquid fuels [15]. In Estonia, oil shale is also used for cement production and in the chemical industry. China processes approximately 14.5 million tons of oil shale annually [16]. More than 90% from this amount is utilized to produce shale oil. The rest of oil shale is used for power production, as in cement, building and chemical industries. In Brazil, the annual consumption of oil shale is 2.6 million tons, which is processed only in oil plants to produce liquid fuels [1].

As can be seen from the figures above, the most widespread way of the utilization of oil shale is oil production, as presently, it provides a higher added value of used primary fuel than power production. The leading world producer of shale oil is China. By 2014, China produced 1 million tons of shale oil through oil shale refinery. Its production volume of shale oil is expected to exceed 3 million tons by 2020 [17]. Shale oil is produced in 9 oil shale retorting plants, involving Fushun, Huadian, Wangqing, Beipiao, Longkou, Yaojie, Dongning, Maoming, and Jimsar, located in 6 provinces. Fushun retort is most often used for oil shale processing in China [18], [19].

Estonia reached the shale oil production level of 1 million tons only in 2017 [15]. This volume was produced by 3 shale oil producers: VKG Oil, Enefit Energiatootmine and Kiviõli Keematööstus. To process oil shale, such retorting technologies as Kiviter and Galoter, as well as Enefit and Petroter, the newest modifications of Galoter technology, are applied [20].

In Brazil, the annual production of shale oil amounts to 180,000 tons. Shale oil is produced in 2 retorts based on Petrosix technology and owned by Petrobras company. The units enable processing in total up to 7,500 tons of oil shale per day [1].

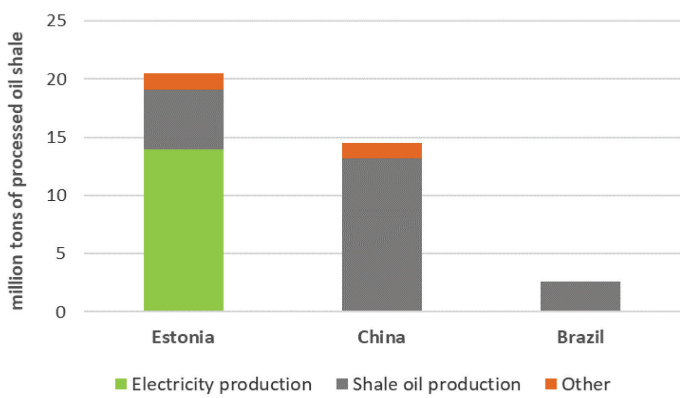

Figure 4. Leading countries with the most well-established oil shale industry in the world.

Shale oil may be produced by applying two different types of the retorting of oil shale: ex-situ and in-situ oil shale retorting. Currently, commercial oil shale production is based on ex-situ retorting, also known as surface or aboveground retorting. In this process, oil shale is mined and transported to the surface, crushed and sieved to the appropriate size and fed to the retort. The products of this process are shale oil, pyrolysis gas and shale char or shale ash. The capital investments of ex-situ retorting are higher, but its oil recovery is also higher in comparison with in-situ retorting [1].

Ex-situ retorts may be, in turn, classified into vertical and horizontal retorts. In vertical retorts, oil shale lumps are heated by hot combustion gas or hot pyrolysis gas that is used as a heat carrier. Due to the low heat transfer coefficient of the shale lump, the heat transfer from the lump surface to the center is very slow. It usually takes 2 - 4 hours for heating up to about 500 ^{0}C, so pyrolysis requires several hours. The commercialized vertical retorts are Fushun's in China with a daily oil shale processing capacity of 100 tons, Kiviter's in Estonia with a daily capacity of 200 tons and 1,000 tons, and Petrosix's in Brazil with a daily capacity of 1,500 tons and 6,000 tons [1].

In horizontal retorts, the Galoter process is applied, where the shale ash is used as a solid heat carrier [20]. Hot shale ash is used to heat particulate oil shale, whereas shale ash in fluidized state, mixed with steam or pyrolysis gas, is used to heat pulverized oil shale. Pyrolysis of particulate oil shale requires several or dozen minutes, whereas pyrolysis of pulverized oil shale requires only about 2 - 3 minutes. At the same time, the retorting of oil shale in fluidized state is associated with dust emissions caused by shale oil vapor. In addition, crushing of raw shale down to the size of fines feed consumes large quantities of electricity that increases the production costs of shale oil [1]. Commercially, horizontal retorts are mainly used in Estonia.

In the process of in-situ retorting, also called as subsurface or underground retorting, oil shale is heated underground without mining. To heat and burn part of oil shale, air and fuel gas or electric heating rods are inserted into the oil shale formation [1]. In-situ retorting of oil shale takes much time (on the scale of years) and requires much energy. Also, it might need a manmade barrier to prevent oil from flowing to unwanted places. At the same time, pyrolysis occurs at lower temperatures, which leads to a lighter oil with a larger gas fraction than in the case of ex-situ retorting. Presently, in-situ technologies are in a development stage and not used in commercial level [2]. The leaders in this field are USA companies, such as Shell and ExxonMobil [1]. However, in recent years, China has been actively developing its in-situ oil shale mining technologies [21]. The diagram of oil shale retorting technologies is shown in Figure 5.

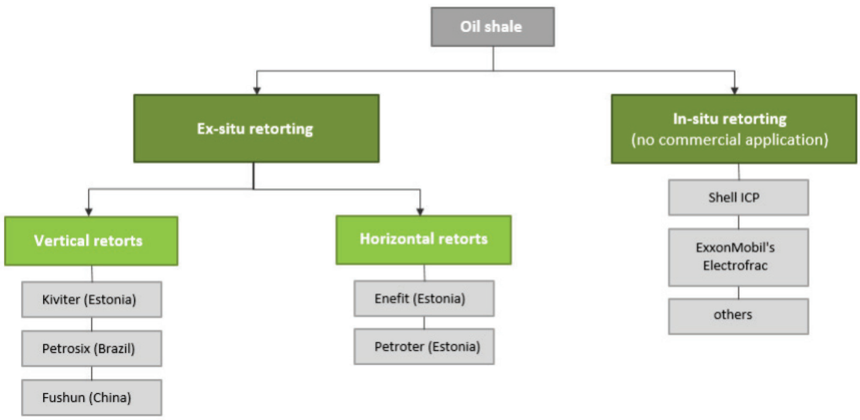

Figure 5. Oil shale retorting technologies [2].

However, it should be noticed that the production of liquid fuels from oil shale has a greater impact on the environment than the production of fuels from conventional oil. The environmental impact of fuel production can be demonstrated from the perspective of life-cycle greenhouse gas (GHG) emissions and water consumption. The life-cycle GHG emission factor evaluates the GHG emission characteristics of a fuel production technology from the viewpoint of global warming. The life-cycle water consumption factor shows the amount of water used for the full life cycle of a fuel production technology. The environmental impact of fuel production from oil shale and conventional oil is presented in Figure 6.

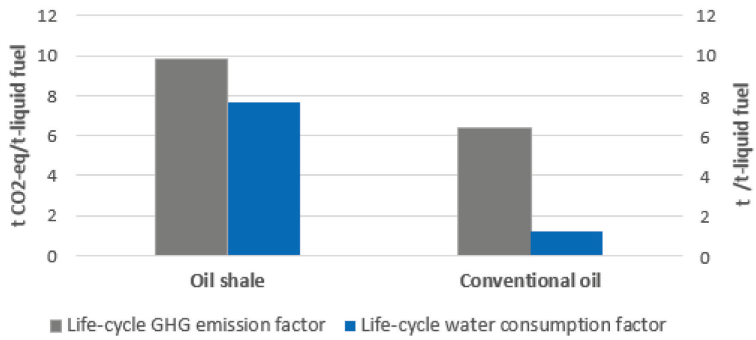

Figure 6. The life-cycle GHG emissions and water consumption of the production of liquid fuels from oil shale and conventional oil [22].

Additionally, shale oil is characterized by a relatively high sulphur content. The sulphur content in shale oil depends on the kind of oil shale (location of oil shale deposits) used for the oil production. For instance, the shale oil produced from Jordanian oil shale contains 8.3-9% of sulphur, while the sulphur content of crude oil regularly arises in the range of 0.5 to 3.5% [23], [24]. Besides sulphur, the content of nitrogen and heavy metals in shale oil is also higher than in crude oil. Therefore, shale oil requires more extensive refining, e.g. cleaning and hydrotreatment, than crude oil that leads to additional costs. Thus, the final unit cost of commercial products derived from shale oil may be higher than those accrued for similar petroleum products [23].

Regarding oil shale-based power production, the world's leading country in this sector is Estonia. The net installed capacity of Estonian oil shale power plants is 1959 MW, which is 64% from the total electricity generation capacity in the country [25]. In 2016, Estonia produced 9.6 TWh of electricity from oil shale, amounting to 79% of its total electricity production [15].

The largest oil shale power plants in the world are those of the Eesti, the Balti and the Auvere in Estonia. These are condensing power plants owned by Enefit Energiatootmine, the subsidiary of state-owned company Eesti Energia. The Eesti power plant, which has been operating since 1969, has seven old units with pulverized oil shale fired (PF) boilers and one modernized unit with the boilers based on circulating fluidized bed (CFB) technology. The installed electrical net capacity of the plant is 1355 MW, which makes it the world's largest oil shale power plant. However, in 2019, three PF units are planned to be decommissioned, as they do not meet the emission standards set by IED. It will reduce the capacity of the plant by 489 MW. The other four PF units are equipped with the flue gas desulfurization facilities and nitrogen oxide removal systems, which allows the emission limit values not to be exceeded.

The Balti power plant has been operating since 1959. Currently, only two units are in operation, an old PF unit and a modernized CFB one, whereas the other old units have been decommissioned. The total installed net capacity of the operational units is 322 MW. The Auvere is the newest oil shale power plant, which was synchronized with the electrical system for the first time in May 2015. It consists of one CFB unit with an installed electrical net capacity of 274 MW. The economic analysis of the Auvere is presented in Publication I.

Besides Estonia, oil shale-based power production is also established in China, but on a small scale. The total installed electrical capacity of Chinese oil shale power plants is 36 MW. The largest power plant with a capacity of 18 MW was built in 1996 in Huadian, Jilin Province. It has three oil shale CFB boilers for combusting particulate oil shale. In 2007, the original pulverized coal boiler of the power plant in Suixi county was reconstructed for utilization of oil shale CFB technology. The installed capacity of the power plant is 12 MW, and it utilizes Maoming Jintang oil shale. Also, an oil shale-fired power plant with two CFB boilers has been recently built in Wangqing, Jilin Province. This is the smallest Chinese power plant that runs on oil shale. Its electrical capacity is 6 MW [1]. Besides Estonia and China, power production from oil shale is presented in the form of small fluidized-bed boilers or separate demonstration plants in Russia, Germany and Israel.

As was mentioned above, power is generated from oil shale by applying PF and CFB technologies. Operation experience has shown that CFB technology has significant advantages over PF technology. The lower combustion temperature in a CFB boiler enables binding of sulfur with the fuel ash that, in turn, reduces or inhibits the formation of SO_2. The emissions of NO_x and fly ash are also lower in the CFB than in the PF technology. Additionally, the thermal efficiency of a CFB boiler is higher by 20% than that of PF [1]. Thus, the environment-friendly and efficient CFB technology is believed to be more perspective under the conditions of renewable and low-carbon energy policy.

1.2 Outlook of the Oil Shale Industry

1.2.1 Future Activities in the World Oil Shale Industry

There are several directions in the development of the oil shale industry in the world, starting with the evaluation of oil shale resources to innovation activities in the field of oil shale technologies. Both countries with well-established oil shale industry and those that do not use oil shale commercially, but have their plentiful deposits, show variable involvement in the study of its comprehensive utilization.

Presently, one of the most active countries that is developing its oil shale resource potential is China. In the frame of the project of the National Oil Shale Resource Evaluation conducted in China from 2003 to 2006, its basic resource potential of oil shale was studied. The results showed that total oil shale resources are estimated at approximately 978 billion tons, i.e. about 61 billion tons of in-place shale oil [21]. However, the oil shale proven reserves in China till now are only about 40 billion tons. It means that further exploration work is needed to find more exploitable reserves. Also, Jordan, Morocco, India and Indonesia are actively investigating their oil shale resources [1].

The projects of the construction of new oil shale-based power production capacities have been initiated in Jordan and China. Currently, Jordan is building the oil shale power plant with the net installed capacity of 470 MW. The plant is scheduled to begin generating electricity for local consumption in the middle of 2020 [26]. It will be the second-largest oil shale power plant in the world after the Eesti in Estonia. China, in its turn, has plans to launch a new oil-shale based power plant with the capacity of 100 MW in Fushun, Liaoning [1].

However, the development of shale oil production is of high significance. Mostly, the reason is that the countries with high crude oil consumption intend to substitute their oil import with domestic production of unconventional oil. The most active countries in this field are China and the USA. In 2007, China National Development and Reform

Commission recognized the shale oil industry belonging to the category, the development of which is to be encouraged by national policy. Presently, China is expanding shale oil production capacities and developing new retorting technologies. It is envisaged to produce more than 3 million tons of shale oil in 2020 and approximately 10 million tons of shale oil in 2030 [1], [17].

There is no commercial production of shale oil by pyrolysis in the USA. All the shale oil produced in the United States nowadays is a part of tight oil extracted from shales. Nevertheless, there are 29 companies involved in the projects of research and development of oil shale processing such as in-situ and surface retorting, shale oil upgrading for producing light liquid fuels [1]. Thus, shale oil production in retorting plants may be expected in the USA in the future.

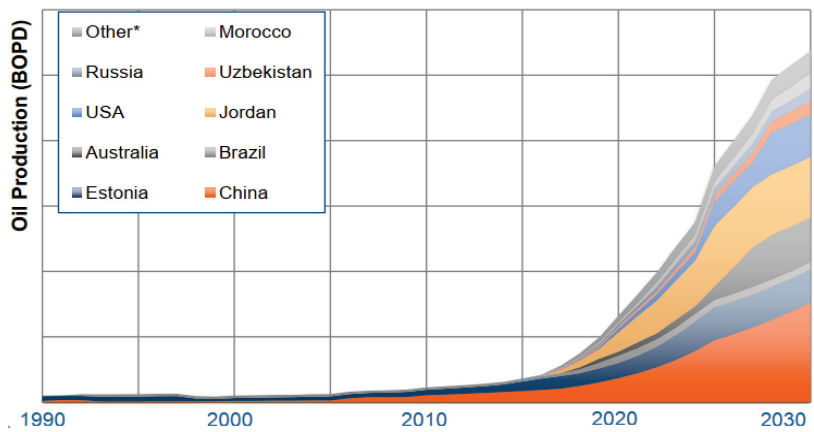

Figure 7. The real and projected quantities of shale oil production by pyrolysis by countries [2].

In the frame of the National Energy Strategy adopted in 2008, Jordan is implementing programs to increase its reliance on oil shale, including development of shale oil production. In recent years, Jordan has signed contracts or memoranda with foreign countries for producing shale oils with different retorting technologies [1]. Currently, they are building a shale oil production plant based on Enefit technology. The plant will have a capacity of approximately 40,000 barrels of daily output, covering 40% of Jordan's current daily energy [26].

Besides the countries listed above, Morocco and Australia intend to launch shale oil plants in the nearest future. Russia and Uzbekistan are also considered as potential shale oil producers. The projected quantities of shale oil production by pyrolysis by countries are presented in Figure 7.

1.2.2 Development of the Oil Shale Industry on the Example of Estonia

The strategy of the development of Estonian oil shale industry is set out by the two main documents – the National Development Plan for the Use of Oil Shale 2016 – 2030 and the National Development Plan of the Energy Sector until 2030. The key aim of the oil shale development plan is to provide effective and efficient use of oil shale as a nationally strategic resource and to ensure the sustainable development of the oil shale sector, reducing, at the same time, its negative impact on the environment. Therefore, the oil shale development plan is prepared in accordance with the Estonian Environmental Strategy until 2030 [27].

The National Development Plan of the Energy Sector until 2030 is based on the objective to ensure energy supply with market-driven prices and availability of consumers in line with the long-term energy and climate targets of the EU, while contributing to the improvement of Estonia's economic climate and environmental status and increased long-term competitiveness. The plan assumes a transition from prevalent oil shale direct combustion technologies to combined shale oil and electricity generation solutions that increase the added value of oil shale, improve the efficiency of the resource use (more than 75% in comparison with 30-40% of direct combustion technologies) and reduce the environmental impact [28].

Thus, to estimate the development prospects of the oil shale industry, it was decided to analyse the implementation of the project of combined shale oil and electricity generation. The analysis was made on the example of Eesti Energia's oil shale energy complex, the largest in Estonia, where the most efficient combined production technology is applied. This shale oil plant based on the Enefit280 technology, a new generation technology, that enables production of shale oil and retort gas as well as generation of electricity. Besides the Enefit280 plant, the complex consists of another oil plant based on the previous generation technology, the Enefit140, and the Eesti and the Auvere power plants described in Section 1.1.

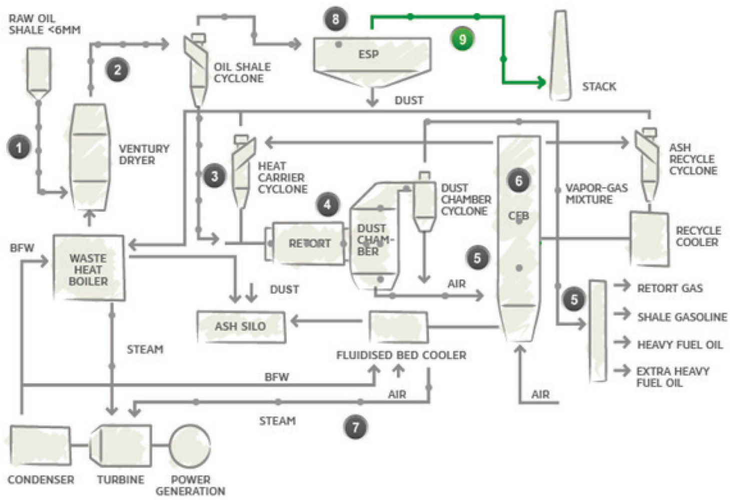

Figure 8. Process diagram of the Enefit280 oil shale retorting technology [26].

According to the Eesti Energia Strategic Action Plan 2016-2020, a new shale oil production plant based on the Enefit280 technology is planned built [29]. The investment decision is expected to be made in the near future. If it is positive, the commission of the new plant is expected to be in 2024. Taking into account that the design lifetime of the current Enefit280 oil plant is 30 years, the potential plant is supposed to be operated until 2054. The process diagram of the Enefit280 technology is presented in Figure 8.

One of the by-products in the process of retorting oil shale to produce oil is retort gas, which has a higher calorific value than natural gas. In the Galoter process, a modification of which is the Enefit technology, retort gas accounts for about a quarter of the energy contained in retorted oil shale. To provide constant oil production, it is required to utilize retort gas. Due to its chemical properties, it cannot be transported far away from the place of production (based on the current level of knowledge), which is why it has to be used locally [28].

Presently, retort gas is utilized in the power plants that are part of the oil shale energy complexes, to generate electricity and heat. However, according to the vision presented in the energy sector development plan, 7 out of 9 power production units of Eesti Energia's energy complex will be decommissioned due to non-compliance with the IED requirement or high depreciation by 2031 [28]. Thus, the expansion of shale oil production capacities may lead to the problem of the utilization of retort gas in the future. Therefore, it was decided to consider a scenario under which the thermal capacities to produce retort gas exceed the thermal capacities to utilize the gas.

The potential construction of a condensing oil shale power plant to utilize retort gas for electricity generation was analyzed as a solution of the problem. The potential power plant is supposed to be based on the CFB technology, where fuel mix from 50% of oil shale and 50% of retort gas is used as primary energy. The CFB technology was considered as it provides high thermal efficiency and very low emissions of SO_2, NO_x and fly ash. The fuel mix from 50% of oil shale and 50% of retort gas has been already applied in one of the boilers of the CFB unit in the Estonia power plant. Thus, the utilization of this share of retort gas of primary energy in an oil shale boiler is technically possible.

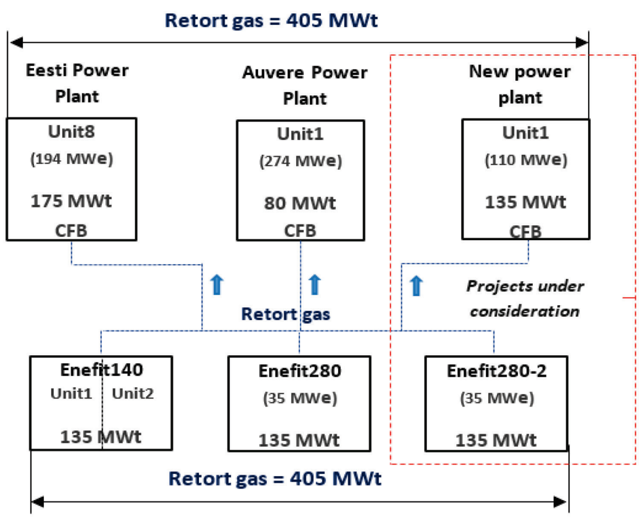

Figure 9. Expected thermal capacities to produce and utilize retort gas in Eesti Energia's energy complex after 2030.

The Auvere plant, the newest among those based on the CFB technology, is a reference plant for that under consideration. The parameters of a potential power plant such as design lifetime, efficiency and availability rate are the same as those of the Auvere. The installed electrical capacity of the plant was calculated on the basis of the total thermal capacity of the retort gas needed to be utilized in Eesti Energia's energy complex in the future. Since it is expected that only two power production units, the total thermal capacity of which to utilize retort gas is 255 MWt, will remain in operation in the complex starting from 2031, it is required to utilize the additional 150 MWt of retort gas if a new shale oil production plant will be constructed. Figure 9 shows the potential thermal capacities of Eesti Energia's energy complex to produce and utilize retort gas, taking into account the Eesti Energia Strategic Action Plan and the long-term vision of available generation capacities presented in the National Development Plan of the Energy Sector [28], [29], [30].

1.3 Summary

The current chapter presented the overview of the world oil shale industry that includes its present state, as well as future activities in this field. The description highlighted the present state of the industry, the leading countries with the most well-established oil shale sector and the currently applied oil shale combustion and retorting technologies. In the outlook of the industry, the main directions of its further development in the world were covered. This chapter also addressed the potential projects of the oil shale industry on the example of Estonia, which were analysed in the thesis as the objects of the economic feasibility study.

2 Calculation of the Cash Flow Model Variables: Data and Assumptions

To estimate the development prospects of the oil shale industry in the light of renewable and low-carbon energy policy, the economic feasibility of new investments in this field was analysed. The analysis focuses on two projects, a shale oil production plant and a power plant to utilize retort gas, which can be potentially realized in the Estonian oil shale sector. To evaluate the economic feasibility of the investments, the cash flows generated by the projects during their lifetime must be specified.

This chapter focuses on the data used to calculate the components of the projects' revenue and costs that are the variables of the cash flow models. The variables are the input data used to compute the projects' cash flows by applying the models. Some variables were defined relying on the projections provided by the competent sources, other variables were forecasted. Thus, the chapter presents the projections that are the basis for some variables, as well as the data and basic assumptions employed to forecast the change of the variables values in the future.

2.1 Oil Plant Project Data

The construction of a shale oil production plant is considered as a potential project that can be realized according to the Eesti Energia Strategic Action Plan 2016-2020 [29]. To calculate the net cash flows received from the project during its lifetime, the project's cash inflows and cash outflows must be specified. In other words, the revenue generated by the project and its costs must be forecasted.

Table 1. Basic data of a potential project of a shale oil production plant [31], [32].

Parameter of a potential shale oil production plant	*Value*
Construction time, years	3
Commissioning year	2024
Design lifetime, years	30
Oil shale processing capacity, tons per hour	280
Installed electrical capacity, MW	35
Annual consumption of oil shale, million tons	2
Annual production of shale oil, thousand tons	257
Annual production of retort gas, million Nm^3	75
Annual production of electricity, GWh	276
Total investment, million euros	301

As was mentioned in Section 1.2.2, the potential oil plant is planned to be based on Eenfit280 technology that enables production of shale oil, electricity and retort gas. The revenue of the plant is supposed to be obtained from the sale of shale oil and electricity. Retort gas, another product of the plant, is a by-product from shale oil extraction. The need to utilize the gas arises in the continuous oil production. Due to its chemical properties, retort gas cannot be transported far away from the place of production. Therefore, it is utilized locally in the power plants of the energy complexes to generate electricity and heat, and, presently, it does not have another field of application. Thus, it is considered as a free product, and, as a result, no revenue will be obtained from its sale. To define the output of the considered oil plant, the data on the annual production of the Enefit280, as a reference oil plant, were used. The data on the annual production of a potential shale oil plant are presented in Table 1.

The potential oil plant will produce two base fractions of shale oil used for sale - heavy fuel oil and gasoline. The price of fuel oil tends to follow the price of heavy fuel oil with 1% sulphur content (heavy fuel oil 1%) traded in the market of Northwest Europe (NWE) and the price of shale gasoline follows the price of NWE naphtha market. However, liquid fuels produced from oil shale are traded at a discount to the reference products due to the differences in chemical composition. The information about applied discount is shale oil producers' internal data. Therefore, to calculate the revenue received from the liquid fuels sale, it is assumed that the potential plant produces only heavy fuel oil. As the price of fuel oil is lower than the price of shale oil petrol, the discount is taken into account due to the price spread. Thus, the price forecast for heavy fuel oil 1% was used to calculate the revenue of the considered shale oil plant.

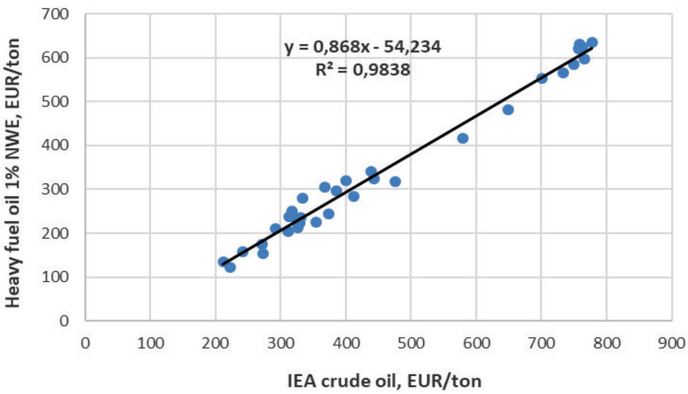

Figure 10. Correlation between average monthly prices of heavy fuel oil 1% and of crude oil[1] [33], [34].

The price dynamics of heavy fuel oil 1% market strongly correlates with price movements in the crude oil market that can be seen in Figure 10. Therefore, the price forecast for heavy fuel oil 1% was made on the basis of crude oil price projection by applying the regression equation presented in Figure 10. The oil price projection is provided by the International Energy Agency (IEA), one of the most credible and competent sources. The projection under the New Policies Scenario was used, since it is a central scenario of the IEA, which reflects both existing energy policies and an assessment of the results likely to stem from the implementation of announced intentions and plans of the governments to develop their energy sectors. This scenario also includes the Nationally Determined Contributions intended to be made by the countries for the Paris Agreement of the UNFCCC [35]. Thus, the New Policies Scenario reflects the development of the energy sectors, taking into account the main initiatives in the field of renewable and low-carbon energy policy.

The oil price projection provided by the IEA is available until 2040, while the price forecast for fuel oil is needed until 2053 (the year of project termination). Therefore, it is assumed that the trend of oil market development will remain the same in the

[1] Observed data cover the period 2014 - 2016.

future. The results of the price forecast for heavy fuel oil 1%, as IEA assumptions for crude oil import price, are shown in Table 2.

Table 2. IEA assumptions for crude oil price and price forecast of heavy fuel oil 1% [35].

Year	*2024*	*2034*	*2044*	*2053*
IEA crude oil price, USD/bbl	82	101	117[2]	128[3]
IEA crude oil price, EUR/ton[4]	544	670	773	846
Heavy fuel oil 1% price, EUR/ton	418	528	617	681

To estimate the revenue received from the sale of electricity generated in the oil plant, electricity price forecast for the Estonian price area presented in Table 3 was used. The forecast relies on the estimations of experts and consultants, and takes into account the major changes expected to be made in the Baltic power system, such as decommission of oil shale power production units in Estonia, desynchronization of the Baltic system from the Russian grid, increase of the production of renewable energy, and construction of new transmission capacities in the region. The influence of the capacity changes in the Nordic power system on the Baltic price pattern is also considered. The major changes are expected to be caused by the launch and decommissioning of nuclear production capacities and expanded connections within the Nordic area and to Central Europe. The new transmission capacities with the rest of Europe will increase, in turn, the influence of the German price and the United Kingdom price on the Nordic power market.

Table 3. Electricity price forecast for the Estonian price area.

Year	*2024*	*2034*	*2044*	*2053*
Electricity price, EUR/MWh	43	49	51	54

Due to the desynchronization of the Baltic electric power system from the Russian grid and the decommissioning of the old Estonian oil shale production capacities, the Baltic price is expected to be significantly higher than the Nordic system price from the middle of 2020s until the middle of 2030s. However, since the early 2030s, the Baltic price level will begin to decrease and to approach the Nordic system price due to the increase of renewable capacities in the region. By this time, Estonia is expected to fulfil its renewable energy target 2030 to achieve 50% of the final electricity consumption to be produced from renewable energy sources. Also, the growth of renewable capacities in the Lithuanian power system is supposed to be fast, as it has a strong intention to reduce dependence on electricity imports. Regarding the Nordic power system, the expected power production from renewable energy sources will reach the level of 74%

[2] Assumption for crude oil price made on the basis of IEA oil price projection.
[3] Assumption for crude oil price made on the basis of IEA oil price projection.
[4] Data are presented in euro per ton for the purpose of convenience to compare them with other data given in the thesis.

of the total annual production by 2030 and approximately 90% of the total production by 2050.

The main production costs of a shale oil plant consist of oil shale purchase costs, environmental costs and operation and maintenance (O&M) costs. The cash outflows caused by the purchase of oil shale were calculated on the basis of the data on annual primary fuel consumption shown in Table 1 and the oil shale price forecast. Since the considered oil plant is the same type as that of the Enefit280, the data on the annual fuel consumption of the Enefit280 were used to calculate oil shale purchase costs for the potential oil plant.

The price projection for oil shale was made on the basis of data on oil shale price in 2015, taking into account the Estonian government's decision from 2016 to lower the oil shale mining fee retroactively since July 2015 [36], [37], [38]. The estimation of oil shale price growth in the future was made on the basis of the price forecast for the major components of oil shale production costs, such as raw materials, electricity, operation and transport costs, oil shale mining fee, other environmental charges and payroll expenses. The forecast was made by relying on the data about Estonian consumer price index [39], [40].

Since a new model, which will allow determination of the oil shale mining fee depending on the value resulting from oil shale use, was under development at the moment of writing the thesis, the current scheme was used to forecast oil shale mining fee in the future. According to this scheme, the fee rate depends on the price of heavy fuel oil 1% traded in the NWE market [37], [38]. Thus, the price forecast of heavy fuel oil 1% presented in Table 2 was used to project the change of the oil shale mining fee in the future. The results of the forecast of oil shale price are shown in Table 4.

Table 4. Price forecast of oil shale.

Year	*2024*	*2034*	*2044*	*2053*
Oil shale price, EUR/ton[5]	15	21	26	31

The environmental costs of the oil plant include the charge for surface water use as cooling water, the charge for disposal of oil shale ash and the charge for the emission of pollutants, such as CO_2, SO_2, NO_x and fly ash, into the ambient air. To calculate CO_2 costs of the plant, CO_2 allowance price forecast for EU under the New Policies Scenario provided by the IEA was used [35]. Since the forecast is available until 2040, it is assumed that the price trend will remain the same during the rest of operation periods of the project. The IEA assumptions for CO_2 allowance price in EU are shown in Table 5.

Under the EU ETS, industrial installations in sectors exposed to a significant risk of carbon leakage are eligible to receive free allowances to support their competitiveness [41]. Estonian shale oil production industry is deemed to be a sector with a significant risk of carbon leakage. It means that the project of the construction of a shale oil plant has a potential opportunity to receive a certain share of free allowances. However, there is no information about the exact amount of free allowances that could be allocated to the plant, which is why they are not taken into account in CO_2 costs calculation. Presently, it is decided to continue the free allocation of emission allowances until 2030 that would cover only six years of the plant operation [41]. Thus, neglecting of such

[5] The heating value of oil shale is assumed to be 2.33 MWh/t.

amount of free allowances should not have essential influence on the results of the calculation of the project feasibility.

Table 5. IEA assumptions for CO_2 allowance price in EU and the forecast of environmental charge rates in Estonia.

Year	*2024*	*2034*	*2044*	*2053*
EU CO_2 allowance price, USD/ton	25	39	54[6]	68[7]
EU CO_2 allowance price, EUR/ton[8]	23	35	49	61
Surface water use as cooling water, EUR /1000 m^3	2	2	3	3
SO_2 emissions charge, EUR /ton	165	201	245	293
NO_x emissions charge, EUR /ton	139	169	206	246
Fly ash emissions charge, EUR /ton	166	202	246	294
Oil shale bottom ash disposal charge, EUR /ton	3	4	5	6

Other environmental costs were calculated using the forecast of the natural resource and pollution charge rates. The data on the initial charge rates were taken from the Estonian Environmental Charges Act [42], [43]. The change of the charges in the future was forecast on the basis of the projection of the annual rate of consumer price index in Estonia presented by the Ministry of Finance [40]. The results of the charges forecast are presented in Table 5. The specific amounts of cooling water, oil shale ash and emissions of the Enefit280 were used to calculate the environmental costs of the potential shale oil plant, since the type of the considered oil plant is the same as that of the Enefit280.

The plant's O&M costs were estimated relying on the techno-economic analysis of oil shale retorting process with solid heat carrier technology, the same technology as those of the considered oil plant [44], [45]. To forecast the growth of the costs during the project lifetime, the projection of Estonian consumer price index was applied [40].

To define the investments into the potential shale oil plant, the investments of the Enefit280 were recalculated for the first year of plant's construction, applying the data on real consumer price index in Estonia and its projection [31], [39], [40], [46]. The data about the calculated investment costs of the considered oil plant are shown in Table 1.

[6] Assumption for EU CO_2 allowance price made on the basis of IEA CO_2 price projection.
[7] Assumption for EU CO_2 allowance price made on the basis of IEA CO_2 price projection.
[8] Data are presented in euro per ton for the purpose of convenience to compare them with other data given in the thesis.

2.2 Power Plant Project Data

The construction of a power plant is considered in the thesis as a possible solution for the problem of the utilization of the retort gas produced in the potential shale oil plant. The power plant is supposed to be an oil shale condensing power plant based on the CFB technology, which provides a high thermal efficiency and low emissions into the ambient air. The potential plant is also supposed to run on the fuel mix from 50% of oil shale and 50% of retort gas. This fuel mix has been already successfully applied in one of the boilers of the CFB unit in the Estonia power plant.

As was mentioned in Section 1.2.2, the installed electrical capacity of the plant was calculated on the basis of the total thermal capacity of the retort gas needed to be utilized in Eesti Energia's energy complex in the future. The newest CFB oil shale power plant of Auvere is a reference plant for that considered here. Therefore, the parameters of a potential power plant such as design lifetime, efficiency and availability rate are the same as those of the Auvere. The basic data about the potential power plant are presented in Table 6.

To estimate the economic feasibility of the construction of a potential power plant to utilize retort gas, the net cash flows generated by the project during its lifetime were calculated. The calculation of the net cash flows was made on the basis of the projection of the project's revenue and costs.

According to the Estonian Electricity Market Act, financial support for electricity generated from retort gas is provided only if it is produced in an efficient combined heat and power mode [47]. As the considered power plant is a condensing one, it will not be subsidized. There is a potential opportunity to produce heat in the power plant. However, due to the lack of heat demand near the considered energy complex, heat production was not taken into account in the analysis. Thus, it is supposed that the cash inflows of the power plant consist only of revenue received from electricity sales. To calculate this revenue, the electricity market price forecast for the Estonian price area presented in Table 3 was used.

Since the forecast of the average annual electricity price was used, the operation of the power plant at full load during its lifetime was assumed to receive the correct results for revenue calculation. The maximum annual output of the power plant, in its turn, was calculated on the basis of the availability rate of the reference plant of Auvere. The calculated annual output is presented in Table 6.

Table 6. Basic data of a potential project of an oil shale power plant [31].

Parameter of a potential oil shale power plant	*Value*
Construction time, years	3
Commissioning year	2024
Design lifetime, years	30
Installed net capacity, MW	110
Power plant efficiency, %	40
Annual production of electricity, GWh	877
Total investment, million euros	276

The production costs of the considered power plant consist of fuel costs, environmental costs and O&M costs. As was mentioned above, the power plant will run on the fuel mix from 50% of oil shale and 50% of retort gas. Since retort gas is a by-product needed to be utilized to provide the continuous oil production, it can be considered as a free product for electricity generation. The fuel costs to produce electricity from oil shale were calculated on the basis of the forecast of oil shale price presented in Table 4.

The environmental costs of the plant include charges for surface water use as cooling water, the charge for disposal of oil shale ash and those for the emission of CO_2, SO_2, NO_x and fly ash into the ambient air. The calculation of CO_2 costs is based on the IEA projection of the annual price of CO_2 allowances for EU presented in Table 5. To define other environmental costs of the power plant, the forecast of the natural resource and pollution charge rates shown in Table 5 were used.

The O&M costs of a potential oil shale power plant were calculated on the basis of data on O&M costs of a coal power plant [48]. The O&M costs of the coal power plant were recalculated for the commissioning year of the considered power plant [39], [40].

As was mentioned previously, a potential power plant is supposed to be of the same type as that of the Auvere. Therefore, the investments into its construction were calculated on the basis of the investments of the Auvere project by adjusting these investments to the capacity of the considered power plant and recalculating them for the first year of its construction [31]. The investments were recalculated using the data on real consumer price index in Estonia and its projection [39], [40]. The investments into the construction of a potential power plant to utilize retort gas are shown in Table 6.

2.3 Conclusion

This chapter presented the data and basic assumptions used to calculate the variables, which are the input data of the models to compute the projects' cash flows. The calculated cash flows were the basis of the further calculation of the projects' appraisal criteria and sensitivity indicators. Since the current study focuses on the analysis of the projects under the conditions of renewable and low-carbon energy policy, the data on the key variables, such as crude oil price and CO_2 allowance price, were obtained from the IEA scenario, which relies on this policy. The regression analysis showed that the price dynamics of crude oil market strongly correlates with the price movements of heavy fuel oil 1%, one more critical variable. Thus, the approach proposed to forecast the price of heavy fuel oil 1% on the basis of the IEA crude oil price projection was also addressed in this chapter.

Besides the forecast of the key variables, the approaches applied to estimate the change of oil shale price and of the natural resource and pollution charge rates, other important inputs, were discussed. The results obtained by applying the proposed approaches, as well as the basic data of the potential projects are also presented.

3 Methodology of the Appraisal of Investment Project Profitability and Sensitivity

This chapter describes the methodology applied to appraise the economic feasibility of the investment projects in the oil shale industry. The methodology relies mainly on the principles of economic analysis, adjusting the appraisal techniques to the peculiarities of the studied projects. Besides the appraisal techniques, the methodology includes two more crucial aspects: principles of the creation of the projects' cash flow models and analysis of the projects under risk by examining their sensitivity to the possible changes in the cash flows. Additionally, the approaches proposed for the break-even analysis for pricing of the considered projects supplement the techniques of the examination of their sensitivity. Thus, the methodology presented in this chapter enables a comprehensive analysis of the potential investments.

3.1 Project Cash Flows

Estimation of the cash flows generated by the project is one of the basic steps in the project appraisal. Cash flows are the amount of money received and paid out by the owner of the project at particular points in time. To simplify cash flow timing, it is assumed that cash flows occur at the end of the year. The investment projects considered in the thesis are extremely large and have long lifetime, therefore within-year cash flow timing details may be neglected without having a noticeable influence on the calculation results. Also, only cash flows relevant to the project were taken into account for its analysis. The relevant cash flows are those that would occur and begin to influence the company's wealth only in the case of the project realization.

Cash flows may be classified into two groups: capital cash flows and operating cash flows. Capital cash flows, in turn, may be separated into three categories: the initial investment, additional "middle-way" investments and terminal flows. Operating cash flows are generated by the project during its lifetime. They include cash inflows from product sales and cash outflows associated with asset operation [49]. The classification of project cash flows is illustrated in Figure 11.

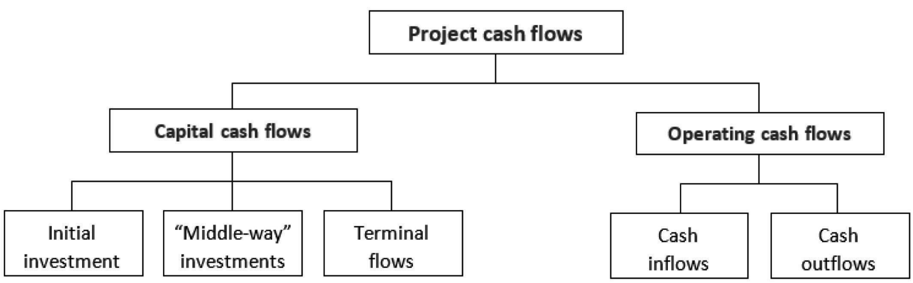

Figure 11. Classification of project cash flows [49].

To simplify the cash flow models of the studied projects, their capital cash flows are considered as initial investments made at the stage of project construction. Terminal flows that occur at the end of the project's lifetime were neglected, as it was supposed that the terminal cash inflows caused by the salvage value of the asset will be approximately the same as the terminal cash outflows associated with the asset demolition.

The components of the projects' cash inflows and cash outflows, as principles employed for their forecasting and calculation were presented in Chapter 2. The results of the calculation of the cash inflows and cash outflows are the basis for the further computation of the net operating cash flows of the project. The operating cash flow C_t means an after-tax net operating cash flow in the year t that is calculated applying the following formula:

$$C_t = \left(C_{I_t} - C_{O_t} - D_t\right) * (1 - k_t) + D_t \,, \tag{3.1}$$

where C_{It} is the cash inflow in the year t, C_{Ot} is the cash outflow in the year t, D_t is depreciation in the year t and k_t is an income tax rate payable in the year t.

Tax payable on company income is a cash outflow. The rate of corporate income tax is set by the taxation legislation, particularly, by Estonian Income Tax Act [50]. The net operating cash flows were calculated assuming that all the regular profit generated by the projects will be distributed and the rate of corporate income tax will remain the same during the projects lifetime.

Taxable income is generally calculated by subtracting asset depreciation as allowable expenses from assessable income. Thus, depreciation has a tax effect by reducing taxable income by the depreciation allowance. Therefore, despite depreciation is not a cash flow, it should be considered in a project economic analysis as a tax deduction. The tax-allowable depreciation was calculated applying the "straight-line" method that allocates an equal amount of the initial cost to each year of the asset's life.

3.2 Project Appraisal Techniques

Techniques applied to appraise the studied projects are based on the discounted cash flow methods. The indisputable advantage of these methods is that they take into account the time value of money by discounting the cash flows generated by a project during its lifetime. In addition to the time value of money, the methods allow accounting such important factors as the required rate of return on investment, the cost of capital and the level of the risk of a project that, in turn, enables correct evaluation of the present value of the future cash flows. To make a detailed economic analysis of the considered projects, such key appraisal techniques as net present value (NPV), internal rate of return (IRR), profitability index (PI), and discounted payback period (DPP) were applied.

The NPV technique is based on the assumption that investors can define the appropriate discount rate to be used to estimate the present value of the future cash flows received from a project. The NPV is calculated by subtracting the present value of the initial investment from the present value of the net cash flows. If the NPV calculation shows a negative value, it means that an investment costs more than it is worth. In such cases, the project should be rejected, as it will be unprofitable. If the NPV is positive, the project is acceptable, as investors will receive a return on the investment. In the projects ranking (upon condition that they are mutually exclusive), the project with a higher NPV should be accepted.

It should be noticed that calculating the project's NPV, investors take into account the estimated cost of capital. If the discount rate used in the calculation of the NPV turns out to be smaller than the actual cost of capital, the project will prove unprofitable despite the previously calculated positive NPV.

The IRR is the discount rate that sets the present value of the project cash flows equal to the initial investment outlay. In other words, the IRR is the discount rate that equates the project NPV to zero. The IRR of a project, therefore, determines the maximum interest rate at which a company would be willing to borrow to finance the project [51].

If the IRR of a project exceeds a company's required rate of return (the cost of capital for the project), that project is desirable, as any project that yields more than its cost of capital will have a positive NPV. If the IRR falls below the required rate of return, the project should be rejected. If the IRR falls between the maximum and minimum value of the estimated cost of capital, the company has to devote additional effort and calculate the project's required return more carefully [49].

The PI is a ratio of the present value of expected future cash flows to the initial cash investment. This indicator represents a present value of return per money unit of the initial investment. The PI is also an alternative way of expressing the NPV, since instead of subtracting initial investment from the present value of cash flows, it is divided by that amount. Therefore, when the present value of cash flows minus initial investment equals zero, the PI will equal one. It follows that when the NPV is more than zero, the PI will be more than one, and, in such case, the project should be accepted.

The DPP is the length of time required to recover the present value of cash flows equal to the cost of initial investment. Projects with a payback less than a maximum DPP specified by investors are accepted, whereas those with a payback beyond this period are rejected. In the case of mutually exclusive projects, the investments with shorter DPP should be preferred as it reduces the risk and uncertainty associated with investments. The DPP indicator as well as the PI are commonly used as additional criteria to the main appraisal techniques such as NPV and IRR in the case of risky projects.

The appraisal techniques listed above were adjusted to the peculiarities of the studied projects, taking into account the duration of their construction periods. In mathematical terms, the formulas for the adjusted techniques are expressed in equations (3.2) – (3.5) presented in Appendix A.

As was mentioned previously, to appraise a project on the basis of discounted cash flow methods, the weighted average cost of capital for the project should be applied. Since it is internal information of a company, the appraisal criteria were calculated for two optional discount rates, 5% and 10%.

3.3 Project Analysis under Risk

This section presents two methods for analyzing projects under risk - sensitivity analysis and break-even analysis for pricing. Sensitivity analysis allows finding which variables (components of project's cash inflows and outflows) have the greatest impact on the project's outcome. In the course of the analysis, the set of selected variables is progressively stepped through their pessimistic and optimistic levels, to determine which variables cause the largest changes in the project's NPV. Break-even analysis for pricing, in turn, finds the limit price of the main product of the project at which the project's NPV is zero. Information about the critical variables received as a result of the risk analysis may be used to develop more reliable forecast for the variables during the project's planning phase or to exercise additional control over their behavior during the project's operating phase.

3.3.1 Sensitivity Analysis

Economic analysis of investment projects is based on the most likely forecast of numeric variables. Since the projects considered in the thesis have a long lifetime, the variables can be influenced by a great number of factors during that time, which is why their actual values may differ considerably from the forecasted ones. Therefore, it is important to test the effects of variations in the key variables on the economic feasibility of the projects. This test may be implemented by applying sensitivity analysis.

Sensitivity analysis is one of the methods for analyzing projects under risk. It focuses on the estimation of the impact of changes in each variable under consideration on the project's IRR or NPV, the two most widely used measures of project worth. Only one variable at a time is analyzed. All other variables are held at their most likely value whilst this one variable is tested. Those variables that have the largest relative impact on the project's estimated IRR or NPV are known as the sensitive variables [49].

To realize sensitivity analysis, the project's IRR or NPV should be calculated using the most likely forecast for each variable. After that, the key variables, changes of which may have a considerable influence on project worth, should be identified. To test variables under consideration, two ranges of their possible forecast values should be analyzed: the range of optimistic values and the range of pessimistic values. These ranges are identified referring to the most likely values. The terms "optimistic" and "pessimistic" are used in the context of impact on the project's net cash flows and the positive wealth of the company. The IRR or NPV should be recalculated for each value of considered variables that belongs to optimistic and pessimistic range. While each particular variable is stepped through each of its values, all other variables are held at their most likely values. To identify the sensitive variable, the change in the IRR or NPV value should be calculated for the pessimistic to optimistic range of each variable [49].

Since the IRR and the NPV show the same direction of the change of project worth (positive or negative), the NPV indicator was chosen to analyze the effect of changes in the variables under consideration to avoid excessive computations. The key variables chosen for sensitivity analysis were identified on the basis of their share of the project's operating cash flows and the probability of the deviation of their actual values from the most likely forecast. Thus, heavy fuel oil 1% price, CO_2 allowance price and oil shale price were identified as the key variables for sensitivity analysis of the potential project of a shale oil production plant. As for the potential project of a power plant, such variables as electricity price, CO_2 allowance price and oil shale price were under consideration.

The studied variables such as heavy fuel oil 1% price driven by the price dynamics in the crude oil market and CO_2 allowance price have strong fluctuations. Therefore, to establish pessimistic and optimistic values for the variables of the interest, the most likely value of each variable was varied in the range from minus 80% to plus 80% with step 10%. Thus, 16 values for each variable were tested to analyze the sensitivity of the projects NPV to the possible changes in the values of the variables.

Sensitivity analysis also allows expressing sensitivity of the NPV criterion in the form of elasticity, also known as sensitivity indicator (SI). The SI shows percentage change in the criterion relative to the percentage change in a variable and demonstrates to which variables the project worth is sensitive. The SI towards the NPV can be expressed as follows:

$$SI = \frac{\frac{NPV_b - NPV_1}{NPV_b}}{\frac{X_b - X_1}{X_b}}, \tag{3.6}$$

where X_b is a value of the variable in the base case (the most likely forecast), X_1 is a value of the variable in the sensitivity analysis, NPV_b is a value of the NPV in the base case, and NPV_1 is a value of the NPV in the sensitivity analysis [52].

Another approach to sensitivity analysis uses switching value (SV), the reciprocal of the SI. The SV of a variable is the value at which the project's NPV becomes zero. It shows the percentage change in the value of the variable needed to turn the project's NPV equal to zero [53]. The SV towards the NPV can be calculated on the basis of the following formula:

$$SV = \frac{100 * NPV_b}{(\mathrm{NPV}_b - \mathrm{NPV}_1)} * \frac{(X_b - X_1)}{X_b}, \tag{3.7}$$

where X_b is a value of the variable in the base case, X_1 is a value of the variable in the sensitivity analysis, NPV_b is a value of the NPV in the base case, and NPV_1 is a value of the NPV in the sensitivity analysis [52].

Thus, the sensitivity analysis of the projects covers the impact of the variables change on the NPV, as well as the calculation of the project sensitivity criteria such as SI and SV.

3.3.2 Break-Even Analysis for Pricing

Break-even analysis is a special application of sensitivity analysis. It determines how low an income variable can fall, or how high a cost variable can rise, before the project breaks even at a NPV of zero [49]. Since the production costs generally are fairly predictable, the real concern for investors from the point of view of possibility of losing money is the level of sales revenue. The projects considered in the thesis have quite determinable sales volume, therefore the major contributor to revenue uncertainty is uncertainty over the unit selling price. Break-even analysis for pricing allows determination of the selling price, at which the project NPV is just zero. If the forecasted market price exceeds this "cut-off" price, the project will have a positive NPV, whereas if the market price is less than the "cut-off" price, the project NPV will be negative.

The formula for the calculation of the NPV of the studied projects is expressed in equation (3.2) presented in Appendix A. Substituting equation (3.1) for the net cash flow C_t in equation (3.2), equation (3.2) can be rewritten as:

$$NPV = \sum_{t=J+1}^{T} \frac{(C_{I_t} - C_{O_t} - D_t) * (1 - k_t) + D_t}{(1+r)^t} - \sum_{j=0}^{J} \frac{I_j}{(1+r)^j}. \tag{3.8}$$

The cash inflow C_{It}, in turn, consists of the revenue received from sales of project production and the cash outflow C_{Ot} includes project variable and fixed costs. As was mentioned in Chapter 2, the revenue of the potential project of a shale oil production plant considered in the thesis consists of sales of shale oil and electricity. Therefore, assuming that production of the oil plant received during the operation year t is sold at the same year, equation (3.8) for the calculation of the NPV of the oil plant project can be expressed as:

$$NPV = \sum_{t=J+1}^{T} \frac{[(Q_{O_t} * P_{O_t} + Q_{E_t} * P_{E_t}) - V_t(Q_{O_t} + Q_{E_t} + Q_{G_t}) - F_t - D_t] * (1 - k_t) + D_t}{(1+r)^t} - \sum_{j=0}^{J} \frac{I_j}{(1+r)^j}, \quad (3.9)$$

where t is the year of the cash flow (operation year), T is the total number of the project operation years, Q_{Ot} is the amount of shale oil produced in the year t, P_{Ot} is the average selling price of one unit of shale oil in the year t, Q_{Et} is the amount of electricity produced in the year t, P_{Et} is the average selling price of one unit of electricity in the year t, Q_{Gt} is the amount of retort gas produced in the year t, V_t is the variable cost of one unit of the production in the year t, F_t is the fixed cost in the year t, D_t is depreciation in the year t, k_t is an income tax rate payable in the year t, r is a discount rate, j is the year of the investment, J is the total number of the project construction years, I_j is the investment in the year j.

As electricity produced in the potential shale oil plant is a secondary product generated in small quantities, the main source of revenue for the oil plant project is sales of shale oil. Therefore, the major contributor to revenue uncertainty is the uncertainty over the selling price of the unit of shale oil. To determine at which oil price the project NPV is just zero, it is required to find the break-even selling price of one unit of shale oil P^*_O. This price may be determined by substituting P^*_O for P_{Ot} in equation (3.9), setting NPV equal to 0, and solving for P^*_O. Thus, the break-even selling price of one unit of shale oil P^*_O can be calculated as:

$$P_O^* = \frac{\sum_{j=0}^{J} \frac{I_j}{(1+r)^j} - \sum_{t=J+1}^{T} \frac{Q_{E_t} * P_{E_t}(1-k_t)}{(1+r)^t} + \sum_{t=J+1}^{T} \frac{\left[V_t\left(Q_{O_t} + Q_{E_t} + Q_{G_t}\right) + F_t + D_t\right](1-k_t)}{(1+r)^t} - \sum_{t=J+1}^{T} \frac{D_t}{(1+r)^t}}{\sum_{t=J+1}^{T} \frac{Q_{O_t}(1-k_t)}{(1+r)^t}}. \quad (3.10)$$

Regarding the potential project of a power plant considered in the thesis, its cash inflow C_{It} will consist of the revenue received only from sales of electricity production and the cash outflow C_{Ot} will include variable and fixed costs. Therefore, equation (3.8) for the calculation of the NPV of the power plant project can be expressed as:

$$NPV = \sum_{t=J+1}^{T} \frac{(Q_{E_t} * P_{E_t} - V_t * Q_{E_t} - F_t - D_t) * (1 - k_t) + D_t}{(1+r)^t} - \sum_{j=0}^{J} \frac{I_j}{(1+r)^j}, \quad (3.11)$$

where t is the year of the cash flow (operation year), T is the total number of the project operation years, Q_{Et} is the amount of electricity produced in the year t, P_{Et} is the average selling price of one unit of electricity in the year t, V_t is the variable cost of one unit of the production in the year t, F_t is the fixed cost in the year t, D_t is depreciation in the year t, k_t is an income tax rate payable in the year t, r is a discount rate, j is the year of the investment, J is the total number of the project construction years, I_j is the investment in the year j.

The major contributor to the uncertainty of the revenue of the potential power plant is the uncertainty over the selling price of the unit of electricity. To determine the electricity price at which the project NPV is just zero, it is required to find the break-even selling price of one unit of electricity P^*_E. This price may be determined by substituting P^*_E for P_{Et} in equation (3.11), setting NPV equal to 0, and solving for P^*_E. As a result, the following formula was derived:

$$P_E^* = \frac{\sum_{j=0}^{J}\frac{I_j}{(1+r)^j} + \sum_{t=J+1}^{T}\frac{\left(V_t * Q_{E_t} + F_t + D_t\right)(1-k_t)}{(1+r)^t} - \sum_{t=J+1}^{T}\frac{D_t}{(1+r)^t}}{\sum_{t=J+1}^{T}\frac{Q_{E_t}(1-k_t)}{(1+r)^t}}. \quad (3.12)$$

The break-even analysis for pricing assumes that the prices P^*_O and P^*_E are constant through the whole life of the projects. Thus, if decision-makers know that this ”cut-off” price is likely to be reached, then they may decide not to proceed with the project. Also, decision-makers can prepare for a worst-case scenario involving the investigated variables being realized during the project’s life. The action to be taken could be to suspend production, to try to make production more efficient or to adjust the selling price [49].

Employing break-even analysis, it should be taken into account that variables selected for the analysis can be tested only one at a time. Similar to the sensitivity analysis, variables investigated in break-even analysis must be tested as if they are independent. Also, the results of the analysis are essentially pessimistic; therefore, break-even figures should be employed only as a last line of defence in project analysis [49].

3.4 Conclusion

This chapter describes the methodology employed to appraise the profitability of new investments into oil shale industry and, as a result, to estimate the development prospects of this field. The methodology addresses three main aspects of the economic analysis of investments: the principles of the calculation of the cash flows generated by the investment projects, appraisal techniques employed to estimate the projects feasibility and project analysis under risk. The assumptions and approaches applied to calculate the cash flows received from the considered projects were discussed. The calculated cash flows were the inputs for the project economic appraisal and risk analysis.

The methodology of economic appraisal, in its turn, relies on the discounted cash flow methods adjusted to the peculiarities of the studied projects. The project analysis under risk consists of the sensitivity analysis and the break-even analysis for pricing. The main principles applied to the sensitivity analysis of the projects were discussed. Also, the chapter presents the approaches proposed to calculate the break-even prices of the main products of the considered projects.

4 Results of Investment Project Appraisal

This chapter presents the projects cash flows, which were calculated using the data and the main assumptions from Chapter 2. The cash flows were derived from the cash flow models created for each studied project. The cash flows were also the basis for the projects economic analysis and risk assessment made by applying the methods and approaches proposed in Chapter 3. The results of the economic analysis are expressed as investment appraisal criteria, which were calculated on the basis of the discounted cash flow methods. The computed sensitivity indicators and break-even prices of the projects main products are the results of the risk analysis. The chapter also presents additional factors that may influence the profitability of the investment projects. Finally, the projects are discussed in the light of the Strategy for a climate-neutral Europe 2050.

4.1 Projects Cash Flow Models

To evaluate the viability of the potential projects considered in the thesis, the net cash flows generated by the projects during their lifetime were calculated. These cash flows were used to appraise the projects feasibility under the assumption of the certainty as well as to analyse their sensitivity and break-even prices for decision support under risk. The projects cash flow models, the outputs of which are the cash flows, are presented in Tables 7-8 in Appendix A. Since the models are very extensive and contain a large amount of data, the general overview of the cash flows received during the operation phase of the projects is shown in Table 9. This table summarizes the cash flows with a resolution of 10 years. Data for Tables 7 – 9 are explained below.

Calendar year and *notional year* are indicated in Tables 7 – 9 for illustrative purposes. The initiation of the projects is denoted in Tables 7-8 as the end of notional year 0 that corresponds to the end of calendar year 2021. The termination of the projects is denoted as the end of notional year 32 that corresponds to the end of calendar year 2053.

The initial capital expenditures of the projects are recorded in Tables 7-8 in the *capital outlay* row. The principles of their calculation were presented in Chapter 2.

The *total revenue* of the potential project of a shale oil production plant is equal to the sum of revenues from shale oil sales and from electricity sales. The total revenue of the potential project of a power plant consists only of revenue from electricity sales. *Revenue from shale oil sales* is obtained by multiplying the total shale oil production by the selling price of the unit of shale oil. *Revenue from electricity sales* is obtained by multiplying the total electricity production by the price of the unit of electricity. The approach to the forecast of the amount of shale oil and electricity production as well as the price forecast of oil and electricity were discussed in Chapter 2.

Total costs are equal to the sum of fuel costs, CO_2 costs, other environmental costs, and O&M costs. *Fuel costs* are obtained by multiplying the total fuel consumption by the selling price of its unit. *CO_2 costs* are obtained by multiplying the total amount of CO_2 emissions by the CO_2 allowance price. *Other environmental costs* are equal to the sum of costs for cooling water, for disposal of oil shale ash and costs for such emission as SO_2, NO_x and fly ash. The principles of the calculation of these costs were presented in Chapter 2.

Table 9. Cash flows of the potential projects received during the operation phase and presented with a resolution of 10 years.

Project phase	*Operation phase of a potential shale oil production plant*				*Operation phase of a potential oil shale power plant*			
Calendar year	2024	2034	2044	2053	2024	2034	2044	2053
End of notional year	3	13	23	32	3	13	23	32
Operating flows								
Revenue from shale oil sales	108	136	158	175	-	-	-	-
Revenue from electricity sales	12	13	14	15	38	43	45	48
Total revenue	*119*	*149*	*173*	*190*	*38*	*43*	*45*	*48*
Fuel costs	35	46	60	70	7	10	12	15
CO_2 costs	17	27	38	47	11	17	24	30
Other environmental costs	6	7	9	10	1	1	1	2
O&M costs	13	15	18	21	4	5	6	7
Total costs	*71*	*96*	*124*	*149*	*23*	*32*	*43*	*53*
Depreciation	10	10	10	10	9	9	9	9
Taxable income	39	44	39	31	6	1	-7	-14
Tax payable	5	6	5	4	1	0	0	0
Net income	33	37	33	27	5	1	-7	-14
Operating cash flow	43	47	43	37	14	10	2	-5
Net cash flow	*43*	*47*	*43*	*37*	*14*	*10*	*2*	-5
Cumulative net cash flow	*-258*	*203*	*661*	*1 014*	*-262*	*-135*	*-71*	-91

Depreciation is calculated by applying the approach described in Section 3.1.

Taxable income is equal to total revenue minus total costs and depreciation.

Tax payable is calculated by applying the approach presented in Section 3.1. It is important to notice that tax is not paid on negative income.

Net income is equal to taxable income minus tax payable.

Operating cash flow is calculated by adding back depreciation to net income. The principle of the calculation of operating cash flow is also expressed by equation (3.1).

Net cash flow is equal to the sum of the capital flow and the operating flow, and presents the overall annual total flow. These net cash flows were used in the calculation of appraisal criteria and in the project risk analysis.

Cumulative net cash flow is the aggregate cash flow generated by the project starting from its initiation up to its termination.

4.2 Calculation Results of Investment Appraisal Criteria

Decision making regarding the acceptance of an investment project mainly relies on the values of the appraisal criteria. To evaluate the economic feasibility of the studied projects, four appraisal criteria based on the discounted cash flow methods were applied: the NPV, the IRR, the PI and the DPP. The NPV and the IRR are the most widely used criteria that provide reliable and comprehensive evaluation of a project, whereas the PI and the DPP are commonly used as additional criteria to support a decision made on the basis of the NPV and the IRR in the case of risky projects. The criteria were calculated for two discount rates, 5% and 10%, by applying equations (3.2) – (3.5) presented in Appendix A. The results of the computation are shown in Table 10.

Table 10. Results of the calculation of the projects appraisal criteria.

Potential project	*Discount rate, %*	*Appraisal criteria*			
		NPV, MEUR	IRR, %	PI	DPP, years
Shale oil production plant	5	336	13	2.2	9
	10	77		1.3	13
Oil shale power plant	5	-141	-8	0.5	-
	10	-169		0.3	-

As can be seen in Table 10, the NPV of the potential project of the construction of a shale oil production plant is positive for both discount rates. It means that, by undertaking the investment project, the company's wealth will increase by 336 million euros at the required rate of return 5% and by 77 million euros at the required rate of return 10%. The IRR of the project shows that its internal earning rate is expected to be 13%. If this value exceeds the cost of the capital for the project, the project is desirable, as any project that yields more than its cost of capital will have a positive NPV. However, if the IRR of 13% falls below the required rate of return, the project should be rejected, as it would generate negative cash flows.

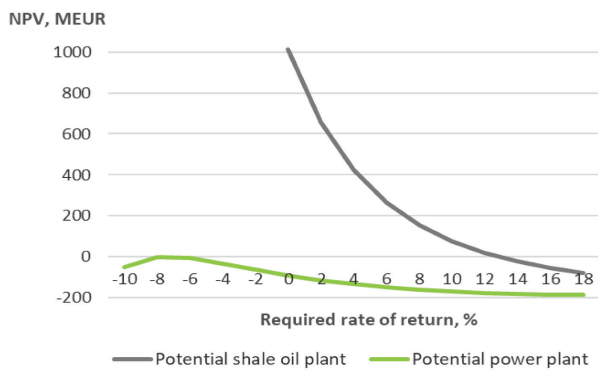

Figure 12. NPV profiles of the potential projects under consideration.

The dependence of the NPV value on the required rate of return for the potential project of a shale oil plant is highlighted in the NPV profile chart in Figure 12. The NPV profile summarizes the profitability characteristics of the investment project. The horizontal axis shows the different discount rates; the vertical axis presents the NPV of the project. The NPV of the project is plotted for all discount rates, starting from zero to some reasonably large rate. As seen in Figure 12, the plot of the NPV of the potential oil plant project crosses the horizontal axis at the rate of return of 13%. This point of intersection, where NPV is equal zero, is the IRR of the investment project.

The profitability of the project also confirms the PI criterion. It presents a ratio of the present value of expected future cash flows to the initial investments. The PI of 2.2 shows that the project net cash flows discounted at 5% are positive and the income generated by the project during its lifetime exceeds the cost of initial investments 2.2 times. If the required rate of return is 10%, the PI of the project is 1.3. It means that, by undertaking the construction of a shale oil plant, the company will receive the positive discounted net cash flows from the project, the sum of which at the discount rate of 10% is 1.3 times greater than investment expenditures.

The DPP criterion shows that the project net cash flows discounted at 5% recoup the initial investment outlays in 9 years after the start of the operation of a potential oil plant. Taking into account the discount rate of 10%, the payback period of the investment project extends by 4 years, reaching 13 years. If the calculated DPP is less than a maximum DPP specified by investors, the project may be accepted.

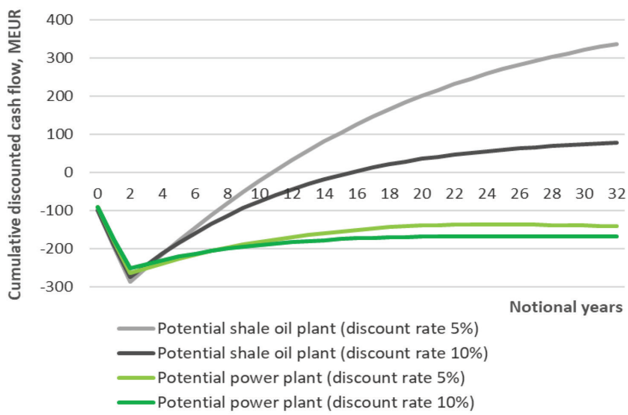

Figure 13. Cumulative discounted cash flow of the potential projects under consideration.

The DPP of the potential project of a shale oil plant can also be seen in Figure 13. The values of the DPP are shown by the point of intersection, where the plot of cumulative discounted cash flow crosses the horizontal axis. However, it should be noticed that the cumulative discounted cash flow presented in Figure 13 covers both the capital flows occurred in the project construction phase and the operating flows occurred in an operation phase, whereas the DPP criterion takes into account only the last one. Therefore, the value of the DPP presented in Figure 13 is greater than the actual DPP shown in Table 10 by the amount of the years of the construction of a potential shale oil plant (by 3 years). Figure 13 also illustrates the NPV of the project for both discount rates, 5% and 10%. This is the value of the cumulative discounted cash flow at the last period of the project operation phase (32nd notional year).

One of Eesti Energia's strategic projects is the construction of a plant for extracting gasoline from retort gas. This should increase the output of the liquid fuels produced in the energy complex by 10%. The extraction plant is planned to be completed by the end 2020 [54]. This increase of fuel output was not taken into account in the planned oil production of the potential oil plant, as the investment decision had not been made by the moment of writing the thesis. However, if this project is realized, the results of the calculation of the project appraisal criteria will be improved. The NPV will increase by 163 million euros if the required rate of return is 5% and by 86 million euros if the required rate of return is 10%, whereas the IRR will reach 16%.

The appraisal criteria of the project targeted at the solving the problem of retort gas utilization show that the construction of an oil shale power plant is not economically reasonable. As can be seen in Table 10, the NPV of the project is negative for both discount rates. It means that, by implementing the project, the company will not recoup the investments and will meet a loss. The loss generated by the project will be 141 million euros if the required rate of return is 5%, and will reach up to 169 million euros at the rate of return of 10%. Figure 12 demonstrates that the project NPV is negative for all considered required rate of returns, except for -8% at which the NPV is equal to 0. This negative IRR shows that the aggregated cash flows caused by the project are lower than the initial investments.

The additional appraisal criteria such as the PI and the DPP also demonstrate that the project is not viable. The PI of 0.5 shows that the sum of the project net cash flows discounted at 5% amounts to only 50% of the initial investments. If the discount rate is 10%, the PI decreases up to 0.3. It means that the sum of the discounted cash flows received from the project during its operation phase amounts to only 30% of the initial investments. Thus, the discounted cash flows of the potential power plant project do not recoup of the initial investment outlays that also can be seen in Figure 13.

4.3 Results of Risk Analysis

The main objective of the risk analysis is to support the investment decisions under risk. To analyze the studied projects under risk, two methods were applied – sensitivity analysis and break-even analysis for pricing. The sensitivity analysis showed the impact of the change in key variables on the projects NPV, whereas the break-even analysis defined the break-even prices of the main products of the projects. The sensitivity analysis was made by employing the approaches and formulas described in Section 3.3.1. The results of the analysis are presented in Table 11.

To analyse the sensitivity of the potential project of a shale oil production plant, the variables such as fuel oil 1% price, CO_2 allowance price and oil shale price were tested. These variables for the analysis were selected because of their share of the project's operating cash flows and the probability of the deviation of their actual values from the most likely forecast. As can be seen in Table 7 presented in Appendix A, the largest share from the revenue of the project is derived from oil sales. At the same time, the greatest project costs are fuel costs and CO_2 costs. The amount of shale oil production as well as fuel consumption and CO_2 emissions associated with the production are quite predictable. Therefore, the sensitivity of the project NPV to fuel oil 1% price, which the price of shale oil tends to follow, as well as oil shale price and CO_2 allowance price should be analysed. The change of these variables from their values in the base case may have the largest impact on the project revenue and costs that may influence the decision regarding the project realization.

Table 11. Results of the sensitivity analysis of the potential projects under consideration.

Potential project	*Tested variable*	*SI*		*Variable influence rank*	*SV, %*		*Variable value change direction*
		Discount rate 5%	Discount rate 10%		Discount rate 5%	Discount rate 10%	
Shale oil production plant	Heavy fuel oil 1% price	4.8	11.2	1	21	9	↓
	CO_2 price	-1.0	-2.2	3	-100	-46	↑
	Oil shale price	-1.7	-3.9	2	-58	-26	↑
Oil shale power plant	Electricity price	-4.4	-2.0	1	-23	-51	↑
	CO_2 price	1.8	0.7	2	56	134	↓
	Oil shale price	1.0	0.4	3	97	228	↓

The results of the SI calculation are summarized in column *Variable influence rank* in Table 11. *Variable influence rank* shows the strength of the change of a tested variable on the project NPV (*1* - the strongest, *3* – the weakest). As can be seen in Table 11, the NPV of the potential project of a shale oil plant is the most sensitive to the change in heavy fuel oil 1% price, whereas the possible change of CO_2 allowance price from its most likely forecast values have the smallest influence on the project profitability as compared to the change of other variables under consideration. The positive value of the SI indicator shows that the values of a tested variable and of the project NPV change in the same direction (the larger the value of a variable, the larger the value of the NPV). The negative value of the SI indicator shows that the values of a tested variable and of the project NPV change in the opposite directions (the smaller the value of a variable, the larger the value of the NPV).

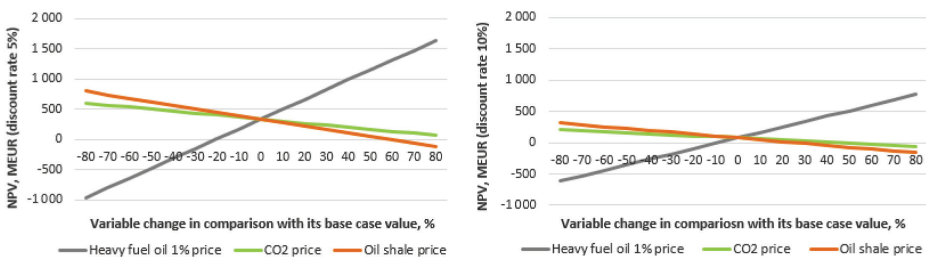

Figure 14. NPV sensitivity graphs for a potential project of a shale oil production plant.

The dependence of the project NPV on the change of the tested variable is illustrated by the NPV sensitivity graphs demonstrated in Figure 14. The horizontal axis shows the percentages of change of a variable from its base case value; the vertical axis presents the NPV of the project. A sensitivity line summarizes the profitability of the project depending on the change in a particular variable. The steeper the sensitivity line, the stronger is the influence of the change of this variable on the NPV of the project.

The left graph presents the NPV calculated for the discount rate of 5%, whereas the right one – for the discount rate of 10%.

The SV shows the percentage change in the value of variable needed to turn the project's NPV equal to zero. As can be seen in Table 11, heavy fuel oil 1% price must decrease by 21% at the discount rate of 5% and only by 9% at the discount rate of 10% to turn the NPV of the oil plant project equal to zero. Taking into account the volatility of oil price in the global market, the probability of these fluctuations in fuel oil 1% price is extremely high.

As was mentioned in Section 2.1, heavy fuel oil produced from oil shale is traded at a discount to the reference product (heavy fuel oil 1%) due to the differences in chemical composition. Thus, shale oil price may be also influenced by policy and legislation focused on the regulation of fuel quality. For instance, according to Fuel Standard for marine distillate fuels, starting from the 1st of January 2020, maximum sulphur content in marine fuels must not exceed 0.5% [55]. Estonian shale oil is used as one of the components for blending marine fuels. Since it contains 0.6% of sulphur, the demand for shale oil may decrease significantly, as its composition will not meet new requirements. The decrease of demand, in turn, will cause shale oil price drop.

The SV indicator for CO_2 allowance price shows that this variable must increase by 100% at the discount rate of 5% and by 46% at the discount rate of 10% to bring the project to the break-even point. This is quite a wide range, within which CO_2 price may fluctuate without turning the project NPV negative. However, essential changes in climate and energy policy may lead to the rapid price growth. For example, in 2018, the creation of the MSR discussed previously caused the increase of CO_2 allowance price by more than 250% in comparison with its average price in 2017. If the further development of the energy sectors of the most countries is brought strongly in line with the objective of the Paris Agreement of the UNFCCC, the CO_2 price will continue to grow intensively. This scenario of the energy sector development is presented by the IEA as the Sustainable Development Scenario. If the scenario is realized, the production of liquid fuels from oil shale will be economically unfeasible. The results of the estimation of the profitability of a shale oil plant project under the Sustainable Development Scenario are demonstrated in Publication III.

Regarding the sensitivity of the project NPV to oil shale price, its increase must amount to 58% at the discount rate of 5% and 26% at the discount rate of 10% to break even the project. Due to low calorific value (7.0 – 11.5 MJ/kg), it is not reasonable to import oil shale, which is why it is utilized locally, near the mining places. Thus, the price of oil shale is not influenced by the volatility of the global market. Presently, only one component of oil shale production costs, mining fee, reflects the price dynamics in the oil market. It depends on the price of heavy fuel oil 1% traded in the NWE market. However, a new model, which will allow determination of oil shale mining fee depending on the value created as the result of oil shale use, is under development. Its implementation may cause essential changes in oil shale price in the future. Additionally, the production costs of oil shale may increase due to investments into the development of new mines, as the existing ones are gradually running out.

Besides the factors mentioned above, national taxation and currency exchange rate are other risks that shale oil production sector may face. Estonian taxation system, which regulates the oil shale industry, is quite complicated. It includes different environmental charges and fines. Part of the charges is related to environmental impacts such as emissions to the ambient air, utilization of cooling water, disposal of mining water and oil shale processing waste (semi-coke and oil shale ash), depositing of mining residue (limestone). The other part is resource charges (mining fees), which are calculated on the basis of each ton of oil shale reserve used [56]. The environmental costs of shale oil production include only environmental charges, whereas fuel costs reflect both the environmental and resource charges caused by the mining of oil shale.

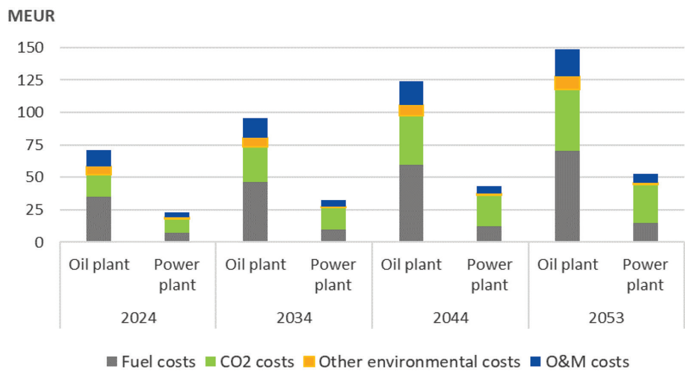

Figure 15. Operating costs of potential projects of a shale oil production plant and an oil shale power plant.

As can be seen in Figure 15, which illustrates the data on the operating costs of the studied projects presented in Table 9, the environmental costs and fuel costs of shale oil production amount to more a half of the total costs (57% in 2024 and 54% in 2053). Taking into account that these costs mainly consist of the the environmental and resource charges, it can be concluded that the national taxation system causes a relatively high level of costs to the shale oil production sector. The major changes in the rates of the charges may impact significantly its state. Thus, to provide a sustainable development of the oil production sector and the oil shale industry as a whole, the analysis of oil shale utilization in terms of the total state long-term revenues should be continuously performed. Its results should be taken into account in the principles of the industry taxation system and be the basis for changes in the tax rates.

The risk of currency exchange rate for the shale oil production sector is associated with the pricing of liquid fuels and of production costs. The fractions of shale oil, heavy fuel oil and gasoline are traded in American dollars, whereas related production costs are calculated in euros. Since the middle of 2014, due to quantitative easing in European monetary policy concurrent with the monetary tightening in the USA, EUR/USD rate decreased from 1.36 to 1.10 by early 2015 [56]. Crossing the lowest level of 1.04 for the last 5 years in the middle of December 2016, EUR/USD rate soared up to 1.25 at the beginning of February 2018, then it began again to decrease. These fluctuations vary the price equivalent of shale oil to euros that, in its turn, leads to the changes in the rate of the revenue received from the sale of liquid fuels to the relevant production costs.

All listed factors make the potential project of the construction of a shale oil production plant quite risky. In their decision making regarding the project, investors should pay additional attention to the critical variables. The results of the sensitivity analysis may be used to develop a more reliable forecast for these variables during the project's planning phase or to exercise additional control over their behavior during the project's lifetime.

The economic analysis of the potential project of an oil shale power plant has already shown that to utilize retort gas this way is not economically feasible. Therefore, the risk analysis of the project was made with an informative aim to demonstrate the positive changes in the key variables needed to bring the project to the break-even point. The tested variables for the power plant project were selected on the basis of the same principles as those for the shale oil plant described previously. The results of the sensitivity analysis of the project are presented in Table 11 and in Figure 16.

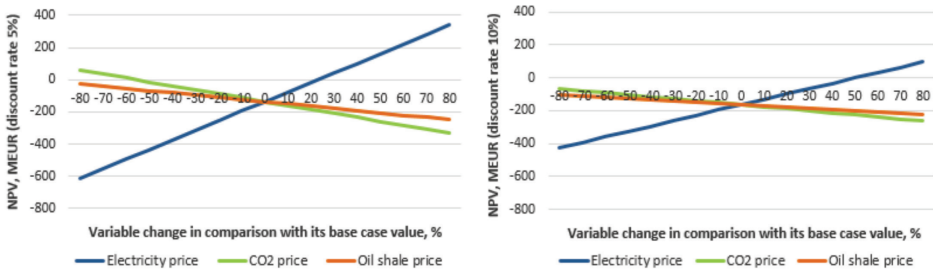

Figure 16. NPV sensitivity graphs for a potential project of an oil shale power plant.

As can be seen in Table 11 and in Figure 16, the project NPV is the most sensitive to the changes in the electricity price and CO_2 allowance price. The SV indicator shows that electricity price must increase by 23% at the discount rate of 5% and by 51% at the discount rate of 10% to turn the NPV equal to zero. As for the sensitivity of the project NPV to CO_2 price, its decrease must amount to 56% at the discount rate of 5% and 134% at the discount rate of 10% to bring the project to the break-even point. Taking into account price dynamics in the EU carbon allowance market and the focus of the current climate and energy policy on the strengthening emission requirements for industrial installations, the probability of the fall of CO_2 price is very small. The climate and energy policy also impacts wholesale electricity prices by promoting the increase of renewable production capacities. The commission of these capacities, some of which are subsidized by the government, drives the prices down. However, in the future, this price trend may change in the Baltic region. The decommission of old Estonian oil shale units and the desynchronization of the Baltic system from the Russian grid may lead to the power shortage in the Baltics. The shortage, in its turn, may cause the decoupling of the Baltic region from the Nordic countries and forming higher wholesale electricity prices than in the price areas of Scandinavia. Nevertheless, the real price growth in the Baltic electricity market should be more than 23% in comparison with the price forecast to turn the NPV of the power plant project to be positive.

To define the "cut-off" prices, at which the NPV of the studied projects turns equal to zero, the break-even analysis for pricing was applied by employing the methodology proposed in Chapter 3. As the sensitivity analysis showed, the change in heavy fuel oil 1% price has the greatest influence on the NPV of the oil plant project, whereas the NPV of the investments into the power plant is the most sensitive to the fluctuations of wholesale electricity price. Therefore, the selling prices of shale oil and electricity were taken as the objects for the break-even analysis. The results of the analysis are presented in Table 12.

Table 12. Results of the break-even analysis for pricing of the potential projects under consideration.

Potential project	*P^*_O, EUR/ton*		*P^*_O, USD/bbl* [9]		*P^*_E, EUR/MWh*	
	Discount rate 5%	Discount rate 10%	Discount rate 5%	Discount rate 10%	Discount rate 5%	Discount rate 10%
Shale oil production plant	420	457	69	75	-	-
Oil shale power plant	-	-	-	-	61	75

As can be seen in Table 12, if the required rate of return is 5%, the selling price of a ton of shale oil must not be lower than 420 euros to bring the project to the break-even point. The "cut-off" price reaches 457 euros in the case of the required rate of return of 10%. As was mentioned above, Eesti Energia plans to construct a plant for extracting gasoline from retort gas that will increase the output of the liquid fuels produced in the energy complex by 10%. If this project is realized, the break-even selling price of a ton of shale oil will reduce to 382 euro (63 USD/bbl) at the required rate of return of 5%. If the rate is 10%, the break-even price will amount to 416 euros (68 USD/bbl).

According to the Goldman Sachs' survey of new oil production projects, half of the cumulative lifetime production is projected to come from projects with break-even oil price above 70 USD/bbl. Moreover, among the projects added recently into the survey, none had a break-even oil price below 70 USD/bbl and most had the price within the 80-100 USD/bbl band. The latter group includes higher-cost USA shale oil and deep-water projects as well as majority of Canadian oil sands projects, which the Goldman Sachs estimates to be the current marginal source of new non-OPEC supply (with the top quintile of production having a break-even oil price of 88-105 USD/bbl) [57]. Thus, the production of shale oil by pyrolysis using the Enefit280 technology is expected to be competitive in the future. This also confirms the forecast of heavy fuel oil 1% presented in Table 2, according to which the market price of the oil is projected to be higher than the calculated break-even selling price during almost the whole lifetime of the project that will provide the positive cash flows. However, the results of the break-even analysis are very pessimistic; therefore, these figures should be considered only as a worst-case scenario. If decision-makers know that these "cut-off" prices are likely to be reached, they should decide not to proceed with the project.

The break-even analysis of the potential project of a power plant showed that the selling price of a MWh of electricity must not be lower than 61 euros to bring the project to the break-even point at the required rate of return of 5%. If the rate is 10%, the price reaches 75 euros. Since 2013, when Estonian electricity market was completely liberalized, the average annual spot price in Estonian price for these last 6 years was 38 EUR. Taking into account this price, the price growth should amount to more than 60% to provide the profitability to the project. Thus, relying on the calculation results of the appraisal criteria and of the sensitivity analysis, an alternative technical solution to utilize retort gas should be considered. The estimation of the economic feasibility of the possible ways for retort gas utilization is presented in Publication II.

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[9] Data are presented in USA dollar per barrel for the purpose of convenience to compare them with the crude oil price.

4.4 Projects discussion under the Climate-Neutral Europe Strategy

As was mentioned in Introduction, one of the key documents, which sets out a long-term vision for climate and energy policy at the global level, is the Paris Agreement of the UNFCCC adopted in December 2015. The central aim of the Agreement is to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels [3].

As part of the decision to adopt the Paris Agreement of the UNFCCC, the Intergovernmental Panel on Climate Change (IPCC) has been invited to produce a Special Report on global warming of 1.5°C above pre-industrial levels and related global GHG emission pathways. The Special Report was approved by the IPCC in October 2018, and it was a key scientific input into the Katowice Climate Change Conference in December 2018. The report highlights a number of climate change impacts that could be avoided by limiting global warming to 1.5°C compared to 2°C. It finds that limiting global warming to 1.5°C would require to reduce global net CO_2 emissions by about 45% from 2010 levels by 2030, reaching "net zero" around 2050. This means that any remaining emissions would need to be balanced by removing CO_2 from the air [58].

The intention to reach "net zero" CO_2 emission level to limit global warming to below 2°C is also reflected in the Strategy for a climate-neutral Europe by 2050 adopted by the European Commission in November 2018 [5]. Thus, the oil shale investments considered in the thesis are not completely in line with the Strategy, as they suppose the construction of the relatively emission-intensive projects that would be in operation up to 2054. However, this issue is relevant not only for the Estonian oil shale industry, but it is related to global use of fossil fuels in the light of the strict climate change mitigation targets.

According to the IEA report called "Perspectives for the Energy Transition - Investment Needs for a Low-Carbon Energy System", to limit global warming to below 2°C, nearly 95% of electricity would need to be low-carbon by 2050, compared with about a third today, led by renewables [59]. The Strategy also assumes the deployment of renewable capacities in the EU power system [5]. Meanwhile, electricity production from renewable energy sources is quite variable. Therefore, it is needed to be covered by stable and continuous electricity production from fossil fuels to provide security of supply. The fossil fuel-based production capacities are also necessary to provide system services. The IEA report declares that fossil fuels in the amount of 40% of energy demand would still be needed in 2050. Additionally, it is noted that the major part of electricity production from fossil fuels is supposed to be based on natural gas, as it is the most climate-friendly fossil fuel to generate electricity [59].

However, the domination of the gas in the fossil fuel power generation mix can lead to the growth of the fuel price and dependence on a primary supplier in the case of insufficient competitiveness in the wholesale market for natural gas. Thus, electricity production from the fuel mix of oil shale and retort gas considered in the thesis could be an alternative to the production from natural gas at the local level. Also, it should be noticed that the level of CO_2 emissions from a power plant that runs on the fuel mix of oil shale and retort gas is lower approximately by 30% than CO_2 emissions from a coal-fired power plant.

To achieve the climate objective, the IEA analysis finds that 7 out of every 10 new cars would need to be electric by 2050, compared with 1 in 100 today. Despite the expectation of a deep transformation of the oil consumption sector, the IEA emphasises the particular importance of oil investments. The decline from oil producing fields is expected to be larger than the decline in demand and would need to be compensated [59]. Thus, the production of liquid fuels from oil shale could be an alternative to the traditional liquid fuel production, which is heavily dependent on crude oil. However, as was mentioned in Section 1.1, the life-cycle GHG emissions of the production of liquid fuels from oil shale are higher than from conventional oil.

At the level of Estonia, the oil shale industry has a great importance. Its contribution to gross domestic product averages 4-5% that is equal to the total contribution of both the food industry and the telecommunication sector. The oil shale industry is also one of the largest employers in Estonia and the primary employer in Ida-Viru County. In 2017, more than 7,300 people were employed in the industry that makes it a significant contributor to society [60].

Presently, there are strong structural changes in the Estonian oil shale industry. It is shifting from power generation to shale oil production. The retorting of oil shale produces, in its turn, approximately 2.5 times less CO_2 emissions than the combustion of oil shale in power plants. Moreover, the modern oil shale retorting technology considered in the current thesis is significantly cleaner than the old ones. Besides this, the industry is making great efforts to reduce and avoid the ecological footprint. During the last five years, oil shale companies have invested a total of over 263 million euros into technologies to reduce environmental impact. The goal of most projects launched and carried out in 2017 is to modernize the production process and improve the quality of ambient air [60]. Thus, the companies are adopting a lot of measures to bring the industry in line with the Strategy for a climate-neutral Europe by 2050.

The purpose of this long-term Strategy is not to set targets, but to create a vision and sense of direction for its realization, to inspire Member States to develop new and innovative industries and associated jobs. The Strategy looks into the portfolio of options available for the States, business and citizens [5]. So, this flexible approach allows the oil shale companies to choose the way how the industry can be further transformed to be sustainable and make its contribution to the objective of the Strategy.

4.5 Conclusion

This chapter presented the results of the estimation of the economic feasibility of two potential projects in the oil shale industry – a shale oil production plant and a condensing oil shale power plant. The estimation was based on the economic analysis and risk assessment made by applying the methodology presented in Chapter 3. The results of the economic analysis were expressed as investment appraisal criteria, whereas calculated sensitivity indicators and break-even prices of the projects main products were the results of risk assessment.

The economic analysis of the potential construction of a shale oil production plant showed that the project is profitable, and its internal earning rate amounts to 13%. The realization of the project of gasoline extraction from retort gas, which will increase the output of the liquid fuels produced in the energy complex by 10%, will improve the profitability of the potential oil plant driving its IRR to 16%. The competitiveness of the considered project also demonstrates the break-even price of a ton of shale oil produced in the plant. However, the risk analysis showed that the project is very sensitive to fluctuations of the heavy fuel oil 1% price, which is driven by the crude oil market. At the discount rate of 10%, the decrease of the price should be only 9% to turn the NPV of the oil plant project equal to zero. Taking into account the volatility of the oil market, it can be concluded that the potential project of the construction of a shale oil production plant is quite risky. In their decision making regarding the project, investors should pay additional attention to this variable.

The construction of an oil shale power plant, which runs on the fuel mix from 50% of oil shale and 50% of retort gas, was considered in this thesis as a potential way to utilize retort gas to provide a continuous operation of the oil plant. The economic analysis of the project showed that this technical solution is not economically feasible. Also, one of the shortcomings of the project is its emission-intensity and, as a result, a great sensitivity to the price fluctuations in the the EU carbon allowance market. Taking into account the focus of the current climate and energy policy on the strengthening emission requirements for industrial installations, such utilization of retort gas is not reasonable. Therefore, an alternative technical solution for this problem should be considered.

This chapter also discussed the potential investment projects in the light of the Strategy for a climate-neutral Europe 2050. The changes needed to be made in energy production and consumption to achieve the objective of the Strategy were presented and the measures adopted by the oil shale companies to bring the industry in line with the Strategy were highlighted.

Summary

The current thesis presents the estimation of the development prospects of the oil shale industry in the light of renewable and low-carbon energy policy. The estimation was based on the analysis of the economic feasibility of new investments in this field. The analysis focused on the two main sectors of the oil shale industry – shale oil production and electricity generation. To estimate the profitability of the investments in the shale oil production sector, the potential construction of a shale oil plant was considered. The expansion of shale oil production capacities leads to an increase of the generation of retort gas, a by-product of oil shale retorting process needed to be utilized to provide constant oil production. Thus, the potential construction of a condensing oil shale power plant, which runs on the fuel mix from oil shale and retort gas, was considered as a possible way to utilize retort gas for electricity generation. Both of the investment projects were studied on the example of Estonian oil shale industry.

To analyse the economic feasibility of the potential projects under the conditions of renewable and low-carbon energy policy, the IEA projections of the key variables that have a great influence on the projects profitability, such as oil price and CO_2 allowance price, were used. The IEA is one of the most credible and competent sources. The projections are based on the New Policies Scenario, a central scenario of the IEA. Besides the announced plans of the governments to develop their energy sectors, the scenario includes the contributions intended to be made by the countries for the Paris Agreement of the UNFCCC, a crucial document that provides the framework for the future global cooperation in the field of climate change. Thus, the projections under the New Policies Scenario reflect the development of crude oil market and carbon allowance market, taking into account the further initiatives of the governments in the climate and energy policy.

Since the price of shale oil tends to follow the price of heavy fuel oil with 1% sulphur content, its forecast was used to estimate the profitability of the investments into new shale oil production capacities. The regression analysis presented in Chapter 2 showed that the price dynamics of heavy fuel oil 1% market, in its turn, strongly correlates with price movements in the crude oil market. Therefore, the price forecast of heavy fuel oil 1% was made on the basis of the IEA crude oil price projection by applying the regression equation. As a result, this forecast also reflects the influence of the climate and energy policy. Wholesale electricity market price, a crucial variable for the potential project of a power plant, was projected, taking into account the future increase of renewable production capacities in the power system. Thus, all the key variables that have a major influence on the projects viability were forecast relying on the further development of the energy sector under the conditions of renewable and low-carbon energy policy. The principles employed to forecast the future values of the other variables of the projects under consideration were discussed in Chapter 2.

To estimate the economic feasibility of the potential investments, the methodology presented in Chapter 3 was applied. The methodology includes the principles proposed to create the cash flow models of the investment projects, the appraisal techniques adjusted to the projects' peculiarities and the approaches employed to analyse the investment projects under risk. The input data of the models were the variable data on the components of the projects' revenue and costs, which were discussed in Chapter 2. The output data of the models were the cash flows generated by the projects during their lifetime. The cash flows, in their turn, were the basis of the further economic analysis and risk assessment of the investment projects. The economic analysis was focused on the calculation of the key appraisal criteria, such as the NPV, the IRR, the PI and the DPP. To assess the risk of the investments, the sensitivity of the NPV to the possible change in the values of the critical variables was analysed. The sensitivity analysis was supplemented by the approaches proposed to calculate the break-even prices of the key products of the considered projects to define the limit parameters of their profitability.

The results of the calculation of the appraisal criteria of the potential project of a shale oil production plant showed that the project NPV is positive for both discount rates and its IRR amounts to 13%. The NPV criterion demonstrated that, by undertaking the investment project, the company's wealth will increase by 336 million euros if the required rate of return is 5% and by 77 million euros if the required rate of return is 10%. Relying on the IRR criterion, it could be said that at the weighted average cost of capital less than 13%, the construction of a potential shale oil plant will be profitable, and the company may proceed with the project. Also, it should be noted that the project IRR will increase up to 16%, if the company realizes the project of a plant for extracting gasoline from retort gas that will increase the output of the liquid fuels produced in the energy complex.

At the same time, the results of the sensitivity analysis showed that the possible deviations of real heavy fuel oil 1% price from its projected values will have substantial influence on the NPV of the oil plant project. According to the results of the calculation of the SV indicator, the real heavy fuel oil 1% price must decrease in comparison with its forecast by 21% at the discount rate of 5% and only by 9% at the discount rate of 10% to turn the project NPV equal to zero. Taking into account the volatility of oil price in the global market, which causes the fluctuations in the heavy fuel oil 1% market, the probability of such decrease is extremely high. Additionally, the fractions of shale oil are actually traded at a discount to the heavy fuel oil 1% due to the differences in chemical composition. Therefore, shale oil price may be also influenced by the policy and legislation that regulate the quality of fuel. According to Fuel Standard for marine distillate fuels, maximum sulphur content in marine fuels must not exceed 0.5% since the 1st of January 2020. Shale oil is used as one of the components for blending marine fuels. Since it contains 0.6% of sulphur, the demand for shale oil may decrease significantly, as its composition will not meet new requirements. The decrease of demand, in turn, will cause shale oil price drop.

The analysis revealed that the NPV of the oil plant project is also sensitive to the possible changes in oil shale price, as in CO_2 allowance price. The SV indicator showed that the increase of real oil shale price in comparison with its projected values must amount to 58% at the discount rate of 5% and 26% at the discount rate of 10% to break even the project. Oil shale is a local fuel and not traded globally. Nevertheless, the plans of the government to implement a new model, according to which oil shale mining fee depends on the value created as the result of oil shale use, may cause essential changes in oil shale price in the future. Additionally, the production costs of oil shale may increase due to investments into the development of new mines, as the existing ones are gradually running out.

The SV indicator for CO_2 allowance price demonstrated that this variable must increase by 100% at the discount rate of 5% and by 46% at the discount rate of 10% to bring the project to the break-even point. This is quite a wide range, within which CO_2

price may fluctuate without turning the project NPV into negative one. However, essential changes in the climate policy may lead to the rapid growth of CO_2 price, as it was in the case of the creation of the MSR. This decision caused the increase of CO_2 allowance price in 2018 by more than 250% in comparison with its average price in 2017. If the further development of the energy sectors of most of the countries is brought strongly in line with the objective of the Paris Agreement of the UNFCCC, the CO_2 price will continue to grow intensively.

Besides the factors mentioned above, national taxation and currency exchange rate are other risks that shale oil production sector may face. The environmental and resource charges regulated by the national taxation system amount to more than a half of the total costs of shale oil production. The major changes in the rates of the charges may impact significantly on the state of the sector. The risk of currency exchange rate is associated with the pricing of shale oil products in American dollars, whereas the relevant production costs are computed in euros. The fluctuations of EUR/USD rate vary the price equivalent of shale oil to euros that, in its turn, leads to the changes in the rate of the revenue received from the sale of liquid fuels to the production costs.

All the factors listed above make the potential expansion of shale oil production capacities quite risky. Investors involved in decision-making regarding the project should pay additional attention to the critical variables. The results of the sensitivity analysis may be used to develop more reliable forecast for these variables during the project's planning phase or to exercise additional control over their behavior during the project's lifetime.

The results of the break-even analysis for pricing showed that if the required rate of return is 5%, the selling price of a ton of shale oil must be not lower than 420 euros (69 USD/bbl) to bring the oil plant project to the break-even point. The "cut-off" price increases up to 457 euros (75 USD/bbl) at the required rate of return of 10%. As was mentioned previously, the profitability of the project may be increased due to the construction of the extraction plant aimed to receive the additional amounts of liquid fuel from retort gas. If this project is realized, the break-even selling price of a ton of shale oil will reduce to 382 euros (63 USD/bbl) at the required rate of return of 5%. It will amount to 416 euros (68 USD/bbl) in the case of the rate of 10%. According to the Goldman Sachs' updated survey on new world oil production projects, all the projects added recently into the survey have a break-even oil price above 70 USD/bbl. Moreover, most of them have the price within the 80-100 USD/bbl band. Thus, despite the high risks associated with the potential project of a shale oil plant, the shale oil technology is expected to be competitive in the global oil market in the future.

Concerning the potential project of an oil shale power plant construction to utilize the retort gas produced in the energy complex for electricity generation, the analysis showed that this technical solution is not reasonable from the economic point of view. Undertaking this project, the company's wealth will decrease by 141 million euros if the required rate of return is 5% and by 169 million euros if the required rate of return is 10%. The additional risks for the project are associated with its sensitivity to the changes in CO_2 allowance price. Escalating price trend in the EU carbon allowance market and the focus of the current climate and energy policy on the strengthening emission requirements for industrial installations make the project unvital.

The break-even analysis for pricing showed that at the required rate of return 5%, selling price of a MWh of electricity generated in the power plant must be not lower than 61 euros to bring the project to the break-even point. The price reaches 75 euros at the rate of 10%. Since 2013, when Estonian electricity market was completely liberalized, the average annual spot price in Estonian price for these last 6 years was 38 EUR. However, in the future, a price growth may be expected in the Baltic region. The decommission of old Estonian oil shale units and the desynchronization of the Baltic system from the Russian grid may lead to the power shortage in the Baltics. The shortage, in its turn, may cause the decoupling of the Baltic region from the Nordic countries and forming higher wholesale electricity prices than in the price areas of Scandinavia. Nevertheless, the real price growth in the Baltic electricity market should be more than 60% to turn the NPV of the power plant project to be positive.

To summarize the results obtained from the current work, it may be stated that the construction of an oil shale power plant is not economically reasonable, as its production is not competitive in the open electricity market, where renewable and low-carbon generation capacities prevail. Neither does the utilization of retort gas, which may be considered as a free product enabling the reduction of emissions, provide the competitiveness of this type of a power plant. Therefore, to support the continuous production of shale oil, other technical solutions for the utilization of retort gas need to be analysed. However, it should be noted that the construction of an oil shale power plant may be reasonable if these capacities are used for system services or in order to ensure security of supply.

The expansion of shale oil production capacities may be a reasonable solution for the countries with a large domestic oil consumption to substitute oil imports. Presently, this strategy is applied, for instance, by the USA and China, where plentiful in-place reserves of oil shale along with a moderate approach to climate policy provide favourable conditions for the development of shale oil production. At the same time, Estonian shale oil production sector, on the example of which this study was made, faces a lot of challenges. Approximately 90% of shale oil produced in Estonia is exported. To comply with fuel standards, which are becoming tougher in the light of the current climate and energy policy, and to stay competitive in the world oil market in the future, Estonian shale oil producers should focus on the improvement of the fuel quality. Also, the national taxation system causes a relatively high level of costs to the sector through the environmental and resource charges. To provide a sustainable development of the oil production sector and the oil shale industry at whole, the analysis of oil shale utilization in terms of the total state long-term revenues should be continuously performed. Its results should be taken into account in the principles of the industry taxation system and be the basis for the changes in the tax rates.

Future Work

The results of the present study showed that the potential project of a shale oil production plant is subjected to a lot of risks, which may have a significant impact on its profitability. Therefore, for a thorough analysis of the project under risk and uncertainty, the following improvements should be made:

- different scenarios for the further development of the crude oil market, which is the main driver of a key variable (heavy fuel oil 1% price), should be considered;
- projections of other critical variables should be revised and, if necessary, corrected;
- appraisal criteria should be recalculated under conditions of uncertainty.

The scenario analysis will provide a vision of the possible ways of the further development of the crude oil market. Since it is a major factor that defines the dynamics of heavy fuel oil 1% price, a key variable, the analysis will allow the evaluation of the profitability of the project under each scenario. The revision of the projections of other critical variables may improve the quality of the calculation results of the project's cash flows, which are the basis for further computation of the appraisal criteria and sensitivity indicators. Also, the approach for calculation of the appraisal criteria under conditions of uncertainty may be proposed to estimate the economic feasibility of the project, taking into account different risk factors.

Some steps to reduce the risks associated with the sector may be made by shale oil producers. For instance, the construction of a refinery plant may be considered to improve the quality of shale oil. It will allow bringing in line the parameters of the oil shale fractions with the tough quality requirements for liquid fuels. A possible solution to the problem of the utilization of the retort gas produced in the oil plants of the energy complex may be modernization of the existing power generation units by increasing their thermal capacity to process the gas. If the thermal capacities to produce retort gas exceed the thermal capacities to utilize it, the construction of a gas turbine power plant or a gas engine power plant that runs on retort gas may be considered. However, this solution requires additional research and development of technologies, as the composition and properties of retort gas differ from those of natural gas. Also, shale oil production capacities may be expanded by applying an improved oil shale retorting technology, where the gas is reused in the technological process that allows avoiding the production of the gas as a by-product.

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Abstract

Development Prospects of the Oil Shale Industry under Conditions of Renewable and Low-Carbon Energy Policy

The reserves of oil shale over the world are plentiful, which provides a great potential for the development of the oil shale industry. The shale oil equivalent of world oil shale proven reserves is close to 420 billion tons. It is much greater than 170 billion tons of recoverable reserves of world crude oil, even greater than 300 billion tons of its estimated resources. However, the oil shale industry has a great environmental impact. In the light of the climate and energy policy, which is focused on the increase of renewable and low-carbon production capacities and on toughening of environmental requirements for emission-intensive industrial installations, the development of the industry faces a lot of challenges.

The main purpose of this thesis is to estimate the development prospects of the oil shale industry under the conditions of the current energy policy. The estimation was based on the analysis of the economic feasibility of new investments in this field. The analysis focused on the two main sectors of the oil shale industry – shale oil production and electricity generation. To estimate the profitability of the investments in the shale oil production sector, the potential construction of a shale oil plant was considered. The expansion of shale oil production capacities leads to an increase of the generation of retort gas, a by-product of oil shale retorting process, needed to be utilized to provide constant oil production. Thus, the potential construction of a condensing oil shale power plant, which runs on the fuel mix from oil shale and retort gas, was considered as a possible way to utilize retort gas for electricity generation. Both of the investment projects were studied on the example of Estonian oil shale industry.

The methodology applied to estimate the economic feasibility of the potential investments includes the principles proposed to create the cash flow models of the investment projects, the appraisal techniques adjusted to the projects' peculiarities and the approaches employed to analyse the investment projects under risk. The input data of the models were the variable data on the components of the projects' revenue and costs. Since the current study focuses on the analysis of the projects under the conditions of renewable and low-carbon energy policy, the data on the key variables, such as crude oil price and CO_2 allowance price, were obtained from the IEA scenario, which relies on this policy. The output data of the models were the cash flows generated by the projects during their lifetime. The cash flows, in their turn, were the basis of the further economic analysis and risk assessment of the investment projects. The economic analysis was focused on the calculation of the key appraisal criteria, such as the NPV, the IRR, the PI and the DPP. To assess the risk of the investments, the sensitivity of the NPV to the possible change in the values of the critical variables was analysed. The sensitivity analysis was supplemented by the approaches proposed to calculate the break-even prices of the main products of the considered projects to define the limit parameters of their profitability.

The results of the calculation of the appraisal criteria of a potential project of a shale oil production plant showed that the project NPV is positive for both discount rates and its IRR amounts to 13%. It means that the construction of a potential shale oil plant will be profitable at the weighted average cost of capital less than 13%. At the same time,

the results of the sensitivity analysis showed that the project is very sensitive to the possible changes in heavy fuel 1% price. Moreover, the fractions of shale oil are actually traded at a discount to the heavy fuel oil 1% due to the differences in chemical composition. Therefore, shale oil price may be also influenced by the policy and legislation that regulate the quality of fuel. Besides heavy fuel 1% price, the fluctuations of oil shale price and CO_2 allowance price have also an essential impact on the project's NPV. In addition to these factors, national taxation and currency exchange rate are other risks that shale oil production sector may face.

However, the results of the break-even analysis showed that the selling break-even price of a ton of shale oil produced in the considered plant is 420-457 euros (69-75 USD/bbl) if the required rate of return is within the range of 5-10%. According to the updated survey on new world oil production projects, all the projects added recently into the survey have a break-even oil price above 70 USD/bbl. Moreover, most of them have the price within the 80-100 USD/bbl band. Thus, despite the high risks associated with the potential project of a shale oil plant, the production of shale oil is expected to be competitive in the global oil market.

Concerning the potential project of a construction of an oil shale power plant to utilize the retort gas produced in the energy complex for electricity generation, the analysis showed that this technical solution is not reasonable from the economic point of view. Undertaking this project, the company's wealth will decrease by 141 million euros if the required rate of return is 5% and by 169 million euros if the required rate of return is 10%. The additional risks for the project are associated with its sensitivity to the changes in CO_2 allowance price. Escalating price trend in the EU carbon allowance market and the focus of the current climate and energy policy on the strengthening emission requirements for industrial installations make the project unvital. Therefore, to support the continuous production of shale oil, the analysis of other technical solutions for the utilization of retort gas is required.

Keywords

Oil shale industry, Shale oil production plant, Retort gas utilization, Oil shale power plant, Renewable and low-carbon energy policy, Investment project, Economic feasibility evaluation, Project cash flows, Cash flow model, Model variables forecasting, Economic analysis, Investment appraisal techniques, Project risk assessment, Sensitivity analysis, Sensitive variables, Sensitivity measurement methods, Break-even analysis, Break-even selling price

Lühikokkuvõte

Põlevkivitööstuse arenguperspektiivid taastuvenergia ja madala süsinikuheitmega tehnoloogia arendamise poliitika tingimustes

Maailmas on mahukad põlevkivi varud, mis pakuvad suurt potentsiaali põlevkivitööstuse arendamiseks. Kinnitatud põlevkivi varud maailmas ulatuvad umbes 420 miljardit tonnini põlevkiviõli ekvivalendis. See on oluliselt rohkem kui 170 miljardit tonni kättesaadavat toornafta varu ja isegi rohkem kui 300 miljardit tonni hinnangulist toornafta varu maailmas. Põlevkivitööstusel on aga märkimisväärne mõju keskkonnale. Praegune kliima- ja energiapoliitika on suunatud taastuvenergia ja madala süsinikuheitmega tootmistehnoloogia arengu toetamisele. Samuti on eesmärk piirata tootmisega kaasnevaid heitmekoguseid. See seab põlevkivitööstuse arendamisele suured väljakutsed.

Antud doktoritöö peamine eesmärk on anda hinnang põlevkivitööstuse arendamise perspektiividele, lähtudes praegusest kliima- ja energiapoliitikast. Hinnang põhineb uute põlevkivitööstuse investeeringute majandusliku tasuvuse analüüsil. Analüüs keskendub kahele põhilisele põlevkivitööstuse harule: põlevkiviõli tootmine ja elektrienergia genereerimine. Põlevkiviõli tootmise kasumlikkuse hindamiseks analüüsiti põlevkiviõli tehase ehituse projekti tasuvust. Uue põlevkiviõli tehase ehitus toob kaasa uttegaasi toodangu suurenemise. Uttegaas on põlevkiviõli tootmise kõrvalsaadus, mida on vaja utiliseerida õli katkestamatu toodangu tagamiseks. Selleks analüüsiti põlevkivi ja uttegaasi segul töötava elektrijaama ehituse majandusliku tasuvust. Mõlema investeerimisprojekti tasuvust analüüsiti Eesti põlevkivitööstuse projektide näitel.

Investeerimisprojektide majandusliku tasuvuse hindamise metodoloogia raames pakuti projektide rahavoogude mudelite loomise põhimõtteid, projektide iseärasustega kohandatud hindamismeetodeid ning lähenemisviise investeeringute riskianalüüsi teostamisele. Rahavoogude mudelite sisendandmeteks ehk muutujateks on andmed projekti tulude ja kulude komponentide kohta. Kuna antud doktoritöö on suunatud projektide analüüsile taastuvenergia ja madala süsinikuheitmega tehnoloogia arendamise poliitika tingimustes, andmeid võtmemuutujate (nafta ja CO_2 kvootide hindade) kohta võeti IEA stsenaariumist, mis baseerub selle poliitika põhimõtetel. Mudelite väljundandmeteks on projekti rahavood, mis tekivad projekti kogu eluea jooksul. Rahavood on aluseks edaspidiseks investeerimisprojektide majandusliku tasuvuse analüüsimiseks ja riskide hindamiseks. Majandusliku tasuvuse analüüs baseerub põhilistel diskonteeritud rahavoogude meetoditel: NPV, IRR, PI ja DPP. Riskianalüüs on teostatud tundlikkuse analüüsi alusel, milles on hinnatud kriitiliste muutujate väärtuste muutuste mõju NPV väärtusele. Tundlikkuse analüüs on täiendatud meetoditega, mille alusel arvutatakse kasumiläve hinda projektide põhitoodetele. Kasumiläve hinnad on aluseks projekti tasuvuse piirparameetrite määramiseks.

Põlevkiviõli tootmistehase majandusliku tasuvuse analüüs näitas, et projekti NPV on positiivne mõlema diskontomäära puhul ning IRR on 13%. See tähendab, et põlevkiviõli tehase ehituse projekt on kasumlik ja investeerimisotsus võib olla vastu võetud, kui selle kaalutud keskmine kapitalikulu on väiksem kui 13%. Samas tundlikkuse analüüs näitas, et projekti tasuvust mõjutab suuresti 1% väävlisisaldusega kütteõli hind. Sellest peale müüakse põlevkiviõli fraktsioonid kütteõli hinnast madalama hinnaga keemilise koostise

erinevuste pärast. Seepärast võib põlevkiviõli hinda mõjutada ka muutused seadusandluses, mis reguleerib kütuste kvaliteedi nõudeid. Peale 1% väävlisisaldusega kütteõli hinda avaldavad samuti projekti NPV-le märkimisväärset mõju põlevkivi hinna ja CO_2 kvoodi hinna kõikumised. Lisaks ülalmainitud mõjuritele võib põlevkiviõli tootmise haru kokku puutuda selliste riskidega kui olulised muutused riiklikus maksusüsteemis ja valuuta vahetuskursis.

Kasumiläve hinnaanalüüsi tulemused aga näitasid, et põlevkiviõli müügihind kasumiläve punktis on 420 eurot tonni kohta (69 USD/bbl), kui soovitud projekti tootlikkus on 5%. Juhul, kui projekti soovitud tootlikkus ulatub 10%-ni, peab põlevkiviõli müügihind olema vähemalt 457 eurot tonni eest (75 USD/bbl), et tagada põlevkiviõli tootmistehase kasumilävi. Vastavalt Goldman Sachs uuringule, mis käsitleb uusi õlitootmise projekte maailmas, kõikidel uutel õlitootmisüksustel on kasumiläve hind üle 70 USD/bbl. Seejuures jäävad enamikutel tootmisüksustel kasumiläve hinnad 80-100 USD/bbl piiridesse. Seega vaatamata sellele, et põlevkiviõli tootmise projekt on seotud suurte riskidega, on oodata, et põlevkiviõli tootmise tehnoloogia saab olema maailma õliturul konkurentsivõimeline.

Põlevkivi ja uttegaasi segul töötava elektrijaama projekti majandusliku tasuvuse analüüs näitas, et see uttegaasi utiliseerimise tehniline lahendus ei ole majanduslikult otstarbekas. Teostades seda projekti, kaotaks ettevõte 141 miljonit eurot, kui võtta arvesse, et soovitud projekti tootlikkus on 5%. Ettevõtte kahjum ulatuks 169 miljoni euroni, kui projekti soovitud tootlikkus oleks 10%. Lisaks sellele on antud projekti NPV väga tundlik CO_2 kvoodi hinna muutuste vastu. Suurenev CO_2 hinnatrend Euroopa Liidu CO_2 kvootide turul ning praeguse kliima- ja energiapoliitika eesmärk karmistada heitmete piirnorme teevad põlevkivil ja uttegaasil töötava elektrijaama projekti mittetasuvaks. Seepärast tuleb põlevkiviõli tootmisel tekkiva uttegaasi utiliseerimise võimalusi edasi analüüsida.

Märksõnad

Põlevkivitööstus, põlevkiviõli tootmistehas, uttegaasi utiliseerimine, põlevkivielektrijaam, taastuvenergia ja madala süsinikuheitmega tehnoloogia arendamise poliitika, investeerimisprojekt, majandusliku otstarbekuse hindamine, projekti rahavood, rahavoogude mudel, mudeli muutujate väärtuste prognoosimine, majanduslik analüüs, investeeringute hindamismeetodid, projekti riskide hindamine, tundlikkuse analüüs, kriitilised muutujad, tundlikkuse hindamismeetodid, kasumiläve analüüs, kasumiläve müügihind

Appendix A – Appraisal Techniques and Cash Flow Models

Appraisal Techniques

In mathematical terms, the formula for the NPV is expressed as follows:

$$NPV = \sum_{t=J+1}^{T} \frac{C_t}{(1+r)^t} - \sum_{j=0}^{J} \frac{I_j}{(1+r)^j}, \tag{3.2}$$

where t is the year of the cash flow, j is the year of the investment, T is the total number of the project operation years, J is the total number of the project construction years, r is a discount rate, C_t is the net cash flow (i.e. cash inflow - cash outflow) in the year t, I_j is the investment in the year j.

The rate of return r can be extracted from the following equation:

$$NPV = \sum_{t=J+1}^{T} \frac{C_t}{(1+r)^t} - \sum_{j=0}^{J} \frac{I_j}{(1+r)^j} = 0, \tag{3.3}$$

where t is the year of the cash flow, j is the year of the investment, T is the total number of the project operation years, J is the total number of the project construction years, r is a discount rate, C_t is the net cash flow in the year t, I_j is the investment in the year j.

The formula for the PI calculation is expressed as follows:

$$PI = \frac{\sum_{t=J+1}^{T} \frac{C_t}{(1+r)^t}}{\sum_{j=0}^{J} \frac{I_j}{(1+r)^j}}, \tag{3.4}$$

where t is the year of the cash flow, j is the year of the investment, T is the total number of the project operation years, J is the total number of the project construction years, r is a discount rate, C_t is the net cash flow in the year t, I_j is the investment in the year j.

The formula for the DPP is expressed in the equation:

$$DPP = (n-1) + \frac{\sum_{j=0}^{J} \frac{I_j}{(1+r)^j} - \sum_{t=J+1}^{n-1} \frac{C_t}{(1+r)^t}}{\frac{C_n}{(1+r)^n}}, \tag{3.5}$$

where n is the year, in which the present value of the cumulative cash flow produced by a project exceeds the cost of initial investment; C_n is the net cash flow in the year n, j is the year of the investment, J is the total number of the project construction years, r is a discount rate, I_j is the investment in the year j, t is the year of the cash flow, C_t is the net cash flow in the year t.

Cash Flow Models

Table 7. Cash flow model of a potential project of a shale oil production plant (MEUR)[10].

Project phase	*Construction*			*Operation*															
Calendar year	2021	2022	2023	2024	2026	2028	2030	2032	2034	2036	2038	2040	2042	2044	2046	2048	2050	2052
End of notional year	0	1	2	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
Capital flows																		
Capital outlay	-100	-100	-100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operating flows																		
Revenue from shale oil sales	0	0	0	108	112	118	125	130	136	141	145	150	154	158	162	166	170	173
Revenue from electricity sales	0	0	0	12	13	13	13	13	13	14	14	14	14	14	14	14	15	15
Total revenue	*0*	*0*	*0*	*119*	*125*	*131*	*138*	*143*	*149*	*155*	*159*	*164*	*168*	*173*	*176*	*181*	*185*	*188*
Fuel costs	0	0	0	35	37	39	41	44	46	49	52	54	57	60	63	65	68	69
CO2 costs	0	0	0	17	18	21	23	25	27	29	31	33	35	38	40	42	44	46
Other environmental costs	0	0	0	6	6	6	6	7	7	7	8	8	8	9	9	9	10	10
O&M costs	0	0	0	13	13	14	14	15	15	16	16	17	17	18	19	19	20	21
Total costs	*0*	*0*	*0*	*71*	*74*	*80*	*85*	*90*	*96*	*101*	*107*	*112*	*118*	*124*	*130*	*136*	*141*	*146*
Depreciation	0	0	0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Taxable income	0	0	0	39	40	42	43	43	44	43	43	42	41	39	36	35	33	32
Tax payable	0	0	0	5	6	6	6	6	6	6	6	6	6	5	5	5	5	4
Net income	0	0	0	33	35	36	37	37	37	37	37	36	35	33	31	30	29	27
Operating cash flow	0	0	0	43	44	46	47	47	47	47	47	46	45	43	41	40	38	37
Net cash flow	*-100*	*-100*	*-100*	*43*	*44*	*46*	*47*	*47*	*47*	*47*	*47*	*46*	*45*	*43*	*41*	*40*	*38*	*37*
Cumulative net cash flow	*-100*	*-201*	*-301*	*-258*	*-170*	*-79*	*15*	*109*	*203*	*298*	*392*	*484*	*574*	*661*	*744*	*825*	*902*	*977*

[10] Because the model is extensive, the results of the calculation of the cash flows received during the project operation phase are presented with a resolution of 2 years.

Table 8. Cash flow model of a potential project of a power plant to utilize retort gas (MEUR) [11].

Project phase	*Construction*			*Operation*															
Calendar year	2021	2022	2023	2024	2026	2028	2030	2032	2034	2036	2038	2040	2042	2044	2046	2048	2050	2052
End of notional year	0	1	2	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
Capital flows																		
Capital outlay	-92	-92	-92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operating flows																		
Revenue from electricity sales	0	0	0	38	40	40	41	42	43	44	45	45	45	45	45	46	47	48
Total revenue	0	0	0	38	40	40	41	42	43	44	45	45	45	45	45	46	47	48
Fuel costs	0	0	0	7	8	8	9	9	10	10	11	11	12	12	13	14	14	14
CO2 costs	0	0	0	11	12	13	14	16	17	18	20	21	22	24	25	26	28	29
Other environmental costs	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
O&M costs	0	0	0	4	4	4	4	4	5	5	5	5	5	6	6	6	6	7
Total costs	0	0	0	23	24	26	28	30	32	34	37	39	41	43	45	47	50	52
Depreciation	0	0	0	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Taxable income	0	0	0	6	7	5	4	2	1	1	-1	-3	-5	-7	-10	-11	-12	-13
Tax payable	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Net income	0	0	0	5	6	5	3	2	1	1	-1	-3	-5	-7	-10	-11	-12	-13
Operating cash flow	0	0	0	14	15	14	12	11	10	10	8	6	4	2	-1	-2	-3	-4
Net cash flow	-92	-92	-92	14	15	14	12	11	10	10	8	6	4	2	-1	-2	-3	-4
Cumulative net cash flow	-92	-184	-276	-262	-231	-203	-178	-156	-135	-116	-98	-84	-75	-71	-71	-74	-79	-86

[11] Because the model is extensive, the results of the calculation of the cash flows received during the project operation phase are presented with a resolution of 2 years.

Appendix B – Included Publications

Publication I

S. Pulkkinen, "Evaluation of investments profitability in conventional power generation sector in Estonia", *12th International Conference on the European Energy Market*, Lisbon, Portugal, 19-22 May 2015, IEEE Conference Publications, DOI: 10.1109/EEM.2015.7216768.

Evaluation of Investments Profitability in Conventional Power Generation Sector in Estonia

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***Abstract*—This paper presents an evaluation of investments profitability in the conventional power generation sector in Estonia under the conditions of liberalized electricity market and European energy and climate policy. Main economic and technical data of the largest new conventional power plant in Estonia were analyzed to study this issue. The results of the study are based on the theoretical analysis using the Net Present Value and the Internal Rate of Return methodology. Additionally, the Levelized Cost of Electricity method was applied to determine the price of electricity that would ensure breakeven to the investors. The results show that it is reasonable to construct new conventional power plants in Estonia only in a complex of shale oil production where the retort gas received as a secondary product is used as a fuel in power plants.**

***Index Terms*--conventional power plant, investment analysis, generation costs**

I. Introduction

Traditionally, the oil shale power generation sector is the conventional power generation sector in Estonia. At present, 86% of electricity generated in Estonia is produced from oil shale, out of which over 99% is produced in the Eesti and Balti Power Plants (the Narva Power Plants), the largest oil shale power plants in the world [1]. However, electricity generation from oil shale is a pollution-intensive industry that makes it very sensitive to CO_2 allowance prices and other environmental charge rates regulated by national acts.

A member of the European Union (EU), Estonia has to act in the framework of European legislation, following all directives and policies, including the European energy and climate policy. According to this policy, by 2020 greenhouse gas emissions should be reduced in the EU by 20% from 1990 levels, 20% of the consumed energy should be produced from renewable resources in the EU countries and the EU's energy efficiency should be improved by 20%. To reach the target, the renewable energy subsidies were set in the Electricity Market Act of 2003 in Estonia. The subsidies are intended for electricity produced from renewable resources and generated in an efficient combined heat and power mode [2].

Thus, under the conditions of liberalized electricity market that fully opened in Estonia in 2013, oil shale power plants are forced to compete with non-pollution-intensive, subsidized power plants. This situation was complicated at the beginning of 2014 when the second cable Estlink 2 that connects Estonian and Finnish power systems was taken into commercial use. As a result, the connection capacity between Estonia and Finland was increased from 350 MW to 1000 MW, which, in turn, created additional competition with the producers from the Nordic countries [3].

In the present conditions, the Narva Power Plants (constructed during the period from 1956 to 1973) are strongly depreciated [4], [5]. At the same time, the use of local fuel such as oil shale for electricity generation offers a potential opportunity to save national energy security. Thus, a feasibility analysis of the construction of new oil shale power plants under the conditions of liberalized electricity market and European energy and climate policy has been initiated. As a result, an evaluation of investments profitability in the conventional power generation sector in Estonia will be made.

II. Case Study

The largest investment project in the conventional power generation sector in Estonia since the construction of the Narva Power Plants has been chosen as a case study for the evaluation of investments profitability in this sector. This project involves the construction of the Auvere Power Plant, a condensing power plant with an installed net capacity of 270 MW where the circulating fluidized bed (CFB) boiler technology will be used. The construction of the power plant was started in the summer of 2011 and its synchronization with the electrical system will take place in February 2015 [6]. The total planned investment is 638 million euros [7]. Both the Auvere power plant and the Narva power plants are owned by Eesti Energia.

The Auvere Power Plant can run both singly on oil shale or on the fuel mix of oil shale and biomass. The share of wood chips in this fuel mix can be up to 50% [7]. Since the power plant is a part of the energy complex, which in addition to that of Auvere, includes one more oil shale power plant (the Eesti Power Plant) and two shale oil plants (the Enefit140 and the Enefit280), there is a potential opportunity to use oil shale retort gas received as a secondary product in the course of shale oil production as a fuel for electricity generation in the Auvere power plants.

Thus, to establish the main parameters under which the investments into the project would be most profitable, it has been decided to consider three possible cases. *Case 1*: the power plant runs only on oil shale. *Case 2*: the fuel mix from 50% of oil shale and 50% of wood chips is used for electricity generation. *Case 3*: the power plant runs on the fuel mix from 50% of oil shale and 50% of retort gas.

III. Methodology and Basic Assumptions

A. *Methodology for evaluation of investments profitability*

To evaluate investment profitability of the project, the Net Present Value (NPV) indicator was used. This indicator shows the present value of an investment by the discounted sum of all cash flows received from the project. The formula for the NPV can be expressed as:

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} - C_0 \,, \qquad (1)$$

where t is the time of the cash flow, T is the total number of periods, r is a discount rate, C_t is the net cash flow (i.e. cash inflow - cash outflow) at time t, C_0 is an initial investment.

If the NPV of the project is negative, the project should be rejected, as the net cash flows received from the project will also be negative. If the NPV is positive, the project may be accepted. However, making a decision on the basis of the NPV, investors should take into account the weighted average cost of capital, which at best is only an estimate. If the discount rate used in the calculation of the NPV turns out to be smaller than the actual cost of capital, the project will prove unprofitable despite the previously calculated positive NPV.

To estimate the efficiency of the project, the Internal Rate of Return (IRR) method was used. This method, also called the discounted cash flow method, measures the internal earning rate of an investment. That rate often used in capital budgeting makes the NPV of all cash flows from a particular project equal to zero [8].

The NPV and the IRR will be calculated for each case presented in section 2 and for two discount rates – 5% and 10%.

B. *Basic assumptions*

To calculate the cash flows to be received from the project during its lifetime, some basic assumptions were made to estimate yearly electricity production and changes of power plant’s profit and costs.

At the moment, the Auvere Power Plant is expected to start operation in the middle of February 2015, and its planned lifetime is 30 years [9]. To calculate the power plant’s average annual electricity production, its operation at full load of 270 MW during all that period is assumed. Also, the duration and frequency of annual and general maintenance works and failure rate are taken into account. The duration and frequency of the works and failure rate were determined on the basis of the analysis of these parameters for the Eesti power plant’s CFB unit, which was modernized to use the same boiler technology as in the Auvere Power Plant. It was determined that annual maintenance works last for one month and they take place every year except the years when general maintenance works take place. General maintenance works last for five months and they take place every five years. The failure rate for the first 10 years has gradually increased from 2% to 4%. It was assumed that by the end of the project’s lifetime it will have increased to 10%.

The main costs of electricity generation in the power plant will consist of fuel costs, environmental costs and operation and maintenance (O&M) costs.

As mentioned in section 2, the profitability of the investment into this project will be evaluated for three cases where three different types of fuel: oil shale, wood chips and retort gas are used. The price for oil shale in 2015 was taken from [10]. The estimation of oil shale price growth in the future was made on the basis of the price forecast for the major components of oil shale production costs, such as raw materials, electricity, oil shale mining charge, environmental charges and payroll expenses. The price forecast for oil shale is presented in Fig.1. The price forecast for wood chips based on the initial data [11] is presented in Fig. 2. Retort gas is a secondary product received in the course of shale oil production, therefore it can be considered as a free product for electricity generation.

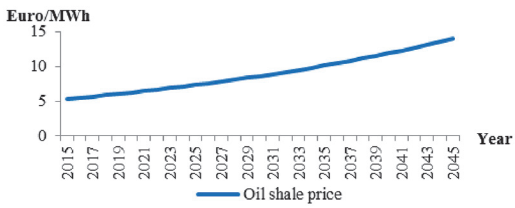

Figure 1. Oil shale price forecast

Figure 2. Wood chips price forecast

To finance the construction of the Auvere power plant, under the permission of the European Commission, the Estonian government allocates a total of 18 million tonnes of free CO_2 emission allowances to Eesti Energia for the period 2013-2020 [7]. Therefore, no CO_2 costs are involved until 2020. It is assumed that the unused allowances will be sold at the end of 2020. To calculate CO_2 costs for the rest of the period, CO_2 allowance price forecast taken from [12] are used. Other environmental costs include the charge for surface water use as cooling water, the charge for disposal of oil shale ash and the charge for the emission of pollutants into the ambient air, such as SO_2, NO_x and fly ash. The environmental costs are calculated using the pollution charge rates set until 2015 in the Estonian Environmental Charges Act, and the recommended growth of the charge rates until 2020 taken from [13]. It is assumed that after 2020, the growth of the environmental charge rates will remain the same. The information on the specific amounts of cooling water, oil shale ash and emissions per MWh of the produced electricity was provided by the owner of the power plant, and it is expected that these amounts remain unchanged during the project lifetime.

Oil shale power plants are not widely spread in the world and there is lack of information on O&M costs for oil shale power plants in European or world statistical database. Thus, it was decided to use average O&M costs of the Narva Power Plants. The average O&M costs were calculated on the basis of data from [14]. The costs for raw materials and consumables, payroll expenses and other operating expenses were taken into account to calculate the fixed costs. Variable costs consist of the current maintenance costs. To recalculate these costs for 2015 and to estimate the growth of the costs during the project lifetime, the average annual rate of inflation in Estonia and its projection for the future were taken into account [15], [16]. Since projection is available only until 2018, it is assumed that the annual rate of inflation will remain on the level of 3% during the rest of the period.

According to the Estonian Electricity Market Act, renewable energy subsidies for electricity generated from biomass or retort gas are provided only if it is produced in an efficient combined heat and power mode. As the Auvere Power Plant is a condensing power plant, the project will not be subsidized and revenues will be received only from electricity sales. The calculation of the project revenue is based on the estimation of electricity production and on the electricity price forecast for Estonia. This forecast is based on the forecast used in the Estonian National Development Plan of the Energy Sector Until 2030 and on the information on the futures contracts for Helsinki, as electricity price convergence between Estonia and Finland is almost 98% [1], [17]. The electricity price forecast for Estonia is presented in Fig. 3.

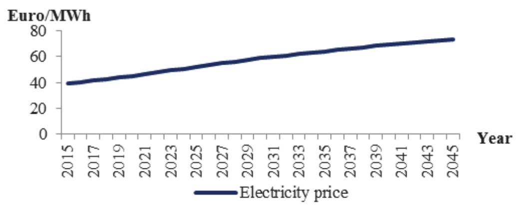

Figure 3. Electricity price forecast for Estonia

The first investments into the project were made in 2011. So, all investments made until 2014 were recalculated, using the average annual rate of inflation in Estonia [18]. It is assumed that investment costs for each case presented in section 2 are the same. The recalculated investment costs and the project costs and profit in 2015 are shown in Table I.

TABLE I. AUVERE POWER PLANT'S COSTS AND PROFIT IN 2015

Year 2015	Case 1	Case 2	Case 3
General information			
Installed net capacity, MW	270	270	270
Approximate construction time, months	42	42	42
Lifetime, years	30	30	30
Power plant efficiency, %	40	40	40
Average net electricity production, TWh	2,0	2,0	2,0
Investment costs, MEUR[a]	662,8	662,8	662,8
Costs			
Fuel costs, MEUR	27,0	50,7	13,5
Environmental costs, MEUR	3,1	1,8	2,1
Variable O&M costs, MEUR	0,8	0,8	0,8
Fixed O&M costs, MEUR	2,5	2,5	2,5
Profit			
Revenue from electricity sales, MEUR	78,9	78,9	78,9

a. Million euros

C. Levelized cost of electricity

To determine the cost of electricity generation for each case considered in section 2, the levelized cost of electricity (LCOE) method was used. The LCOE is equal to the present value of the sum of project discounted costs divided by the total production adjusted for its economic time value:

$$LCOE = \frac{\sum_{t=0}^{n} \frac{I_t + O\&M_t + F_t + En_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+r)^t}}, \quad (2)$$

where I_t is investment costs in year t, $O\&M_t$ is operation and maintenance costs in year t, F_t is fuel costs in year t, En_t is environmental costs in year t, E_t is the amount of electricity produced in year t, r is a discount rate, and n is the lifetime of the project.

Also, the LCOE is equal to the price at which electricity must be generated from a specific source to break even over the lifetime of the project. Thus, using the LCOE method, it is possible to determine the limit electricity price for each case considered in section 2, which allows investors to break even on this project. The LCOE will be calculated for two discount rates, 5% and 10%, and using data and assumptions presented in Part B of section 3.

IV. RESULTS AND DISCUSSION

A. Net Present Value and Internal Rate of Return

Clearly, financing of a project, including that in the power generation sector, is reasonable only if the investors can receive a satisfactory profit. To evaluate the profitability and efficiency of the investments made into the Auvere Power Plant, the NPV and the IRR methods were used. The calculation of the NPV and the IRR is based on the data presented in Part B of section 3. The NPV and the IRR were calculated for three potentially possible cases for this project considered in section 2. The results of the calculation for each case are shown in Table II.

TABLE II. NET PRESENT VALUE AND INTERNAL RATE OF RETURN OF THE PROJECT

Case	Discount rate, %	NPV, MEUR	IRR, %
Case 1	5	-214	-6
	10	-315	
Case 2	5	-348	-16
	10	-426	
Case 3	5	327	10
	10	0	

As can be seen in Table II, the NPV and the IRR are positive only in Case 3. It means that investments into the Auvere Power Plant will be profitable only if the fuel mix from 50% of oil shale and 50% of retort gas is used for electricity generation. Also, it should be noted that this case is acceptable for the project investors if the weighted average cost of capital is lower than 10%. In that case only the investors may receive return from the project.

The NPV and the IRR calculated for Case 1 and Case 2 show that the project will be unprofitable if only oil shale (Case 1) or fuel mix from 50% of oil shale and 50% of wood chips (Case 2) are used for electricity generation in the power plant. It can be explained by high expenses for fuel, while in Case 3 expenses for fuel are considerably smaller, because retort gas can be considered a free fuel for electricity generation.

Discounted net cash flows received from the project over its lifetime in Cases 1-3 are shown in Figs. 4-6. As can be seen in Figs. 4-5, discounted net cash flows become negative after 24 years of operation of the power plant in Case 1 and after 27 years in Case 2. Despite a longer period of positive net cash flows in Case 2, these cash flows are two times smaller than in Case 1, which is caused by the highest fuel costs, as wood chips are 2.5 times more expensive than oil shale. This difference in cash flows cannot be compensated even by a larger revenue received in the 6th year from unused CO_2 allowance sales that makes investments in Case 2 most unprofitable. However, it should be noted that the use of wood chips for electricity generation may be reasonable at very high CO_2 allowance prices.

As can be seen in Fig. 6, discounted net cash flows in Case 3 are positive during the whole project lifetime, which provides positive NPV and IRR for this project in Case 3. However, project investors should take into account that the cost of capital should be lower than the IRR to provide revenue from these investments. Only in this case the use of fuel mix from 50% of oil shale and 50% of retort gas for electricity generation makes this project profitable.

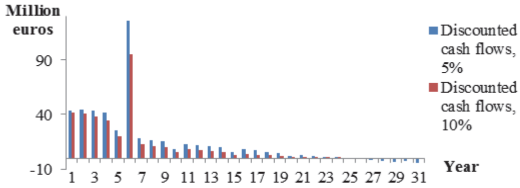

Figure 4. Discounted net cash flows in Case 1

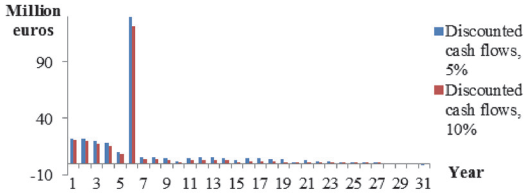

Figure 5. Discounted net cash flows in Case 2

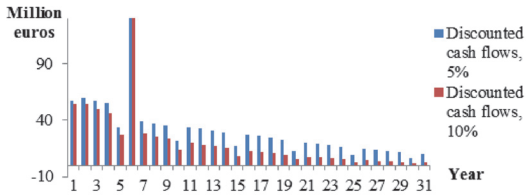

Figure 6. Discounted net cash flows in Case 3

B. *Levelized cost of electricity*

To compare costs of generating electricity for the cases considered in section 2, the LCOE method was applied. Also, using the LCOE method, it is possible to define the price at which electricity must be generated from a specific source to break even over the lifetime of the project. The calculation of the LCOE is based on the data and assumptions presented in Part B of section 3. The results of this calculation for Cases 1-3 are shown in Fig. 7.

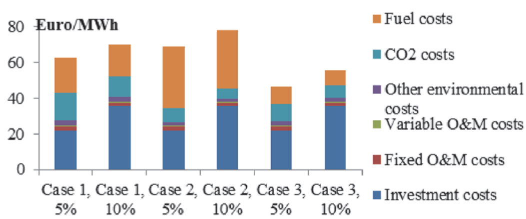

Figure 7. Levelized cost of generating electricity

As can be seen in Fig. 7, electricity generated from the fuel mix that consists of 50% of oil shale and 50% of wood chips has the highest levelized cost. To receive profit from the investments in this case, all electricity generated during the lifetime of the project must be sold at the price that exceeds 69 EUR/MWh (discount rate 5%) or 78 EUR/MWh (discount rate 10%). In Case 2, fuel costs are the largest share of electricity cost, which is explained by the high price of wood chips. However, CO_2 costs are the smallest, which makes it reasonable to use that fuel mix for electricity generation at very high CO_2 allowance prices.

Electricity generated from the fuel mix that consists of 50% of oil shale and 50% of retort gas has the lowest cost. To receive profit from the investments in this Case, all electricity generated during the lifetime of the project must be sold at the price that exceeds 46 EUR/MWh (discount rate 5%) or 56 EUR/MWh (discount rate 10%). Also, electricity generation from this fuel mix has the lowest fuel costs, which is explained by the fact that retort gas is a free fuel for electricity generation. Additionally, in this case, an electricity producer has low CO_2 and other environmental costs that reduce sensitivity of this generation to CO_2 allowance price volatility.

To break even on the project in Case 1, all electricity generated during the lifetime of the project must be sold at the price of 63 EUR/MWh (discount rate 5%) or 70 EUR/MWh (discount rate 10%). However, in this case, an electricity producer has high fuel and CO_2 expenses that make use of 100% of oil shale for electricity generation unprofitable in the future.

V. CONCLUSION

This paper has analyzed profitability of investments in the oil shale power generation sector in Estonia. The analysis shows that under the conditions of the liberalized electricity market and European energy and climate policy, conventional electricity generation from oil shale will be unprofitable. At the same time, the results show that the use of fuel mix from oil shale and retort gas for electricity generation will provide a significant return on new investments into conventional power plants in the future. Thus, it can be concluded that the conventional power generation sector will exist at high profitability in Estonia in the future only in a complex of shale oil production where the retort gas received as a secondary product will be used as the main fuel for electricity generation in conventional power plants.

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Publication II

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Economic Evaluation of Retort Gas Utilization for Electricity Generation

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***Abstract*— This paper analyzes the economic feasibility of the construction of new generation capacities to utilize the retort gas received from a new shale oil plant for electricity production. Three different power generation technologies are studied. To evaluate the profitability of the investment into the project, the Net Present Value and the Internal Rate of Return methods were used. In addition, the Levelized Cost of Electricity method was applied to estimate electricity cost of these power generation technologies. Our analysis shows that it will be most profitable to construct a combined-cycle gas power plant for the utilization of the retort gas. It provides 11% of return on the investment into this project.**

***Index Terms*-- Retort gas, Energy complex, Power generation technologies, Investments evaluation**

I. Introduction

The power industry in Estonia is mainly based on a local fuel such as oil shale. Until recently, oil shale was generally used for electricity generation. However, the present use has shifted to shale oil production. For instance, in 2007, 17% of the oil shale consumed in Estonia was used in that branch and by 2013 the share reached 24% [3]. Along with the growth of shale oil production, the amount of retort gas received as a secondary product in this process is increasing as well. Thus, the need to utilize the gas arises in the continuous oil production. At present, the retort gas is used for electricity and heat generation. Potentially, it can be utilized in the chemical industry, but additional research and development of technologies are required for its application.

There are three companies in Estonia that produce shale oil: Eesti Energia Õlitööstus AS, VKG Oil AS and Kiviõli Keemiatööstuse OÜ. In 2014, the total volume of the oil produced by these companies reached a record high of 770,000 tons; as a result, more than 1,200 million m^3 of the retort gas was produced [2]. Companies utilize the gas in their power plants (PPs) for power generation. For example, in Estonia in 2014, a total of 534 GWh of electricity and 637 GWh of heat were produced from the retort gas that constituted 8% and 9% of Estonian final electricity and heat consumption respectively [3]. Presently, no power generation technologies that would run solely on the retort gas are applied in Estonia. Therefore, the gas is burnt with oil shale in the boilers of condensing and combined heat and power plants. Furthermore, the amount of the gas that can be recovered by a flare burner is limited and such gas recovery is permitted only for start-up or shut-down of shale oil plants (OPs) and in case of emergency.

The OPs and the PPs that utilize the retort gas are located close enough and constitute a single energy complex, as the transportation of the gas by pipeline for long distances is quite complicated due to its physical properties and thus adds extra costs. The largest energy complex in Estonia is owned by Eesti Energia, which is going to expand its liquid fuel production and build two more new OPs in the future [4]. This expansion will increase retort gas production and, as a result, will need higher power generation capacities for additional amounts to be utilized. Thus, the aim of this paper is to examine opportunities for the construction of new generation capacities that will enable retort gas to be utilized for power generation and to analyse the profitability of investments into these projects to evaluate the economic feasibility of this construction on the example of Eesti Energia.

II. Eesti Energia's Energy Complex

Eesti Energia's energy complex consists of two shale OPs, the Enefit140 and the Enefit280, and the Eesti and the Auvere condensing oil shale PPs. The Enefit140 oil plant (OP), which was launched in 1980 and then modernized in 2010, has two units, each able to process 140 tons of oil shale per hour. The OP has the capacity to produce up to 1.5 million barrels of liquid fuel and 60 million Nm^3 of retort gas per year. The Enefit280 was launched at the end of 2012 and its design lifetime is 30 years. It is equipped with improved technology that enables to produce shale oil and retort gas as electricity. The maximum production capacity of the plant is 1.7 million barrels of shale oil, 75 million Nm^3 of retort gas and 280 GWh of electricity per year [5]. The total thermal capacity of retort gas produced by the two OPs is 270 MW_{th} [6].

The present Eesti power plant (PP), which has been operating since 1969, has seven old units with pulverized oil shale fired (PF) boilers and one modernized unit with circulating fluidized bed (CFB) boilers. The installed electrical net capacity of the plant is 1355 MW, which makes it the largest oil shale PP in the world. The thermal capacity of the CFB unit to process the retort gas is 80 MW_{th} and six out of seven PF units are able to burn every single moment 40 MW_{th} of the gas each one [6]. The boiler of another PF unit has been recently modernized and can now utilize up to 120 MW_{th} of the retort gas.

The new Auvere PP was synchronized with the electrical system for the first time in May 2015. Its installed electrical net capacity is 274 MW. The plant has one CFB boiler, which according to the plant project, can utilize up to 80 MW_{th} of the gas [6]. In addition to the Auvere and Eesti PPs, Eesti Energia owns one more oil shale PP, the Balti PP. However, it is located more than 20 kilometers from the energy complex and to transport the gas to the PP the construction of a pipeline is required. The thermal capacities of the PPs available for the utilization of the retort gas are presented in Fig. 1.

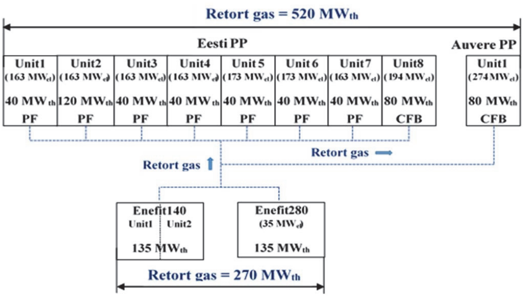

Figure 1. Thermal capacities of the Eesti and the Auvere power plants available for the utilization of the retort gas

As can be seen in Fig. 1, the present Eesti and the Auvere PPs have enough thermal capacities to utilize the maximum volume of the retort gas that can be produced in the Enefit140 and the Enefit280 OPs. However, the situation can change in the future. Since 2016, according to the requirements of the Industrial Emissions Directive (IED), the operating hours of unit 1, unit 2 and unit 7 will be limited as they are unequipped with the flue gas desulfurization facilities and NOx removal systems and, as a result, will not meet the emission limit values. These units cannot be operated for more than 17,500 operating hours after 1 January 2016 and not beyond 31 December 2023. Another PF units of the Eesti PP complies with IED requirements, but because of strong depreciation, these units will be gradually decommissioned. Taking into account Eesti Energia's plans to expand its liquid fuel production, solutions have to be found how to utilize additional amounts of the retort gas in the future.

III. The Object of Study

To find a solution to the problem that arises from the need to process the retort gas received as the result of expansion of shale oil production, opportunities for the construction of new generation capacities were explored. We studied three different power generation technologies. First, we examined a condensing PP based on the CFB technology that can run on the fuel mix from 50% of oil shale and 50% of retort gas. Second, we analyzed a combined-cycle gas turbine (CCGT) PP that runs only on the retort gas, and third, we examined a gas engine power plant (GEPP) where the retort gas is used as the main fuel as well. Also, the units decommissioning in the Eesti PP and the construction of a new OP are analyzed below to determine the capacity required for the PP and the start-up term.

Presumed by the state as the owner, Eesti Energia should cover Estonia's average electric power consumption through at least 2023. In 2014, the average consumption in Estonia was 901 MWh [7]. According to Estonian system operator's forecast, the annual growth of the consumption will be 1.1% up to 2025. Thus, it was calculated that the average electric power consumption will reach the level of 994 MWh in Estonia in 2023. To cover that consumption, it is required to have two old PF units in operation through that year in addition to the Auvere PP and two modernized CFB units (unit 8 in the Eesti PP and unit 11 in the Balti PP). Additionally, one more PF unit should be available until 2024 in case of maintenance or failure of other units. In terms of strong depreciation, it is assumed that the units non-compliant with IED requirements will be operated during the first three years since 2016 and will be decommissioned at the end of 2018. One more PF unit is intended to be decommissioned in 2022.

The construction of new shale OPs is economically reasonable if the oil price in the world market is no less than \$75 per barrel (bbl). According to the New Policies Scenario provided by the International Energy Agency in 2015, the oil market rebalances over the next few years in a way that leaves the oil price (in real terms) back at \$80/bbl by 2020, with further steady increases after that taking it to \$113/bbl by 2030 and \$128/bbl by 2040 [8]. Since no large-scale investments are planned by Eesti Energia until 2020 because of the large loan load, it is assumed that the construction of the first new OP that will use the Enefit280 technology will not start before 2021. Since the plant construction is completed in three years, it will be taken into operation in 2024. Further, it is assumed that investment decisions regarding the construction of an OP and the increase of retort gas utilization capacity will be made simultaneously. Therefore, the capacity of the PP and the start-up term are determined by the launch of the first new OP. The scenario of thermal capacity changes for the production and utilization of the retort gas in Eesti Energia's energy complex is shown in Table I.

As can be seen in Table I, thermal capacity shortage to utilize the retort gas will not occur before 2024, after the launch of the first new shale OP and decommissioning of three last PF units in the Eesti PP. Until that time, the capacities available in the PPs will be sufficient for processing the gas due to Eesti Energia's decision to increase the ability of unit 8 to burn up to 50% of the retort gas from consumed primary energy since 2018 [9].

Thus, it was decided to consider the economic feasibility of the construction of a new PP to be taken into operation in 2024 to eliminate the capacity shortage for gas utilization. To construct the PP with the thermal capacity of 55 MW_{th} means that all units should operate at full load all the time to utilize the required amount of the gas. Therefore, the capacity of the new plant should be larger to enable down-load of the units during off-peak hours when the market prices are lower than the units' variable costs and to cover the capacity shortage at the failure or maintenance of one of the units.

TABLE I. SCENARIO OF THE CHANGE OF THERMAL CAPACITIES TO PRODUCE AND UTILIZE THE RETORT GAS IN EESTI ENERGIA'S ENERGY COMPLEX

Year	Thermal capacities to utilize the retort gas, MW	Reason for utilization capacity change	Thermal capacities to produce the retort gas, MW	Reason for production capacity change	Capacity shortage to utilize the retort gas, MW
2018	510	Decommissioning of three PF units, increase of the thermal capacity of unit 8	270	No changes	0
2022	470	Decommissioning of one PF unit	270	No changes	0
2024	350	Decommissioning of three last PF units	405	Launch of the first OP	-55

Consequently, to cover the capacity shortage of 55 MW_{th} and to substitute the unit with the largest thermal capacity of 270 MW_{th} (the unit 8), the new PP should be able to process up to 325 MW_{th} of the retort gas. Taking into account the efficiency of the PP and its own consumption rate (approximately 10%), the installed electrical net capacity of the oil shale PP based on the CFB technology should be 234 MW, the CCGT plant should have the capacity of 161 MW and the GEPP – 137 MW [10].

IV. METHODOLOGY

A. Evaluation of the economic feasibility of power plant construction

Economic feasibility of the construction of a new PP can be evaluated on the basis of the profitability of an investment into a project that, in turn, is indicated using the Net Present Value (NPV) method. This method shows the present value of an investment by the discounted sum of all cash flows received from the project. The formula for the NPV can be expressed as:

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} - C_0 \, , \qquad (1)$$

where t is the time of the cash flow, T is the total number of periods, r is a discount rate, C_t is the net cash flow (i.e. cash inflow - cash outflow) at time t, C_0 is an initial investment.

The project should be rejected if the NPV is negative, as the net cash flows received from the project will also be negative. The project may be accepted if the NPV is positive. However, making a decision on the basis of the NPV, investors should take into account the weighted average cost of capital, which at best is only an estimate. If the discount rate used in the calculation of the NPV turns out to be smaller than the actual cost of capital, the project will prove unprofitable despite the previously calculated positive NPV.

Additionally, to evaluate the attractiveness of a project, the Internal Rate of Return (IRR) method is used. This method estimates the efficiency of the project and measures the internal earning rate of an investment. That rate often used in capital budgeting makes the NPV of all cash flows from a particular project equal to zero [11]. If the IRR of a new project exceeds a company's required rate of return, that project is desirable. If the IRR falls below the required rate of return, the project should be rejected.

The calculation of the NPV and the IRR for each type of the PP presented in Section III will be made for two discount rates – 5% and 10%.

B. Basic assumptions

Since the NPV and the IRR are calculated on the basis of the cash flows to be received from the project during its lifetime, some basic assumptions were made to estimate the PP's revenue and costs in the future.

The calculation of the PP's revenue is based on the estimation of electricity production and on the electricity price forecast for Estonia. Since the average annual electricity price forecast is used, the PP's operation at full load during its lifetime is assumed to receive the correct result for revenue calculation. Also, to calculate the electricity production, the maintenance works and failure rate are taken into account using the availability factor [10].

The main costs of electricity generation in the PP consist of fuel costs, environmental costs and operation and maintenance (O&M) costs. As was pointed out in Section III, the considered PPs will use oil shale and retort gas as the main fuel. The price for oil shale in 2015 was taken from [12]. Oil shale price growth in the future was estimated on the basis of the price forecast for the major components of oil shale production costs, such as raw materials, electricity, oil shale mining charge, environmental charges and payroll expenses. Retort gas is a secondary product received in the shale oil production, therefore it can be considered as a free product for electricity generation.

To calculate CO_2 costs, CO_2 allowance price forecast taken from [8] was used. Other environmental costs include the charge for surface water use as cooling water, the charge for disposal of oil shale ash and the charge for the emission of pollutants into the ambient air, such as SO_2, NO_x and fly ash. The environmental costs are calculated using the pollution charge rates set until 2015 in the Estonian Environmental Charges Act, and the recommended growth of the charge rates until 2020 taken from [13]. It is assumed that after 2020, the growth of the environmental charge rates will remain the same. The specific amounts of cooling water, oil shale ash and emissions of the Auvere PP were used to calculate the environmental costs of the oil shale PP, since the considered PP type is the same as that of the Auvere. These data were provided by the owner of the PP. To calculate the environmental costs for the CCGT plant and the GEPP, the specific amount of cooling water taken from [14] and emissions per MWh of produced electricity taken from [6] were used.

Since oil shale PPs are not widely spread in the world, there is lack of information on O&M costs for oil shale PPs in European or world statistical databases. Therefore, the data for a coal PP were used to estimate O&M costs of the oil shale PP [15]. The information on O&M costs for the CCGT plant and the GEPP were taken from [16]. To estimate the growth of the costs during the project lifetime, the average annual rate of inflation in Estonia and its projection for the future were taken into account [17].

TABLE II. POWER PLANTS' REVENUE AND COSTS IN 2024

Year 2024	Oil shale PP (CFB)	CCGT plant	GEPP
General information			
Installed electrical net capacity, MW	234	161	137
Approximate construction time, months	42	24	16
Lifetime, years	30	25	20
Power plant efficiency, %	40	55	47
Availability, %	85	86	92
Average net electricity production, TWh	1.7	1.2	1.1
Investment costs, MEUR[a]	603	234	231
Costs			
Fuel costs, MEUR	15.8	0.0	0.0
Environmental costs, MEUR	22.0	12.2	14.2
Variable O&M costs, MEUR	0.8	2.1	1.1
Fixed O&M costs, MEUR	2.8	1.7	2.7
Profit			
Revenue from electricity sales, MEUR	60.6	42.2	38.5

a. Million euros

As compared to a natural gas, retort gas is a dirty gas and hydrogen sulphide, gasoline and solid particles should be removed to enable its application for a gas turbine and a gas engine. Also, when it is used as the main fuel in a PP, additional cleaning of the flue gases may be required to bring the level of emissions into compliance with the IED requirements. The construction of a CCGT plant and a GEPP that run on the retort gas requires special technical solutions to adjust these generation technologies for the properties of the gas that, in turn, increases their cost. Thus, in fact, to estimate the investments into these technologies, the investment costs of a combined-cycle natural gas power plant and a natural gas engine power plant are increased by 50% to cover extra costs caused by special development of technologies and the construction of the retort gas and flue gas cleaning facilities [16].

The new oil shale PP is of the same type as the Auvere PP, therefore its investments were calculated on the basis of Auvere's investments [18]. The investments of the considered PPs are calculated for the year their construction starts, using the projection of the average annual rate of inflation in Estonia [17]. The recalculated investment costs and the PPs' costs and revenue in 2024 are shown in Table II.

C. Levelized cost of electricity

The levelized cost of electricity (LCOE) method is used to determine the cost of electricity generation for each generation technology considered in Section III. The LCOE is equal to the present value of the sum of project discounted costs divided by the total production adjusted for its economic time value:

$$LCOE = \frac{\sum_{t=0}^{T} \frac{I_t + O\&M_t + F_t + En_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{E_t}{(1+r)^t}}, \tag{2}$$

where I_t is investment costs in year t, $O\&M_t$ is operation and maintenance costs in year t, F_t is fuel costs in year t, En_t is environmental costs in year t, E_t is the amount of electricity produced in year t, r is a discount rate, and T is the lifetime of the project.

The LCOE will be calculated for two discount rates, 5% and 10%, and using data and assumptions presented in Part B of Section IV.

V. RESULTS AND DISCUSSION

To evaluate the economic reasonability of the construction of the PP to utilize the retort gas received from the new shale OP, the NPV and the IRR methods were used. The calculation of the NPV and the IRR is based on the data presented in Part B of Section IV. The NPV and the IRR were calculated for three different generation technologies considered in Section III. The results of the calculation for each technology are shown in Table III.

TABLE III. NET PRESENT VALUE AND INTERNAL RATE OF RETURN OF THE INVESTMENTS INTO THE POWER PLANTS

Power Plant	Discount rate, %	NPV, MEUR	IRR, %
Oil shale PP (CFB)	5	-387	-3
	10	-461	
CCGT plant	5	153	11
	10	9	
GEPP	5	18	6
	10	-62	

As can be seen in Table III, the project of the construction of a CCGT plant for the utilization of the retort gas has the highest NPV and the IRR. It means that as compared to two other generation technologies, investments into this project will be most profitable. However, it should be noted that this project is acceptable for the investors if the weighted average cost of capital is lower than 11%. In that case, only the investors may receive return from the project.

The utilization of the gas in a GEPP will be less profitable, as the IRR of this project is only 6%. It can be explained by the fact that CO_2 costs and fixed O&M costs for this power generation technology are higher than the costs for a CCGT plant. Higher CO_2 costs and fixed O&M costs, in turn, raise the levelized cost of electricity generated in this PP. For instance, the levelized cost of electricity generated in a GEPP will be 46 EUR/MWh for the discount rate of 10%, whereas the levelized cost of electricity generated in a CCGT plant will be 39 EUR/MWh for the same discount rate. The levelized cost of electricity of the power generation technologies considered is presented in Fig. 2.

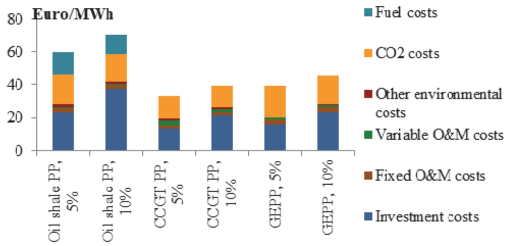

Figure 2. Levelized cost of electricity of the power generation technologies considered

The construction of an oil shale PP for burning up to 50% of the retort gas from the primary energy is economically unreasonable, as the NPV of the project is negative. It means that the net cash flows received from the project will also be negative. The unprofitability of this project is explained by the high investment costs and fuel costs. The reason is that along with the retort gas, which can be considered as a free product, such fuel as oil shale is used for electricity generation, which brings extra expenses. Due to these high costs, the levelized cost of electricity generated in this PP from the fuel mix of oil shale and retort gas is almost twice as expensive as the levelized cost of electricity generated in a CCGT plant (70 EUR/MWh for the discount rate of 10%).

Despite the acceptable IRR of the investment into a CCGT plant, it is required to examine the possibilities to increase the thermal capacities of the existing units to utilize the retort gas received from the new OPs. In 2024, in addition to unit 8 of the Eesti PP, where will be possible to burn up to 50% of the retort gas since 2018, the Auvere PP and modernized unit 11 of the Balti PP will be in operation as well. The Auvere unit and the Balti unit 11 are based on the same technology as unit 8. It means that these units are potentially able to utilize up to 50% of the gas from the consumed primary energy as well. The increase of thermal capacities of these two units would enable processing of up to 640 MW_{th} of the additional amount of the retort gas. Since the modernization of the Auvere unit and the Balti unit to increase the volume of the burnt gas requires a tailor-made technical solution, there is no information on the investments into similar projects to refer. Therefore the evaluation of the economic feasibility of this modernization is not considered in the paper.

VI. Conclusion and Further Research

The aim of this paper was to examine the opportunities for the construction of new generation capacities to utilize the retort gas received from the new shale OP for electricity generation and to analyze the profitability of the investment into these project on the example of the energy complex of Eesti Energia. The analysis showed that it is most profitable to construct a CCGT plant for the utilization of the retort gas, the project providing 11% of return on the investment. At the same time, the possibilities to increase the thermal capacities of the existing units to utilize the retort gas should be examined, as it would provide a more efficient and affordable way for gas processing.

As a basis in this paper, it is assumed that the production of shale oil is always profitable and shale OPs operate at the full load during the lifetime of the considered PP. However, oil price in the world market is highly volatile, therefore it is required to study further the economic feasibility of the construction of new generation capacities to utilize the retort gas from the point of view of the profitability of the whole energy complex.

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Investments in the shale oil industry under risk and uncertainty

***Abstract**. This paper considers investments in the Estonian shale oil industry, analysing the economic reasonability of the construction of new oil production capacities on the example of a possible new shale oil plant in the Enefit Energiatootmine, the largest energy complex in Estonia. To estimate the profitability of the investments into the project, the methods of the Net Present Value and the Internal Rate of Return were used. Also, the scenario analysis was applied to assess the impact of uncertainty in the further development of the global oil market on the return on the investments.*

Streszczenie.** IW artykule oceniono możliwości wykorzystania złóż palia łupkowgo wydobywanego w Estonii. Do tej oceny użyto takich narzedzi jak Net Present Value I Internal Rate of Return. Uwzględniono także niepewność ogólnego rynku paliw. **Inwestowanie w paliwa łupkowe – ryzyko I niepewności

Keywords: shale oil industry, investments profitability evaluation, scenario analysis, break-even analysis.
Słowa kluczowe: paliwa łupkowe, paliwa łupkowe w energetyce.

Introduction

In the light of European energy policy that intends to limit CO_2 emissions substantially and to promote energy production from renewable energy sources, the emission-intensive power industry in the EU countries faces more and more challenges. One of such countries is Estonia, where 79% of electricity is produced presently from fossil oil shale [1]. Due to the rapid growth of the price of CO_2 emission allowances and increasing competition on the wholesale electricity market caused by Nordic renewable power producers, the old generation units of Estonian condensing oil shale power plants become non-competitive. According to the study in [2], even use of new power generation technologies is economically unreasonable if electricity is produced from oil shale only rather than from fuel mix.

Some countries, the power industry of which is based on the utilization of fossil fuels, tend to modernize existing generation units and implement new power technologies with a high level of efficiency to make the industry more competitive and compliant with the requirements of EU energy legislation [3]. Estonia has another alternative way to keep its oil shale-based power industry – production of shale oil. New generation of oil plants enables production of shale oil, as production of electricity and retort gas. The retort gas, in its turn, is utilized in the power plants located close to the oil plants, which reduces their fuel costs and CO_2 costs. Thus, the production of shale oil maximizes the added value of used oil shale.

Due to the rise of oil and fuel prices along with the growth of energy use around the world in the period from 1999 to 2008, Estonian shale oil producers realized the full business potential of the branch and shifted their focus on the development of oil shale retorting technology and on the construction of new oil plants. However, under the circumstances of economic crisis in 2008 and the world oil market price drop in 2014-2015, the plans had to be revised.

Currently, three Estonian companies are producing shale oil: Enefit Energiatootmine AS, VKG Oil AS and Kiviõli Keemiatööstuse OÜ. In 2016, the total volume of their oil production reached a level of 852,000 tons [4]. At present, the shale oil producers' decisions are targeted to further expansion of fuel production and construction of new capacities. The aim of this paper is to analyse the profitability of investments into the construction of a new shale oil plant under oil market risk and uncertainty. Therefore, different scenarios for the further development of the global oil market were considered.

Expansion of shale oil production capacities

The economic analysis of the project of launch of new oil production capacities will be based on the example of a new shale oil plant construction for Enefit Energiatootmine AS. Presently, it is the owner of the largest energy complex in Estonia, which consists of two condensing oil shale power plants with the total net installed capacity of 1,629 MW_{el} and two oil plants with the total capacity to produce up to 477,000 tons of shale oil per year. The oil plants are based on the Enefit technology that applies a horizontal cylindrical retort, where the shale ash is used as a solid heat carrier. The dried oil shale is mixed with the hot ash carrier, and it is pyrolyzed in the reactor at 500°C [5]. The first oil plant is equipped with the Enefit140 technology, and it has two units. Each unit enables processing up to 140 tons of oil shale per hour. The maximum production capacity of the plant is 220,000 tons of liquid fuel and 60 million Nm^3 of retort gas per year [6].

The second oil plant is based on the Enefit280, improved Enefit technology. The primary modification is replacement of a semi-coke furnace with a circulating fluidized bed (CFB) combustion furnace. The improved technology also incorporates fluid bed ash cooler and waste heat boiler commonly used in coal-fired boilers to convert the waste heat to steam for power generation. The technology allows complete combustion of carbonaceous residue. It has short retorting time and improved energy efficiency thanks to maximum utilization of waste heat [5]. The process diagram of the Enefit280 technology is presented in Fig. 1.

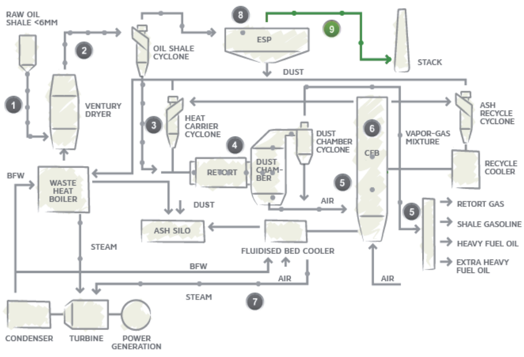

Fig.1. Process diagram of the Enefit280 oil shale retorting technology [7]

The Enefit280 plant can process up to 280 tons of oil shale per hour. It has the capacity to produce up to 257,000 tons of shale oil, 75 million Nm^3 of retort gas and 280 GWh of electricity per year [6, 8].

According to the Strategic Action Plan 2016-2020, a new shale oil plant based on the Enefit280 technology will be built by Enefit Energiatootmine in the future. The timing of the investment decision depends on the market situation and the intention of the owner to extend the combined production of oil, electricity and gas [9]. However, as it has been notified by the company, no large-scale investments are planned until 2020 because of company's large loan load. Therefore, to analyse the economic feasibility of the launch of new oil production capacities, it is assumed that shale oil plant construction will not start before 2021. As the construction is completed in three years, the plant will be taken into operation in 2024. Taking into account that the design lifetime of the current Enefit280 oil plant is 30 years, the new plant is supposed to be operated until 2054.

Investments profitability evaluation criteria

To analyse the economic feasibility of the construction of a new shale oil plant, the profitability of the project investments was evaluated employing the Net Present Value (NPV) and the Internal Rate of Return (IRR) criteria, the most reliable and widely used investments evaluation criteria. The NPV shows the present value of an investment by the discounted sum of all cash flows received from the project. The formula for the NPV can be expressed as:

$$NPV = \sum_{t=J+1}^{T} \frac{C_t}{(1+r)^t} - \sum_{j=0}^{J} \frac{I_j}{(1+r)^j}, \tag{1}$$

where: t – time of the cash flow (operation period), j – time of the investment, T – total number of the project operation periods, J – total number of the project construction periods, r – discount rate, C_t – net cash flow at time t and I_j – investment at time j.

If the NPV criterion shows a negative value, the investments into the project will be unprofitable, as the net cash flows received from the project will also be negative. If the NPV is positive, the project may be accepted, as investors will receive a return on the investments. However, at decision-making on the basis of the NPV, investors should take into account the weighted average cost of capital, which at best is only an estimate. If the discount rate used in the calculation of the NPV turns out to be smaller than the actual cost of capital, the project will prove unprofitable despite the previously calculated positive NPV.

The IRR shows the efficiency of the project and measures the internal earning rate of an investment. That rate often used in capital budgeting makes the NPV of all cash flows from a particular project equal to zero. If the IRR of a new project exceeds a company's required rate of return, that project is desirable. If the IRR falls below this rate, the project should be rejected.

The NPV and the IRR criteria were calculated for each oil market development scenario and for two discount rates – 5% and 10%.

Scenario analysis

The global oil market is very volatile; therefore, to analyse the expansion of shale oil production capacities under oil market uncertainty, scenario analysis was applied. The price of shale oil tends to follow the price of heavy fuel oil with 1% sulphur content (heavy fuel oil 1%) traded in the market of Northwest Europe. The price dynamics of heavy fuel oil 1% market, in turn, strongly correlates with price movements in the crude oil market that can be seen in Fig. 2 [10, 11].

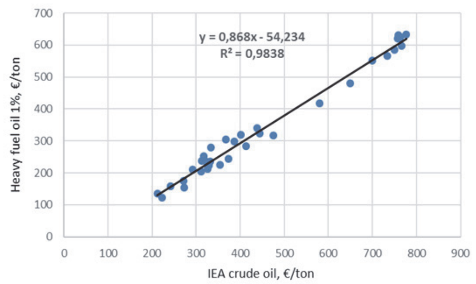

Fig.2. Correlation between average monthly prices of heavy fuel oil 1% and crude oil[1]

Therefore, the scenarios of the development of heavy fuel oil 1% market are based on the scenarios for crude oil market provided by the International Energy Agency (IEA), one of the most credible and competent source. The New Policies Scenario (NPS), the IEA central scenario, reflects both existing energy policies and an assessment of the results likely to stem from the implementation of announced intentions and plans of the governments to develop their energy sectors. The Current Policies Scenario (CPS) is based only on those policies that are in place as of mid-2017; this scenario for the global energy system is a benchmark against which the impact of "new" policies can be measured. The Sustainable Development Scenario (SDS) sets out a pathway to achieve the key energy-related components of the United Nations Sustainable Development agenda: universal access to modern energy by 2030; urgent action to tackle climate change (in line with the Paris Agreement); and measures to improve poor air quality [12].

Table 1. Crude oil price and EU CO_2 price assumptions by scenario

Real terms (€2016)	NPS		CPS		SDS	
	2025	2040	2025	2040	2025	2040
IEA crude oil, €/barrel	75	100	88	123	65	58
IEA crude oil, €/ton[2]	550	735	642	901	477	424
EU CO_2, €/ton[3]	23	43	20	36	57	126

[1] Observed data cover the period 2014 - 2016.

[2,3] Data are presented in euro per ton for the purpose of convenience to compare them with other data given in the paper.

Along with projection of oil prices, the scenarios present the forecast of CO_2 allowance prices that was also used in the analysis of the project. IEA assumptions for crude oil import price as well as for CO_2 price in the EU are shown by scenario in Table 1 [12].

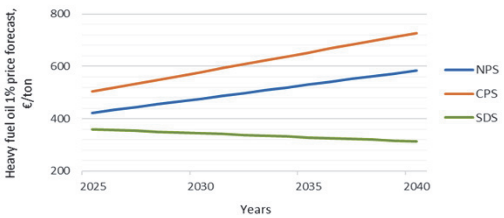

Fig.3. Price forecast for heavy fuel oil 1% by scenario

The price forecast for heavy fuel oil 1% under each scenario was based on IEA crude oil price projection by applying the regression equation presented in Fig.2. The results of the forecast were used for the calculation of the revenue received from the sale of shale oil under each scenario and are shown in Fig. 3.

Break-even analysis

Break-even analysis determines how low an income variable can fall, or how high a cost variable can rise, before the project breaks even at a NPV of zero**Błąd! Nie można odnaleźć źródła odwołania.**. Since production costs generally are fairly predictable, the real concern for investors from the point of view of possibility of losing money is the level of sales revenue [13].

The oil plant project has quite determinable sales volume, therefore the major contributor to revenue uncertainty is uncertainty over the unit selling price. Break-even analysis allows us to determine the selling price, at which the project NPV is just zero.

The general formula for the calculation of the NPV is expressed in equation (1), where C_t, the net cash flow at time t, represents the difference between the cash inflow C_{In_t} and the cash outflow C_{Out_t} at the time t. The cash inflow C_{In_t}, in turn, consists of the revenue received from the sales of project production and the cash outflow C_{Out_t} includes project variable and fixed costs. The revenue of the shale oil plant consists of sales of shale oil and electricity, since retort gas is considered as a free product for electricity generation in the power plants of the energy complex. This is because retort gas is a by-product to be utilized to provide continued shale oil production. Additionally, it is not used in other industries except power production. Assuming that the fuel produced in the oil plant during the operation period t is sold at the same period, equation (1) for the calculation of the NPV of the oil plant project may be expressed as:

$$(2) \quad NPV = \sum_{t=J+1}^{T} \frac{(Q_{Oil_t} {*} P_{Oil_t} + Q_{El_t} {*} P_{El_t}) - V_t(Q_{Oil_t} + Q_{El_t} + Q_{RG_t}) - F_t}{(1+r)^t} - \sum_{j=0}^{J} \frac{I_j}{(1+r)^j},$$

where: t – time of the cash flow (operation period), j – time of the investment, T – total number of the project operation periods, J – total number of the project construction periods, r – discount rate, Q_{Oil_t} – volume of shale oil produced at time t, P_{Oil_t} – selling price of one unit of shale oil at time t, Q_{El_t} – volume of electricity produced at time t, P_{El_t} – selling price of one unit of electricity at time t, Q_{RG_t} – volume of retort gas produced at time t, V_t – variable cost of one unit of the oil plant production at time t, F_t – fixed cost at time t and I_j – investment at time j.

As electricity is produced in the shale oil plant in small volume, the main source of revenue for the oil plant project is sales of shale oil. Therefore, the major contributor to revenue uncertainty is uncertainty over the selling price of the unit of shale oil. To determine the oil price at which the project NPV is just zero, it is required to find the break-even selling price of shale oil P^*_{Oil}. This price may be determined by substituting P^*_{Oil} for P_{Oil_t} in equation (2), setting NPV equal to 0, and solving for P^*_{Oil}. Thus, the break-even selling price of shale oil P^*_{Oil} can be calculated by:

$$(3) \quad P^*_{Oil} = \frac{\sum_{j=0}^{J} \frac{I_j}{(1+r)^j} - \sum_{t=J+1}^{T} \frac{Q_{El_t} {*} P_{El_t}}{(1+r)^t} + \sum_{t=J+1}^{T} \frac{V_t(Q_{Oil_t} + Q_{El_t} + Q_{RG_t}) + F_t}{(1+r)^t}}{\sum_{t=J+1}^{T} \frac{Q_{Oil_t}}{(1+r)^t}}.$$

The break-even analysis assumes that the price P^*_{Oil} is constant through the whole life of the project. The project will have a positive NPV if the forecasted market price exceeds this “cut-off” price. If the decision-makers know that this ”cut-off” price is likely to be reached, then they may decide not to proceed with the project.

The break-even price P^*_{Oil} was calculated for each oil market development scenario and for two discount rates – 5% and 10%.

Data and basic assumptions

To define the NPV and the IRR of the investments of a new shale oil plant, the cash flows received from the project during its lifetime must be calculated. Therefore, some basic assumptions were made to estimate the future revenue and costs of the plant.

As was mentioned above, the revenue will be received from the sale of shale oil and electricity. As return on the investments into the oil plant mainly depends on the revenue received from the sale of shale oil, three different scenarios for further oil market development discussed above are assumed to define the revenue for each case. Since the oil price projection is available until 2040, while the price forecast for fuel oil is needed until 2054, it is supposed that the trend of oil market development will remain unchanged in the future. To estimate the cash inflows from electricity sale, electricity price forecast for the Estonian price area of Nord Pool was used because according to an assumption, electricity produced in the oil plant will be sold on the Nordic power exchange.

To estimate the annual production volume of the oil plant, it is assumed that the oil plant meets European emission standards and, as a result, can operate at full load during its lifetime. Therefore, the data on the maximum annual production of the Enefit280 plant shown in Table 2 were used to calculate the revenue of the new plant, as it is of the same type as those of the Enefit280.

The main production costs for the shale oil plant consist of oil shale purchase costs, environmental costs and operation and maintenance (O&M) costs. The assessment of cash outflows caused by the purchase of oil shale is based on the annual primary fuel consumption and its price growth in the future. Oil shale price projection, in turn, is made on the basis of the price forecast for the major components of oil shale production costs, such as raw materials, electricity, oil shale extraction charge, environmental charges and payroll expenses. According to the Estonian Environmental Charges Act, from 1st of July 2015, oil shale extraction charge rate depends on the price of heavy fuel oil 1% [14]. Therefore, the forecast of the extraction charge was made for each scenario of the fuel oil market development, assuming that the principles of the calculation of the oil shale extraction charge rate will remain unchanged in the future.

The environmental costs of the oil plant include the charge for surface water use as cooling water, the charge for disposal of oil shale ash and the charge for the emission of pollutants, such as CO_2, SO_2, NO_x and fly ash, into the ambient air. As was mentioned above, to calculate CO_2 costs of the plant, IEA forecast of CO_2 allowance price for EU presented by scenario was used [12]. Since the CO_2 price projection is available until 2040, the CO_2 market trends are supposed to remain the same until 2054 when the project will be terminated. Other environmental costs were calculated using the natural resource and pollution charge rates set until the end of 2017 in the Environmental Charges Act of the Republic of Estonia [14]. The growth of the charge rates in the future was estimated on the basis of the projection of the average annual rate of inflation in Estonia presented by the Ministry of Finance [15]. The specific amounts of cooling water, oil shale ash and emissions of the Enefit280 were used to calculate the environmental costs of the new shale oil plant, since the type of the considered oil plant is the same as that of the Enefit280. These data were provided by Enefit Energiatootmine.

To calculate O&M costs, the payroll expenses of the Enefit280 were used, as they account for approximately 50% of the total O&M costs of the oil plant. To estimate the growth of the costs during the project lifetime, the forecast of the average annual rate of inflation was used [15].

To define the investments into the construction of the new plant, investments of the Enefit280 were recalculated for the first year of its construction, using the historical data on the consumer price index in Estonia and the forecast of this indicator [15, 16, 17].

Table 2. General information about a new shale oil plant

Parameter	Value
Investment costs, million euros	304
Construction time, years	3
Design lifetime, years	30
Oil shale processing capacity, tons per hour	280
Installed electrical capacity, MW	35
Annual consumption of oil shale at the maximum capacity, million tons	2.26
Maximum annual production of shale oil, thousand tons	257
Maximum annual production of retort gas, million m^3	75
Maximum annual production of electricity, GWh	280

Information regarding construction time, design lifetime, consumption of oil shale and production capacity for the new oil plan is also gathered on the basis of corresponding data for the Enefit280. General information about the construction project is presented in Table 2 [6, 7, 8, 16].

Results of the investments profitability study

To assess the profitability of the Estonian shale oil industry in the future, the economic feasibility of the construction of new oil production capacities was analysed taking into account the possible scenarios for price dynamics in the global oil market. The analysis of the investments was made by employing the NPV and the IRR methods. The results of the calculation of the NPV and the IRR for each scenario are shown in Table 3.

As can be seen in Table 3, the construction project of a new shale oil plant has the highest NPV and the IRR under the CPS. It means that investments into the shale oil industry will be most profitable if the developments within the global energy system follow an assumption that the implementation of some existing commitments would be sluggish and only the lower level of new policies and measures would be attained in the future. This scenario projects the largest growth of crude oil prices in the global market and the lowest prices of CO_2 allowances in the EU, which provides the highest return on investments into the shale oil production sector in comparison with the NPS and the SDS.

Table 3. Results of the calculation of the project evaluation criteria by scenario

Scenario	Discount rate r, %	NPV, million euros	IRR, %
NPS	5	358	13
	10	77	
CPS	5	699	18
	10	251	
SDS	5	-870	-
	10	-496	

The NPS reflects the policies and measures that are already established as new declared policy intentions. If the energy sectors are developed by their governments according to this scenario, the future energy system will provide quite favourable environment for the expansion of liquid fuel production and for the launch of new capacities to produce shale oil. However, as for the considered project, decision-makers should take into account that the weighted average cost of capital must be lower than 13% to provide the positive NPV for the project under the NPS.

Under the SDS, the construction of new oil production capacities is economically unreasonable, showing strongly negative NPV. It means that investments into the shale oil industry will be totally unprofitable if the SDS relied on the key energy-related aspects of the United Nations Sustainable Development Goals is realized. According to the scenario, extremely high prices of CO_2 allowances in the EU are projected that drastically increase environmental costs for this emission-intensive power industry, making it unfeasible from the economic point of view. The growth of the share of environmental costs from the total operating costs of the shale oil plant can be clearly seen in Fig. 4.

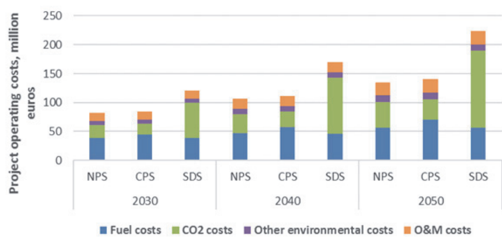

Fig.4. Operating costs of a new shale oil plant by scenario

The results of the calculation of project's NPV were confirmed by the results of the project break-even analysis presented in Table 4.

Table 4. Results of the break-even analysis of the project by scenario

Scenario	Discount rate r, %	Break-even price P^*_{Oil}, €/barrel	Break-even price P^*_{Oil}, €/ton
NPS	5	55	405
	10	60	438
CPS	5	57	417
	10	61	447
SDS	5	82	603
	10	83	608

As can be seen in Fig. 3 and in Table 4, the forecasted market price of heavy fuel oil 1% exceeds the "cut-off" selling price of the project only under the NPS and the CPS. It means that investments into the shale oil industry will have a positive NPV if the further development of the energy sectors follows the pathway according to one of these two scenarios.

Conclusion

The aim of this paper was to study the profitability of investments in the Estonian shale oil industry, taking into account different scenarios of further developments in the global oil market. The focus of the analysis was on the economic reasonability of the construction of a new shale oil plant for Enefit Energiatootmine's energy complex, the largest energy complex in Estonia.

The results of the analysis showed that the project of the construction of a new shale oil plant is most profitable under the CPS implementation, which assumes that only the lower level of existing commitments and new political intentions would be attained in the future. This scenario expects very high crude oil prices in the global market and, as a result, high prices of heavy fuel oil 1%, which follow the shale oil price that provides the large return on investments into the project. The low growth of CO_2 allowance prices in the EU that was projected according to the scenario also promotes the profitability of the project.

If the development of the global energy system follows the NPS, which assumes the realization of new declared policies and measures, the investment environment in the shale oil industry becomes less attractive, providing quite moderate IRR for the project. Meanwhile, the NPS is the central scenario of the IEA that is supposed to have a high probability of implementation.

The analysis of investments in the Estonian shale oil industry under risk and uncertainty was focused on the evaluation of the investments profitability under different scenarios for the further development of the oil and CO_2 allowance markets, and on the estimation of the break-even price of the unit of shale oil for each scenario. Although the changes in the price dynamics of oil and CO_2 allowances are ones of the most important factors that influence on return on investments in the shale oil industry, there are a lot of other potential risks that may occur during the implementation and operation phases of a project. Since there are long-term and investment-intensive projects in this branch, such factors as possible fluctuations in capital expenditures, changes in energy policy and legislation should be considered before making any investment decision. Thus, it may be concluded that the risks associated with shale oil production projects should be carefully weighted and included in a discount rate for reliable estimation of the project's profitability to provide return on investments after the project launch.

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