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EFFECT OF INNOVATION IN UNCONVENTIONAL OIL INDUSTRY: CASE OF ESTONIA AND CANADA

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Abstract. *The objective of this paper is to compare the economic effects of innovation in an unconventional oil industry, based on Estonian and Canadian experiences with oil shale and oil sands, respectively. Both unconventional oil resources face similar challenges and need to resolve these through innovation. Based on empirical evidence, this paper concludes that innovation is a key mechanism of increasing efficiencies and triggering investments. Investments themselves, due to their nature, represent the best measure of the economic effect of cumulative innovation in the unconventional hydrocarbons industry.*

The paper proceeds in the following manner. First, we will briefly review the relevant literature and identify definitions of innovation and its impact on economic growth. In the second part, we will point out the effects of innovation in the energy industry on economic growth, and the uniqueness of energy innovation. Then we will present data on public and private R&D expenditure in the oil sands industry in Canada, as well as evidence of the results and economic effect comparatively to the R&D effort in Estonian oil shale industry. Lastly, we will draw conclusions by discussing our findings. The results are relevant to indicate R&D expenditure necessary to sustain investments and economic effects of developing unconventional hydrocarbon mineral resources.

Keywords: *unconventional oil industry, national energy policy, industrial policy, innovation policy.*

Part 1. Innovation and its economic impact

The creation and application of new knowledge and technology is a major contributor to overall human wellbeing and economic growth and has thus

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become on the agenda of different policies [1]. For example, the European Union (EU) has set a strategy for improving the conditions for research and development and is pursuing this goal through increasing combined public and private investment in R&D to 3% of GDP [2].

Endogenous growth models, which estimate that growth has been driven by technological change through R&D, have been known for some time [3, 4]. The difference in R&D between countries can explain some of the gap between their growth levels and economic development stages [5, 6]. Endogenous growth models link knowledge accumulation through education, training and research to innovation or new technology, which in turn influences overall output. Therefore, setting the agenda for innovation through increased R&D investments seems straightforward.

However, the notion of innovation remains ambiguous in some contexts. In a survey of literature on innovation, Edison et al. [7] found over 40 definitions. The most widely used definition develops on the core ideas of Joseph Schumpeter [8] and is now used in the Community Innovation Survey by Eurostat as defined on p. 46 in the Oslo Manual: "Innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations" [9]. The key is implementation, i.e. introduction to the market, which distinguishes innovation from invention.

Besides R&D, the local or national innovation system influences innovative activity [10, 11]. The innovation system theory itself describes the institutional environment and its synergy, how well the different features are interlinked and supporting each other. These features can be framework institutions such as the financial legislative environment, attitude towards entrepreneurship or taxes, but also educational environment for human capital, infrastructure, business support, financial services or business standards, and governing political environment [12]. There are complementarities involved for the innovating agent even within some of these links, such as the university-industry R&D [13].

Still, one of the most widely accepted policy instruments is dealing directly with R&D expenditure [14]. Seminal works from Arrow [15] and Nelson [16] have pointed out the need for public support for entrepreneurs due to the lack of demand certainty and return on investments leading to suboptimal levels of investment and, hence, societal loss. This gap between private and social returns is the principal argument for government intervention in innovative activity. A straightforward linear model in case of which R&D turns into inventions, products and sales dates from the 1940s [17]. Much later, studies have indeed estimated that social returns to R&D have been greater than private returns, effectively arguing for R&D subsidies to generate spillovers [18, 19].

Studies have measured R&D and its effects, rate of return and spillovers since the late 1950s. Hall et al. [20] conclude that on the whole the R&D rate of return in developed economies is positive and is most likely between 20 and 30%. Measuring social returns is more complex. These spillovers can be in the form of knowledge or rent [19]. This means that knowledge generated from an R&D project can be used by other firms for their own purposes. Hall et al. [20] point out four spillover sources for a firm: a) other firms in the same sector, b) firms in other industries, c) public research laboratories and universities, and d) firms, laboratories, universities and governments in other countries. There is no universal rate of return of R&D spillovers; measurements across countries, sectors and time have high variability, implying that R&D spillover rate of return is different in different locations, but it should be noted that it is almost always positive. Parsons and Phillips [21] estimate that the Canadian median R&D domestic external rate of return is 56%. The investigators have not found evidence for a similarly constructed study in Estonia.

Part 2. Innovation in energy industry and its economic effects

The energy sector has an abundance of multinational enterprises and R&D spillovers should be measured on an international level. Innovations have a cumulative nature and incremental innovations tend to diffuse over time, turning into widespread technological innovations [22]. To illustrate, it took several decades from the 1860s to 1920s to have wide use of petrol as transportation fuel [23]. In the energy sector, commercialization of innovations is costly, therefore R&D is linked also with demonstration. This happens at the early stage of technical development, before commercialization, and it may never be followed by actual deployment [24]. Another element of innovation, learning-by-doing, applies to all stages of innovative activity, from the early stages of R&D to reducing costs in production through experience.

Bettencourt et al. [25] studied global energy patents from 1970 to 2009 in conjunction with R&D investments. They found that market-driven investments and public R&D complemented each other in creating technological development. They added that according to their modelling, the effect of these investments persisted over the long term, supporting the ideas of tacit knowledge and absorptive capacity.

Innovation in the energy sector has led to higher supply (making difficult resources economically accessible), lower costs and prices to consumer, lower environmental impact, higher safety (especially relevant in nuclear energy) and security of supply. On a large scale, these elements cannot be captured as private rent, but accrue benefit to the wider society, justifying public funding of related R&D. Each innovation can also lead to major wealth transfer effect and macroeconomic benefits, for example, utilization of tight oil and gas in the USA has led to a substantial decrease of oil imports and increased oil supply, as well as oil industry, transport and other professional services within the USA [26].

It has been estimated that the decline of technological innovations in the US energy sector between the 1970s and 1990s was mostly influenced by reduction of investment in government funded R&D [27, 28]. Margolis and Kammen [28] conclude that this disinvestment hampers the US ability to provide long-term energy security and deal appropriately with global environmental sustainability. Indeed, by the 2000s US oil imports had grown to levels that started to be considered a strategic security problem [29].

Significant volatility and inconsistency in funding can also have significant adverse effects and in the USA there have been substantial funding shifts from year to year for both large research fields (e.g., coal, nuclear power) and smaller research areas (e.g., carbon capture and sequestration, nuclear safety) [30]. It is also telling that the US energy industry invests only 0.42% of its revenue in research. In contrast, the pharmaceutical industry puts 20.5% of sales into R&D, and the aerospace and defense industry spends 11.5%. At US federal level 60% of R&D spending goes on defense, about 25% on health and the energy sector receives just 2% [31].

Part 3. Data on public and private R&D expenditure in the oil sands industry in Canada and evidence of the results and economic effect comparatively to Estonian oil shale industry

Canadian oil sands are either loose sands or partially consolidated sandstones containing a naturally occurring mixture of sand, clay, and water, saturated with a dense and extremely viscous form of petroleum technically referred to as bitumen. Athabasca-Wabiskaw oil sands in Canadian province of Alberta cover over 140 000 square kilometers and contain approximately 1.75 Tbbl (280 × 109 m^3) of crude bitumen. About 10% of the oil in place, or 173 Gbbl (27.5 × 109 m^3), is estimated by the Government of Alberta to be recoverable at current prices, using current technology. This recoverable quantity amounts to 75% of total North American petroleum reserves. Only about 20% of the recoverable oil contained in the 3% of the oil sands area can be produced by surface mining, so the remaining 80% will have to be produced using in-situ wells.

Already in 2014, 58% of the oil sands volumes were produced using in situ methods. Alberta will continue to rely to an ever increasing extent on in situ production in the future, as 80% of the province's proven bitumen reserves are too deep underground to recover using mining methods [32]. In situ or Steam Assisted Gravity Drainage (SAGD) was indeed developed in 1984–87 by the publicly funded Alberta Oil Sands Technology and Research Authority (AOSTRA) Underground Test Facility [33]. This technology has led to several billions of dollars in investment and annual revenue from production facilities. The multiplier effect of this particular innovation is in the order of multiple thousands. AOSTRA has been converted to Alberta

Innovates – Energy and Environment Solutions (AI-EES) which has set itself equally high targets for 2030 [34]:

- 50% reduction in GHG intensity;
- 20% of new in situ production partially upgraded; and
- 15% production from challenging reservoirs.

In 2015 it invested $17.5 million in 89 projects aligned to meet these targets. The value of these projects over their lifetime is $312.2 million, of this AI-EES will have provided $82.9 million, leading to an approximate leverage factor of 2.8. AI-EES supports the development of innovation capacity by investing $7.7 million at universities for two Centres, 12 Chairs, and 36 individual researches [35]. In 2015 it completed the Oil Sands Competitiveness Study.

The major focus of AI-EES is National Partial Upgrading Program. Started as the "next generation upgrading" initiative over 10 years ago, AI-EES realized that given the market conditions, full upgrading of the heavy bitumen was uneconomical for the near future. Therefore the Competitiveness Study quickly evolved into an exercise to quantify the partial upgrading opportunities for Alberta's bitumen. In this three-stage study, AI-EES worked with industry and governments of Alberta, Saskatchewan and Canada to understand: a) the refining value of Western Canadian bitumen in different regions; b) selection of partial upgrading technologies with most potential; c) the potential value back to the producer for a partially upgraded product in Western Canada. The program has funded two technologies for development and commercialization. Results of the Competitiveness Study show a partial upgraded crude product could net an additional $5 to 10 billion in annual gross revenue for Western Canadian producers by 2035 [36].

Also Alberta Innovates Technology Futures funds in large-scale oil sands related R&D. Its 2015–2016 budget was approximately $150 million, while in 2014, about $50 million came from the private sector and $100 million from the public sector [37]. One example of research focus can be Materials and Reliability in Oil Sands (MARIOS) program initiated in 2009 to reduce maintenance cost and unscheduled shutdowns. It is estimated that the oil sands sector spends over $3 billion on maintenance every year and forfeits another $5 to $7 billion in lost revenue due to both scheduled and unscheduled shutdowns. As a result, there is a strong incentive for oil companies and their supply chain to improve the run-life and reliability of components, equipment and processes in their operations.

At national level, Sustainable Development Technology Canada (SDTC) has been leading Canada's investment in energy, agriculture, forestry, mining, transportation and energy efficiency industry since 2000. In 2015, SDTC approved 32 projects for funding by it, bringing the total number of SDTC funded projects to 320 with 928 million dollars allocated. Out of the 320 supported projects, 73 were commercialized as of 2015. SDTC's support has enabled these companies to raise estimated $2 billion follow-on financing. This has in total created 9200 jobs direct and indirectly. Estimated

Annual Revenues generated by SDTC funded companies in the market at the end of 2015 were $1.4 billion. Of the 141 SDTC funded projects completed by December 2015, a total of 73 have climate change mitigation benefits and together these technologies have realized an annual GHG emissions reduction of approximately 6.3 megatons CO_2e in 2015 [38].

Having been established in 2005 in partnership with Imperial Oil, the University of Alberta Institute for Oil Sands Innovation (IOSI) is the leading oil sands centre in basic research to find breakthrough technologies for oil sands processing. To date, IOSI has received funding amounting to $51 million from public and private funds and supports more than 160 top researchers from around the world. In 2015 they published 21 academic technical papers and during 2007–2015 carried out 18 study projects on cleaning and partial upgrading, 16 on extraction, and 5 on tailings process fundamentals [39].

The key for the innovation to have economic impact is its penetration into wider use. While innovation by individual company creates competitive advantage, sharing and wider penetration of technology can actually be limited. Oil sands producers have overcome this problem by a mutual technology sharing platform called Canada Oil Sands Innovation Alliance. It consists of 13 member oil sands companies that have shared 814 distinct individually developed technologies and innovations that cost almost $1.3 billion to develop [40]. These innovative solutions reduce greenhouse gases, minimize impact on land, reduce water use and improve tailings management.

In 2015–16, when oil prices were below 50 USD/bbl, the focus of innovation shifted to cost reduction and revenue maximization. Findlay [41] has found in his study "The Future of the Canadian Oil Sands" that the challenge for current and proposed mining and steam-assisted gravity drainage projects is to develop technological improvements to a magnitude that meet, and ideally exceed, the detriment of decreasingly prolific rock. There certainly is hope with novel solutions like in situ tech-solvent extraction, Electro-Thermal Dynamic Stripping Process and microwave heating. Producers have their own large R&D budgets – Canadian Natural Resources Limited leads the pack with 450 million CAD spent in 2014, while Suncor, Syncrude, Imperial Oil and Cenovus each spend roughly 100–200 million CAD annually.

Research groups such as CERA, IHS, and the Conference Board of Canada, among others, have developed in-depth calculations to demonstrate the economic value added by oil sands development. Though the estimates vary, annual GDP impact hovers around CAD$100 billion and supported more than 478 000 direct, indirect and induced Canadian jobs in 2012 (3% of all jobs in the country), though this did drop in 2015 with the depressed prices for crude and reduced capital investment. This amounts to approximately 5% of Canada's GDP. In 2012, oil sands production directly accounted for almost one-third of Alberta provincial government revenues and 6% of federal revenues [42].

In the first decade of the 21st century alone, $117 billion oil sands-related investment has taken place. The Conference Board of Canada's analysis shows that $1 billion in oil sands investment generates 2200 person years employment direct effect, 2700 supply chain and 1400 in income effect person years employment in Alberta [43]. Additional employment will take place also in British Columbia due to transportation and refining of products and Ontario due to supply chain and income effects in the most populous Canadian province. The Figure illustrates the extension of supply chain effect to various sectors of the economy.

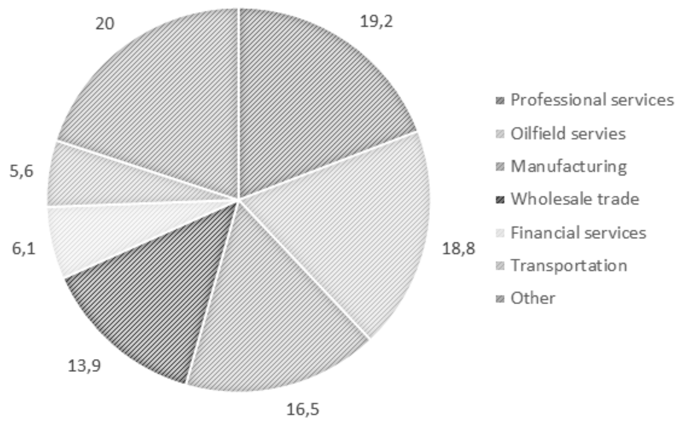

Figure. Sectors experiencing supply chain effects (share of employment, %) [43].

Canadian public research and development financing totaled 9.5 billion CAD in 2013, yet its total R&D funding has fallen from 2.09% of GDP in 2000 to 1.61% in 2014 [44]. The total government energy sector research funding was estimated to be $941.9 million for 2014–15 (CAD 439 million federal and CAD 503 million provincial and state-owned enterprises), down from CAD 1.34 billion in 2013–14, according to the International Energy Agency (IEA). IEA suggests increasing public R&D funding for energy projects [45].

However, Canadian R&D funding ecosystem is very robust, providing support in all stages from basic research to applied, demonstration, commercialization and market development. Each of those is crucial to have economic impact from R&D. Canada has every reason to fund energy research as it has substantial conventional coal, gas and oil reserves, and the country has developed its own original nuclear power reactor design on heavy water called CANDU. Canada also possesses substantial hydropower and renewable energy potential, but technically and environmentally the most challenging and with the highest economic potential are large Alberta oil sand deposits.

A technically and environmentally similar unconventional hydrocarbon resource is Estonian oil shale that has been mined and utilized mainly for oil production and power generation since 1916. After Estonia re-established its independence in 1991, there have taken place structural and proprietary changes in the oil shale industry as well and today, it consists of one state-owned and two private companies with a combined turnover of 933 million euros in 2014 and with 15 million tons of oil shale mined annually. Since the increase of oil prices in 2005–2007, the companies have invested substantially in research and development to work out new techniques to reduce environmental impact, increase energy efficiency, and process effectively fine oil shale, which accounts for the majority of material produced by mining.

In 2012–2013, the oil shale sector R&D expenditure was more than 20% of total Estonian R&D expenditure. It needs to be noted that substantial innovative technology investments (such as part of cost of Enefit 260 and Petroter oil shale processing units) were listed as R&D expenditure. Based on the Estonian Patent Office's data, Estonian oil shale research accounts for approximately 9% of all patents and 6% of all useful models issued.

In 2012–2013, the largest Estonian oil shale company, Eesti Energia AS, in partnership with a Finnish Outotec company, invested in a technology development company Enefit Outotec Technology. Through its subsidiaries Eesti Energia invested in the feasibility studies of Utah and Jordanian oil shale projects. By the spring of 2017, the latter project will be finalized as a 2.1 billion USD agreement in place on building a 554 MW oil shale-fuelled power plant.

The economic impact of oil shale industry in Estonia is quite relevant in terms of GDP impact, net exports, government revenue, and as employer. Indirectly, the industry offers employment to 17 372 people [46]. In 2014, the net government revenue from the oil shale industry was 174 million euros [47].

Estonian public funding of energy related applied R&D has been significantly driven by the European Union's Structural Funds and criteria, with the EU funds financing amounting to about 50% of total funding. Started in 2010, three major programs are: 1) Support of Energy Technology Research and Development managed by Enterprise Estonia (EAS) and Archimedes (7.1 million euros), 2) Smart Specialization (26 million euros), and 3) Support of Strategic R&D managed by the Estonian Research Council (28 million euros, with the EU funding of 23.7 million euros). The former program was totally focused on energy technology and 40% of financing was used for oil shale related research. The latter two programs include some elements of oil shale and energy related research, but these account for no more than 10–20% of the total program. In the case of EU funded programs there have been set rules for program management and financing, which enables no proactive research agenda direction by a program managing organization.

An exception is the Environmental Investment Centre that funds studies and research related to energy and environment from environmental fee revenues, albeit the share of R&D is still smaller than in the abovementioned programs. In the case of the Support of Energy Technology Research and Development program, there was prepared an interim report containing several recommendations for improvement [48], but no final report on the results and economic effect of the studies was presented. Thus, the economic impact, the leverage factor of the studies, is to a great extent unreported. According to oil shale field professionals, the practical effectiveness of the program funded research is yet low.

In its 2013 report about Estonian energy sector, the International Energy Agency concludes that the country's pertinent policy agenda has been set in a number of documents such as various development plans until 2020, and recommends, among other things, "to continue to promote research and development of oil shale technologies" [49]. According to the European Commission, Estonia with Germany are the only two EU member states that are not using any R&D tax incentives in any form [50]. In general, with 1.4% of GDP, Estonia's R&D funding is lower than the EU's average (2.1%) or the official goal set in the Estonian Entrepreneuship Growth Strategy 2020 (2%) [51] or the 3.2% of GDP of the leading peer group countries, Sweden and Finland equally [52].

According to the IEA, in 2014 the share of energy related research in total R&D in its member countries was on average 4%, being far down from the 11% of 1981. With 12% Japan was the leading country in 2014. In the EU member states, the equivalent is much lower, averaging 3%, with Finland's figure being, for example, 9% and Estonia's 1.6%. The average ratio of public energy research, development and demonstration (RD&D) budget per unit of GDP is 0.4 (RD&D budgets per thousand units of GDP) and varies greatly, ranging from less than 0.1 in Portugal and Spain to over 1 per thousand in Finland. Among fossil fuel producers, the respective US figure is 0.35, Canada's 0.7, Norway's 0.86 and Poland's 0.23. Estonia with 0.12 strikes the eye as a country with one of the lowest public energy RD&D budgets per unit of GDP, spending almost 6 times less than Canada (see Table 1) [53].

Table 2 presents comparative economic output data for power and oil production in Estonia. Comparative data for Canadian oil sands and Estonian oil shale industries are presented in Tables 3 and 4, with an obvious difference in magnitude. However, several clarifications are necessary: only one-third of oil shale mined in Estonia is processed for oil production, the rest is used for power generation. There is a substantial economic difference between the two applications summarized in Table 2, the main difference being in that the value generated per unit of raw material is more than twice higher, and labor intensity is higher as well [54].

Table. 1. R&D spending of selected International Energy Agency member countries in 2014

Member country	Energy related research in total R&D funding, %	Public energy RD&D budget per 1000 units of GDP
Finland	9.0	1.0
Canada	7.2	0.7
Estonia	1.6	0.12
IEA average	4.0	0.4

Table 2. Comparative economic output of power and oil production from oil shale in Estonia [54]

Economic indicator	Power generation	Oil production
Energy efficiency, %	35–40	65–78
Capital intensity, mil eur per mil t oil shale processed a year	265 (Auvere CFB)	87 (Petroter I)
Labour intensity, persons per mil t oil shale processed a year	25	125
Secondary outputs	Heat	Power, heat

Table 3. Summary of economic impacts of unconventional hydrocarbons production in Canada and Estonia for the year 2014 [55-57]

Economic indicator	Canada (oil sands)	Estonia (oil shale)
Oil production, bbl/d	2300000	22000 (60000)*
Sales revenue, mil eur	40000	450/933**
Investment, mil eur	22700	263
Public energy R&D, mil eur	650	3.2
Private R&D, mil eur	606	5.2
Direct employment	22340	6683
Indirect employment	478000	17372
Government revenue, mil eur	4800	174

* – 60000 bbl/d would be oil production if all mined oil shale would be processed to oil. It is necessary to calculate relative impact in Table 4 because data on oil shale industry R&D, investment, sales, employment, etc., is not distributed between oil and power generation.

** – includes produced heat and power revenue.

Also evident from Table 4 is, on a relative scale, the lower investment ratio that can be explained by a very active investment period of Canadian oil sands of the period and presence of legacy capacity in Estonian oil shale. The difference in R&D effort is evident in both the private and public sectors. Substantially larger direct employment of oil shale compared to oil sands is an expected result. Maybe less expected result of comparison is the larger direct government revenue from oil shale. Explanation for the latter is a 100% government ownership and dividend revenues from the largest oil shale company, Eesti Energia.

Table 4. Comparison of economic impacts of unconventional hydrocarbons production in Canada and Estonia per millions of barrels produced for the year 2014

Economic indicator	Canada (oil sands)	Estonia (oil shale)
Sales revenue	47.6	42.4
Investment	27.0	12.0
Public energy R&D	0.8	0.15
Private R&D	0.7	0.24
Direct employment	26.6	303.0
Indirect employment	569.4	789.0
Government revenue	5.7	7.9

Part 4. Innovation led energy industry investments as a proxy for economic effect

Multiplier effect captures the indirect and induced effects of a particular economic activity. However, estimating multiplier effects is not precise and their variability in time is significant given commodity price, employment, cost structure changes, etc. Generated by research & development, the size of investment is a measure in the capital-intensive energy industry, which remains constant after the investment is made, and has to create economic activity, employment and revenue to earn back the investment and return. Investments themselves, due to a well-defined investment decision based on the best available information, the need to earn back the invested capital over time as well as the need to employ a large amount of direct and indirect economic inputs over time to ensure economic production, represent the best measure of the economic effect of cumulative innovation in the energy industry. Thus, we suggest using investment as a best proxy to measure the economic effect of research and development.

In 2009–2015 Estonian oil shale companies spent a total of 25.9 million euros on research and development, which contributed to the 434.6 million euros' worth innovation led investments in physical capital in the whole value chain of oil shale mining and processing by three companies (see Table 5). Thus during that period the multiplier factor of research and development was 13.2. In the same period, the total investment by company was as follows: 428.8 million euros for Viru Keemia Grupp, 60 million euros for Kiviõli Keemiatööstus and 1100 million euros for Eesti Energia, totalling 1589 million euros.

Oil shale industry in future has high potential for further value added gains through research and development. Most relevant is the aspect that shale oil trades as heavy fuel oil with 1% at substantial 30% price discount compared to crude oil dated Brent. This is due to the unique chemical composition of shale oil having high sulphur, arsenic, nitrogen and oxygen contents and some ash content, which makes its processing impossible even if blended with other crude oils in regular refineries. However, it is entirely possible and likely that with research and development upgrading of shale oil to higher value oil products is possible, increasing the value of the product 30–40% and necessitating investments of several million euros in the upgrading of processing units. This partial upgrading opportunity of Estonian oil shale is very similar in nature to that of Canadian heavy bitumen.

Table 5. R&D expenditure and innovation led investments by Estonian oil shale companies (based on company data gathered by the authors)

Year	2009	2010	2011	2012	2013	2014	2015
Total R&D expenditure	440460	8791 51	2014245	3405938	4339255	5196411	1792327
R&D led investments	38965817	27028862	2857538	118801217	109131259	90261953	47589366

Another potential is processing of the pyrolysis gases to separate out more valuable ethylene (C_2H_4), ethane (C_2H_6), butene (C_4H_8) and other gases that comprise 31% of total pyrolysis gases of Enefit and Petroter technologies and are of higher value as chemicals than as burning fuel [58]. There is also potential to increase mining efficiency with long-wall mining under study by Eesti Energia, increase utilization of beneficiation waste limestone, oil shale ash and low-pressure heat. Even the production units already in exploitation are subject to intensive innovation. For example, Petroter III oil shale processing unit, which was built in 2013–2015 after Petroter II unit (built in 2012–2014), underwent about 60 minor and major innovations [59].

All suggested measures pertaining oil shale related research will require substantial public and private effort relatively similar to Canadian R&D expenditure given in Table 4. Then, provided suitable price environment as well, it is likely to lead to further investments and these in turn to related economic impact.

Part 5. Discussion and conclusions

Compared to other policy options for unconventional hydrocarbons development and economic impact, such as taxation, mineral resource allocation, environmental regulation, R&D has the highest economic effect. It is only due to innovation that we are able to utilize more sophisticated energy sources than human labor. After ratification of the Paris climate agreement, reduction of greenhouse gas emissions in unconventional hydrocarbons production and carbon capture demand a high level of attention. This cannot be resolved through other means than innovative processes developed through constant trial and error together with healthy scientific and commercial competition methods.

Canadian oil sands industry has a multitude of major and minor companies developing innovative solutions to maintain competitive edge and improve bottom line to their investors. Almost all companies are competing for mineral rights concessions and for investors at the stock exchange. Alberta Province and Canadian government consider it justified to support the industry research and development effort on a large scale.

Estonian oil shale industry is fairly segmented with a major state-owned company and two smaller private companies. None are stock exchange listed and competition for resource is limited to a legal battle in court and with the permitting authority. In addition, their budget for R&D is much more limited. However, the relative size of oil shale industry for Estonia is just as significant as that of oil sands industry for Canada. Given the legal status of minerals (they are state-owned), it is justified that Estonian government is more engaged in R&D effort to ensure the economic and environmental sustainability of the mineral sector.

Considering the competitive and environmental challenges of the oil shale industry and other energy sector needs, the authors suggest that compared with the 2014 levels, Estonian government should increase its energy related research and expenditure 7 to 8 times and private businesses 3 to 4 times. Also, given the relative low effectiveness of the 2010–2015 Support of Energy Technology Research and Development program and based on Canadian example, skilled innovation management institution or professionals are necessary for the government to have R&D funding that has practical value added to the industry as well as economic effect. It is also relevant that research programs with the corresponding mechanism are continuous, as innovation is not a project, but a non-linear process of trial and error. Externalities justify Estonian government also to act to facilitate innovation cooperation similarly to Canada Oil Sands Innovation Alliance's.

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