DOCTORAL THESIS

ESG Risk Assessment Model for the Exploitation of Phosphorite and Related Resources in Estonia

Andrus Paat

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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 submitted for doctoral or equivalent academic degree.

Andrus Paat

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signature

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ESG riskihindamise mudel fosforiidi ja sellega seotud ressursside kasutamiseks Eestis

ANDRUS PAAT

Contents

List of papers

The list of author's papers, on the basis of which the thesis has been prepared:

I **Paat, A**., Veetil, S. K. P., Karu, V., & Hitch, M. (2021). Evaluating the potential of Estonia as European REE recycling capital via an environmental social governance risks assessment model. *The Extractive Industries and Society*, *8*(4), 100767. https://doi.org/10.1016/j.exis.2020.07.001. (ETIS 1.1).

II **Paat, A**., Roosalu, T., Karu, V., & Hitch, M. (2021). Important environmental social governance risks in potential phosphorite mining in Estonia. *The Extractive Industries and Society*, *8*(3), 100911. https://doi.org/10.1016/j.exis.2021.100911. (ETIS 1.1).

III **Paat, A**., Majak, J., Karu, V., & Hitch, M. (2024). Fuzzy analytical hierarchy process based environmental, social and governance risks assessment for the future phosphorite mining in Estonia. *The Extractive Industries and Society*, *17*, 101438. https://doi.org/10.1016/j.exis.2024.101438. (ETIS 1.1).

Author’s contribution to the papers

Contribution to the papers in this thesis are:

I The author is the corresponding author of the paper. The author designed the study, conducted the literature review, developed the research methodology, including data collection and analysis, and interpreted the results. I also drafted the manuscript and revised the text to ensure coherence in the final version.

II The author is the corresponding author of the paper. The author conceived and designed the study, carried out the literature review, contributed to developing the research methodology, including an overview and selection of ESG frameworks, defined the most significant ESG risks, prepared the questionnaire, organised data collection, and analysed and interpreted the data. Finally, the manuscript was drafted based on the data results, and the text and coherence were reviewed and revised in the final version.

III The author is the corresponding author of the paper. The author conceived and designed the study, conducted the literature review, contributed to developing the research methodology, collected data, and interpreted the results. The author also drafted the manuscript and reviewed and revised the text to ensure coherence in the final version.

Abbreviations

(C)RM	(Critical) Raw material
CSR	Corporate social responsibility
CSRD	Corporate Sustainability Reporting Directive
EIA	Environmental impact assessment
ESG	Environmental, social and governance
ESRS	EU Sustainability Reporting Standards
EoL	End-of-Life
EU	European Union
FAHP	Fuzzy analytical hierarchy process
GDP	Gross domestic product
GHG	Greenhouse gas
GRI	Global Reporting Initiative
IFC	International Finance Corporation
MCDM	Multicriteria decision-making methods
OECD	Organisation for Economic Co-operation and Development
OS	Oil shale
P	Phosphorus
P_2O_5	Phosphorus pentoxide
PEA	Prospective exploration areas
R&D	Research and development
SASB	Sustainable Accounting Standard Board
SLO	Social license to operate

Introduction

Resilience and sustainability have quickly become core concepts for the raw material (RM) industry, where non-financial variables besides financial ones have now looked almost as relevant for the industry's long-term success. Phosphorite and rare earth elements (REE) are essential resources and drivers of development in today's global economy. Phosphorite is indispensable in food production, and most REEs are key RMs in applications that contribute to the transition to a low-carbon economy. Both resources occur within the Estonian bedrock. This thesis examines the potential use of these two resources in Estonia via the lens of environmental, social and governance (ESG) risks.

Estonian phosphate rocks, or shelly phosphorites, are sandstones with biogenic brachiopod detritus, which may include up to 35% P_2O_5. In the productive phosphorite seams, the content of P_2O_5 is in the range of 4–20% (Raukas & Teedumäe, 1997). Estonia's phosphate rock reserves have been historically estimated to be 2.954 billion tons (see Figure 2 in Section 1.4). Phosphorite was mined on a small scale in Estonia from the 1920s until 1991 to produce a low-quality phosphorite meal, mainly for domestic use. In the 1980s, a large-scale expansion of phosphorite mining was planned. However, it faced powerful public opposition, mainly due to environmental concerns and a probable large influx of labour from the other soviet states. Consequently, public acceptance was never gained, and public protest helped to bring about the suspension of phosphorite mining in Estonia (Reinsalu, 2016).

Besides phosphorus (P), some shelly phosphorite deposits in Estonia are enriched in REE, thus making REE a potential co- or by-product of phosphorite mining. REE content in phosphorite and phosphatic detritus has been reported to reach up to 2000 ppm, but this requires further assessment (Soesoo, 2021). Additionally, the extraction and processing of P in an environmentally friendly manner could be challenging (Tõnsuaadu et al., 2020). Since 2018, the Geological Survey of Estonia has led novel exploration studies using modern methods and internationally recognised standards to determine the potential exploitability of phosphate rock and REEs. In the coming years, the geological framework, technological and environmental conditions of phosphorite mining, and its economic potential should be clarified. This will allow for the following decisions regarding the use of these reserves.

Although mineral exploration is ongoing, it is possible to anticipate the questions that will arise once studies indicate the feasibility of further developing this industry. These questions revolve around the choice of economically viable mining and processing technologies, the environmental risks that arise, and potential social tensions and confrontations. An ESG risk assessment model may be a suitable tool to answer these. The novelty of this thesis lies in applying the ESG perspective, recognising that resource exploitation, if pursued, must be conducted sustainably, balancing environmental, social, and economic considerations.

Recently, growing attention has been paid to whether companies contribute to or harm the public good, making corporate responsibility increasingly relevant each year. For a company to remain competitive in the markets, it must be sustainable and responsible in the long term. Therefore, understanding responsibility in a company's activities creates more value because an accountable company can generate greater trust and improve relations with stakeholders, such as customers, investors or employees. The origins of organisations collecting data on social and environmental issues related to companies' activities date back to the late 1970s, often called corporate social responsibility (CSR). However, ESG is increasingly used today and is a broader concept than CSR (Gillan et al., 2021).

Today, many companies have started to prepare sustainability or environmental, social and governance reports, which are non-financial information about the company's impacts. This allows the company to be more responsible and transparent about the risks and opportunities it faces, thereby attracting investors to invest in entities with greater sustainability. In ESG reporting, ‘E’ stands for how the company's activities affect the environment and what they do to minimise these impacts. ‘S’ addresses the company’s interaction with social dimensions such as employees, suppliers, local community, etc., and ‘G’ monitors the company’s transparency, diversity and independence, e.g., shareholder rights, anti-corruption, tax transparency, etc (Maybee et al., 2023). ESG is closely linked to well-known sustainability initiatives, such as the United Nations Sustainable Development Goals and the European Union's `Green Deal` initiative.

In the context of this thesis, however, the following must be emphasised from an ESG perspective:

i. Although the thesis examines the attitudes of different stakeholders regarding ESG risks from the perspective of a hypothetical company, mining and processing phosphorite and related resources, the subject of the ESG assessment is the country, not the company. This is because there is no production of phosphorite and REEs in Estonia today, and the significant ESG risks identified in the papers would first help the state, as a developer, to better and more consciously plan the development of this industry. If significant ESG risks are known, the state can plan risk mitigation measures more specifically before starting a potentially significant development.
ii. The risks identified in this work concern actions or inactions with potential impacts, rather than opportunities. However, there has been a growing trend in recent times to also map ESG opportunities in business (Khalid et al., 2021).

The main research question addressed in the thesis is: **Can an ESG risk assessment model be used to identify significant risks that the state can consider when planning the future deployment of Estonia's mineral resources – phosphorite and rare earth elements?** More specifically, the following research questions (RQs) are addressed:

i. RQ1: Can a country-comparative ESG risk assessment model be applied to help decide on the development location as an investment environment based on sustainability principles?
ii. RQ2: What are the most significant ESG risks from the perspective of different stakeholders that affect the deployment of phosphorite and related resources in Estonia?

The main arguments have been developed in three original papers, which focus on the applicability of the ESG assessment model in cross-country comparisons and identifying significant ESG risks in the Estonian context. **The first paper (I)** investigates the feasibility of establishing an REE recycling industry in Estonia for the European Union (EU), using an ESG risk evaluation model. The goal is to assess and compare the performance of countries—Estonia, Belgium, and the EU average across selected ESG indicators relevant to the potential establishment of an REE recycling industry. Applying the ESG assessment model to compare countries is a novel approach. The aim was to test whether comparing countries based on sustainability principles is applicable and, in principle, useful for selecting development locations. **The second paper (II)** focuses on Estonians' perceptions of potential phosphorite extraction and processing across four stakeholder groups. It identified the key ESG risks they would want addressed if such production were to take place. **The third paper (III)** extended this work by involving mining experts in Estonia, as possible `resource developers`, who assessed the same ESG risks. The aim was to understand the essential ESG risks in phosphorite mining and processing from the perspective of mining experts and to identify similarities and differences compared to the broader stakeholder groups. The results from papers II and III help clarify which risks should receive greater attention in further development.

The thesis is structured as follows. After the introduction, Chapter 1 provides an overview of the phosphorite and REE reserves, their applications and their importance for the EU, and the current state of exploration in Estonia. It also outlines the strengths and weaknesses of ESG reporting and provides an overview of well-known reporting standards. Chapter 2 describes the data and methodology used in the papers. Chapters 3 and 4 summarise the results of the research questions and discuss key findings along with their potential applicability. The final chapter presents concluding remarks, acknowledges limitations and suggests avenues for future research.

1 Literature overview

1.1 Non-financial risks for the development of the mining and CRM industry

To combat climate change and environmental degradation, there is a global trend today to transition to a greener economy, i.e., a low-carbon economy. In practice, this means emphasising renewable energy sources such as wind turbines and solar panels and the development of battery-based electric cars and energy storage technologies, which require essential minerals (Lehtimäki et al., 2024). Unfortunately, this trend has created a particular paradox - the `transition` agendas require even more extraction. Yet, mining is already considered a decisive driver of the current ecological and climate crisis (Buu-Sao et al., 2024). Therefore, the need for sustainable mining practices and technology is increasing, and the sector is under increasing pressure to adjust to the changing economic landscape and seize new possibilities presented by the green economy (An et al., 2023).

Achieving sustainable mining requires constantly searching for a balance between economic growth, environmental protection, and social capital. Mining is an activity with a significant ecological footprint, which can be mitigated, for example, through measures such as increasing the recycling and reuse of residues from the mining process stages (Lim & Alorro, 2021) and implementing effective mining water treatment technologies (Matebese et al., 2024). Practice has shown that using renewable energy sources in the extractive industry can reduce high energy consumption (Onifade et al., 2024). The list of challenges also includes the depletion risk of desirable minerals, as the most accessible deposits are being exhausted, and over-extraction may lead to resource scarcity. Mining in more challenging deposits, where meeting high environmental standards increases costs, leads to higher operating expenses, and elevated raw material prices can harm profitability (Vikström, 2020). Adding to this geopolitical risks, such as the armed conflict in Ukraine, which has led to policy changes and disruptions in the European energy market, further increases the extractive industry's vulnerability to economic challenges (Brodny & Tutak, 2022).

The third dimension of challenges for the mining industry is potential social conflicts, the root causes of which are often weak legislation and low trust in the government, as well as insufficient dialogue between the miner and the local community, where the latter feel that their concerns are not being addressed (Jijelava & Vanclay, 2017). The conceptual meaning of the term `social license to operate` (SLO) remains ambiguous in the scientific literature, organisations often struggle to understand how to achieve it (Stuart et al., 2023). In the mining sector, SLO is commonly used to indicate the level of public approval of mining projects (Parsons et al., 2014). It is generally accepted that legitimacy, credibility and trust are prerequisites for forming SLO, which means building trust in governance and the fairness of procedures and mining companies (Zhang et al., 2018). In the European context, this has been studied by Lesser et al. (2021) who notes that, compared to the rest of the world, the European SLO process is characterised by greater trust in governing bodies and their role in prioritising the interests of citizens.

Unsurprisingly, industry representatives themselves identify the challenges described above as top risks (Ernst & Young, 2024). As such, the challenges facing the extractive industry are multifaceted, requiring a holistic approach to develop balanced solutions across environmental, social, and economic dimensions. This also applies to the possible use of phosphorite and related mineral resources in Estonia.

1.2 Review of phosphorus sources, applications and importance for the EU

According to the OECD (2015) over 80% of phosphorus is used in fertiliser production, around 10% in animal feed, and the rest in other applications like cleaners, detergents, food and beverages, metal surface and water treatment, flame-retardants, etc. Phosphate rock resources occur mainly as sedimentary marine phosphorites. The largest sedimentary deposits are found in northern Africa, the Middle East, China, the US, and other major extraction regions. The world's production was around 230 million tons in 2022, and total world resources are estimated to be more than 300 billion tons, see also Figure 1 (U.S. Geological Survey, 2024). Phosphorus scarcity is connected to food production. Global phosphorus demand is claimed to surpass global supply after 2040, mainly due to world population growth, but this can also happen later if phosphorus recycling rates are significantly improved (Nedelciu et al., 2020). Although aspects of phosphorus economic scarcity have also been questioned (Scholz & Wellmer, 2013; Ulrich & Frossard, 2014), the uneven geographical distribution of phosphate rock reserves is known. The regions where the balance is negative, i.e., total demand exceeds supply, also include Europe. However, it is predicted that the most considerable dependency on phosphate imports lies in the future in regions that experience high population growth rates, such as Latin America and the Caribbean, South Asia, and Sub-Saharan Africa.

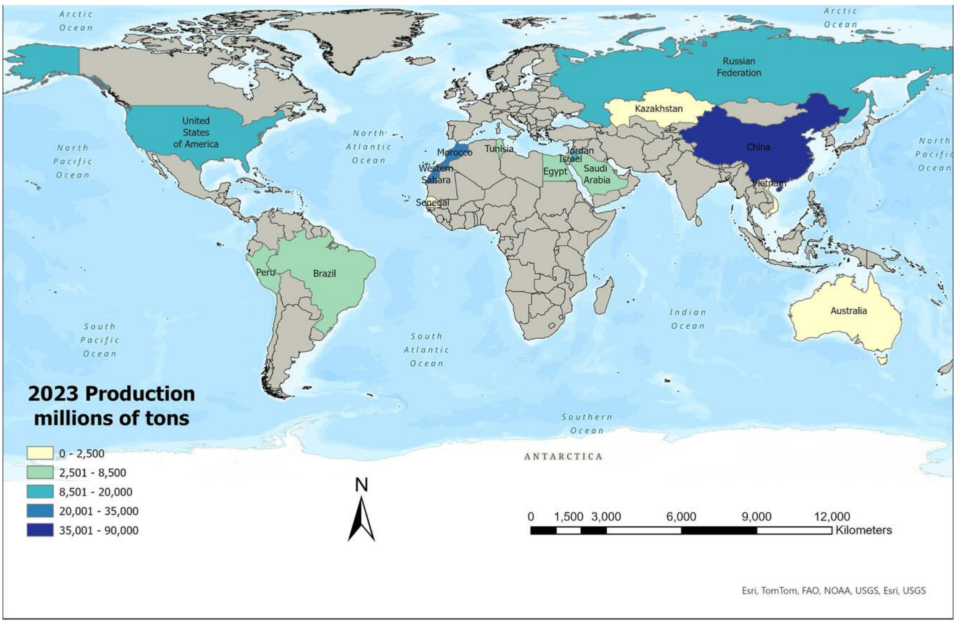

Figure 1. Map of 15 countries with the highest phosphate rock mine production in 2023. Source: U.S. Geological Survey (2024).

Besides economic scarcity, there might also be environmental implications in phosphorus production and dissemination, such as eutrophication and the generation of toxic and radioactive waste. The former arises mainly from agricultural runoff and, to a lesser extent, untreated wastewater inputs (Scholz & Wellmer, 2015). The latter arises during phosphate fertiliser production, where the manufacture of phosphoric acid generates phosphogypsum as a by-product. Phosphogypsum is kept in tailing ponds or waste piles, posing a potential risk of heavy metal and radionuclide release into the surrounding environment (De Boer et al., 2019). However, the potential impact depends strongly on-site management, containment practices, and mitigation measures. Other rock types that commonly occur with phosphorites and make up waste rocks in respective mines, e.g., black shale, might add to the environmental risk of phosphorite mining due to the content of heavy metals and self-combustion tendency. With population growth, the demand for food and fertilisers is expected to rise, driving further mining and processing of phosphate rock. State-of-the-art processing technologies are essential to minimise both the volume and hazard of phosphogypsum, while robust prevention measures are needed to limit phosphorus runoff and enhance recycling from phosphogypsum tailings (Awad et al., 2024). Improving efficiency and recycling can lessen phosphorus losses and reliance on imports, thereby mitigating associated environmental, social, and economic impacts.

Due to their high supply risk and economic importance, the EU has declared that phosphate rock and elemental phosphorus obtained from phosphate rock are critical raw materials (Fahimi et al., 2024). Currently, China is the dominant producer of these resources; however, Morocco possesses an overwhelming majority of the known phosphate reserves on Earth (Walan et al., 2014). Demand is driven by fertilisers used in agriculture and strongly connected with global population growth. It can be expected that the international market will become increasingly dependent on Morocco as reserves in other countries will be depleted in the next 30 years (Daneshgar et al., 2018). Currently, within the EU, only one operating mine in Finland extracts phosphate rock; therefore, import reliance is around 90% for the EU (Van Dijk et al., 2016). Since Morocco will lead phosphate rock production in the long term, this poses a geopolitical risk. This can partially be mitigated by increasing primary phosphate rock production in Europe or recycling from secondary sources, e.g., wastewater and animal manure (European Commission, 2023). Although Estonia has the largest phosphate rock reserves in Europe, these reserves have been estimated by historical studies and require novel re-assessment. There are other potentially large-scale P extraction projects in the region. Recently, the extraction potential of P and REEs from iron ore mines in northern Sweden has been considered, and the construction of a demonstration plant will begin to verify and develop the process for extracting P and REEs. If the trials are successful, their extraction as a by-product of iron ore mining will be realistic, presumably by 2030 (LKAB, 2025).

1.3 Review of REE sources, applications and importance for the EU

According to the International Union of Pure and Applied Chemistry, REEs can be divided into light and heavy groups (Pathapati et al., 2023). In the Earth's crust, REEs do not occur as individual elements but are found together in various ores or accessory minerals as trace or minor constituents. Though REEs are found in a wide range of minerals, including silicates, carbonates, oxides, and phosphates, their enrichment above crustal average concentrations and ore formation is limited to specific geological environments. The principal economic sources of REE minerals are bastnäsite, monazite, loparite, and the lateritic ion-adsorption clays (Dostal, 2017). According to the U.S. Geological Survey

(2024), global REE production was estimated to be 300,000 tons of rare earth oxide equivalent in 2022, with most processing and refining carried out in China, the United States, Australia, and Myanmar. In recent years, there has been an increase in REE mining outside of China due to adjustments in the international REE market (Chen et al., 2024). The REEs are commonly used in magnetic, electronic, optical, aerospace, biomedicine, information sciences, energy storage, and catalytic applications (Goodenough et al., 2018; Swain & Mishra, 2019). According to Binnemans et al. (2013), REEs such as neodymium (Nd), europium (Eu), terbium (Tb), dysprosium (Dy) and yttrium (Y) are identified as more critical because of their relatively low abundance in the Earth's crust and substantial use in many applications. Nd and Dy are essential as they form the basis of NdFeB permanent magnets, which are crucial in electric vehicle traction motors and direct-drive wind turbine generators (Nkiawete & Vander Wal, 2025). The REE ore processing has led to environmental and health impacts like the release of dust and solutes containing toxic and radioactive metals, as well as processing chemicals, into the air and surrounding water bodies (Balaram, 2019). One of the ways to tackle the shortage of REEs in the future is to concentrate on their recycling possibilities. Although there are existing promising technologies to recover REEs from waste, according to Dutta et al. (2016) and Guyonnet et al. (2015), the challenges ahead are significant, mainly because of the insufficiency of End-of-Life (EoL) waste collection and dismantling infrastructure, the small REE content in the goods, and the non-cost-effectiveness of the individual REE extraction method (Jowitt et al., 2018). The REE recycling potential is more sensible in EoL products with higher REE content, such as permanent magnets and phosphorus lighting applications (Binnemans et al., 2015; Rollat et al., 2016). The environmental impact of REE recycling is, for example, related to the complexity of REE separation chemistry, specifically the separation and purification of individual REEs, which might require extensive use of different solvents (Binnemans et al., 2013). The potential environmental risks largely depend on the treatment technology, but the technological readiness level of such methods remains low, and comprehensive life cycle assessments are largely lacking.

Although there are many REE mineral deposits worldwide, production along the entire value chain (i.e., from mining to manufacturing and recycling) is heavily concentrated in China (Fernandez, 2017). The EU imports 100% of its REEs, and most individual REEs are imported from China. Therefore, the EU has named REEs as critical RMs for its economy due to significant dependence on China and its foreign policy (Van Gaalen & Slootweg, 2025). The latter has established export quotas for REEs, considerably influencing REE prices and making the REE market volatile. Although several initiatives have been reported in Europe and elsewhere to recover and recycle REEs from secondary materials, REE recycling is still very low, usually under 1%, especially in Europe, because of the lack of efficient collecting systems and prohibitive costs of building REE recycling capacities. Higher recycling input rates for europium, yttrium and terbium are reported only thanks to the recycling of fluorescent lamps (European Commission, 2023). There is no primary REE mine production in Europe, although a few efforts for the exploitation of REEs are taking place in some EU countries: Sweden (Norra Karr deposit), Norway (Fens field deposit) and Greenland (Kvanefjeld deposit). Still their exploitation is at a preliminary stage (i.e. feasibility study or earlier), and the primary REE ores and mid-products processing infrastructure outside of China could only handle very limited material volumes (Ilankoon et al., 2022). The lack of primary production of REE and the reduction of dependence on China can be addressed through diversified sourcing. Recently, the

European Commission adopted its first list of 13 Strategic Projects focused on strategic raw materials located outside the EU. Some of these projects aim to establish mutually beneficial partnerships for REE extraction and processing with host countries, thereby enhancing the EU's security of supply for REEs (European Commission, 2025b).

1.4 Status of phosphorite and REE exploration in Estonia

Estonia's unexploited phosphorite reserves are distributed across four regions, forming the Rakvere, Toolse, Aseri, and Tsitre deposits (Figure 2).

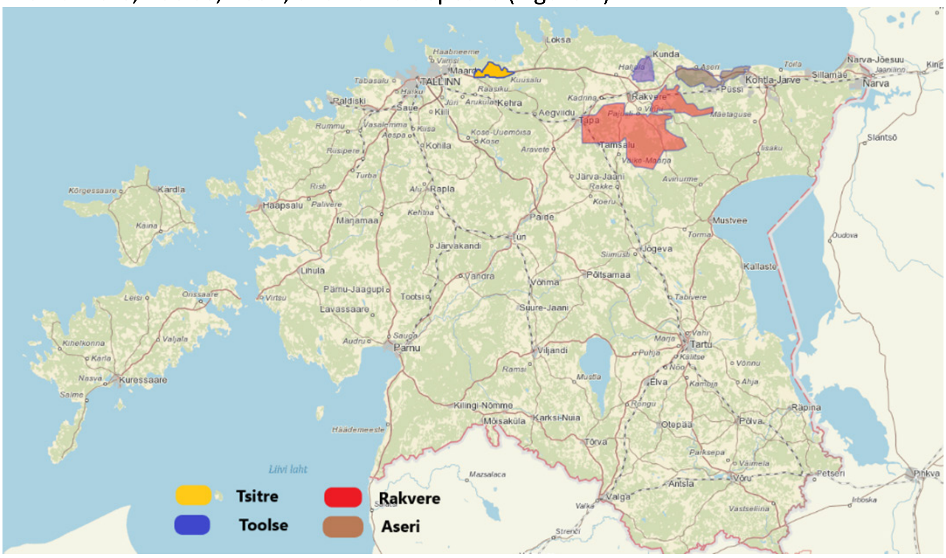

Figure 2. Phosphorite deposits of Estonia. Source: Paper II.

Between 2020 and 2023, several limited-scale studies were conducted to assess the preliminary development potential of phosphorite and its associated resources, including REE and vanadium. Joosu et al. (2023) focused on the distribution of phosphorite and the geotechnical and geochemical characteristics of the Aseri, Toolse, and Rakvere phosphorite deposits. Historical drill core data were digitised and modelled, with new drill holes added to validate the historical geochemical data and refine the geological model. The findings showed good agreement between the new and old data regarding phosphorus distribution. Additionally, this study, along with some others, examined the distribution of REEs, toxic elements, and CRMs, such as molybdenum and vanadium, in the black shale layer, which serves as an overburden for the phosphorite deposits. However, due to the thinness of the metalliferous black shale layer (<1.5 m) and the additional processing and environmental challenges associated with metal extraction, the future economic feasibility of exploitation of this resource remains uncertain. The REE concentrations in Toolse and Aseri phosphorite deposits were higher than in Rakvere. For both Toolse and Aseri deposits, a strong correlation was observed between P_2O_5 and REEs, suggesting that REEs are incorporated into the apatite structure and can be concentrated during ore beneficiation. Notably, the number of toxic elements in Estonian phosphorite was significantly lower than in other sedimentary phosphorite ores mined globally.

Joosu et al. (2022) analysed potential prospective exploration areas (PEAs) for further assessment. First, based on the size and quality of the geological reserves of phosphorite, three PEAs were identified within the Toolse and Rakvere deposits. For all of them, initial mining and enrichment costs were calculated for both surface and underground mining scenarios, and the impact of mining on groundwater was assessed. During the work, three additional areas were delineated in the neighbouring regions, with the primary criterion being a minimum share of private land, even if this required compromises on the size and quality of the reserves. The cost of mining and the hydrogeological impact were not calculated for additional areas. The study concluded that there are presumably fewer technological risks and social contradictions for phosphorite development in the expanded Aru-Lõuna area within the Toolse deposit, which largely overlaps with the existing Aru-Lõuna limestone quarry. The disadvantages of Aru-Lõuna are expected to be higher unit cost and a low amount of resources, about 4.8 Mt P_2O_5.

Between 2023 and 2025, studies are being conducted to gain a more detailed understanding of the technological valorisation potential of Estonian phosphorite (Eesti Geoloogiateenistus, (n.d.)). The aim is to identify the most effective extraction technology for phosphorus and evaluate the feasibility of recovering REE concentrates as by-products of phosphorite processing. These technological studies will also map potential environmental impacts, assess the economic outlook, and include pilot-scale testing of the most promising technologies. In addition, the area's hydrogeological model will be updated alongside baseline studies for groundwater conditions. No detailed investigations are currently planned for other exploration areas.

If the ongoing studies' results support phosphorite use, an initial decision on whether further development is justified is expected in 2026. If so, detailed follow-up studies will be needed, including a comprehensive geological survey, feasibility study, environmental impact assessment (EIA), and, if required, a socio-economic assessment of the selected area. The state's goal is to maximise the value of phosphorite and related minerals, and it may take another decade before a final decision on their extraction and processing is made (Kliimaministeerium, (n.d.)b). Work has already begun to establish the legislation's concession mechanism and principles of social benefit. The concession model would award mining rights through a competitive process based on state-defined criteria. These may include, for example, long-term socio-economic and environmental performance, added value creation, and post-closure land use. This means that society, especially the affected local community, would receive a fair and maximum possible return for extracting the phosphorite, revising the current revenue distribution frameworks, and developing a local benefit instrument for affected residents (Kliimaministeerium, (n.d.)a).

1.5 ESG reporting and standards

1.5.1 General status of ESG reporting

Today, the ESG ecosystem encompasses a vast array of data vendors (e.g., MSCI, Video-EIRIS, etc.) that offer a wide range of products, including overall rankings, issue-specific sub-ratings, company rankings, and tools that provide customised assessments of a company's ESG performance. Depending on the topic and geographic focus, data vendors collect the ESG information needed for rankings periodically, typically annually, and in various ways. They use company surveys, analyses of company documents such as sustainability reports, and interviews with employees and other stakeholders such as unions (Eccles & Stroehle, 2018).

Despite challenges with ESG reporting, studies by major accounting firms such as KPMG and PwC show that companies' ESG reporting has grown steadily over the years. It has become a part of everyday business practice for most of the largest companies and an important indicator for investors when making investment decisions based on disclosed ESG information published by companies (KPMG, 2022, 2024; PwC, 2021). Thus, the provision of ESG information as part of companies' activities is an increasing trend.

1.5.2 Strengths and weaknesses of ESG reporting

Recent years have seen extensive academic research on the strengths and weaknesses of ESG reporting. These have identified the following ESG benefits: a positive relationship between corporate sustainability indicators (e.g., factors of effective corporate governance) and financial performance, especially in the long-term (Friede et al., 2015); increased transparency, information accuracy, and investment efficiency through ESG disclosure (Ellili, 2022; Krueger et al., 2024); increased reputation, awareness, and loyalty (Sanchez-Planelles et al., 2020); and a better understanding of the company`s values by stakeholders, e.g., investors, shareholders (Janicka & Sajnóg, 2022; Zumente & Bistrova, 2021).

Although previous empirical studies suggest a positive impact of ESG reporting, some studies also provide a critical overview due to potential problems. The primary issue is the absence of a unified approach to interpreting ESG data, characterised by discrepancies in methods for calculating different ESG scores employed by data vendors and the lack of a benchmark for analysing ESG data (Agosto et al., 2023; Kotsantonis & Serafeim, 2019). Another problem is the abundance of ESG reporting standards or, rather, the absence of a globally recognised standard. Thus, reporting companies are pressured by various stakeholders to prepare reports using multiple systems, depending on group preferences and considering the many voluntary reporting structures and their voluntariness (Sulkowski & Jebe, 2022). In addition, the abundance of reporting standards and the complexity of ESG scoring methods affect their quality, thereby creating the risk of greenwashing – the deliberate disclosure of a company's positive environmental performance while failing to disclose adverse information (Lokuwaduge & De Silva, 2022).

1.5.3 Different reporting standards

As ESG data disclosure is increasing, various ESG reporting standards and guidelines have been developed. Some disclosure standards cover all three dimensions (i.e. environmental, social and governance), the best known of them GRI (Global Reporting Initiative), SASB (Sustainability Accounting Standard Board) and CSRD (Corporate Sustainability Reporting Directive). However, there are also several topic-specific reporting standards, such as the CDP (The Carbon Disclosure Project), which focuses on climate impact disclosure, or the WDI (The Workforce Disclosure Initiative), which focuses on workforce theme disclosures within companies and along the value chain. A distinction can also be made between management system standards (e.g., ISO standards) and even commodity-specific standards, such as the Responsible Jewellery Council (RJC) standard for the sustainable jewellery and watch industry. A separate group is also formed by stock exchange ESG reporting guidelines, which are used where local exchanges have set such requirements. The world of ESG reporting standards is diverse, but the most widely used in the market are GRI, SASB, and CSRD, the latter of which will become compulsory in Europe.

In this thesis, GRI and SASB disclosure standards are applied to develop an assessment framework. The CSRD has not been used because the EU Sustainability Reporting Standards (ESRS), created on a Directive basis, were not yet developed at the time the papers were written. It may be assumed that the ESRS standards—mandatory within the European Union—will apply to the company engaged in phosphorite mining and rare earth production in the context of sustainability assessment.

When comparing the GRI and ESRS disclosure standards, both standards have significant overlap, i.e. both standards help to identify the impact of a company in all three dimensions, thereby ensuring better transparency of the company in the eyes of stakeholders, including investors' interest in financing more sustainable companies. The most significant difference is that the ESRS standard clearly states the principle of double materiality assessment, which forces to conduct a more thorough impact, risk and opportunity analysis by assessing the effect that the company itself or the parties in its value chain have on the environment and people (impact materiality) and risks and opportunities that arise from sustainability matter that may affect the company's operations (financial materiality). GRI primarily shows the organisation's impacts that may become financially significant over time and are the basis for financial materiality judgments (Deloitte, 2022).

1.5.4 Usage of ESG standards in the EU

The CSRD Directive, which entered into force in 2023, has been applied since 2024 to large public-interest entities in the European Union with an average of more than 500 employees. From 2025, it will extend to all large companies that meet at least two of the following criteria for two consecutive years: 250 or more employees, net turnover exceeding 50 million euros, or total assets exceeding 25 million euros. From 2026, the reporting obligation will arise for the remaining listed companies (except micro-enterprises), as well as for small and non-complex credit institutions and, from 2028, for third-country companies with a net turnover in the European Union of more than 150 million if they have at least one subsidiary or branch in the European Union exceeding the threshold. The data must be submitted together with the company's annual report according to ESRS, and an independent auditor must verify the information provided. Moreover, the sustainability report must be in line with the EU taxonomy. The ESRS standards currently consist of 2 cross-sectoral standards that set out general requirements for preparing, presenting and disclosing sustainability information and 10 thematic standards in the environmental, social and governance areas. Sector-specific standards are also planned to be developed for 2026.

However, it must be emphasised that the European Commission has recently proposed measures to alleviate the ESG reporting burden, including the postponement and simplification of reporting requirements (will be mandatory only for large undertakings with more than 1000 employees and a turnover of over 50 million euros), as well as a review of the mandatories of some ESRS data points, a need for auditing according to the sustainability assurance standards, and considering to abandon the development of sector-specific reporting standards (European Commission, 2025a).

2 Data and methodology

The empirical findings of this thesis are based on case studies that address the research questions using quantitative and qualitative methods. Quantitative analysis includes data collection primarily from the Eurostat database (Paper I), the evaluation of questionnaire results (Paper II), and the fuzzy analytical hierarchy process (FAHP) method outcomes (Paper III). Qualitative data collection was employed in Paper II, utilising a non-probability sampling approach combined with quota and snowball sampling methods.

The first paper addresses RQ1 by examining whether the country's comparative ESG assessment model can be applied to selecting a development location based on sustainability principles. The ESG assessment method was chosen because of its capability to identify financially and responsibly successful companies, although in this case, the investigated subject is a 'country' instead of a 'company'. Hence, the methodology is based on a structured ESG indicator-driven assessment employing a comparative analytical framework. Environmental, social, and governance variables were operationalised through standardised indicators derived from established ESG reporting guidelines and populated primarily using harmonised datasets from Eurostat and international indices. The indicators have been chosen and modified in such a way that they characterise and express the capacity of the Estonian State to establish REE recycling management. Country-level performance was evaluated through cross-sectional comparison with a selected peer state, i.e Belgium, and EU aggregates to identify relative strengths, constraints, and systemic risks relevant to REE recycling deployment.

Papers II and III address RQ2, examining Estonians' perceptions of the potential extraction and processing of phosphorite among different stakeholder groups using the ESG risk assessment model. The aim was to identify significant environmental, social, and governance risks that stakeholders would consider relevant if such production were to occur in Estonia. Although both papers share this objective, they utilise different methodological approaches.

In Paper II, an online questionnaire was conducted among four stakeholder groups: the local community, the local business sector, policymakers, and environmental activists. These groups are considered the primary stakeholders most affected by the acceptance of phosphorite extraction and processing at the regional level. Empirical studies have shown that their perceptions often differ from those of resource developers (Mzembe & Downs, 2014; Viveros, 2016). Before the questionnaire, however, defining the relevant ESG risk-based questions in the Estonian context was necessary. The process began with a review of applicable ESG reporting frameworks, which resulted in the selection of three that the authors considered most suitable. These were the GRI, SASB and IFC (International Finance Corporation Performance Standards) reporting frameworks. Their comparison first identified 101 ESG risks, from which risks unlikely to materialise in Estonia were excluded, as there is a functioning legal framework and control mechanisms. For example, risks related to the use of child or forced labour were excluded. The first round of screening left 59 risks, which were, in turn, validated in the second round by a small group of experts (5 members in total) representing stakeholders. They were asked to assess which ESG risks they would further exclude so that, ideally, there would be 35-40 risks left to present to the four stakeholder groups. In the end, the questionnaire contained 40 questions and a final open question. The paper's authors considered this the maximum, so the respondents would be interested in answering the questionnaire. The respondents had to evaluate each question's importance on a Likert scale from 1 to 7, broken down as follows: 1 – not at all important; 2 – not important; 3 – rather not important; 4 – so and so; 5 – rather important; 6 – important; 7 - very important. Responding to the survey was anonymous. From a total of 40 questions, seven questions represented governance risks (questions 1 to 7), 20 questions represented environmental risks (questions 8 to 27), and 13 questions stood for social risks (questions 28 to 40).

In the case study, a non-probability sampling method was used to obtain preliminary conclusions and quota, and snowball sampling methods were applied in more detail. The former seeks to gain detailed knowledge of a specific phenomenon, i.e., ESG risks' importance to different stakeholders. For quota sampling, the authors set 120 responses (30 from each stakeholder) as a target, which, according to the authors' belief, is sufficient to draw preliminary conclusions about which ESG risks are most important for respondents from different stakeholders in phosphorite mining and processing. The latter, the snowball method, represents a technique where the first respondents lead on to the following respondents. For that, the authors first mapped potential organisations and people who redistributed the questionnaire in their networks. The questionnaire was conducted online in November 2020 using the Google Forms platform, and Microsoft Excel was used to analyse the results. In total, 134 responses were received, more than the original target of 120 responses. Although the intended target 30 responses per stakeholder group was not achieved, this limitation applied solely to environmental activists.

In Paper III, mining experts in Estonia, as possible ‘resource developers‘, assessed the same ESG risks. In the study, mining experts evaluated three ESG criteria and their associated indicators with the FAPH methodology, explicitly accounting for the inherent uncertainty in decision-makers' judgments. To overcome this, multicriteria decision-making methods (MCDM) are commonly used. Several MCDM methods have been used in various fields. An overview of popular MCDM methods and where they have been applied for problem-solving is given in Paper III. Among the MCDM methods, the FAHP method was utilised in the study because it is a broadly applied multi-criteria decision-making method to determine the weights of criteria and priorities of alternatives in a structured manner based on pairwise comparisons. As subjective judgments during comparison might be imprecise, fuzzy sets have been combined with AHP. This is called fuzzy AHP or FAHP (Liu et al., 2020; Vinodh et al., 2014). The AHP method has also been successfully applied in the mining industry, where a smaller set of experts, usually 9-15, had to give their judgment in problem-solving (Banda, 2019; Dong et al., 2018; Jiskani et al., 2021). Hence, it was considered that this method is also suitable for our eight-member mining expert group of decision-makers who filled a pairwise comparison matrix. The questionnaires were held via e-mail from March to April 2022. It is important to emphasise that when applying the FAHP method, the authors found it difficult to assess the 40 ESG risks. Therefore, to determine the importance of the ESG risks given to mining experts, similar ESG risks were grouped, leaving 29 ESG risks for assessment, i.e., 11 fewer than used in Paper II, where the importance of 40 ESG risks was assessed. However, no risks were eliminated to maintain the possibility of comparison.

3 Results

This chapter summarises the main results of this thesis, providing general findings from the ESG risks assessment model country comparison (RQ1) and the results of the important ESG risks assessment (RQ2).

3.1 RQ1: Can a country-comparative ESG risk assessment model be applied to help decide on the development location as an investment environment based on sustainability principles?

Since the aim was to assess Estonia’s suitability for establishing a REE recycling industry within the European context, a cross-country comparison was required. For this purpose, the authors selected ESG indicators that were considered appropriate. Notably, to the authors’ best knowledge, this was the first attempt to apply ESG indicators to assess a country’s performance in this context. Many indicators not included in the final selection were also considered during the selection stage, and it is possible that some relevant indicators that characterise the study subject were omitted in the process. Therefore, the selected sustainability indicators should not be viewed as definitive but rather as an initial attempt to determine whether ESG-based country comparisons serve as a tool for assessing a country’s suitability for investment. Risks were evaluated in Paper I in three dimensions: environmental, social and governance.

3.1.1 Environmental findings

Regarding environmental indicators, the focus was on energy efficiency, air emissions, waste generation and recycling, environmental use taxation, and internationally recognised indices that characterise a country's `environmental health` and efforts to improve its environmental performance, e.g. through improving environmental policy. These indicators, stated in Paper I, show the country's capacity to implement environmental goals and provide an idea of whether the investment environment is suitable from the point of view of environmental indicators. In terms of Estonia’s environmental indicators, one cannot ignore the high share of oil shale (OS) use in the energy sector, which has ensured a low dependence on energy imports (less than 10%) but has kept resource productivity, i.e., the amount of materials used in the economy about gross domestic product (GDP), low and has historically dictated a high generation of waste (both hazardous and non-hazardous), greenhouse gas (GHG), and other air pollutants. However, considering the green energy transition, especially in recent decades, Estonian energy production has shifted towards renewable energy, reaching approximately 30% in 2017, as noted in Paper I. This is almost twice the European average and three times higher than, Belgium. Diversifying the energy production portfolio has decoupled Estonia more from OS, significantly reducing OS waste generation, GHG, and other air emissions, respectively, by half in terms of GHG and even more in terms of different air pollutants compared to the base year 1990.

A downside effect can be considered lower municipal waste recycling by the end consumer, almost half lower than the European average and comparable Belgium. This reflects the population's low willingness to reduce waste generation and, to a certain extent, the mindset about resource use, which may not be beneficial for the development of the REE recycling industry. Another factor limiting investment may be the higher share of environmental taxes (mainly fuel taxes, taxes on means of transport, and taxes on pollution and resource use) in total taxes compared to the European average and Belgium. For example, in 2017, it was approximately 8.8% in Estonia, 6.1% on average in the EU, and 5.0% in Belgium. This may mean a higher tax burden for the developer, but it is inherently dependent on the selected REE-recycling technologies.

3.1.2 Social findings

The social findings in Paper I concentrated on indicators such as health issues, education and training, labour costs and earnings, and social inclusion and protection. The aim was to measure countries' ability to realise the potential of their human capital. The standard baseline for all EU countries is ageing according to the 2100s projected old-age dependency ratio. Regarding possible workforce health issues in the REE recycling industry, Estonia has a weaker position compared with others. On average, Estonian healthy life years are 7 years shorter than in Belgium and the EU average, although Estonians are absent less from work due to personal health problems. The leading cause for this might be that Estonians named financial reasons as the primary concern for not visiting medical services, two times higher than the EU average (30.8 and 14.8%, respectively). Education quality is similar in Estonia, Belgium, and the EU, as indicated by the high employment rate of recent graduates. One noted discrepancy is the percentage of adults participating in learning activities (i.e. the population aged 25 to 64), which was higher in Estonia (19.7%) than in Belgium (8.5%) in 2018. A similar ratio has remained to this day, showing that, most likely, adults in Estonia are more motivated for lifelong learning, and this could be a benefit while establishing a REE industry in Estonia. Estonia has reduced the earnings gap between the EU average and Belgium; however, in terms of volume, earnings in Estonia were more than twice as low compared with the EU and triple as low as Belgium in 2014. A recent comparison with the latest 2022 data reveals that Estonia is rapidly closing the gap with the European average, which is now less than twofold. The earnings ratio with Belgium has remained the same. This reduction, however, has put pressure on the growth of labour costs. This can be both a blessing and a curse, as lower labour costs can be an advantage over wealthier countries, but it may not attract local and foreign specialists to the labour market. In any case, Estonia is losing its reputation as a country with low labour costs, and developers will have to consider this in the long term. Estonia has a legislative framework with relevant acts to engage interested parties in new business ventures and investment initiatives. Local authorities and communities can express their thoughts and concerns regarding planned developments. They have used that right loudly in the past, which has stopped several developments in Estonia, e.g., the wood refinery establishment near Tartu (Tartu Postimees, 2017), and, in recent times, slowed down the planning of wind farms across Estonia (Eesti Ekspress, 2025).

3.1.3 Governance findings

Regarding governance risks, indicators such as overall GDP statistics, governance finance ‘health status’, anti-corruption, research and development (R&D) investments, and the taxation system were observed in Paper I. In 2018, the GDP of purchasing power parities, which shows adjusted local price levels across countries, was lower in Estonia (82) than in the EU-28 (set to equal 100) and Belgium (118). The ratio has not changed today. The real GDP growth rate was around 4% above zero in 2018 but has declined to below zero, at- 3.0% in 2023, probably due to several crises, e.g., COVID-19, the energy crisis, and the war in Ukraine. These crises have increased the government's overall gross debt (% of

GDP) from 8.4% in 2018 to 20.2% in 2023 to cope with the high costs of the crises compared to the state's earned revenues. Despite the increase, this indicator continues to be the lowest in Europe; for example, in more recent data from 2023, it is 103.1% in Belgium and, on average, 80.8% in the EU. The costs incurred in the crises have also contributed to the government's deficit, which has been in a slight deficit for the last 7-8 years but increased sharply in 2020 (-5.4% of GDP), having started to decrease again and remained below minus three percentage points in 2023. The crises of recent years have led to the decline of the Estonian economy and unbalanced government revenues and expenditures. Recently, there has been a slight recovery in the economy, and the state is making efforts, for example, by cutting state spending or raising certain taxes to reduce the budget deficit. Unfortunately, this is not an easy task in the new geopolitical situation, requiring a significant increase in defence spending.

Estonia’s expenditures on the R&D sector were lower than in Belgium and the EU. The fight against corruption was well performed both in Estonia and Belgium. According to the Tax Foundation report, Estonia`s tax system was among the finest in the OECD countries in 2018 and remained so in 2024. In Estonia, tax rates are relatively flat, which favours investing. Meanwhile, Belgium's tax system competitiveness is downsized by its high tax burden on labour (53%), high withholding tax rates on dividends, royalties, and interest payments, and relatively high estate tax and a financial transaction tax. International indices that reflect, for example, economic freedom and the perception of corruption, assess the capabilities of Estonia and Belgium equally in the corruption perception ranking. Still, in the economic freedom ranking, Estonia has a higher performance.

3.1.4 Main outcomes of the findings

In general, the results from Paper I suggest that the ESG risk evaluation model can be applied as a sustainability assessment framework to compare countries, revealing key similarities and differences. Based on the evaluation, Estonia is a fertile ground for investing in new businesses, e.g., establishing an REE recycling industry. This is assured by the reduction in environmental burden, driven by more excellent decoupling from OS and a shift to renewable energy sources, thus diversifying the energy production portfolio. Estonia has a highly educated and skilled workforce and education system, although lower earnings might hinder the attraction of relevant specialists. The Estonian economy is very open to foreign investments, and the taxation system is among the finest in the EU. However, the Estonian economy has declined for some time now due to several crises and the new geopolitical reality due to the war in Ukraine. To address the recent economic downturn, the government has reduced public spending and introduced new taxes, such as a car tax, to strengthen public finances.

Nevertheless, a good example that Estonia is a suitable country for the REE industry is the recently opened magnet plant in Narva, eastern Estonia, which produces magnets made from rare earths for modern technology, such as electric vehicles, wind turbines, smartphones, medical equipment, artificial intelligence applications and precision weaponry. The factory`s current capacity is to produce 2,000 metric tons of rare earth magnets, with the possibility to scale it up to 5,000 tons. This is predicted to fulfil around 10% of the EU’s demand for rare earths, currently being met by China (CNBC, 2025). This indicates that the REE industry, including the REE recycling industry, is possible in Estonia, and outcomes from the ESG risk assessment model, presented in Paper I, can be considered realistic to use in such a country comparison. However, despite the usefulness of the ESG assessment method, it also has constraints, which are discussed in more detail in the next chapter.

3.2 RQ2: What are the most significant ESG risks from the perspective of different stakeholders that affect the deployment of phosphorite and related resources in Estonia?

3.2.1 ESG risks importance by stakeholders from Paper II

Four stakeholder groups were first surveyed to identify the significant ESG risks: the local community, the local business sector, policymakers and environmental activists. They were asked 40 questions on a significance scale of 1 to 7 regarding environmental, social and governance risks, which had been compiled using several ESG reporting frameworks by the authors of the original study and the expert group (see the methodology chapter). Additionally, the survey included an open-ended question at the end, allowing respondents to provide comments or justify their opinions. The aim was to map the respondents' fears and worries, i.e., what risks are considered important from their perspective if a phosphorite mining and processing company were to operate in Estonia.

Figure 3 presents the average significance of ESG risks across all stakeholders, where risks were generally rated as significant or very significant.

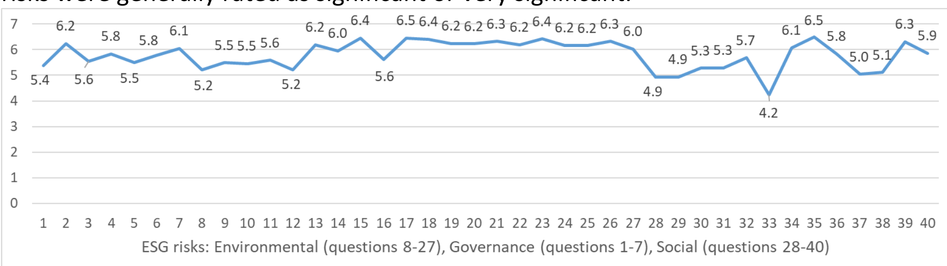

Figure 3. ESG risks average importance by questions, scale 1….7 (see questions in Appendix 4). Source: Paper II.

The results show that environmental risks are generally the most important across the addressed sample, and social risks are the least important, leaving governance risks in the middle. In the spectrum of environmental risks, water-related risks (e.g., q. 13, 15 and 17), impacts on protected areas (q. 18-19) and generation of waste and air emissions (q. 21-22 and 23-25) were considered more significant, while material (q. 8-9) and energy (q. 10-12) use risks were considered less important. Moreover, the number of environmental violations in the company was also considered a significant risk. From the perspective of social risks, two risks related to the local community stood out, being considered very important - the company's activities significant negative impact on the living environment of the local community (q. 35), as well as land acquisition and resettlement operations (q. 39). The rest of the social risks, mainly related to employees, political support, and a safe working environment, are the least important, i.e., among the 10 least significant risks, seven risks were social ones. From the governance perspective, it was considered essential to understand whether the company thinks about the effects of climate change in its activities (q. 2) and, least importantly, whether the company makes a profit (q. 1).

As seen in Figure 4, a comparison between the stakeholder groups reveals that environmental risks were considered the most important by the local community and environmental activists. At the same time, the local community also considers social risks much more critical than others. On the other hand, environmental activists consider social risks to be the least important. The business sector considers governance-related risks the most important, followed by environmental and social risks. Policymakers assess all three risk categories in a reasonably even manner.

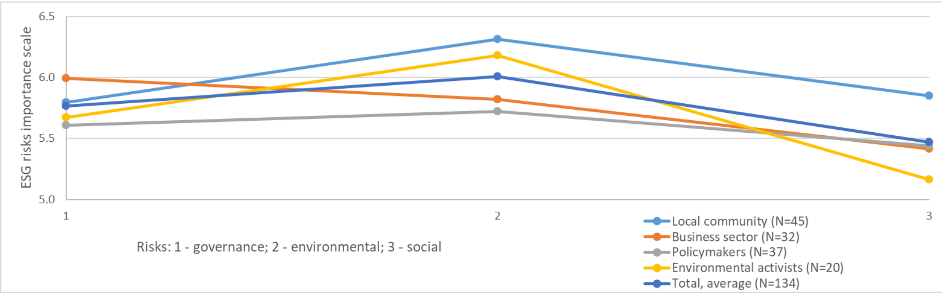

Figure 4. Average importance of ESG risks by stakeholders. Source: Paper II.

The following observations can be drawn while comparing the most significant differences in stakeholder groups' responses:

i. Governance risks were the most important for the business sector. This is illustrated by the fact that, compared with other stakeholders, they value the company's profitability, purchase of products or services from local suppliers and partners, and payment of taxes the most.

ii. Social risks were much more critical for the local community than for other stakeholders, especially environmental activists. This is evidenced by the answers to questions 28, 30, 31, 33, and 40, which reflect that issues related to job creation, a safe working environment, and employee training are relevant to them. This indicates that despite concerns about environmental risks, they also value creating jobs for residents.

Considering that gender inequalities (Jenkins, 2014), a need for an educated workforce in the mining sector (Kazanin & Drebenstedt, 2017), and cross-generational differences (Nugin et al., 2016) might shape people's values and, thus, opinions, the study also surveyed stakeholder groups' perceptions by gender, education, and age. Results by gender, education and age showed no significant differences between them. However, it should be stressed that in some cases, the number of respondents in the sample, e.g., respondents over the age of 65 or respondents with primary and tertiary education, was too low, which may affect the reliability of the results. Therefore, far-reaching conclusions cannot be drawn from this, and to obtain more accurate comparative data, the number of respondents needs to be increased.

Responses to the open-ended question, which allowed better justification of expressed opinions, revealed generally low social acceptance of potential phosphorite exploitation. The respondents expressed concern that such activities could lead to long-term or even irreversible negative impacts, which they found unacceptable. Modern production technologies should be used to ensure the lowest environmental impact if this production is to be considered. In addition, the respondents emphasised that production should be maximally valorised locally in Estonia, the revenues should benefit a larger population, and alternative production activities should also be considered in addition to the mining and processing of phosphorite.

3.2.2 ESG risks importance by the mining experts from Paper III

If we add to the results the assessment of the importance of ESG risks by mining experts, which was investigated in Paper III, the results become even more diverse. The mining experts ranked governance risks as the most critical and social risks as the least important, leaving environmental risks in the middle. The most crucial governance risks for this stakeholder group are earning a profit and considering the impacts of climate change. Among the environmental risks, hazardous tailing waste generation due to phosphorite mining and its processing steps was considered the most critical. This aligns with global practice in environmental risk management in phosphorite mines, where the resilience of the tailings dam is a significant challenge and has caused several ecological disasters in the past (Dong et al., 2020). Nevertheless, in the Estonian context, groundwater protection during mining and the management of naturally occurring radioactive material waste from black shale overburden may pose equally significant environmental challenges. Of the spectrum of social risks, the risk related to occupational accidents involving employees was considered the most important. The importance of other social risks received much less attention.

3.2.3 ESG risks importance comparison from Papers II and III

In Appendix 4, the table presents the combined results of Papers II and III, along with the questions posed. The comparison shows that mining experts prioritise governance risks, while other stakeholders consider environmental risks the most significant. A breakdown by question reveals the greatest differences in views: mining experts ranked the impact on the local community's living environment among the lowest risks, whereas other stakeholders viewed it as the most critical. On the other hand, the mining experts rated earning a profit as the most critical risk, but it was assessed as a relatively low risk by other stakeholders. Common ground was found when considering the impact of climate change on the company – this was seen as an essential risk by all stakeholders. However, the questionnaire did not clarify what respondents understood by 'climate change', indicating a need for more precise framing in future surveys. Nonetheless, the responses suggest that climate change concerns are significant and closely tied to long-term value creation. The assessment of mining experts on the importance of ESG risks was most consistent with the opinion of the local business sector, specifically that governance risks, including earning a profit, were considered the most vital.

Comparison indicates that differences in expectations lead to divergent risk perceptions. While profitability is the 'core' of every company, it cannot come at the expense of significant environmental degradation and major adverse impacts on the local community. The conflicting risk assessments across stakeholder groups demonstrate this. There is and will be an inherent contradiction between the E, S and G pillars, but how can it be reduced in the maximum way, and what can the state do to make the potential extraction and processing of phosphorite and REE in Estonia sustainably possible? These questions will be further tackled in the next chapter.

4 Discussion

This chapter discusses the applicability of the ESG assessment model for selecting a development region for CRM valorisation industry and explores strategies to mitigate the most important ESG risks within the proposed development framework.

4.1 ESG assessment model for site selection - practical tool or not?

Although the ESG assessment model shows some reliability and can, in principle, be applied to cross-country comparisons as presented in Chapter 3.1, it also has some limitations, as described below.

Academic research has yet to extensively examine the competitiveness of countries in attracting mining investments. Although new mining projects can positively impact the region's socio-economic development (Ejdemo & Söderholm, 2011), mineral commodity prices are considered critical in investment decisions due to their volatility and unpredictability, creating substantial uncertainty (Foo et al., 2018). According to Jara (2017), a country’s competitiveness in attracting mining investments depends on its geological potential, including a sufficient exploration level of resources and a favourable investment climate, including stable governance and a rational tax system. The study shows that earlier assessments of geological potential commonly relied on variables such as the share of mining exports, the mining sector’s GDP contribution, mining production, estimated resources and reserves, national GDP and total population. However, the best indicator of the geological potential of a country was considered to be its land area, and for investment climate characterisation, the Index of Economic Freedom (Khindanova, 2011). Jara et al. (2020), who utilised the same variables in a cross-country comparison covering the years 1996 to 2014, also concluded that the selected variables are relevant. Still, despite the usefulness of these variables in explaining the attractiveness of mining investments, the use of these proxies can be questioned as they are not specific enough to the mining industry. They recommended conducting an analysis of mineral commodities and including more sector-specific indicators, such as the effective tax rate on mining, to improve the relevance and accuracy of such assessments. In addition to geological potential factors influencing investment decisions, the Fraser Institute also highlights the importance of public policy factors in its annual surveys. It measures the impact of government policy on attitudes towards exploration investments. The mining and exploration sector responses indicate that political factors determine approximately 40 per cent of their investment decisions today. Thus, stability and transparency in political decisions are increasingly important in shaping the investment climate (Mejía & Aliakbari, 2024).

The findings of this study, which employs a risk assessment model incorporating a broader range of dimensions and related parameters (e.g., energy production, life expectancy, purchasing power) to evaluate countries’ competitiveness for mineral sector investments, are more comprehensive than previous studies, suggesting that ESG frameworks may serve as effective tools for cross-country comparison. Thus, the environmental indicators used assess the country's environmental health more broadly and the extent to which it is making efforts to improve it. For example, they examine the country's ecological status, i.e., how much the generation of pollutants and waste has changed, what the share of fossil and renewable energy sources is, and the level of energy independence. Also, the share of environmental taxes in total taxes might be a limiting factor, hindering investment decisions. On the social side, comparing the education system and the skilled workforce within the ESG framework highlights the potential to train the necessary workforce. Moreover, knowledge of labour costs and the earnings gap changes provides relevant information and indicates the trend in labour cost growth. This is certainly important when making an investment decision. Governance indicators such as GDP, labour cost growth rates, and government debt indicate the state of a country's fiscal policy and its sustainability. Information on the tax system assesses its simplicity or complexity, and thus how it favours investing.

However, relying on national-level ESG indices as primary selection criteria may also entail several limitations.

First, the outcome of country comparison—namely, investment decisions—depends heavily on the selection of ESG indicators. In the studied scenario, which examined the establishment of a REE recycling industry in Estonia, it is uncertain whether the ESG indicators used in the model effectively capture the specific nature of the planned activity, as most are general country-level indicators rather than activity-specific ones. The choice of ESG indicators used in this model is up to the evaluator, and no standardised procedure currently exists for their selection. This represents the main source of uncertainty in applying the model. Using ESG indicators that do not successfully characterise the subject being assessed can lead to misleading results and flawed conclusions. Therefore, selecting appropriate ESG indicators is crucial.

This point is reinforced by prior studies suggesting that the competitiveness variables should be more mining-specific. For example, Sobczyk et al. (2017) highlight the importance of indicator selection in their AHP-based analysis of four European countries as potential sites for a zinc and lead ore mine and processing plant. Their study demonstrated the complexity of selecting and weighing 20 indicators, covering geological and mining conditions, infrastructure, environmental impact, capital investment costs, and socio-political risk. The findings emphasise the importance of social and ecological risks, where SLO often determines the initiation of new mines.

Another essential limitation, which is also derived from the conclusions of Paper I, is that the model describes only existing ESG risks, i.e., the current 'as is' situation. However, this is typically insufficient for making high-stakes investment decisions (Fikru et al., 2024). Potential investors also want long-term certainty that the investment environment, here, the country, will remain stable and sustainable. This requires predicting future trends to assess the potential `to be` scenario. The model used in the study does not allow such forecasting, making it only partially applicable to well-founded investment decisions. The model should be improved or used alongside forecasting tools that project future ESG indicator trends to increase reliability. This way, achieving integrity and ensuring the legitimacy of the results and conclusions is possible. That said, forecasting is inherently challenging when assessing countries or specific developments. In the case of REE development, forecasting future REE prices may be the Achilles' heel because different rare earth elements have different market demands, which dictate the cost and thus can affect the result of the cost-benefit analysis before development (García et al., 2017). On a broader scale, the sustainability of a country and investment certainty can also be affected by unpredictable external factors, such as geopolitical instability. Recent examples include the ongoing war in Ukraine and the continuing threat of further Russian aggression, particularly in Eastern Europe, including Estonia.

4.2 Mitigating the most significant ESG risks within the proposed development framework

The study results indicate significant concern about the environmental impacts of developing phosphorite resources. The effect on the local community, their involvement, and consideration of climate change and the activity's profitability were also considered essential. These outcomes are consistent with miners' assessment of the extractive industry's modern challenges (Ernst & Young, 2024). However, the respondents' assessments in this study were sometimes contradictory. What drives these differences, and how can they be addressed?

4.2.1 Key components of the development framework

The scale of environmental impact largely depends on the planned activity's scope and the site's environmental conditions. Phosphorite production could have significant adverse environmental effects, as shown in a recent review from Kazakhstan by Aliaskarov et al. (2025). The activity's size and, therefore, its environmental impact are determined by the type of resources to be extracted and the planned level of on-site valorisation. Multiple development scenarios for the phosphorite and related resource industry are possible in Estonia. One of the key questions is whether the extraction should focus solely on the main product, e.g., phosphorus, or also include by-products like REEs or vanadium. Environmental risks also vary depending on the intended intermediate products for on-site valorisation, e.g., mechanical concentrates, merchant-grade, food-grade, tech-grade or battery-grade phosphorus acids. Each option comes with specific environmental risks and production requirements.

Any development of this scale will inevitably affect residents to some extent. The thesis revealed that social acceptance, i.e., SLO, is low. The expectation is that if such production is planned, the affected citizens should receive social benefits from it, i.e., considering the magnitude of the impact, they will be compensated for the effects. Ensuring distributive fairness is essential. Several studies suggest that distributive justice is among the most important aspects influencing public trust and acceptance of mining (França Pimenta et al., 2021; Zhang et al., 2015). However, studies on the fairness of wind energy project distribution indicate that achieving fairness is often challenging. Compensation schemes do not always succeed in addressing perceptions of unequal distribution (Leer Jørgensen et al., 2020), and preferences for distributive justice frequently vary across countries (Vuichard et al., 2022). Despite the complexity of implementing a social benefit, it is necessary that a so-called better local benefit instrument in the mineral sector be developed. The state has already started with the latter. For this purpose, an amendment to the Environmental Charges Act has been initiated, the aim of which is to review the current mining rights fees in such a way that society, especially residents of nearby areas and local governments, would earn a fair and maximum return from the exploitation of critical minerals, such as phosphorite. The discussion on the solution is still in its early stages. Still, it is assumed that the development of a local benefit instrument will be guided by the model of the wind energy environmental disturbance compensation fee that has been developed to date (Eelnõude infosüsteem, (n.d.)). According to this, a certain proportion of the fee for producing electricity from wind energy is paid to the local government and homeowners in the area of influence. It can be assumed that this increases social acceptance, but whether it will ensure SLO is another question. Nonetheless, it is likely a step in the right direction.

The third component, cost-effectiveness, depends primarily on whether the environmental tolerance allows the planned activity, what mitigation measures are necessary and their associated costs. The decisions described above regarding the choice of technology and the valorisation level are also critical. These questions require further study. In essence, cost-effectiveness analysis must account for the costs of technology selection, the development scale (including projected production volumes and required infrastructure), site-specific conditions (existing infrastructure, potential workforce, proximity to services), labour needs, the environmental mitigation costs, land acquisition costs, and more —all weighed against the expected financial return. Reviews by consulting companies confirm that in the extractive industry, the projected cost overrun has increased due to the growing size and complexity of projects. Only one-fifth of the investigated projects delivered the financial returns predicted at the feasibility stage (McKinsey&Company, 2019).

4.2.2 Assumptions and prospects for implementation of the development framework

Since mining is a global industry where prices are set on world markets, the development of the mining sector depends on global trends, including the clarity of legislation concerning mineral resources and its attractiveness to investors. A stable, transparent, and predictable legal framework and a clear tax regime are prerequisites for the respective industry's planning. Under Estonia's current regulatory practice, companies select areas for exploring specific mineral resources. Unfortunately, this approach overlooks important factors when granting exploration and use rights, such as valorisation, state revenue clarity, socio-economic considerations, and adoption of best technologies throughout the entire process, from prospecting to closure. This is especially true for strategic and critical resources, the accessibility of which is complex and requires more detailed investigation and clarification of the most significant added value. The state must lead more in directing exploration and granting mining rights to change this. To this end, Estonia plans to amend the regulation in force to include the principles of concession, which will allow the state greater decision-making power in granting and processing reserves, considering a holistic view (Kliimaministeerium, (n.d.)a). A concession defines the rights and obligations in a specific part of the Earth's bedrock for geological exploration, mining, and valorising extracted raw materials. The bidder and winner of the concession procedure are determined based on a specific threshold, and it is essential to involve the affected parties, such as the local government on whose territory the concession object is located, as early as possible in developing the related criteria. Since the amendment to the regulation is still in its early stages, conclusions cannot be drawn at this time. Enabling a concession with the local benefit instrument allows the state to find a development partner in the most transparent way possible, which forms the basis for further development planning.

The author proposes a development framework for further phosphorite exploitation studies, illustrated in Figure 5. This framework is based on a novel ESG risk assessment model and the mitigation of identified key risks. However, it is essential to note that this framework only applies if the ongoing studies, as outlined in Chapter 1.4, first show that extracting phosphorite and related resources is economically viable and technologically feasible.

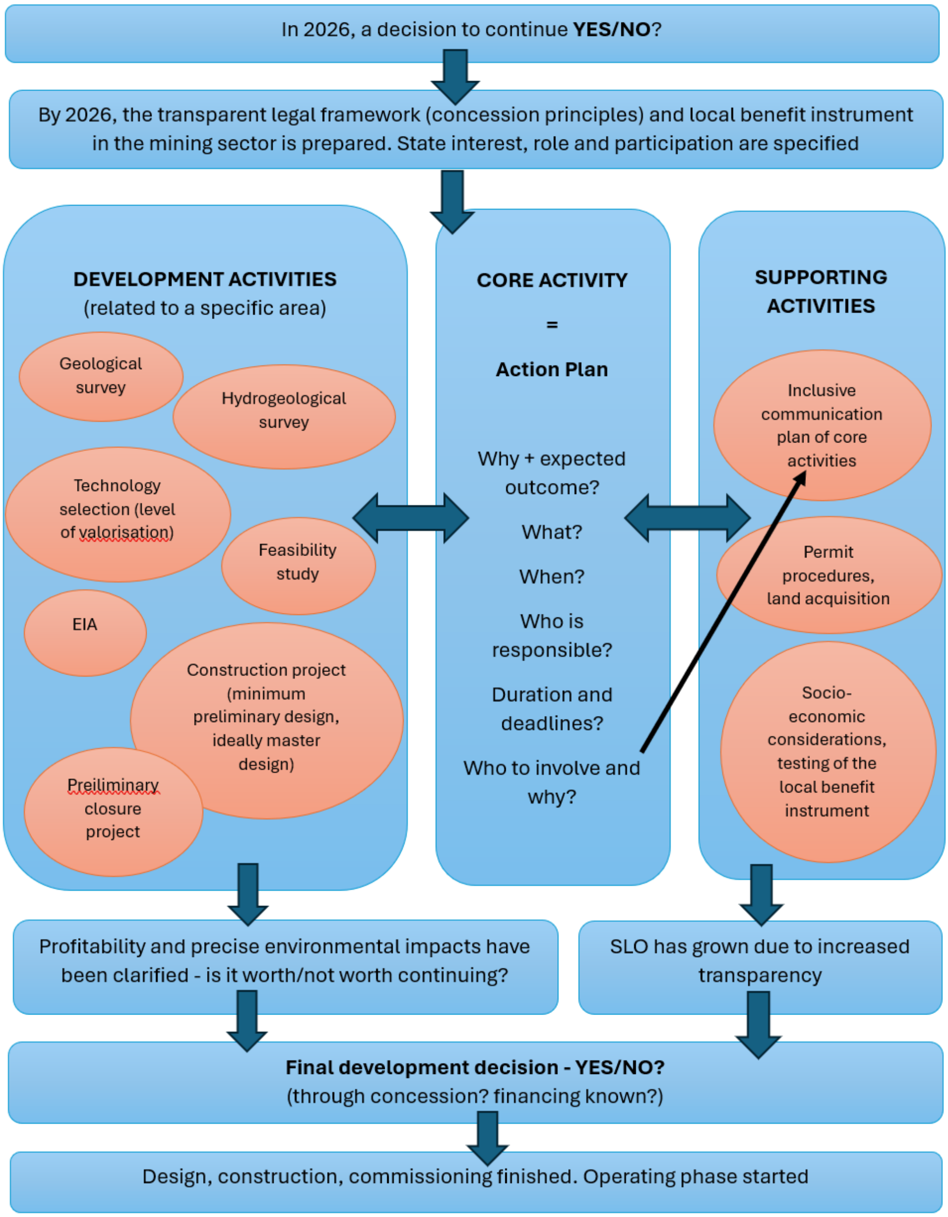

Figure 5. Development framework for the phosphorite and related resources industry planning based on identified key ESG risks.

If today's studies demonstrate the feasibility of development, and the legal framework is adjusted accordingly, a clear and well-thought-out action plan is essential for managing the most significant ESG risks. Various follow-up actions are required in a specific development area, all of which must address the six questions outlined in the action plan. In addition, follow-up activities are often interconnected, where the result of one affects the outcome of another, and their logical sequence must be established. The magnitude of the impact begins with decisions on the resource(s) to be extracted, the mining method and the level of valorisation, the scope of which is already specified by related studies. In assessing environmental impacts, however, one cannot be limited to the effects of development alone; one must apply a broader view, considering the cumulative impacts, for example, the effects of black shale handling and other nearby activities. The latter is firmly rooted in the impact assessment methodology but has been poorly implemented in practice so far (Murray et al., 2025). Typically, costs are underestimated in large-scale projects. To address this problem and obtain a more detailed cost-effectiveness analysis, it is recommended that the design accuracy (ideally to the master design, i.e. MD, stage) be maximised in the project's initial phase when preparing the cost-effectiveness analysis (Flyvberg, 2008). Follow-up activities must address the following questions: Does the planned activity not exceed environmental tolerance limits? Are the proposed environmental measures realistic and feasible? Is profitability achievable considering the expected development costs?

The only way to achieve the SLO is to be as transparent as possible, which begins with consistently communicating a realistic action plan and identifying and involving relevant stakeholders. The content of follow-up activities and the needs and expected results must be explained at every stage to involve the public and other stakeholders. Public trust can be earned if the distributive justice associated with the impact is understandable and the distribution principles are justified when developing the local benefit instrument (Escosteguy et al., 2024). Implementing these supporting activities creates the ground for acceptance of this type of development.

5 Conclusions

This thesis examines the applicability of ESG as a balanced development framework for the potential future exploitation of phosphorite and related resources in Estonia. The primary objective was to determine whether the ESG risk assessment model can effectively identify related significant environmental, social and governance risks. Such information is essential as it enables the state, as one of the primary stakeholders and the creator of the development framework, to plan targeted measures to mitigate significant risks before large-scale development can be considered.

Paper I (RQ1) finds that the ESG risk assessment model is effective for initial screening and selecting development locations within a sustainable framework, highlighting key similarities and differences between countries. Based on this assessment, Estonia appears suitable for investment in RM valorisation businesses, such as those in the REE recycling industry. Nevertheless, the approach has limitations. Previous studies show that a country's attractiveness for mining investment depends on its geological potential and investment climate. While various indicators have been used to evaluate these factors, they are often not mining specific. Similarly, the ESG risk assessment model utilised here, though incorporating variables across environmental, social, and governance dimensions, shares this weakness. Namely, selecting suitable indicators is crucial for assessing a country’s competitiveness, which depends on the subject being evaluated, i.e., the specific planned activity. The decision-making indicators should be as mining specific as possible if the goal is to attract mining investments. The selected indicators must most closely reflect this area if the goal is to initiate a REE recycling industry. Misaligned ESG indicators that do not successfully characterise the subject being assessed can lead to inadequate results and incorrect conclusions. Another shortcoming is that the model describes current ESG risks (‘as is’). However, for a potential investor, it is necessary that the investment environment, in this case, the country, is stable and sustainable in the long term, i.e., it considers the so-called future situation (‘to be’). The model applied in the study does not directly allow this. Therefore, to strengthen the model’s reliability, its findings should be supported with forecasts of relevant ESG indicators.

To identify key ESG risks for potential phosphorite exploitation in Estonia (RQ2), five stakeholders were surveyed: the local community, the local business sector, policymakers, environmental activists (134 respondents in Paper II) and mining experts (8 respondents in Paper III). Overall, environmental risks were ranked highest, followed by governance, with social risks considered the least important. The comparison of stakeholders showed that the local community and environmental activists considered environmental risks the most important. In contrast, the business sector and mining experts emphasised governance-related risks. Social risks were essential to the local community but ranked lowest by environmental activists and mining experts. Policymakers rated all three risk categories relatively evenly. Analyses by gender, education, and age (Paper II) revealed no significant differences, though small subgroup sizes may limit the reliability of these findings. Notably, the most considerable divergence was on the impact on the local living conditions, which were viewed as low risk by mining experts but as the highest by other stakeholders. Conversely, mining experts saw profit-making as the most critical risk, while other stakeholders, except businesses, considered it less important. Climate change impacts were seen as a significant risk by all groups.

The study results highlight widespread concern about the potential negative impacts on the environment and the local community, with differing perceptions of social risks across stakeholder groups. This suggests that social acceptance of the proposed activity is currently low, underscoring the need for developers to engage meaningfully with local communities. Responses, including open-ended feedback, reveal an expectation for creating a fair and beneficial local benefit instrument to improve acceptance. The greater importance of social risks to the local community and the significance of governance risks among local companies also indirectly suggest that creating new jobs and consuming local services and products are essential to locals as a stimulus for the regional economy. However, this must not come at the expense of the environment. For most stakeholders, profitability becomes relevant only after environmental concerns are addressed and the local community are prioritised. This implies that assessing profitability is meaningful only once key decisions—such as the degree of resource valorisation and technology choices, which shape environmental impact—are clearly defined.

If ongoing technological and economic studies confirm the feasibility of development while addressing key ESG risks, a clear, well-designed action plan for a specific development area becomes essential. This plan should define the project's expected profitability and outline the scale and mitigation measures for its environmental impact through concrete follow-up actions. Public trust, i.e., SLO, can only be earned when a reasonably perceived local benefit instrument is developed and implemented, and transparent communication of the action plan's steps is applied, with the active involvement of all relevant stakeholders.

The main limitation of the ESG risk assessment was the use of a non-probability sampling method, which means that the results are not representative of the broader Estonian population. Ensuring representativeness would require a probability sampling approach, which was not feasible due to budget constraints. However, as stakeholders' views on ESG risks related to phosphorite use had not been systematically studied in Estonia, the pilot studies presented in this thesis provide valuable initial insight.

Despite the limitations, the thesis results represent a first attempt to investigate the sustainable exploitation of phosphorite and its related resources through a holistic ESG assessment approach. The study's outcomes could serve as a guideline for policymakers to adjust future activities, thereby mitigating environmental risks, avoiding potential social conflicts, and ensuring profitability.

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Abstract

ESG risk assessment model for the exploitation of phosphorite and related resources in Estonia

Exploiting phosphorite and related resources, especially rare earth elements, could represent a major economic opportunity for Estonia, but it also carries certain risks. Due to growing demand and high supply risk, both are critical raw materials. Research is underway in Estonia until at least the end of 2025 to assess whether their extraction and processing are technically feasible and economically viable. If the findings support continued development, it is essential that further research focuses on ensuring the most sustainable use of these resources by identifying risks across three dimensions – environmental (E), social (S) and governance (G).

This doctoral thesis aims to assess whether an ESG risk assessment model can identify significant risks associated with the potential exploitation of phosphorite and related resources. Mapping ESG risks is necessary because it provides the state, as the creator of the development framework, with a basis for planning targeted measures to manage significant risks prior to possible large-scale development. Based on the purpose of the study, the doctoral thesis addressed research questions such as the applicability of the ESG risk assessment model in comparing countries (RQ1) and the identification of significant ESG risks affecting the use of phosphorite and related resources in Estonia (RQ2).

To answer the research questions, the doctoral thesis is built on the results of case studies. To address RQ1, the suitability of the ESG risk assessment model was first tested to support decision-making on the choice of a development location—in this case, a country (Paper I). The aim was to assess whether Estonia is a suitable country for investment, specifically for establishing a REE recovery industry in Europe. To this end, the selected ESG indicators were quantitatively compared across Estonia, Belgium, and the European Union average. To answer RQ2, the perceptions of different stakeholders were examined regarding the most significant ESG risks that they believe affect the use of phosphorite and related resources in Estonia. A target online survey was conducted among the local community, the local business sector, policymakers and environmental activists. A qualitative non-probability sampling approach was used to collect data, combined with quota and snowball sampling methods, and the results were analysed quantitatively (Paper II). To identify ESG risks relevant to Estonian conditions, the most common ESG reporting frameworks—such as GRI, SASB and IFC—were used, along with input from a small expert group to screen for context-appropriate risks. A total of 40 risks were applied in the study. The significance of ESG risks among one stakeholder group, mining experts, was quantitatively examined using the FAHP method (Paper III).

The results show that the ESG risk assessment model can be effectively applied to decision-making regarding location selection. According to the ESG indicators used, Estonia is a suitable location for investing in new businesses, such as establishing a REE recycling industry. However, the model's disadvantage is that it describes existing ESG risks (`as is`). At the same time, it is important for investors to perceive the long-term sustainability of the country. To ensure the legitimacy of the results and conclusions, it is necessary to supplement the model or use it with forecasts for the estimated ESG indicators. It is also important to choose appropriate ESG indicators that depend on the specific planned activity to obtain adequate and comparable results. The better the

selected ESG indicators reflect the nature of the planned activity, the more accurate the result will be.

The aggregated results for the most important ESG risks across stakeholders show that environmental risks are generally the most important, followed by governance risks and then social risks. However, this order did not always hold across stakeholders, with the business sector and mining experts considering governance risks the most important. The most significant difference in stakeholder responses was on the question of the impact on the living environment of the local community. Mining experts considered this to be one of the least important risks, while other stakeholders, particularly the local community, believed it to be the most important, meaning they were most interested in knowing about the impact of the proposed activity on local residents.

The research findings show concerns regarding potential negative impacts on the environment and local communities. The level of social acceptance (SLO) for permitting the proposed activities is currently low. However, there is an expectation that the impacts will be fairly compensated to affected parties by establishing a mechanism that ensures fair and maximum benefits (a local benefits instrument). The arrival of a new industry will also stimulate the local economy through job creation and the consumption of local services and products. This is likely to have a positive impact on the SLO. However, this cannot be done at the expense of the environment, as shown by the high importance of environmental risks. For most stakeholders, the importance of activity's profitability only becomes apparent when environmental risks are mitigated and local residents are prioritised. When planning further development activities, a clear and well-thought-out action plan is necessary, specifying the magnitude of the activity's environmental impact, measures and profitability.

The application of the ESG risk assessment model, which identified significant risks, is a novel approach to planning the potential deployment of phosphorite and associated resources. The thesis results can help policymakers design sustainable and balanced frameworks and activities where environmental risks and social tensions are mitigated and profitability is ensured.

Lühikokkuvõte

ESG riskihindamise mudel fosforiidi ja sellega seotud ressursside kasutamiseks Eestis

Fosforiidi ja sellega seotud ressursside, eriti haruldaste muldmetallide, kasutamine oleks Eesti jaoks tõenäoliselt suur majanduslik võimalus, kuid sellega kaasnevad ka teatud riskid. Kasvava nõudluse ja suure tarneriski tõttu on mõlemad maavarad kriitilise tähtsusega toorained ning Eestis on käimas uuringud vähemalt 2025. aasta lõpuni, et teha kindlaks, kas ja kuidas on nende ressursside kaevandamine ja töötlemine tehniliselt teostatav ja majanduslikult tasuv. Kui uuringud viitavad arenduse jätkamise otstarbekusele, on ülimalt oluline järgnevates uuringutes adresseerida nende ressursside võimalikku kasutamist maksimaalselt jätkusuutlikul viisil, st tuvastada riskid kolmes dimensioonis – keskkond (E), sotsiaal (S) ja valitsemine (G).

Käesoleva doktoritöö eesmärk on hinnata, kas ESG riskihindamise mudel suudab tuvastada olulisi riske, mis on seotud fosforiidi ja sellega seotud ressursside potentsiaalse kasutamisega. ESG riskide kaardistamine on vajalik, sest annab riigile kui arendusraamistiku loojale aluse planeerimaks sihipäraseid meetmeid oluliste riskide juhtimiseks enne võimalikku suuremahulist arendust. Lähtuvalt töö eesmärgist käsitleti doktoritöös uurimisküsimusi (UK) nagu ESG riskide hindamise mudeli rakendatavus riikide võrdlemisel (UK1) ning fosforiidi ja sellega seotud ressursside kasutamist mõjutavate oluliste ESG riskide kindlakstegemine Eestis (UK2).

Uurimisküsimustele vastamiseks on doktoritöö üles ehitatud juhtumiuuringute tulemustele. UK1 vastamiseks testiti esmalt ESG riskihindamise mudeli sobivust, mis aitaks otsustada arenduskoha, antud juhul riigi, valiku üle (Artikkel I). Eesmärk oli hinnata, kas Eesti on sobiv riik investeeringute tegemiseks, konkreetsemalt REE taaskasutustööstuse rajamiseks Euroopas. Selleks võrreldi kvantitatiivselt valitud ESG näitajaid Eestis ja Belgias Euroopa Liidu keskmistega. UK2 vastamiseks uuriti erinevate sidusrühmade arusaamu kõige olulisematest ESG riskidest, mis nende arvates mõjutavad fosforiidi ja sellega seotud ressursside kasutamist Eestis. Selleks viidi läbi sihtrühmapõhine veebiküsitlusuuring kohaliku kogukonna, kohaliku ärisektori, poliitikakujundajate ja keskkonnaaktivistide seas. Andmete kogumiseks kasutati kvalitatiivset mittetõenäosuslikku valimi meetodit kombineerituna kvoodi- ja lumepallivalimi meetoditega ning tulemusi analüüsiti kvantitatiivselt (Artikkel II). Eesti oludesse sobivate ESG riskide tuvastamiseks kasutati enimlevinud ESG aruandlusraamistikke, nagu GRI, SASB ja IFC ning väikese ekspertgrupi abi Eesti konteksti sobivate riskide väljasõelumiseks. Kokku rakendati uuringus 40 riski. ESG riskide olulisust ühe sidusrühma—kaevandusekspertide—seas uuriti kvantitatiivselt FAHP meetodil (Artikkel III).

Tulemused näitavad, et ESG riskihindamise mudelit saab tõhusalt rakendada asukohavalikut puudutavate otsuste tegemisel. Kasutatud ESG näitajate järgi on Eesti sobiv asukoht uutesse äridesse investeerimiseks, näiteks REE taaskasutustööstuse rajamiseks. Mudeli puuduseks on see, et see kirjeldab olemasolevaid ESG riske, st olemasolevat olukorda. Samas on investoritele oluline tajuda riigi pikaajalist jätkusuutlikkust. Tulemuste ja järelduste õiguspärasuse tagamiseks on vaja mudelit täiendada või kasutada seda koos prognoosidega hinnatud ESG näitajate kohta. Samuti on oluline valida sobivad ESG näitajad, mis sõltuvad konkreetsest kavandatavast

tegevusest, et saada adekvaatseid ja võrreldavaid tulemusi. Mida paremini valitud ESG-näitajad kajastavad kavandatava tegevuse iseloomu, seda täpsem on tulemus.

Olulisemate ESG riskide koondtulemused sidusrühmade lõikes näitavad, et keskkonnariskid on valimis üldiselt kõige olulisemad, järgnevad valitsemisriskid ja seejärel sotsiaalsed riskid. See järjekord ei kehtinud aga alati sidusrühmades, näiteks ärisektor ja kaevanduseksperdid pidasid kõige olulisemaks valitsemisega seotud riske. Sidusrühmade vastuste kõige olulisem erinevus ilmnes küsimuses, mis käsitles mõju kohaliku kogukonna elukeskkonnale. Kaevanduseksperdid pidasid seda üheks vähem oluliseks riskiks, samas kui teised huvirühmad, eriti kohalik kogukond, pidasid seda kõige olulisemaks, mis tähendab, et nad soovisid kõige rohkem teada kavandatava tegevuse mõjust kohalikele elanikele.

Üldistatud uuringutulemused näitavad muret seoses võimalike negatiivsete mõjudega keskkonnale ja kohalikule kogukonnale. Ühiskondlik aktsepteerimine (SLO) kavandatud tegevuste lubamisel on praegu madal. Siiski on ootus, et õiglast ja maksimaalset kasu tagava mehhanismi loomisega (kohaliku kasu instrument) hüvitatakse mõjud mõjutatud osapooltele õiglaselt. Uue tööstuse tulek elavdab ka kohalikku majandust töökohtade loomise ning kohalike teenuste ja toodete tarbimise kaudu. Sellel on tõenäoliselt SLO-le positiivne mõju. Seda ei saa aga teha keskkonna arvelt, mida näitab keskkonnariskide suur tähtsus. Enamiku huvirühmade jaoks ilmneb tegevuse tasuvuse tähtsus alles siis, kui keskkonnariskid on maandatud ja kohalikud elanikud on seatud esikohale. Edasiste arendustegevuste kavandamisel, on vajalik selge ja läbimõeldud tegevuskava, milles on täpsustatud keskkonnamõju suurus, meetmed ja tegevuse tasuvus.

ESG riskihindamise mudeli rakendamine, mis tuvastas olulised riskid, on uudne lähenemisviis fosforiidi ja kaasnevate ressursside võimaliku kasutuselevõtu kavandamisel. Doktoritöö tulemused võivad aidata poliitikakujundajatel kavandada jätkusuutlikke ja tasakaalustatud raamistikke ning tegevusi, kus keskkonnariskid ja sotsiaalsed pinged on maandatud ning kasumlikkus tagatud.

Appendix 1

Paper I

Paat, A., Veetil, S. K. P., Karu, V., & Hitch, M. (2021). Evaluating the potential of Estonia as European REE recycling capital via an environmental social governance risks assessment model. The Extractive Industries and Society, 8(4), 100767. https://doi.org/10.1016/j.exis.2020.07.001. (ETIS 1.1).

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Original article

Evaluating the potential of Estonia as European REE recycling capital via an environmental social governance risks assessment model☆

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ABSTRACT

The rare earth elements (REEs) are cornerstone metals of modern society and are used in many applications. Europe is dependant on other continents for the safe supply of rare earth elements as these are to date not mined in Europe. In order to circumvent the shortage of supply, the rare earth elements recycling, especially from End-of-Life (EoL) products are imperative. This article evaluated the feasibility of Estonia as viable REEs recycling hub in Europe via an environmental, social and governance risks evaluation model. The model assessed the pros and cons of Estonia`s environmental, social and governance indicators, and concluded that Estonia is very suitable for the establishment of REEs recycling industry. The environmental indicators showed continuous improvement in environmental health. The Estonian education system is of excellent quality and has produced a highly skilled workforce over the past years. The country's economic indicators are good, management is transparent and business opportunities are diverse. The environmental, social and governance situations show that Estonia mostly meets the prerequisites for the establishment of a rare earth element recycling industry. The existence of such business will increase the quality of the labour force and economic growth in the long term.

1. Introduction

The exploration and extraction of rare earth elements (REEs) have always been linked to the socio-economic tension between their need (since atomic era), and production risks (Klinger, 2015, 2018). The REEs are being used in an increasing number of applications due to the uniqueness in REE's physical and chemical properties. Most of REE's are irreplaceable and are very imperative in the day-to-day life of Europeans, both in terms of the economy and secured supply. The European Union (EU) Commission has declared REEs as critical raw materials for the EU's economy and consistently tracking its criticality via the Critical Raw Material (CRM) list (Ferron and Henry, 2015). The global REEs production was estimated to be 213,000 tons of rare earth oxide (REO) equivalent in 2019 (U.S Geological Survey, 2020). The long-term quantitative predictive models suggested by Wang et al. (2020) provide both the highest and lowest projection of REEs production over the next 100 years. The REEs are divided into light (LREE) and heavy (HREE) based on their atomic number and the classification made by various agencies, especially the IUPAC (The International Union of Pure and Applied Chemistry). The latter is less abundant in nature. Presently, the REEs such as Neodymium (Nd), Europium (Eu), Terbium (Tb), Dysprosium (Dy) and Yttrium (Y) are being identified as more critical because of their relatively less occurrence in the earth's crust and substantial use in many applications (Binnemans et al., 2013). The REEs are commonly used in magnets, alloys, catalysts, polishing agents, glass, ceramics, batteries and lamp phosphorus (Swain and Mishra, 2019). Amongst the aforementioned applications, the first three have growing markets due to low carbon economy.

The importance of recycling of REEs in Europe arises from its increased demand in supply for extensive applications. At present, mining is the primary and major source of REE, however, in future, recycling (secondary resource) could complement mining only when there is an inflation of REEs prices and shortage of supply. The REEs recycling could diminish the geopolitical dependency in future; contributing more room to the secured supply of critical metals, and thereby reduce the inflation of REE price. Nevertheless, one should be noted that, during the past years the REEs prices dropped significantly at the level of the price average before the 2011 crisis (Barakos et al., 2018;

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Cox and Kynicky, 2018). The REEs recycling has many good aspects, but it is not yet implemented on a massive scale. The main constraints are inadequacy in End-of-Life (EoL) waste collection and dismantling infrastructure, the less REEs content in terms of mass in the goods and the non-cost-effectiveness individual REE extraction method (Jowitt et al., 2018).

Previous studies have mostly investigated various wastes worth for REE recycling and corresponding technologies to recover it (Guyonnet et al., 2015; Dutta et al., 2016). In those studies, examples of REEs recycling companies are mentioned, whereas the capacity of a State; as a larger administrative unit to recycle rare earth has not been assessed. Therefore, this is a first time attempt to investigate the feasibility of establishing a REE recycling industry in Estonia for the EU via an Environmental, Social and Governance (ESG) risk evaluation model. The paper contributes a methodology of data collection and analysis, the boundaries and the research scopes for ESG risks evaluation, and its usefulness as a model to assess REEs recycling potential in Estonia. The study discusses and summarises the recent developments, current frontiers, challenges and future perspectives of REEs recycling in the EU based on the available literature. Furthermore, based on the ESG assessment outcomes and findings, the study investigated the feasibility of developing Estonia as the EU home ground for REEs recycling. The ESG model highlights the main indicators used in the Estonian context and summarises the major ESG risks associated with the establishment of the European REEs recycling industry in Estonia. It is also important to note that the ESG indicators have never been used before to assess and compare the performance of countries. Since it is a first attempt of using the ESG indicators to evaluate a country's performance, this paper caveats the readers that the results should be treated with precautions, as the choice of indicators was at the sole discretion of this study. Furthermore, the depicted study is strictly based on the ESG evaluation of a European member state (Estonia) and does not assert any detailed economic, political and comparative analysis which are far beyond the scope of this study.

2. Methodology

The ESG is a report, created by companies, which describes the environmental (E), social (S) and governance (G) factors of their performance. The factors of ESG cover a broader picture than a normal financial analysis. Therefore, it has been used as a tool by responsible investors to measure company's future performance and identify the places to invest money. The practice of ESG investment begun in the 1970s and previous studies indicate that the integration of ESG in the investment process most likely leads to better returns and long-term value creation (Friede et al., 2015; Virah-Sawmy, 2015).

The present study also applied similar principles of the ESG reporting, but in a customized way. This study has also evaluated the ESG factors, but in this case, the investigated subject is a 'country' instead of a 'company'. The reason for choosing ESG assessment method is because of its special proven capability of identifying financially and responsibly successful companies. For the identification of indicators, the study followed the guideline for the integration of ESG data into corporate performance reporting (Garz et al., 2010). The named guideline was used because it sets out the overall requirements of ESG reporting and proposes key performance indicators (KPIs) from many economic subsectors for the ESG data collection. The indicators have been chosen and modified in such a way that characterise and express the capacity of the Estonian State to establish REEs recycling management.

The data collection is mainly carried out from 'Eurostat' database (cited in Table 1 according to the published year) while domestic reports, legislation and statistics, and internationally known indices were also used for exceptional cases. The study used the most recent published data (since 2016) and compared the Estonian figures with a Member State (Belgium) and the European average at all applicable places. Some of the past studies and information are also included to

Table 1
ESG evaluation model for REEs recycling in Estonia.

Indicator	Specifications	References
Environmental indicators		
Energy efficiency	Share of fossil fuels in gross available energy (%); energy dependency rate (%); share of renewable energy from final consumption (%), energy productivity (indexed to reference year 2000)	(Eurostat, 2019c, 2019d)
GHG emissions and SOx, NOx, VOC emissions	GHG emissions reduction (%) (in CO_2 equivalent) and other main air pollutants reduction (%), compared base year 1990	(European Environment Agency, 2020; Eurostat, 2020a)
Hazardous and non-hazardous waste produced and recycled	Hazardous waste generated total (Mt); non-hazardous waste generated total (Mt); re-used from total generated waste (%); recovery rate of municipal waste (%); municipal waste generation (kg per capita)	(Eurostat, 2020b; Estonian Environment Agency, 2019a)
Environmental taxation	Environmental taxes revenues,% from taxes and social contribution in 2017 (% of GDP)	(Eurostat, 2019e)
International indices related with environmental performance	Climate Change Performance Index (CCPI), Environmental Performance Index (EPI)	(Wendling et al., 2018; Germanwatch, 2019)
Social indicators		
International indices related with social performance	Human Development Index, Human Capital Index	(World Economic Forum, 2017; United Nations, 2019)
Health status, health care and death causes	Healthy life years and life expectancy at birth by sex (years); absence from work due to personal health problems (% of all age classes); self-reported unmet needs for health care (% of all age classes)	(Eurostat, 2019g)
Education and training	Tertiary educational attainment (% of population aged 30 to 34); employment rate of recent graduates (% of persons aged 20 to 34); adult participating in learning (% of population aged 25 to 64); PISA test results in 2018	(Eurostat, 2019b; OECD, 2019)
Labour costs and earnings	Labour costs index (2016=100); monthly and annual earnings comparison between SES 2010 and 2014 (€)	(Eurostat, 2019i)
Income and social inclusion	People at risk of poverty or social exclusion in 2018 (%)	(Eurostat, 2019h)
Social protection	Expenditures on social protection in 2017 (% of GDP)	(Eurostat, 2019k)
Community engagement in large scale development projects	Existing legislative framework (Planning Act, EIA Act, etc.) to engage local communities into developments decision-making process	(Tartu Postimees, 2018)
Governance indicators		
Overall GDP national statistics	GDP in PPS (purchasing power standards) index in 2018; real GDP growth rate in 2018 (%); nominal unit labour cost growth rate in 2018 (%)	(Eurostat, 2019j)

(continued on next page)

Table 1 (*continued*)

Indicator	Specifications	References
Government finance statistics	Government deficit in recent three years (% of GDP); general government gross debt in 2018 (% of GDP)	(Eurostat, 2019f)
Anti-corruption policy in Estonia	Info on policies and compliance with relevant laws, relating to bribery, fraud and money laundering	(GRECO, 2018; 2019)
Expenditures to the innovation and usage of ICT	Research and development expenditure in 2017,% of GDP; persons employed in the ICT sector in 2017 (% of total employment)	(Eurostat, 2019a)
Taxation system in Estonia	Info of taxation system; International Tax Competitiveness Index 2019	(Tax Foundation, 2019)
International indices related with governance performance	Economic Freedom Index 2019, Corruption Perseption Index 2018, Doing Business report 2019	(The Heritage Foundation, 2019; The World Bank Group, 2019; Transparency International, 2019)

%- percentage; Mt– million tons; GDP– gross domestic product; GHG– greenhouse gas; ICT– Information and Communications Technology; EIA– Environmental impact assessment; PISA– Programme for International Students Asssessment; SES– Structure of Earnings Survey.

better understand the global evolution in this field. Belgium was chosen because this Western European country has shown that recent interest is effective and fast-growing in the REEs recycling field. One best example is a company called `Umicore`, which effectively recycled REEs from EoL NiMH batteries. This comparison has been carried out to fortify the effectiveness of the ESG risk assessment model. The ESG factors considered in this evaluation model are given in Table 1 and under each factor, the main indicators with specification and references in the Estonian context are highlighted. Based on the ESG evaluation, a summary of the major findings of the study are furnished in detail and further provided with an insight into the REE recycling feasibility in Estonia.

3. Recycling potential of REEs in EU from various end-products- an overview

Wastes containing REEs can roughly be divided into three categories: REEs from industrial waste streams, wastes during processing and from EoL products. Industrial wastes of low REEs concentration, typically less than 1%, is the main obstacle keeping it less economically attractive towards a secondary source. The content of REEs in the EoL products are higher and therefore its recycling potential is considered to be more economically sensible (Binnemans et al., 2015). Recycling of REEs from EoL waste streams consists of a series of important steps. The pre-processing steps such as shredding, screening, magnetic, and other separation techniques to segregate REE containing components from other materials is rather complicated. The successfulness of pre-processing is often determined by the economic meaningfulness of the later processes (Ahonen et al., 2015). The extraction and purification after pre-processing to recover REEs with high purity is quite challenging and burdensome to the environment. This is doable via hydrometallurgical or pyrometallurgical routes. Both routes have advantages and disadvantages; however, the former is considered to be more viable and commercially matured for REEs recovery (Tunsu et al., 2015). Previous studies have indicated that the top three viable and valuable products for potential recycling of REEs from EoL wastes are permanent magnets, phosphorus and NiMH batteries (Rollat et al., 2016). These products are significantly concentrated with REEs and some of them have high demand in future.

3.1. *Permanent magnets (PMs)*

The major applications where permanent magnets (NdFeB) were used are electric bicycles, air conditioners, loudspeakers, magnetic separators, hard disk drives (HDDs), hybrid-electric vehicles (HEVs), wind turbine generators, other industrial and automotive applications and small electronics. To recover the highest volumes of permanent magnets in short term, HDDs and loudspeakers recycling seems to be the most beneficial, because these have magnets of significant REEs concentration (Lixandru et al., 2017). However, for long-term, wind turbines and HEVs could become the main sources for REEs recovery. This is because they contain a significant amount of REEs, especially scarce Nd, and its consumption is being increased due to the increased use of green energy technologies (Machacek and Fold, 2018). It is forecasted that, by 2030, 9% of Nd and 7% of Dy global demand could be possibly recovered from the aforementioned waste streams (Rademaker et al., 2013). Ciacci et al. (2019) estimated that ideally, up to 50% of the annual Nd demand in Europe could be met by domestic secondary supply; once the latent recycling potentials have turned into actual capacity.

The permanent magnets found in mixed electronics are usually in shredded forms. In this case, REEs stick to the ferromagnetic components, which makes its recovery very challenging. Another constrain is the extraction of detected magnets, despite some improvements recently achieved in this field. Hitachi announced that the company was recently implementing a machine to allocate rare earth magnets from HDDs and compressors (Lee et al., 2018). Despite some success stories in magnets processing steps, its recycling remains challenging. Novel cost-effective extraction methods are required to be in place. The same applies for the betterment of REE-containing components detection and separate collection systems, especially prior to shredding which can significantly increase the potential recycling capacity.

The future recycling potential of PMs could be shaped by the benefits of using REE-based technology and REEs prices increase. For instance, in the wind power sector, the demand for REEs, e.g. in permanent magnet synchronous generators, is predicted to increase because of the discernible growth rate of wind energy (IEA, 2019), while switching from conventional fuel to renewable (Vikström, 2020). It may take more than 10 years to have the first EoL magnets from the wind turbine. Therefore, in order to install the first large-size recycling operation, one should initiate the REEs recycling research and development action now as it will take five to ten years to be successfully installed on a large-scale operation (Schüler et al., 2011). Nevertheless, initiatives have been reporting in developing a cost-effective solution to replace (substitution) or reduce REE's utilization in PMs to avoid the REEs supply risks and price inflation rate (Pavel et al., 2017). The recent research development shows that the direct re-use of magnets in new turbines is possible if the coatings were chosen correctly (Hogberg et al., 2017). Moreover, the study shows that REEs in NdFeB magnets in modern HEVs are uneconomical to recycle as a separate stream considering the REEs prices in 2015. This is because of the high dismantling costs and low REEs prices, which inhibit the recycling economic performance (Nguyen et al., 2020). All of the aforementioned factors could possibly diminish the recycling potential of REEs from EoL magnets. Therefore, precaution should be taken while investing in REEs recycling of PMs as this has a lot of uncertainty in terms of profitability.

3.2. *Phosphorus*

Phosphorus stands as the second most promising source of REEs via recycling from EoL products. Phosphorus is mainly used in lighting and screens. Nowadays, REEs extraction from fluorescent lamps (FLs) represents the highest recycling potential, which contains critical HREEs and is collected separately from other waste streams. The most used recycling method is the attack of the phosphorus via the hydrometallurgical route to recover the REE content using several extractants

(Ahonen et al., 2015). The recent profitability study based on the REO's market prices indicates that the recycling of REOs from EoL FLs is economically unfeasible (Innocenzi et al., 2016). There have been many REE recovery processes from FLs which were successfully tested and developed (Wu et al., 2014; Van Loy et al., 2017), but most of them are unfeasible from an economic point of view, mainly because of the REEs prices (Tkaczyk et al., 2018).

The recycling of REOs from EoL lighting technologies as a secondary supply requires the characterisation of both future REOs demand and EoL streams from lighting technologies. During the past decade, the FLs have been replaced by light-emitting diodes (LEDs) of low REEs content, mainly because of its energy efficiency (Machacek et al., 2015). Consequently, there is a decrease in the volume of REEs in lighting phosphorus and the markets for Eu, Tb, and Y should experience a significant drop in demand (e.g. since 2015, the company 'Solvay' stopped phosphorus recycling operation in France). The main reasons reported are the low REE prices and substitution of FLs by LEDs in the market share (Guyonnet et al., 2018).

3.3. NiMH batteries

Another waste source which relatively contains REEs (Cerium (Cr), Lanthanum (La), Neodymium (Nd), Praseodymium (Pr)) is NiMH batteries. These batteries are used in renewable energy technologies (e.g. HEV power sources) and in transportable devices (e.g. mobile phones). Currently, NiMH batteries market share in the automotive industry shows a reduction in use, due to its substitution by lithium batteries (LIBs) (Li et al., 2019). However, REEs containing NiMH batteries retain a large market share in automotive applications.

The HEV market share in EoLVehicles (ELVs) is forecasted to increase. The recycling of REEs from EoL HEV NiMH batteries has got an attractive future scope since it contains REEs in large amount (Xu et al., 2016). There have been reported attempts which successfully recovered REEs from NiMH batteries in lab-scale (Meshram et al., 2016); however, few of them have implemented it in a commercial scale. The company 'Umicore' could recycle a substantial amount of EoL NiMH and Li-ion batteries via their UHT technology (Tytgat, 2013). The 'Umicore' recycling plant in Belgium could annually recycle a total of 7000 t of NiMH and Li-ion batteries.

4. Feasibility of a REEs recycling industry in Estonia - A Model evaluation

The immense growth of green and smart technologies may result to a rise in the global overconsumption of REEs. The recycling of REEs from EoL products has growing attention in the EU, as most of its supply is mainly controlled by one foreign country and the future possible local primary extraction in Europe is still ambiguous. In order to alleviate this issue, the present study identified and scrutinised the feasibility of adapting a potential REEs recycling unit in Estonia by evaluating the ESG risks. The main E, S and G findings based on the assessed indicators are latterly summarised in this article.

4.1. Environmental findings

There are many environmental factors which need serious attentions of developers. The energy indicators given in Table 2 reveals that Estonia is the most energy independent country in the EU. Estonia`s energy independency is low due to the utilization of a traditional domestic fossil fuel (oil shale – OS). The OS is still used in large volumes and therefore resource productivity, i.e. amount of materials directly used by an economy in relation to GDP, in Estonia is lower than Belgium and the EU average. Recently, however, energy consumption is shifting more towards renewables, where consumption is well above the Belgium and EU average.

Compared to the base year 1990, Greenhouse gas (GHG) emissions have dropped significantly in Estonia, which is more than Belgium and the EU average. Although GHG emissions per capita in Estonia is still almost twice higher than in Europe. Other main air pollutants have also dropped remarkably (Table 3). The same trend is observed in water consumption as well. Water usage for industrial purposes has declined around 35% in the last 15 years and water quality parameters have significantly improved (Estonian Environment Agency, 2019b). The main reasons are declined OS usage in the energy sector which gradually has been replaced by renewable resources and other technological developments.

Table 2
Energy indicators. (Eurostat, 2019c, 2019d).

Summary and comparison of used energy indicators (2017 data)	Estonia	EU-28	Belgium
Overall import dependency (%)	4.1	55.1	74.4
Share of energy from renewable sources (% share of gross final energy consumption)	29.1	17.4	9.0
Resource productivity (indexed to reference year 2000)	94.2	138.4	124.1

EU-28– European average of 28 Member States.

Waste generation is strongly affected by the OS industry in Estonia. The volumes of hazardous (ashes and semi-coke) and non-hazardous (solid waste rock) wastes produced are large, accordingly 9.8 and 14.6 Mt respectively in 2016 (Estonian Environment Agency, 2019a). However, it is vital to note that, the majority of previous hazardous OS ashes are classified as non-hazardous in Estonia according to the recent legal amendment. This is because of its similarity in properties with lignite combustion ashes class C. The latter are not classified as hazardous waste in Europe according to the decision of the European Commission waste list 2000/532/EC. The rate of reused percentage and landfilled rate of total generated wastes in the last ten years, on average, were 41 and 50%, respectively. Major re-use driver was the utilization of solid waste rock in road construction. About 97% of all waste generation comes from the OS mining and energy sector. Another constrain is the lower municipal waste recovery rate (28%), which is around half as compared to the EU average (46%) and Belgium (54%) in 2016. This is because Estonia incinerate majority of its municipal waste (over 50%); however, incineration is not considered as recovery step. Nevertheless, Estonia (390 kg) generated less municipal waste per capita (in kg) in 2017 than Belgium (409 kg) and the EU average (486 kg).

The developers should bear in mind that the environmental taxes share of total taxes in Estonia (8.8%) is higher than that of Belgium (5.0%) and the EU average (6.1%). The International Climate Change and Environmental Performance indices has ranked Estonia`s efforts in climate and environment protection rather high on a global scale, but it is still lower when compared to Eastern Europe and North America.

4.2. Social findings

Social aspects that are related to international indices measures of life expectancy, education, income, political freedom, human rights, and

Table 3
The main air pollutant indicators. (European Environment Agency, 2020; Eurostat, 2020a).

Air pollutants	Base year (1990)	EU-28 (2017)	Estonia (2017)	Belgium (2017)
GHG emissions reduction trend (in CO_2 equivalent), %	100	-22.70	-48.00	-20.30
NOx reduction trend,%	100	NA	-58.00	-57.00
SOx reduction trend,%	100	NA	-85.80	-90.00
VOC reduction trend,%	100	NA	-65.70	-67

NA- Not Available.
EU-28– European average of 28 Member States.

gender equality, have globally ranked Estonia in a relatively strong position (Table 4). Human Capital report stated that Estonia has high education quality in all education levels, which is expressed in high figures of high-skilled and medium-skilled personnel in employment shares. This is almost equivalent to that of Belgium as well. The risk factor in both countries is the lower labour force participation rate, which reflects that these countries are not utilizing its human capital enough to contribute to the economic activity. However, the labour participation rate in Belgium is almost 10% lower than Estonia (World Economic Forum, 2017).

Estonia`s population is ageing and its 2100′s projected old-age dependency ratio (58.3) is equivalent to Belgium and the EU average (54.3 and 57.3, respectively). In order to change this forecast, higher fertility rate or higher immigration rate should be achieved. Healthy life years of Estonian's on an average is 7 years shorter than in Belgium and the EU-28. Estonians are less absent from work due to less personal health problems. This figure in 2014 was 28.6% in all age classes, while for the EU-28 and Belgium, they were 34.5 and 39.1%, respectively. Health care is well organised in Estonia and the number of hospital visits is less than, on average, in the EU. Conversely, the main cause for unmet health care is financial reasons, which is double when compared to the EU average (30.8 and 14.8%, accordingly).

In view of education, on average, Estonia has more tertiary graduates and adults participating in learning than in the EU. The latter indicator is surprisingly low in Belgium. The employment rate of recent graduates, on average, is high as in the EU and Belgium (Table 5). In the last decade, the number of international students increased while the overall number of graduates are decreasing. This is mainly due to population decline and ageing. Education quality in Estonia is also high in primary and secondary education levels. For instance, Program for International Student Assessment (PISA) 2018 test results revealed that Estonian students ranked as first place in the mean score amongst EU countries in reading, mathematics, and science (OECD, 2019).

The labour costs index was one of the highest in Estonia (125.4 in the 3rd quarter of 2019). During the same time, the EU-28 and Belgium average were 108.7 and 105.1, respectively. Estonia has reduced the earnings gap between the EU average, although in terms of volumes, earnings in Estonia is very small when compared to the EU-28 (Table 6). The lower earnings might not attract local and foreign professionals to the labour market and this explains the high pressure on the labour costs index.

In 2018, 24.4% of the Estonian population lived at the risk of poverty while 21.8 and 20.0% respectively in the EU-28 and Belgium. The data difference between Estonia and the EU average is expressively seen in the age group of 65 years or over, where Estonia rate at-risk-of-poverty (37.3%) was almost double than in the EU-28 (20.5%). In 2017, expenditures on social protection such as pensions in Estonia were 16% of the GDP. This is almost half of Belgium and the EU-28 average, which were 28.8 and 28% of the GDP, respectively.

The legislative framework to engage interested parties in developments is well established in Estonia. This is mainly possible through the Planning Act, Environmental Impact Assessment (EIA) and Environmental Management System Act, and other related Acts. Thus, local authorities, local communities and individuals can take part and express thoughts and concerns regarding planned developments. However, one should always be cautious while communicating a new business proposal as the scepticism of local people could sometimes be high, which might stop the activities well before the EIA. This happened once in 2018, where a wood refinery establishment proposal near to the city of Tartu was cancelled because of local people's scepticism and protest. In this particular proposal, the developer's plan was not specific and transparent (Tartu Postimees, 2018).

Table 4
Social aspects related international indices. (World Economic Forum, 2017; United Nations, 2019).

International index, year	Estonia	Belgium	Total evaluated countries
The Human Development Index (HDI), 2018 ranking	30	17	189
The Global Human Capital Report, 2017 ranking	12	15	130

Table 5
Education and training indicators. (Eurostat, 2019b).

Indicator (2018 data)	Estonia	EU-28	Belgium
Tertiary educational attainment,% of population aged 30 to 34	47.2	40.7	47.6
Adult participation in learning,% of population aged 25 to 64	19.7	11.1	8.5
Employment rates of recent graduates,% of persons aged 20 to 34	81.7	81.6	83.4

EU-28– European average of 28 Member States.

4.3. Governance findings

The GDP of purchasing power standards (PPS) index in 2018, on average, was lower in Estonia (82) than in the EU-28 (set to equal 100), and Belgium (118). In the meantime, the real GDP growth rate was more than double in Estonia (4.8%) when compared to Belgium (1.5%) and the European average (2.0%). The average nominal unit labour cost growth rate in 2018 was higher in Estonia (6.5%) than in the EU and Belgium (1.7%). The government's "health status" in Estonia is also relatively in good condition. Nevertheless, Estonia has had slight government deficit, which varied between -0.5% and -0.8% of GDP in the recent three years. The general government gross debt was only 8.4% of GDP in 2018. This is substantially lower when compared to Belgium (98.6%) and the EU average (79.3%).

The success of anti-corruption activities is assessed via international assessments, mainly conducted by GRECO (The Group of States against Corruption). The GRECO assessments in the years 2018 and 2019 concluded that both countries performed well in the fight against corruption with minor recommendations. Estonia's expenditures on research and development (R&D) were lower than in Belgium and the EU-28. The main difference in expenditures is in the business enterprise sector where Estonia figures are lower than half of the EU-28. Estonia actively uses the technical possibilities of information and communication technologies (ICT), especially when interacting with public authorities. Around 4% of the population works in the ICT sector and this is amongst the highest of the EU-28.

The business establishment and taxation system, are well structured in Estonia. An effective tax code is neutral and competitive; i.e. tax rates are low. In Estonia, tax rates are relatively flat and it favours investing. Estonia's corporate income tax (20%) system only taxes distributed earnings, allowing companies to re-invest their profits tax-free. Personal income tax (20%) does not apply to individual dividend income and property tax only apply to the value of the land. The effective taxation system in Belgium is downsized by its high corporate tax rate (29.6%), the high tax burden on labour (52.7%), and taxes from real estate, net wealth, and financial transactions. The Tax Foundation has recognized Estonia as one of the best tax code countries in the OECD.

Estonia stands a top position while considering the three main international indices that measure governance performance. Economic freedom in Estonia is high, the taxation system is transparent and the economy is very open to foreign investments. However, some concerns have been raised regarding increased government spending and labour freedom. Recently, financial and monetary freedom of the country has destabilised due to exposed money-laundering schemes related to Russian assets in the banking sector. Corruption in the public sector and bribery risk are very low, the State effectively exploits opportunities

Table 6
Earnings from Structure of Earnings Survey (SES). (Eurostat, 2019i).

Structure of Earnings Survey (SES)	EU-28 SES 2010	SES 2014	% change	Estonia SES 2010	SES 2014	% change	Belgium SES 2010	SES 2014	% change
Monthly earnings, €	2097	2278	8.63	777	999	28.57	2749	2956	7.53
Annual earnings, €	31,176	34,210	9.73	10,585	13,609	28.57	45,280	47,257	4.36

EU-28– European average of 28 Member States.

offered by the ICT sector so as to produce opportunities for starting a new business in Estonia (Table 7).

4.4. Summary of ESG factors comparison between Estonia and Belgium

The summary of the comparison between the two States is given in Table 8. The comparison of ESG factors between the two States indicates that both countries are equivalent in many aspects (Table 8). However, Estonia stands a step forward in performance in certain aspects which makes the State more suitable to establish a REEs recycling business.

4.5. Future development of REE recycling industry in Estonia

Starting a REEs recycling business in Estonia or in any other Member State is only possible upon the complication of the EU regulations. The objectives of the regulations have been incorporated into the national legislation, including Estonia. The requirements of the directives, such as strict environmental restrictions on air emissions and waste recovery rates, will certainly have an impact on the recycling of REEs. However, it is certain and the State's history in compliance with these regulation shows that the country strictly follows the EU regulations and directives in place. It is imperative to adapt the EU legal framework to motivate and facilitate the recycling of rare earths business as well. The present study does not intend to give a detailed analysis of the impact of the regulations and directives as it is strictly beyond the current scope of this study.

The establishment of a REE recycling entity in Estonia is a long process, which will take at least five to ten years for a large size operation in the field. Extensive research and development, identification of material and waste streams, appropriate logistics solutions, and cost-effective collection and treatment methods are required to be in place to establish an effective recycling plant. In the course of development, most likely a pilot plant should be first needed to justify the reliability and profitability of the total operation. The establishment of the recycling of rare earth entails high financial risks and uncertainty due to the fluctuation of REEs, energy, and raw material prices. Although a number of laboratory-scale methods for separating REEs have been developing rapidly, few have been turned into pilot scales to be rolled out cost-effectively on industrial scales. However, recent studies have suggest that it may be possible, as Amato et al. (2019) proposed a hypothetical and profitable REEs recycling plant to recover REEs from fluorescent powders, fluid catalytic cracking catalysts, and permanent magnets. The economic potential of REE recovery has also been identified using electrochemical (Venkatesan et al., 2018) or bioleaching (Thomson et al., 2018) methods. This all induces the expectancy of a viable and economically efficient REEs recycling on an industrial scale in the near future.

Table 7
Governance aspects related international indices. (The Heritage Foundation, 2019; The World Bank Group, 2019; Transparency International, 2019).

International index, year	Estonian	Belgium	Total evaluated countries
Economic Freedom Index, 2019 ranking	15 7th in EU region	48 25th in EU region	180 44 from EU region
Corruption Perceptions Index (CPI), 2018 ranking	18	17	180
Doing Business Index, 2019 ranking	16	45	190

Table 8
Summary of ESG factors comparison between Estonia and Belgium.

Indicators	Comparison summary
Environmental	Estonia is much less energy dependant and with highest share of renewables in energy consumption Both countries have excellent performance in reduction of air emissions Belgium generate more municipal waste, but has higher recovery rate compared to Estonia
Social	The quality of education and qualified workforce are equivalent in both Estonia and Belgium, whereas Belgium has a lower labour force participation rate Estonia has lower earnings, but this may be an advantage over Belgium to keep the labour cost lower
Governance	The tax burden and government spending in Belgium are higher compared to Estonia Both countries are struggling with labour productivity and employment growth Starting a business is a relatively quick process in both countries, although Estonia's indicators are better than Belgium, including companies establishing costs

5. Conclusion

The REEs consumption around Europe is ever-growing and no forthcoming plans at present are in place to start primary extraction of REEs in Europe. Therefore, REE recycling has the greatest potential and importance in the EU to be established to meet its future secured supply. The highest REE recycling potential identified are from the permanent NdFeB magnets, NiMH batteries, and fluorescent lamps, these contain significant quantities of most valuable REEs.

The proposed model shows that the use of the ESG indicators is also suitable for assessing the country's performance for a new business scope. The ESG risks evaluation model demonstrates that Estonia is suitable for establishing a potential REEs recycling industry. The country`s environmental burden seems to be reduced due to the decrease of OS mining while switching to renewable energy sources. The environmental health in Estonia is good and there are no significant constraints to establish a REE recycling industry. In view of the social aspects, Estonia has a highly educated and skilled workforce and the education system is of high quality. In addition, people are interested in lifelong learning and upgrading skills, even in older ages. The State's lower average earnings could turn into an advantage to keep daily costs low. The establishment of a REE handling industry should definitely increase the number of people participating in the labour market and contribute to economic growth. The country's economy is very open to foreign investments, workforces and the taxation system is amongst the finest in the EU, which all makes Estonia as a fertile ground to start a new business.

Although obtaining REEs from waste, especially EoL waste, has untapped potential, it is not yet a complete alternative for the extraction of natural resources. Whereas, this acts as a supplementary option to meet the future REEs demands. The ESG risk assessment model, indicate that the implementation of a REE recycling industry in Estonia cannot be achieved before 2030. This is because the development of such projects, including research and development, environmental assessment, cost-benefit analysis and running test plants, takes a long time to get completed. In addition, there is a need for more clarity in the profitability of REEs treatment methods that can be applied at the industrial level. The present study does not assert any investigation on the state-of-art or current lab-scale practices in the REE recycling research. However, the study tries to promote a new business case in Estonia by assessing the present ESG risks and factors in the country.

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Appendix 2

Paper II

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Original article

Important environmental social governance risks in potential phosphorite mining in Estonia

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ABSTRACT

The country`s national resources must be used sustainably, considering the environmental, social, and economic aspects. Estonia's potential reserves of phosphorite are among the largest in Europe, but its extraction has been a historically sensitive issue. The current study was focused on Estonians` perceptions about the potential extraction and processing of phosphorite in four stakeholder groups: the local community, the business sector, policymakers and environmental activists. An Environmental Social Governance (ESG)-risks based survey was conducted that examined the significant environmental, social and governance risks that stakeholders would like to know if such production exists. The results obtained reveal that environmental risks were more important and social risks were less important. In the cross-stakeholder comparison, environmental risks were most important for the local community and environmental activists, social risks were most important for the local community and less important for environmental activists, with the business sector valuing the importance of governance risks the most. Policymakers had more or less a similar assessment in all ESG categories. To address the multifaceted challenges of phosphorite uptake, the authors suggest creating a framework that will act as a guideline for policymakers in the future on phosphorite resource sustainable use.

1. Introduction

Estonian phosphate is Obolus sandstone, i.e. shelly phosphorite. It is a composition of quartz and biogenic phosphate, represented by remnants of brachiopods. The brachiopod shells and detritus contain up to 35–37% industrially useful P_2O_5. In the whole phosphorite layer, the content of P_2O_5 is in a range of 3–25%. Enrichment (flotation) of Estonian phosphorite enables the achievement of a concentrate with a P_2O_5 content of 31–33% (Raukas amd Teedumäe, 1997; Raudsep, 2008). What makes Estonian phosphorite potentially valuable is it`s low or medium content of hazardous substances like Cadmium (Cd), Uranium (U), and Strontium (Sr), compared to other common phosphorite deposits in the world. The harmful substances influencing Estonian phosphate excavation and processing are dolomitic cements and pyrite. The latter has a tendency to self-ignite due to pyrite oxidation when graptolite argillite (black shale) layer above phosphorite is exposed to atmospheric conditions during excavation, as was experienced in the past. This has caused environmental problems such as the emissions of hazardous gasses and substances (Veiderma and Viisimaa, 1989; Petersell, 2011).

Although phosphorite has been mined in Estonia on a small scale since the 1920s as low-quality phosphorite meal mainly for domestic use, more intensive phosphorite surveys took place in the 1970s and 1980s. Exploration culminated in a plan to start large-scale phosphorite mining in the second half of the 1980s by Soviet Union authorities, and this plan met with strong social opposition, which can broadly be divided into two. Firstly, large environmental impacts were feared, where the main threats were the drainage of groundwater aquifers, the leaching of hazardous substances from graptolite argillite layer, and the lack of extraction technologies in underground mining conditions (Petersell, 2015; Reinsalu, 2016). Secondly, the less talked about reason was the great need for labor, which meant a large influx of new workers, probably from other republics of the Soviet Union (Noorkõiv, 1988). The re-emergence of Estonians' aspirations for independence to restore their republic and their desire to decide for themselves remained in the same period. The result was a national movement, known as the `phosphorite war` to suspend phosphorite mining plans (Aare, 1999). Thus, social acceptance became very low, and the so-called social license to operate (SLO) was lost. SLO can be defined as public acceptance of mining

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operations by local residents and other stakeholders (Prno, 2013; Parsons et al., 2014). Higher levels of SLO are achieved gradually as an operation establishes legitimacy, credibility, and trust. Achieving SLO is an ongoing process that must be earned and maintained, as it can be withdrawn at any stage of the operation (Litmanen et al., 2016).

A consequence was that phosphorite mining stopped in 1991 and phosphorite reserves named as passive reserves by the Estonian Mineral Resources Commission's decision No. 96–27 of 15.05.1996 (Keskkonnaministeerium, 1996). Phosphorite mining and exploration became a taboo subject and have not been systematically studied for the past 30 years. Phosphorite reserves in Estonia are estimated to be 2.954 billion tons and they are located in four mineral deposits: Rakvere, Toolse, Aseri and Tsitre, see Fig. 1 (Republic of Estonia Land Board, 2020). Among them, the Toolse and Rakvere deposits are the most promising in the context of potential phosphorite mining.

According to U.S. Geological Survey (2020) the phosphate rock traded world production was around 250 million tonnes in 2018 and total world resources are estimated at more than 300 billion tonnes. The main phosphate rock extracting countries are the US, China and Morocco. The largest sedimentary deposits are found in northern Africa, the Middle East, China, and the US. The majority of phosphorus (over 80%) is used to make fertilizers, around 10% is used for animal feed, and the rest for other industrial applications like cleaners, detergents, food and beverages, metal and water treatment, flame-retardants, etc. Its extraction has steadily increased in the last decades (OECD, 2015). Since Europe is almost entirely dependent on phosphate rock import from the rest of the world and its supply disruption risk, mainly from politically unstable North-Africa and the Middle East countries, is high, the EU has named phosphate rock as critical raw material for Europe (European Commission, 2020).

In addition, phosphorite also contains valuable rare earth elements (REE), and in nearby graptolite argillite layer Vanadium (V), and Molybdenum (Mo). The REEs and V are also critical raw materials for Europe. The REEs are commonly used in magnets, alloys, catalysts, polishing agents, glass, ceramics, batteries, and lamp phosphorus. To date, they are not mined in Europe, and Europe is entirely dependant on their import (Paat et al., 2020). Their exact concentration, distribution in the deposit, and processing technologies need further clarification (Tõnsuaadu et al., 2020).

Phosphorite mining is not a sensitive issue only in Estonia, but also in other parts of the world (Carver, 2019; Martinez-Escobar and Mallela, 2019). There are fears of damaging the environment and great social skepticism about this activity. To overcome this, it is essential to map the relevant risks and improve the SLO. Therefore, ESG risks assessment methodology as a tool was used in the current study to find the answer to the question what are the most important environmental, social, and governance risks when phosphorite reserves are mined in Estonia. The created tool was tested in a pilot study, where respondents ranked the most important (and also less important) risks if hypothetically this reserve is extracted. In the next section, ESG is shortly introduced, followed by the methodology explanation of how the most important ESG risks are identified. In Sections 4 and 5, the results of the pilot study is demonstrated and discussed and in the final section, the main findings are summarized and the limitations and prospects of the study in the light of future research related to the named reserves are presented.

2. What is ESG and the variety of ESG frameworks

Today's globalized economy increasingly put pressure on businesses to be accountable and transparent for their actions, which can have a notable influence on the environment and society. Therefore, more and more companies report their non-financial information on how they affect the surrounding environment and society where they operate. It is called environmental (E), social (S), and governance (G) reporting, where E stands for how a company`s operations impact the environment and what they do to minimize its impacts. S reveals how the company interacts with employees, suppliers, the local community, etc. This can include the health and safety of the employees, commitment to the local

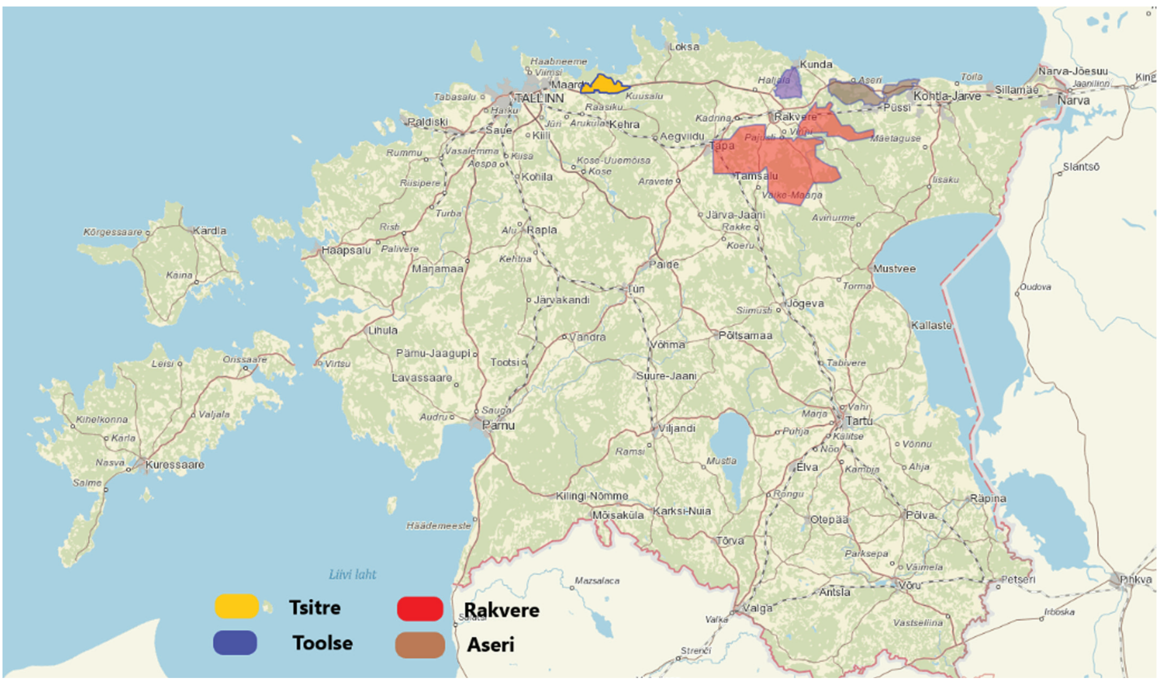

Fig. 1. Phosphorite deposits of Estonia (adapted from Republic of Estonia Land Board map application).

community, and other relevant dimensions. G is observing transparency, diversity, and independence of the company, e.g. shareholders' rights, fight against corruption, tax transparency, etc.

It is more evident that ESG influences are becoming an essential part of the business activities that generate organizational worthiness. Further to this, disclosure of ESG information attracts investors who're seeking possibilities to invest in entities with higher sustainability. Several comprehensive studies have revealed that companies who operate according to the ESG principles have positive (or at least non-negative) relation to their financial performance (Friede et al., 2015; Ramic, 2019).

Quite a number of initiatives and standards provide guidance on how companies should report their ESG data. They can be conditionally divided into several subcategories. These could be industry-specific initiatives such as The Mining Association of Canada's (MAC) Towards Sustainable Mining standard, developed for Canadian mining companies. A distinction can also be made between management system standards (e.g. ISO 14,001: Environmental Management System Standard), international voluntary initiatives (e.g. Extractive Industries Transparency Initiative), reporting and disclosure standards (e.g. Global Reporting Initiative), socially responsible investing indices (e.g. Dow Jones Sustainability Index) and financing standards such as the International Financing Corporation Performance Standards. Further to this exists also commodity-specific standards like Responsible Jewelry for sustainable jewelry and watch industry or International Cyanide Code for responsible use of cyanide in the gold mining industry.

As can be seen, the range of possible ESG reporting frameworks is diverse. However, due to the lack of commonly agreed and harmonized ESG reporting practices or disclosure standards, the comparability of disclosed ESG information remains still problematic (de Silva Lokuwaduge and de Silva, 2020).

3. Methodology

The approach employed in this study to identify the most important ESG risks is given in Fig. 2 and in more detail below.

3.1. Implementation stages of the methodology

In the first phase, more than twenty known ESG reporting frameworks were reviewed and, based on their complexity, relevance, clarity and user-friendliness, three frameworks were selected for a pilot study, in which a total of 101 risks was counted. These were:

- ✓ Global Reporting Initiative (GRI). GRI is known as the most widely used reporting framework that nowadays companies use to disclose their impacts. A Consolidated set of GRI sustainability reporting standards 2020 were used in the study (Global Sustainability Standards Board, 2020)
- ✓ Sustainability Accounting Standards Board (SASB). SASB Standards focus more on the information that is financially material. Metals and Mining Sustainability Accounting Standard 2018 were used in the study (Sustainability Accounting Standards Board, 2018)
- ✓ International Finance Corporation (IFC) Performance Standards (PC). IFC PCs provide clients guidance on how to identify, avoid, mitigate, and manage environmental and social risks at the project-level and they are mandatory to follow if a project is financed by IFC. By its nature, the extraction and processing of phosphorite is also a development project and is therefore suitable for us. IFC 2012 Performance Standards were used (International Finance Corporation, 2012).

Moreover, as one of the main objectives of the study was to examine the views of different stakeholders, one of the preconditions was also to identify the most relevant stakeholders. For us, they are "key players" who are affected the most in the acceptance of phosphorite extraction and processing at the local level and many empirical studies point to different perceptions between them and the developer (Mzembe and Downs, 2014; Viveros, 2016). Therefore, in the context of this study, the following four stakeholders were considered to be the most important, where the first three are geographically located mainly in the Toolse and Rakvere phosphorite deposit areas (see Fig. 1.):

- ✓ local residents and organizations such as village societies (hereinafter local community) who live near reserves and will be directly exposed to the positive (e.g. job creation) or negative (e.g. environmental hazards) impacts of the activities;
- ✓ local representatives of industry and business (hereinafter business sector) from various fields such as mining, tourism, farmers, trade, etc. The planned activities may affect their business interests both positively (e.g. as a subcontracting service provider) and negatively (e.g. the value of agricultural land might decrease for farmers);
- ✓ policymakers at both national (ministries) and local (local government officials) levels. Politicians from local branches of political parties were also included in this stakeholder group in our pilot study. They set the regulations for mining, environmental, public,

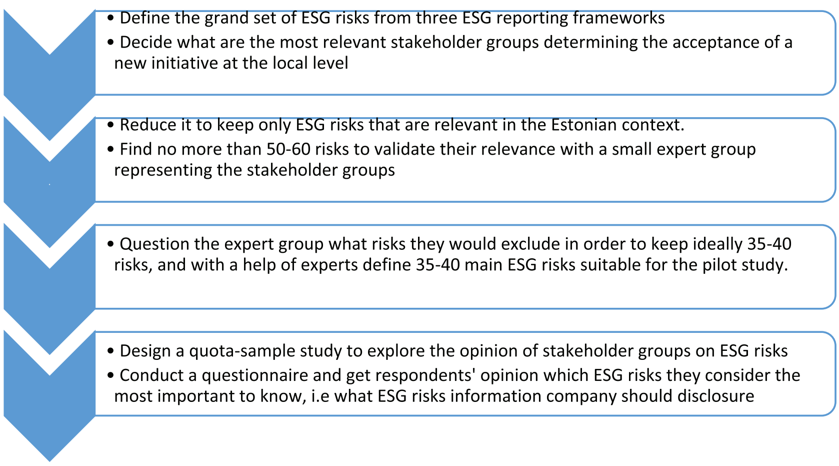

Fig. 2. Approach for defining the most important ESG risks.

and occupational protection, and quite often their decisions can be unpopular for different stakeholders;

✓ environmental activists from various environmental associations in Estonia. Above all, they appreciate the preservation of the environmental value and are mostly opposed to the establishment of similar large-scale industries.

Further to this, authors also surveyed the beliefs of stakeholder groups by gender, education, and age, as these parameters are important in shaping people's values and thus opinions. For example, the changing roles of women exert pressure to reduce gender inequalities in the extractive industry (Jenkins, 2014), also there is a clear need for highly educated workers in this rather unpopular industrial sector (Kazanin and Drebenstedt, 2017) and cross-generational differences often mean a change in values from openness in the younger generation to deep conservatism in the older generation (Lilleoja and Raudsepp, 2016). Therefore, it is useful to know how opinions differ on the importance of ESG risks and where the biggest discrepancies lie. The authors did not study the parameters related to nationality and language, but this may be important in the Estonian context because historically the Russian-speaking minority in Estonia is more represented in the mining profession, as discussed in the related thesis (Kesküla, 2012). The reason why the Russian-speaking minority was not included in this study was that they live in a different county and not close to the phosphorite reserves, i.e. they don`t represent the local community.

In the second phase, the 101 ESG risks were reviewed and with the help of a small group of experts prioritized 59 risks that were relevant in the Estonian context. For example, child and forced labor and other risks that are not pertinent in Estonia according to author`s and experts` understanding were excluded. The expert group consisted of five people who reflected the chosen stakeholder groups, i.e. they represented the views of policymakers, local business and people, and environmental protection. The involvement and input of experts were held in the form of an interview. In the final step, the authors asked the experts to further assess which of these risks are less important according to their personal expertise, perceptions and beliefs, and in the end, the most significant 40 risks identified that formed the basis of the questionnaire.

3.2. Sampling methods and data collection

In the pilot study, a non-probability sampling method was used meaning that the results do not reflect the representativeness of the whole population, i.e. Estonian residents. There were two main reasons for choosing the named method. First, the aim of the study was to map the differences between stakeholders on the significance of ESG risks on the use of phosphorite, which has not been systematically studied in Estonia before. For this, the representativeness of the sample is not currently relevant. Secondly, to ensure representativeness, it is necessary to use a probability sampling method, which is financially expensive and authors did not have the budgetary means to do so. Hence, as this was also a pilot study, it was more reasonable to use a non-probability sampling to obtain preliminary conclusions, where the methods of quota sampling and snowball sampling were applied in more details. The former seeks to gain detailed knowledge of a specific phenomenon, i.e. in our case the importance of ESG risks in different stakeholders. For quota sampling, authors set as a target 120 responses (30 from each stakeholder), which according to the authors' belief is sufficient enough to draw preliminary conclusions about which ESG risks are most important for respondents from different stakeholders in phosphorite mining and processing. The latter, snowball method, represents a technique where the first respondents lead on to the next respondents. For that, authors mapped at first potential organizations and people who redistributed the questionnaire in their networks.

The questionnaire contained 40 questions and a final open question. The respondents had to evaluate each question importance on a scale from 1 to 7, broken down as follows: 1 – not at all important; 2 – not important; 3 – rather not important; 4 – so and so; 5 – rather important; 6 – important; 7 - very important. Responding to the survey was anonymous. From a total of 40 questions, 7 questions represented governance risks (questions 1 to 7), 20 questions represented environmental risks (questions 8 to 27), and 13 questions stand for social risks (questions 28 to 40). See questions in Appendix.

The survey was conducted in November 2020 in an online format using the Google Forms platform and MS Excel was used to analyze the results.

4. Results of the pilot study

In total, 134 responses were received, which distribution by the stakeholders' group can be seen in Fig. 3 and the affiliation of respondents by gender, education, and age in Table 1. This was more than our original target of 120 responses, although achieving 30 responses from each stakeholder group wasn`t obtained only among environmental activists. The reason for that might be that the use of the snowballing method wasn`t effective enough in this stakeholder group.

4.1. Average relevance of ESG risks in the sample

Looking at the average significance of the ESG risks in each question in all stakeholder groups, all risks were generally considered to be significant or very significant. The mean value of each question ranged from 4.24 to 6.50 (see Fig. 4).

The most important risk that respondents want to know is the company's activities, which have a significant negative impact on the living environment of the local community (6.5 points out of 7). Many risks related to the environment were assessed as important or very important risks, including water-related risks (q. 12, 15, and 17), the company's impact and activities on protected areas (q. 18 and 19), waste generation (q. 23) and air emissions (q. 21). Moreover, the number of environmental violations within the company was also considered a very important risk to know about (q. 26). From the social point of view, in addition to the effects on the living environment of the local community, land acquisition and resettlement operations (q. 39) were also considered important. From the governance perspective, it was considered important to know whether the company takes into account the effects of climate change in its activities (q. 2). In addition, the mining method (quarry or mine) for phosphorite extraction was also considered important (q. 20).

As a rule, social risks were considered to be the least important to know, i.e. among the 10 least significant risks, as many as 7 were social risks. Risks related to employee training (q. 33), employee qualifications, and remuneration (q. 28) and employee satisfaction (q. 29) were considered to be the least important. Relatively insignificant risks, compared to other risks, were also whether the company evaluates the socially correct behavior of its partners and subcontractors (q. 37), politicians support (q. 38), and risks related to a safe working

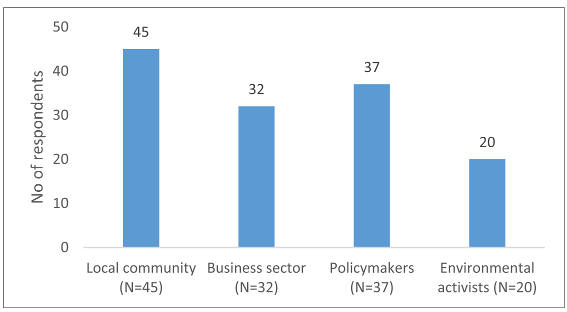

Fig. 3. Distribution of respondents by stakeholders (total $N = 134$).

Table 1
Affiliation by gender, education, and age (number and %).

	Total		Gender (%)			Level of education (%)		Age composition (%)			
	N	%	Men	Women	Not revealed	Higher	Primary and secondary	<25	26–45	46–65	>65
Local community	45	34	38	62	–	62	38	20	27	42	11
Business sector	32	24	75	22	3	88	12	–	50	50	–
Policymakers	37	28	43	54	3	84	16	–	46	54	–
Environmental activists	20	15	55	40	5	85	15	20	45	35	–
Total	%	100	51	47	2	78	22	11	29	36	4
	N	134	68	63	3	104	30	13	54	62	5

N – number of respondents.

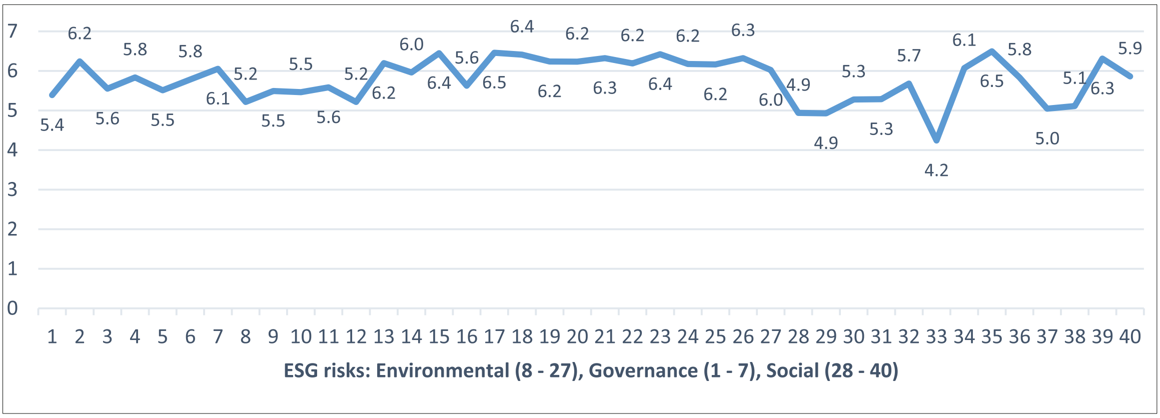

Fig. 4. ESG risks average importance in each question, scale 1…7 (see questions in Appendix).

environment and accidents at work (q. 30 and 31). In terms of the environment, the least important risks compared to others were which materials the company uses in its production (q. 8) and how much it has reduced its energy consumption (q. 12). From the governance perspective, the least important risk to know about was whether the company makes a profit (q. 1).

When comparing averages for the relevance of environmental, social, and governance-related risks across the sample, environmental risks are the most important, and social risks are the least important. However, there are some differences between the stakeholder groups (see Fig. 5). The local community and environmental activists consider environmental risks as the most important. At the same time, the local community also considers social risks much more important than others. This assessment is very logical, as they are the most affected stakeholder in the case of potential mining. The business sector considers governance-related risks as the most important, followed by environmental and social risks. Policymakers assess all three risk categories fairly evenly, although environmental risks are considered slightly more important than others. Environmental activists consider social risks to be the least important than others.

If to compare the biggest differences of stakeholder groups in the questions, where the average of the answers differs by more than 1.0

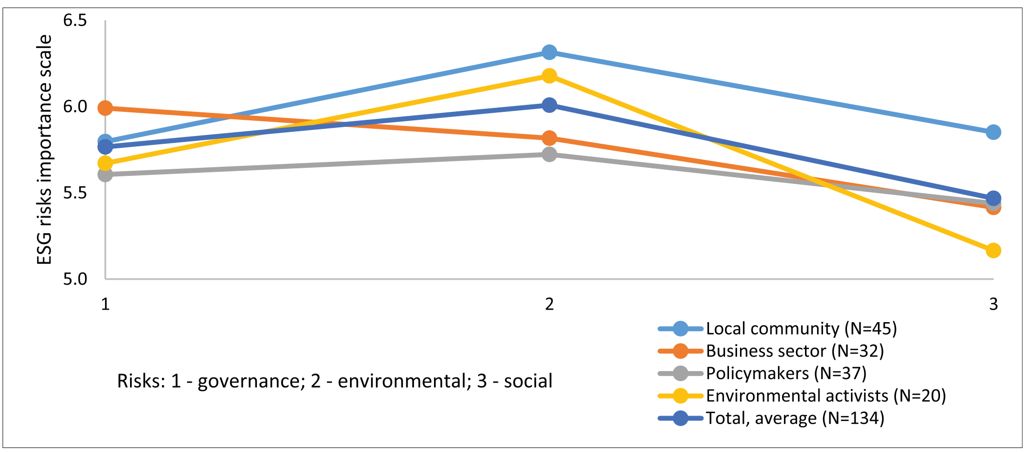

Fig. 5. Average importance of ESG risks by stakeholders.

point, the following observations can be drawn:

- ✓ Governance risks were considered most important by the business sector. This is illustrated, for example, by the fact that the business sector wanted to know most about the company's profitability, the purchase of products or services from local suppliers and partners, and the payment of taxes in a hypothetical phosphorite mining and processing company.
- ✓ Knowledge of the social risks of hypothetical phosphorite mining and processing is much more important for the local community than for other stakeholders. This is evidenced by the answers to questions 28, 30, 31, 33, and 40, which the local community considers to be more important than others, especially environmental activists. For example, issues related to job creation, a safe working environment, and employee training are much more important for them.
- ✓ There are no major variations in the differences in environmental risks between stakeholders, i.e. in general they are less than 1.0 point. It can be pointed out that on average knowledge of various environmental risks is more important for the local community and environmental activists than for the business sector and policymakers.

4.2. *Results by gender*

There were no major differences between male and female opinions, i.e. they assessed the importance of the different issues in a relatively similar way. For all 40 questions, the difference between the male and female answers was 0.26 point on average. The difference between the responses of men and women was most visible at question 9 (0.81) and question 10 (0.91), i.e. what materials the company uses in its production and how much energy it consumes was more important for women than for men.

However, a comparison between men and women according to an average of environmental, social, and governance risks reveals that environmental risks were more important for women than for men, see Fig. 6. This is mainly due to the views of the business sector and policymakers, as in these stakeholder groups, women rated environmental risks more important than men. It should be emphasized, however, that the proportion of female respondents in the business sector was low, which may distort the results.

4.3. *Results by education*

The data analysis revealed that the respondents with primary and secondary education versus higher education assessed the importance of the different questions very similarly (i.e. the difference between the answers was 0.27 point on average) and no large differences were found between the questions. According to Fig. 7, when comparing environmental, social, and governance risk averages, environmental and social issues were considered slightly more important by respondents with primary and secondary education. However, it should be stressed that there was a large predominance of respondents with higher education in the sample, which may affect the reliability of the results.

4.4. *Results by age*

As there were few respondents over the age of 65, the average for all age groups is not well comparable. It can be pointed out that people over the age of 65 rated social risks much more important than other age groups (see Fig. 8). The biggest difference in some questions (i.e. more than 2 points) was between the answers over 65 and under 25. For example, respondents over the age of 65 considered it much more important to know what training the company offers to its employees and whether the company has assessed the social behavior of its subcontractors. However, in order to obtain more accurate comparative data, the number of these age groups in the sample needs to be increased.

4.5. *Results of open question*

A total of 23 out of 134 respondents answered the open question. Environmental activists were the most 'vocal' in answering the open question (8), while the business sector (4) and policymakers (5) commented the least. Six people from the local community responded. The following conclusions can be drawn from the answers to the open question:

- ✓ Among every stakeholder group there was at least one reply stating that the extraction and processing of phosphorite is unacceptable.
- ✓ Among every stakeholder group, someone mentioned the need to use state-of-the-art production technologies to ensure the least environmental impact and damage. If these technologies do not exist and the environmental impact is significant, it would be preferable not to extract this resource.
- ✓ From the comments of the local community, it was suggested to think of other alternative production activities what this company could do additionally while mining.
- ✓ It was thought from the business sector that the whole of Estonia should receive a large part of the revenue from phosphorite processing, not only the narrower business community and that

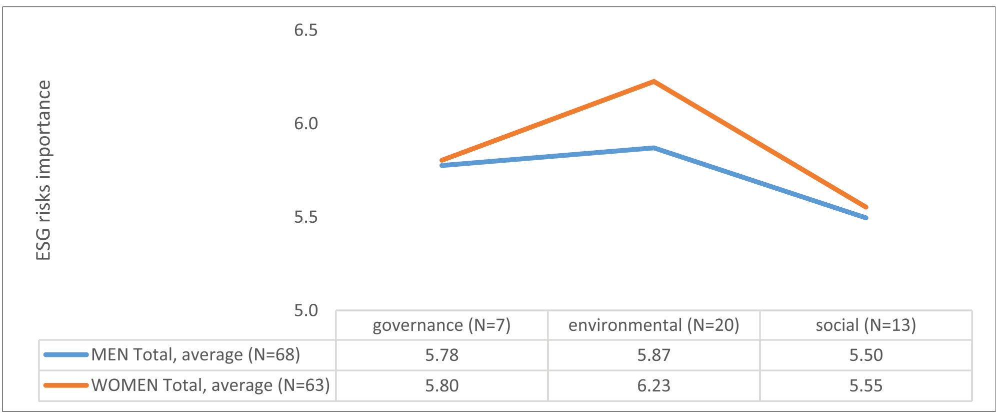

Fig. 6. Average importance of ESG risks by gender.

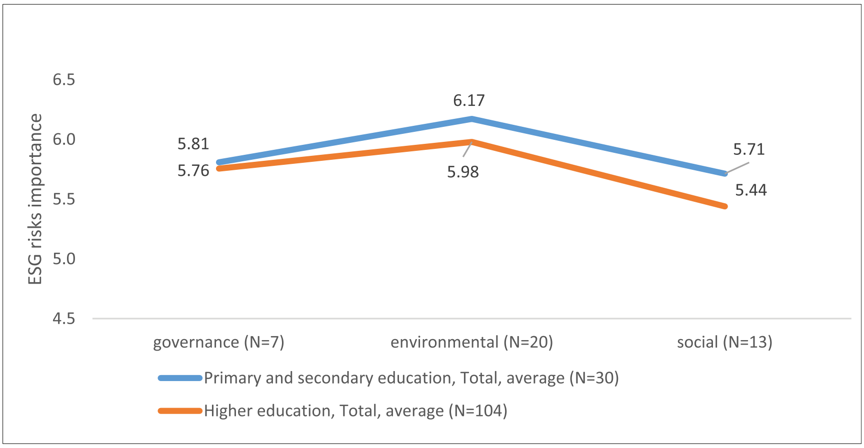

Fig. 7. Average importance of ESG risks by education.

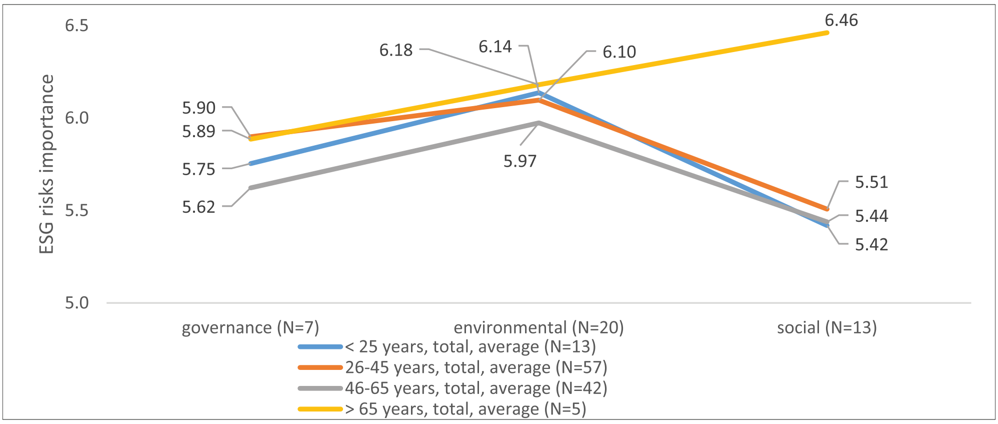

Fig. 8. Average importance of ESG risks by age.

phosphorite ore should be valorized at the highest level on the spot in Estonia (e.g. produce fertilizers) and not to be exported elsewhere.

✓ In addition, policymakers consider it important to know the views of local people, i.e. whether and under what conditions they agree to mining.

✓ Environmental activists would like to know what the long-term impact of mining is and will it be taken into account on both time and space-scale, including the impact on the change in the value of ecosystem services.

4.6. Dispersion analysis

A dispersion analysis for each respondent within each stakeholder group was also performed and compared their average between different stakeholder groups. With this analysis, the size of the standard deviation was estimated, i.e. whether the respondents' answers are usually far or close to the general average. A comparison of the mean of the standard deviation between stakeholder groups is presented in Table 2. The results show that the means of the standard deviation between the stakeholders are relatively similar and the standard deviation around 1.0 if the estimation could be between 1 and 7, can be considered small. This means that the respondents have been quite unanimous in their answers, although there were a couple of respondents in each stakeholder group whose assessments varied widely.

Table 2
The mean of the standard deviation within stakeholders.

The mean of the standard deviation within stakeholder groups	
Local community ($N = 45$)	1,04
Business sector ($N = 32$)	1,10
Policymakers ($N = 37$)	1,11
Environmental activists ($N = 20$)	1,28

N – number of respondents.

5. Discussion

This ESG risks-based survey is novel and the first in a long time to examine people's perceptions of potential phosphorite mining. It maps people's fears and worries, i.e. what risks are most important to know if such production exists. The outcome of the work could be an input to policymakers in planning further research and mitigating risks. Paramount for the potential extraction and processing of phosphorite were the environmental risks, which were assessed relatively equally in all aspects, i.e. water, waste, air emissions, biodiversity, material and energy use, although the latter was a bit less substantial. These risks require systematic research, including the change and magnitude of the impact over time, taking into account the quantity and quality of geological reserves, the expected location of the mining and processing area, the assessment of the use of state-of-the-art mitigation technologies, local community expectations, etc. Another important risk group is the risks related to the involvement of the local community and the occurrence of negative effects on them (questions 34, 35 and 39). Although not directly explored in the survey, both historical legacy and the answers to an open question, point to low social acceptance of the exploitation of phosphorite reserves. In addition to researching and mitigating environmental issues, obtaining an SLO is an equivalent precondition, where trust plays a central part in gaining the license.

Recent empirical studies identify the following key factors in achieving SLO at the local community level: (i) procedural fairness, i.e. communities are treated respectfully and have a voice in the decision-making process; (ii) impacts on social infrastructure, which can be positive (e.g. job creation) and negative (e.g. housing availability and affordability increases for locals), and (iii) contact quality, which creates positive or negative intergroup relations (Moffat and Zhang, 2014). Another study by Zhang et al. (2015) at the national level define as SLO key components distributional fairness, procedural fairness, and confidence in governance to achieve the public`s acceptance of the mining. The former can be understood as a fair share received from resource exploitation, procedural fairness implies engagement in the decision-making process, and confidence in governance means how strongly governmental institutions protect the public interest and hold the industry accountable in terms of their social and environmental performance. Nevertheless, despite the evolving importance of SLO in Europe, which is ranked as a top industry challenge (Ernst and Young, 2019), its practical implementation has been more studied mainly in Nordic Countries so far (Koivurova et al., 2015; Suopajärvi et al., 2019; Jartti et al., 2020). It is clear that the discourse of SLO in Europe is still in its infancy, but SLO may help explain the difficulties Europe is currently experiencing around potential new mining projects. A first attempt on this matter is seen in the work of Lesser et al. (2020), where SLO conceptual model was created in the European context.

If we look at the developments of obtaining an SLO in the context of the Estonian extractive industry, then the distributional fairness needs the most clarity in the Estonian legislation. Activities exceeding the environmental limit values are prohibited by law. However, there is a vague situation where the thresholds are not exceeded, but there is an impact on the locals. Therefore, it is important to improve the compensation of the effects of the company's activities on the local community (i.e. local benefits) and to assess whether such agreements increase the local `tolerance interest`, i.e. the readiness of the community to accept this type of business. In the current practice, companies pay environmental use fees to the state, of which only 25% of the revenue goes to the local government for bearing environmental disturbance, or additional agreements are established between the developer and affected party to compensate for the impacts. It does not motivate the development of entrepreneurship at the local level, nor does it ensure that compensation reaches the people affected by the negative effects, nor is it inclusive of the local community. We can say that the current practice of local benefit agreements in Estonia is deficient. Recent studies by Alkranel OÜ (2019) and Kasemets et al. (2020) suggest a revision of the local government financing model, where the majority of environmental taxes go to the local government budget and the compensation reaches those whose lives actually deteriorate due to business activities. In the case of mine construction, it is important to record the local conditions in advance and to consider the extent, distribution and duration of the impact, including estimating external costs. These steps, in addition to the more active involvement of affected stakeholders and equal treatment of businesses, will help to better reach an agreement between local government, business, and the local community. The current legal bases are not sufficient to implement local benefit instruments, and changes in the existing laws are needed.

Another important aspect that emerged from the study and that needs to be taken into account when using potential resources is the long-term consequences of climate change. This refers to people's "concerns" about the influences of climate change and forces the sustainable use of resources. The latter is also in line with the country's crust policy (Ministry of the Environment, 2017). According to a recent survey, Estonian residents' awareness of their mineral resources is not high, but it is worth noting that the majority of respondents are in favor of mining if it is done sustainably and with the least possible environmental damage. It is also interesting that more than half of the respondents think that phosphorite needs to be explored and that the impacts of all three aspects - environmental, economic, and social, need to be studied. Among them, the environmental impact was considered the most essential. Estonian residents are only seen as the third beneficiaries of mineral extraction, after entrepreneurs and the state (Turu-uuringute AS, 2017).

A comparison of different stakeholders shows that risks such as job creation and remuneration, a safe working environment, and training are important for the local community. Also, the company`s profitability and the purchase of local products and services are more important to the business sector. This indicates that the potential phosphorite mining and processing industry will be seen as one of the contributors to the region's economy through job creation and the use of local services. However, this is not recommended without unduly damaging the environment, as shown by the high importance of environmental risks in the survey responses.

The results suggest that the following important preconditions need to be met prior to potential phosphorite mining and processing. Firstly, the extractive value must be guaranteed, i.e. the environmental impacts must be thoroughly studied and the exploitation of the reserves must be clearly economically justified. Secondly, people want to understand why this is necessary because phosphor-based fertilizers can also be exported? Mineral resources must be used in a way that creates as much value for Estonia as possible. There is a need for integrated exploration and exploitation of competitive mineral resources, which can be used to produce products that are in demand both now and in the future within the country and on the world market. Therefore, the quality and extractability of rare earth elements or vanadium stocks must also be studied, and their extraction with phosphorite should be seriously considered. These are critical minerals used in electric cars, battery technologies, and wind turbines and are therefore essential for achieving climate neutrality thru a European Green deal strategy (European Commission, 2019). It is likely that the use of these resources will provide greater added value and will be accepted more than the use of phosphorite alone would. Thirdly, state-of-the-art production technologies must be used to ensure that the environmental impact is kept to a minimum. Respondents tend to be of the opinion that if such technologies do not exist, the use of the resource is not reasonable. In practice, this means using as automated and autonomous solutions as possible, or an approach with a completely new concept, which is being explored, for example, in the Robominers project (Robominers project, 2019). The latter is still in the project phase and the technology operating in the real environment has not yet been proven. Fourth, a broad-based social impact assessment (or assessments) of the potential use of phosphorite is necessary and is an integral part of the process. To date, little research has been done on this topic, but it can provide the necessary information in the context of social acceptance.

6. Conclusions, limitations and future prospects

This empirical study examined the opinion of the different stakeholder groups about the potential extraction and processing of phosphorite and the significant environmental, social and governance risks that they would like to know if such production existed.

The pilot study used the ESG risk assessment methodology, which companies apply in practice to measure and disclose their impacts. The risk assessment was based on the three most appropriate ESG reporting frameworks according to the authors where 101 risks were identified. In further assessment, 59 significant risks were chosen in the Estonian context, and during their validation, the 40 most important ESG risks were selected for the questionnaire by the chosen expert group. Assessing ESG risks before building a potential industry is a novel approach. The developed ESG risk questionnaire can be further used and developed as a tool to find out which risks are considered important by different stakeholders and what their differences are. It also allows for better planning of follow-up activities in the development to mitigate significant risks that have been identified in advance by the ESG risk assessment.

A total of 134 people from four stakeholder groups responded to the questionnaire – representatives of the local community, the business sector, policymakers, and environmental activists. In general, environmental risks were considered to be the most important and social risks to be the least important. Risks related to the involvement and influence of the local community distinguished from social risks as these were considered to be very important. From governance risks, the most important risk was associated with taking climate change into account in the company's operations.

This research, however, had also several limitations The survey was inherently a non-probability sampling, ie it was not representative of the study population (Estonian residents). A mixture of quota sampling (authors set a target of 120 responses) and snowball sampling was used. Therefore, very far-reaching conclusions cannot be made on the basis of the survey results, and the authors recommend conducting a representative population survey of a larger sample size. As it is also very important to find out the local community-based opinion when using phosphorite, authors recommend that other communities or regions in Estonia and their stakeholders be additionally included in the study in order to obtain comparative data. Another minor suggestion for future research would be to apply qualitative in-depth analysis, for example in the form of an interview, as the current online format did not allow to hear what respondents actually commented on or how they justified their opinions. Moreover, in order to motivate responding and avoid too long questionnaire, the ESG risk survey took into account 40 risks and did not include all identified 59 risks from ESG frameworks in the Estonian context. Thus, it is possible that of these 59 risks, some significant risk(s) were excluded from the survey and might appear relevant when in fact a mining project would be launched. In addition, the national difference, which may be important in the Estonian context, was not studied, as Estonia has a rather large Russian-speaking community, and especially since many of them are related to the existing mining industry today. Therefore, in the future, it would be useful to map their opinion as well and conduct the survey in bilingual form.

The problems with the potential uptake of phosphorite are multifaceted, and it is advisable to establish a framework to address these issues. This must cover all relevant ESG risks and preconditions, such as demonstration of extractive value (i.e. thorough environmental impact and economic feasibility studies), obtaining SLO through social impact assessment including improving distributional (fair compensation to the affected party) and procedural fairness (voice and engagement in decision-making), use of best technologies and when possible, co-valorization of high-demand Estonian mineral resources such as phosphorite, REE and V. The framework could act as a guideline for policymakers to exploit these resources and be a future prospect of the current study.

Declaration of interest

None of the authors of this paper has a financial or personal relationship with other people or organizations that could inappropriately influence or bias the content of the paper.

It is to specifically state that "No Competing Interests are at stake and there is No Conflict of Interest" with other people or organizations that could inappropriately influence or bias the content of the paper.

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Appendix

Questionnare on ESG risks.

Let's suppose there is a hypothetical phosphorite mining and processing company. Is it important for you to know …?

Governance risks:

1 Does the company make a profit?
2 Does the company take into account the effects of climate change in its operations?
3 Has the company received government loans, tax relief and other subsidies?
4 What investments has the company made in the infrastructure of the local community?
5 What products or services does the company buy from local suppliers and partners?
6 Have there been any cases of corruption in the company?
7 How much does the company pay taxes (eg social tax, environmental taxes, etc.)?

Environmental risks:

8 What are the company's main raw material components?
9 What is the percentage of recycled materials used in the company?
10 How much energy does the company consume and what is the share of renewable energy?
11 What is the energy efficiency of the company?
12 How much has the company reduced its energy consumption?
13 How does a company use water as a shared resource with other users in the region?
14 What is the company's water consumption?
15 How much and what quality of wastewater does the company discharge back to the nature?
16 How much does the company reduce water consumption in its production process?
17 How much does the company divert acid mine water to the nature?
18 What is the impact of the company on protected areas?
19 What is the company's activity in protecting or restoring protected areas?
20 What is the company's expected mining method (quarry or mine)?
21 How much does a company emit hazardous air emissions?
22 Is the company doing anything to reduce its air emissions?
23 How much waste does the company generate as a result of its activities?
24 How much of the company's waste is reused, recovered and landfilled?
25 How much so-called tailings waste is created and reused during phosphorite extraction and processing steps?
26 How many environmental violations has the company had?
27 Has the company assessed the environmental performance of its subcontractors and partners?

Social risks:

28 What employee qualifications level does the company need and what is the remuneration of the employees?
29 What is the satisfaction level of employees in the company?
30 Does the company have an occupational health and safety management system and how is a safe working environment ensured?
31 How many employee-related accidents were in the company?
32 What are the working conditions for the company's employees and do they have any adverse health effects?
33 What training does the company offer to its employees?
34 How does the company identify and involve the local community in its plans and activities?
35 What are the activities of the company that have a significant negative impact on the living environment of the local community?
36 What activities does the company do with the local community?
37 Has the company assessed the social behavior of its subcontractors and partners?
38 Have business owners supported politicians?
39 What are the land acquisition and resettlement operations (expropriation) of the population?
40 what is the preservation of cultural heritage objects as a result of the company's activities?

Open question: Do you want to add anything else that you think has been overlooked in the survey?

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Appendix 3

Paper III

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Original article

Fuzzy analytical hierarchy process based environmental, social and governance risks assessment for the future phosphorite mining in Estonia

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ABSTRACT

Although Estonia has significant phosphate rock reserves within the EU, their extraction and processing in Estonia has been a sensitive issue in the past. The current study focuses on identifying and understanding the most critical Environmental Social Governance (ESG) risks for any potential phosphorite mining and processing by compiling and analysing the opinions of Estonian mining experts and identifying similarities and differences between the perceptions of mining experts and wider society groups. The results indicate that governance risks are more critical and social ones are less significant, leaving environmental risks in the middle. A comparison with other stakeholders' opinions from the earlier studies reveals that governance risks are most important for mining experts, while environmental risks are more critical for other stakeholders.

A deeper insight also shows that mining experts do not consider the risk of negative impacts on the living environment of the local community and that their engagement is not particularly important for the company`s activities. However, other stakeholders have valued it the most. Mining experts have considered profitability as the most critical risk, while this is less the case for other stakeholders. As a result, the findings of the ESG risk analysis conducted can be outlined as follows: the importance of risks is multi-layered and differs among stakeholders; if phosphorite is planned to be extracted in Estonia, significant ESG risks need to be mitigated for different stakeholders at different stages of development; a framework should be developed for policymakers to use for sustainable phosphorite extraction.

1. Introduction

Estonia holds the largest not-exploited sedimentary phosphate rock reserves in the European Union, containing about 700 million tonnes of P_2O_5 (Yang et al., 2021). Reserves contain up to 35–37 % industrially useful remnants of brachiopod shells (P2O5), while in the whole phosphorite layer, the content of P2O5 varies from 3 % to 25 %. It also has less cadmium (Cd), uranium (U), and strontium (Sr), which are typical hazardous heavy metals of this type of deposit compared to other common phosphorite deposits in the world. The consistency of pyrite and its tendency to spontaneously combust has been a major problem in the past, leading to environmental issues (Raukas and Teedumäe 1997; Petersell, 2011).

Although it was mined on a small scale in Estonia from the 1920s until 1991, mainly for domestic use as a low-quality phosphorite flour, large-scale production was planned in the 1980s. However, this never materialised, mainly due to environmental concerns. This uncertainty and the authorities' plan to begin large-scale phosphorite extraction at the end of the Soviet era led to significant public protests, which ended with the ban on extracting phosphorite in Estonia in 1991 (Reinsalu, 2016; Petersell, 2015; Aare, 1991). Since then, it has not been adequately mined or explored.

According to the Organisation for Economic Co-operation and Development (OECD, 2015), the USA, China, and Morocco are the most important countries that mine phosphate rock. The largest sediment deposits are located in North Africa, the Middle East, China, and the USA. Over 80 % of phosphorus is used for the production of fertilisers, around 10 % for animal feed, and the rest for other industrial applications such as cleaners, detergents, food, and beverages. The European Commission declared in 2017 that phosphorus is a critical raw material for Europe because of its high dependency and supply disruption risk.

Moreover, the Estonian phosphate also contains valuable rare earth

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elements (REEs), and its nearby black shale-graptolite argillite layer contains some important metals like vanadium (V) and molybdenum (Mo). These elements are essential for transitioning to a carbon-free/low-carbon economy. For instance, REEs are commonly used in magnets, alloys, and catalysts, considered crucial product components for transitioning to a green economy (Paat et al., 2021b). Recent studies have revealed a relatively enriched but variable REE content in Estonian phosphate shells. The total amount of REEs can reach up to 3600 ppm. On average, however, they are between 1000 and 2000 ppm. Currently, the metals mentioned cannot be considered as an economic source. Nevertheless, they could become economically utilisable as they are possible co-products of phosphorous production. In the case of REEs, the most considerable difficulty lies in the technology for REE extraction in parallel with phosphorous acid production, which needs to be further developed (Soesoo, 2021; Soesoo and Kirsimäe, 2020).

The transition to the much-discussed green economy has been vital in Europe for several years. Nevertheless, the Russian invasion in Ukraine in 2022 has further raised the momentum and importance of the topic. The aforementioned invasion could change the geopolitical balance of power and increase the need for increased extraction and utilisation of European countries' resources. Therefore, extracting Estonian phosphorite with as many valuable metals as possible by-products could become a more pressing issue. In recent years, there has been renewed discussion in Estonia about studying phosphorite and the associated rare earths and their extractability. It needs to be clarified whether there are technological solutions for this, whether the activity falls within the scope of environmental restrictions, and whether it is economically viable and acceptable to society (Raig, 2021; Pau, 2020). This could become very important in light of the war between Russia and Ukraine as a long-term war and global sanctions against Russian and Belarusian potash and nitrogen could lead to higher fertiliser prices and a shortage of fertiliser supply (Kennes et al., 2022). Fertiliser production from Estonian phosphorite can minimise these effects.

Although the mobilisation of European resources may soon be necessary for geopolitical reasons, we must acknowledge the complexity of phosphorite mining in Estonia, as this has been a sensitive issue in the past. Therefore, ESG risk assessment tools could be applicable. In general, ESG reflects how businesses influence their surrounding environment and society and how they mitigate their impact within and outside the company (Maybee et al., 2023). Companies that have integrated ESG principles into their daily activities and disclosed ESG information have a favourable impact on the company's financial performance (Chen and Xie, 2022). However, the direct link between ESG and the company's financial performance remains unclear (Ellili, 2022; Khan, 2022).

Nevertheless, in a recent study (Paat et al., 2021a), Estonian perceptions about the potential extraction and processing of phosphorite in Estonia via an ESG-risk-based survey were investigated. The study questionnaire was addressed to four stakeholder groups - the local community, the business sector, policymakers, and environmental activists. It examined these groups' significant environmental, social, and governance risks.

The current study is an extension of the previous study mentioned above, in which mining experts in Estonia now assessed the same ESG risks. The aim of this work is, therefore, to understand the essential ESG risks in phosphorite mining and processing through the lens of mining experts` opinions and to find similarities and differences between the mining experts and the broader societal groups previously surveyed. The comparison outcome contributes to defining the commonalities of ESG risks and developing a so-called framework for the policymakers to design phosphate mining in a way that considers, manages, and mitigates all relevant environmental, social, and governance risks.

In the current study, a Fuzzy analytical hierarchy process (FAHP) based procedure is developed for evaluating alternatives (criteria/indicators), providing a flexible approach for handling uncertainties and imprecise data caused by judgements of mining experts. The FAHP allows replacing the fixed value judgments in AHP with interval judgments in FAHP, simplifying the decision makers' evaluations. The procedure developed can be utilised for the analysis of similar mining problems. Furthermore, policymakers can benefit from studies performed for future decision-making regarding phosphorite mining in Estonia.

In the next section, the methodology is introduced, where the FAHP is used to analyse the estimates of the mining experts. Sections 3 and 4 present and discuss the results of the multicriteria decision-making process. In the two final sections, the main findings are summarised, the limitations are highlighted, and the study prospects in the light of future research are outlined.

2. Methodology

Before describing the solution procedure, the decision hierarchy should be introduced (see Fig. 1). Fig. 1 represents questions from mining experts in governance, environmental, and social domains to identify significant ESG risks (described in detail in Appendix A). Furthermore, the questions to the mining experts align with those asked in the previous study, where four other stakeholder groups were considered (Paat et al., 2021a).

In Fig. 1, the indicators are grouped by criteria, which allows the application of short notation (I1, I2,..) for indicators (different from Table 8 where indicators for all criteria are mixed and long notation for indicators is utilised).

At this point, it can be assumed that the criteria and indicators/risks are selected, and the next step is the evaluation of the impact of each criterion/indicator.

Step1. Selection of multicriteria decision-making method (MCDM).

The problem considered is a multicriteria decision-making problem with two levels. The research group for the current study has long-time experience with solving design optimisation problems using gradient-based, evolutionary and hybrid algorithms (Majak and Pohlak, 2010; Paavel et al., 2017a, 2017b). However, the currently considered

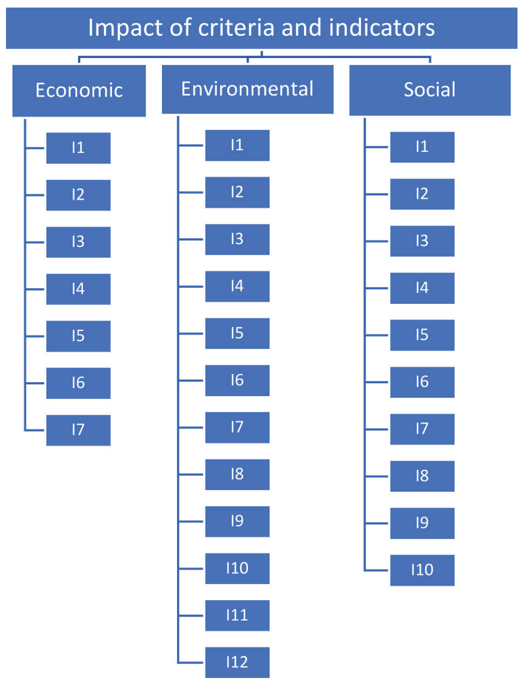

Fig. 1. Decision hierarchy tree for criteria and indicators.

problem has a specific feature - decision-maker's judgments, which include uncertainty. In the latter case, the multicriteria decision-making methods (MCDM) are more suitable. An overview on popular MCDM methods like fuzzy analytical hierarchy process (FAHP), Preference-Ranking Organization Method for Enrichment Evaluations (PROMETHEE), Elimination and Choice Translating Reality (ELECTRE), Vlsekriterijumska optimizacija IKompromisno Resenje (VIKOR), the weighted sum model (WSM) and weighted product model (WPM) can be found in the review paper (Emovon and Oghenenyerovwho, 2020). In the case of the PROMETHEE method, a comparison of the amplitude of deviations between the evaluations of the alternatives within each criterion is performed.

Here are extra tools for evaluating the weights of the criteria. In the case of the ELECTRE method, the solution based on an outranking relationship between two alternatives is developed. In the literature, the application of this method is estimated to be rather complex than simple. In the VIKOR method, the optimal solution is obtained by computing the closeness of alternatives to an ideal alternative. In the case of conflicting scenarios, this method may lead to complexities. In the case of WSM and WPM, additional considerations or tools are needed to specify the weights' values. The above-listed MCDM methods have been applied successfully for solving a wide range of problems arising in various research areas like risk assessment (Ilbahar et al., 2022; Pikner et al., 2022), renewable energy (Wang et al., 2020), engineering (Grimes and Maguire, 2020), economics (Kaganski et al., 2018) and environmental problems (Huang and Zhang, 2020). A recent review of FAHP methods can be found in (Liu et al., 2020).

Herein, the FAHP method is utilised. The FAHP relies on fuzzy sets and an analytic hierarchy process (Vinodh et al., 2014). In the case of FAHP, the fixed value and interval judgements are utilised, respectively. Using interval judgements is a principal simplification for decision-makers.

Step2. Triangular Fuzzy numbers.

The fuzzy set theory introduced by Zadeh is a widely used methodology for pairwise comparisons. The FAHP approach proposed for the evaluation of criteria is based on triangular fuzzy numbers (TFN) defined as,

$M = (l, m, u)$ where $(l \le m \le u)$, l and u are lower and upper values, m is the middle value of M and the membership function is defined as (Chang, 1996).

$$\mu_M(x) = \begin{cases} \dfrac{x}{m-l} - \dfrac{l}{m-l}, \ x \in [l,\ m], \\ \dfrac{x}{m-u} - \dfrac{u}{m-u}, \ x \in [m,\ u], \\ 0,\ otherwise, \end{cases} \tag{1}$$

The basic operations with fuzzy numbers are given as

$$\mathrm{M}_1(\oplus)\mathrm{M}_2 = (\mathrm{l}_1 + \mathrm{l}_2, \mathrm{m}_{1+}\mathrm{m}_2, \mathrm{u}_{1+}\mathrm{u}_2), \tag{2}$$

$$\mathrm{M}_1(\otimes)\mathrm{M}_2 \approx (\mathrm{l}_1\mathrm{l}_2, \mathrm{m}_1\mathrm{m}_2, \mathrm{u}_1\mathrm{u}_2), \tag{3}$$

$$\mathrm{M}^{-1} \approx (1/\mathrm{u}_1, 1/\mathrm{m}_1, 1/\mathrm{l}_1). \tag{4}$$

Step3a. Composing pairwise comparison matrix for criteria.

The fuzzy sets-based approach allows us to apply linguistic assessments corresponding to the natural representation of the judgment (Bakioglu and Atahan, 2021). The linguistic variables used in Table 1 are based on (Polat et al., 2017).

The eight-member expert group of decision-makers (e.g., highly skilled Estonian mining experts, industrial and academic members) filled the pairwise comparison matrix. On average, their experience in the mining sector is over 20 years. The questionnaires (see Appendix A for details) were held in March–April 2022 via e-mail. At first glance, some experts did not understand the questionnaire very well. Therefore, MS Teams meetings were held, where the questionnaire's content and how to fill it out were explained. The linguistic "grades" of one expert are given in Table 2 as an example.

Table 1
Linguistic variables for the evaluation of the criteria.

The relative importance of criteria in terms of linguistic variables		Fuzzy triangular	Reciprocal fuzzy
Equally Preferred (EqP)	1	1, 1, 1	1, 1, 1
Equally to Moderately Preferred (Eq-MP)	2	1, 2, 3	1/3, 1/2, 1
Moderately Preferred (MP)	3	2, 3, 4	1/4, 1/3,1/2
Moderately to Strongly Preferred (M-SP)	4	3, 4, 5	1/5, 1/4, 1/3
Strongly Preferred (SP)	5	4, 5, 6	1/6, 1/5, 1/4
Strongly to Very Strongly Preferred (S-VSP)	6	5, 6, 7	1/7, 1/6, 1/5
Very Strongly Preferred (VSP)	7	6, 7, 8	1/8, 1/7, 1/6
Very Strongly to Extremely Preferred (VS-ExP)	8	7, 8, 9	1/9, 1/8, 1/7
Extremely Preferred (ExP)	9	8, 9, 9	1/9, 1/9, 1/8

The upper triangular matrix elements are omitted in Table 2, since these terms can be computed based on lower triangular matrix elements as numbers of turns of the corresponding symmetric element.

Step3b. Composing pairwise comparison matrices for indicators.

The pairwise comparison of indicators/risks is performed similarly to criteria in terms of linguistic variables using Table 1 by the same group of eight experts (here, we have three matrices with higher dimensions).

Step4a. Computing aggregated comparison matrix for criteria.

The aggregated evaluation matrix was computed by applying a fuzzy geometric mean as (Polat et al., 2017).

$$r_{ij} = \left(\prod_{n=1}^{N} c_{ijn} \right)^{1/N}. \tag{5}$$

In Eq. (5), c_{ijn} stands for the fuzzy comparison value regarding the TFN of criteria i to criteria j given by the nth expert, and N is the total number of decision-makers involved ($N = 8$).

Step4b. Computing aggregated comparison matrices for indicators.

The Eq. (5) was utilised for three comparison matrices i.e. a fuzzy geometric mean is applied.

Step5a. Computing fuzzy comparison values for aggregated criteria matrix.

The fuzzy comparison values $r_i = (l_i, m_i, u_i)$ are calculated as (Polat et al., 2017):

$$r_i = \left(\prod_{j=1}^{Ncrit} r_{ij} \right)^{1/Ncrit}. \tag{6}$$

In (6) *Ncrit* indicates the number of criteria used.

Step5b. Computing fuzzy comparison values of aggregated indicators matrices.

Like the criteria, the formula (6) was utilised for all three aggregation matrices computed for indicators.

Step6a. Computing fuzzy weight values of criteria.

The triangular fuzzy weight w_i of criteria i is computed as

$$w_i = (l_i, m_i, u_i) = r_i \otimes (r_1 \oplus r_2 \oplus \ldots \oplus r_{Ncrit})^{-1}, \ldots i = 1, \ldots, Ncrit. \tag{7}$$

Step6b. Computing fuzzy weight values of indicators.

The formula (7) was applied for all three group of indicators.

Step7a. Computing crisp weight values of criteria.

Applying defuzzification to fuzzy weights for criteria, the crisp weights can be computed as

Table 2
Pairwise comparison matrix for criteria.

C1	C2	C3
EqP		
Eq-MP	EqP	
1/SP	1/MP	EqP

$$w_i^{Crisp} = l_i + [(u_i - l_i) + (m_i - l_i)]/3. \tag{8}$$

Step7b. Computing crisp weight values of indicators.

The defuzzification was also applied for computing crisp weight values for three groups of indicators.

Step8. The consistency check (criteria & indicators).

The consistency ratio (CR) was calculated as (Polat et al., 2017)

$$CR = \frac{CI}{RI}, \tag{9}$$

where,

$$CI = (\lambda_{max} - n)/(n-1). \tag{10}$$

In (10) λ_{max} stands for maximum eigenvalue of the aggregated comparison matrix and n is a matrix dimension. The experts' estimates can be considered consistent if CR is less than 0.1.

Step9. Normalised crisp weights and ranks (criteria & indicators).

The normalised crisp weights were calculated for both criteria and indicators as final results.

Step10. Computing global weights of indicators.

The global weight of each indicator is determined as the product of the indicator's weight and weight of the corresponding criteria to which this indicator belongs. Global weight characterises the global importance of this indicator (Mammadli et al., 2022; Barakos and Mischo, 2021).

3. Results

The results are obtained by applying the solution procedures described in the methodology section. Most of the intermediate results are omitted, and the focus is on the final results.

The aggregated matrix for criteria, given in terms of fuzzy triangular numbers, is presented as an exception to get a better picture of the approach used (Table 3).

Table 4 presented Fuzzy and Crisp weights of the criteria and their rankings.

As can be seen from Table 4, the mining experts value mostly economic/governance criteria, followed by environmental and social criteria.

The Fuzzy and Crisp weights of the criteria and ranks of the indicators are given in Tables 5–7, respectively. Here it should be noted that these weights and ranks of the indicators are local, inside the corresponding group (economic, environmental, social).

Among governance/economic criteria, the risks that mining experts believe the most important are to earn a profit (I1) and consider the impacts of climate change (I2) – these 2 risks stand out the most from the others. Moreover, earning a profit is quite reasonable important risk in every other commodity, not only in phosphorite industry.

From the environmental risks aspect, the so-called hazardous tailing waste generation due to phosphorite mining and its processing steps are considered the most important by the mining experts (I10). This is considered a significant risk due to the generation and management of hazardous tailings being a major challenge in all phosphorite developments worldwide. Unfortunately, several ecological disasters have occurred in the past (Dong et al., 2018, 2020)

Experts' responses to social risks criteria reveal that occupational accidents involving employees, including fatal cases (I4), are considered the most essential risk by experts. This risk received a significantly higher score than other social risks. Most likely, this is due to the Estonian mining industry's occupational hazards and accidents receiving serious attention over the years. Avoiding accidents has always been a top priority, although it has not always been possible to prevent them entirely and occasionally, they occur (Veskioja, 2015). In the wider perspective, the importance of occupational safety and how to avoid mining accidents have always been an important subject in the worldwide mining industry and much literature has been published on this matter (Ismail et al., 2021; Tomassi, 2024).

The global normalised crisp weights and ranks of all risks are given in Table 8.

Let us look at the weights of all risks (Table 8), which reflect their importance among mining experts. The governance risks, in general, are regarded as more important, followed by environmental risks, and social risks are the least important.

The consistency of the experts' estimates was confirmed by computing the values of the consistency rate CR using formulas (9) and

Table 3
Aggregated pairwise comparison matrix for criteria.

Criteria	C1	C2	C3
Economic (C1)	(1.00; 1.00; 1.00)	(0.94; 0.85; 1.35)	(1.77; 2.26; 2.73)
Environmental (C2)	(0.74; 1.17; 1.07)	(1.00; 1.00; 1.00)	(1.17; 1.65; 2.10)
Social (C3)	(0.37; 0.44; 0.57)	(0.48; 0.61; 0.85)	(1.00; 1.00; 1.00)

Table 4
Fuzzy and crisp weights of the criteria and how they rank.

Fuzzy weights	Crisp weights	Rank
(0.325; 0.397; 0.583)	0.435	1
(0.250; 0.397; 0.494)	0.380	2
(0.153; 0.206; 0.296)	0.218	3

Table 5
Fuzzy and crisp weights of the indexes of economic criteria and ranks.

	Fuzzy weights	Crisp weights	Normalised crisp weights	Rank
I1	(0.159; 0.219; 0.298)	0.225	0.218	1
I2	(0.147; 0.207; 0.287)	0.214	0.207	2
I3	(0.068; 0.097; 0.139)	0.101	0.098	5
I4	(0.050; 0.069; 0.098)	0.072	0.070	7
I5	(0.053; 0.072; 0.102)	0.076	0.073	6
I6	(0.141; 0.189; 0.253)	0.194	0.188	3
I7	(0.109; 0.147; 0.202)	0.152	0.147	4

Table 6
Fuzzy and crisp weights of the indexes of environmental criteria, ranks.

	Fuzzy weights	Crisp weights	Normalised crisp weights	Rank
I1	(0.033; 0.047; 0.067)	0.049	0.047	12
I2	(0.036; 0.051; 0.073)	0.053	0.051	11
I3	(0.062; 0.088; 0.122)	0.091	0.087	6
I4	(0.068; 0.098; 0.139)	0.102	0.098	4
I5	(0.047; 0.068; 0.100)	0.072	0.069	8
I6	(0.073; 0.103; 0.145)	0.107	0.103	3
I7	(0.041; 0.059; 0.086)	0.062	0.059	10
I8	(0.061; 0.086; 0.122)	0.090	0.086	7
I9	(0.065; 0.094; 0.136)	0.098	0.094	5
I10	(0.095; 0.134; 0.190)	0.140	0.134	1
I11	(0.077; 0.109; 0.155)	0.113	0.109	2
I12	(0.043; 0.063; 0.02)	0.066	0.063	9

Table 7
Fuzzy and crisp weights of the indexes of social criteria, ranks.

	Fuzzy weights	Crisp weights	Normalised crisp weights	Rank
I1	(0.074; 0.111; 0.166)	0.117	0.110	3
I2	(0.068; 0.107; 0.165)	0.113	0.107	4
I3	(0.100; 0.155; 0.240)	0.165	0.155	2
I4	(0.177; 0.269; 0.399)	0.282	0.265	1
I5	(0.051; 0.077; 0.121)	0.083	0.078	5
I6	(0.040; 0.062; 0.099)	0.067	0.063	7
I7	(0.031; 0.047; 0.076)	0.051	0.048	9
I8	(0.039; 0.058; 0.090)	0.062	0.059	8
I9	(0.027; 0.041; 0.065)	0.044	0.042	10
I10	(0.047; 0.072; 0.110)	0.076	0.072	6

Table 8
The global normalised crisp weights and ranks of all risks.

	Normalised crisp weights	Rank
I1_eco	0.092	1
I2_eco	0.087	2
I6_eco	0.079	3
I7_eco	0.062	4
I4_soc	0.056	5
I10_env	0.049	6
I3_eco	0.041	7
I11_env	0.040	8
I6_env	0.038	9
I4_env	0.036	10
I9_env	0.035	11
I3_soc	0.033	12
I3_env	0.032	13
I8_env	0.032	14
I5_eco	0.031	15
I4_eco	0.029	16
I5_env	0.025	17
I12_env	0.023	18
I1_soc	0.023	19
I2_soc	0.023	20
I7_env	0.022	21
I2_env	0.019	22
I1_env	0.017	23
I5_soc	0.017	24
I10_soc	0.015	25
I6_soc	0.013	26
I8_soc	0.012	27
I7_soc	0.010	28
I9_soc	0.009	29

(10).

It can be observed from Table 9 that the expert estimates are consistent. Corresponding CR values are less than the theoretical limit value of 0.1.

4. Discussion

As stated in the introduction, the results of the current study are compared with the earlier analysis by Paat et al. (2021a) to identify the most significant similarities and differences of opinions between mining experts and other stakeholders (local community and business sector representatives, policymakers, and environmental activists) previously questioned. The authors can draw from this comparison that governance risks are most important for mining experts, but ecological risks are essential for other stakeholders. Interestingly, mining experts valued earning a profit risk (I1_eco) as the highest, but it got a relatively low-risk importance assessment by different stakeholders. On the other hand, other stakeholders considered the most critical risks are those having a significant negative impact on the living environment of the local community and their engagement with the company`s plans and activities. However, this risk was among the lowest in the mining experts' opinion (I6_soc).

Moreover, mining experts considered employee occupational accidents (I4_soc) as the most important social risk, but other stakeholders assessed this risk importance as relatively low. The common ground of risk importance was found by considering the effects of climate change in the company (I2_eco) – this was an essential risk among all stakeholders. However, the questionnaires do not reflect what respondents mean by this, i.e. what climate change means to them. It should be more specified in future studies, but responses indicate that climate change concerns are important.

Table 9
The consistency ratios were computed for the expert estimates.

	Criteria vs criteria matrix	Economic indicators	Environmental indicators	Social indicators
CR	0.016	0.038	0.034	0.033

When examining which stakeholder group from the previous study was most in agreement with the mining experts, it was the local business sector. Both stakeholder groups generally rated governance risks as most critical and social risks as less important, e.g., earning a profit was essential for both.

As seen from the comparison, the difference in opinion is quite significant. Differences in expectations create different perceptions. It is expected that, according to mining experts (and business), making a profit is the most important thing because, with it, such a business activity makes sense. At the same time, other stakeholders consider the environmental impacts of a potential phosphorite mining and processing company and how they influence and involve the local community in decision-making more important than profit.

It can be concluded that all risks are essential, and one cannot be overemphasised at the expense of another. Highlighting the involvement of the local community and the effects on them as an important risk clearly shows the level of social acceptance. There is already a prejudice that locals are not considered enough. It can be broken by doing things differently, and more than legal procedures require. Such large-scale projects require cost-effectiveness analyses, choosing the most suitable technology and its accompanying impact, including environmental impact assessments and sociological research to understand people's concerns. It is necessary to get out of the so-called business-as-usual framework, i.e., not only to implement the typical special planning-environmental impact assessment-project design and construction models but to strengthen this process with regular dialogues, discussions, and information exchange stages with the developer and interested parties. Important emphasis must be placed on considering different alternatives, including the accompanying effects and cost-effectiveness, and communication of the results - only this approach increases social acceptance. Nevertheless, one must find out if it will be guaranteed. Typically, projects of this scale only reach a satisfactory result for some; someone will always be affected, but finding a greater common ground is essential.

To manage significant ESG risks, a so-called framework must be created that guides policymakers. According to the authors, the following key steps must be addressed in the guide to managing ESG risks. With clarity on these points, we can discuss mitigating ESG risks in the planned development. This article looks more at the former.

1. There will be much public interest in the development. It is important to explain the necessity of the activity to society and clarify the necessity, i.e. why it is necessary, whether it is done only with someone's business interests in mind, or if it also has a more comprehensive social benefit for the citizens, so-called distributional fairness. Several studies imply that distributional fairness is among the most important aspects influencing public trust and acceptance of mining (Pimenta et al., 2021; Zhang et al., 2015). In addition, it is important to determine whether, and in what form, the local community will be affected by the accompanying effects and whether they will be compensated. Studies about distributional fairness on wind projects reveal that fairness is not always easily achievable, not even in Denmark, where not all compensation schemes are successfully offsetting perceptions of unfair distribution (Leer et al., 2020), and preferences for distributional justice often differ even between countries (Vuichard et al., 2022). It is also essential to specify the role of the state and the relationship with the developer in the process, i.e. the state must prudently use its natural resources, including phosphorite - is thus ensured, and how? For instance, is the role of the state only to clarify and finance the development related to mineral exploration and extractability, or the entire development, or something in between, for example, in the form of a concession as public-private cooperation? Moreover, it cannot be ruled out that a broader sociological study for planned development is needed, which will better map people's fears and expectations because if they

are known, development can and should be planned against these results.

2. The existence of mining and processing technology, evaluation, and effectiveness of these various alternatives are important. This and the next stage are closely intertwined and interdependent. For example, the choice of mining technology depends on the characteristics of the ore body, its depth and inclination in the Earth's crust, the thickness of overburden, and the proximity of human settlements. The latter can significantly narrow the choice of mining technology where mine roof subsidence must be prevented. Therefore, the most suitable field is a room and pillar or backfilling-type underground mining method (Li et al., 2022).
3. Assessment of the environmental impact of technology alternatives, i.e. what changes or effects each alternative brings and how it affects the surrounding environment.

The horizontal line running through all stages assesses profitability and especially the involvement of the local community (as well as society in general) in the process. Profitability must be viewed not only from the point of view of profit but also from the affected or lost environmental values due to development in general, i.e., it must be assessed whether and to what extent the impact of development is on the ecosystem services that we as humans consume and that create well-being for us. For example, if the development has a significant adverse environmental impact on forest habitats, because of which important natural biotic community and coherence are strongly affected, is the development feasible, or can the impact be mitigated or compensated, and at what price? In the process of involvement, it is necessary to ensure that the information of the different stages reaches the interested parties, that a discussion arises where they are listened to and reasons are given as to why it is possible or not, or in what respect their opinion can be considered when finding the greatest possible common ground. It is important to note that all these main steps are interrelated; they must be placed in a logical time sequence, parts of which can be done in parallel, but some activities are interdependent.

5. Limitations and prospects

This empirical study investigated the opinion of Estonian mining experts to identify the most significant ESG risks in cases where potential phosphorite is extracted and processed in Estonia. The current study extends a previous study where the same ESG risk importance was assessed among wider stakeholder groups - the local community, the business sector, policymakers, and environmental activists. The study found similarities and differences between mining experts' and wider social groups' opinions about relevant ESG risks. Such comparison facilitates finding common ground about ESG risks among stakeholders, the most significant differences, and what should be undertaken so all relevant environmental, social, and governance risks are considered, managed, and mitigated.

The current study questioned an eight-member mining expert group from Estonia covering industrial and academic domains. An FAHP method was used to get their opinion and compare it with previous answers from other stakeholder groups. FAHP is a well-known multi-criteria decision-making method which uses respondents' uncertain judgments. The method is suitable for smaller or medium size groups.

However, this research also had some limitations. The authors of the study emphasise that small sampling was used. FAHP method effectively allows the collection and analysis of fewer respondents (max 15–20). Therefore, our eight mining experts were sufficient. For the sake of truth, the Estonian mining community and people involved in the mining community industry are few, and eight experienced experts were selected carefully and persuaded to participate in this survey. The consistency check confirmed that all expert estimates are consistent (see Table 9).

However, no fundamental conclusions can be drawn from the opinions of people from the Estonian mining industry in the form of these eight experts. Another limitation relates to the questions in the survey. The number of questions for mining experts was reduced to 29 in this study. In a similar study for other stakeholder groups, however, there were 40 questions (Paat et al., 2021a). This was done for two reasons: to motivate responding and because using the FAHP method makes it difficult for the interviewee to answer too many questions. The authors emphasise that although the number of questions was reduced, this was done at the expense of grouping questions and ensuring that all topics from the previous questionnaire were retained. However, it cannot be ruled out that there may have been minor differences or a different understanding of the questions.

This work confirms which ESG risks are considered more important and which have the greatest contradictions between the importance of different interest groups. This knowledge can be the basis for creating a so-called framework in which important ESG risks are focussed and mitigated at different stages of development. Following this framework, the mining and processing phosphorite, including by-products such as rare earths and some other precious metals, is possible.

6. Conclusions

The results of the current study (as well as the previous one) imply that the assessment of the significance of risks is multifaceted and is evaluated differently by different interest groups. One risk cannot be overemphasised at the expense of another, but some common conclusions can be outlined as:

- The mining experts assessed the governance risks as more important and the social risks as less important, leaving the environmental risks in the middle, with the profit risk receiving the highest score. The comparison with other stakeholders from the previous study reveals that governance risks are most important for mining experts, while environmental risks are most important for other stakeholders.
- The other stakeholders generally attached relatively little importance to the risk of making a profit. However, they rated the risks of negative impacts on the local community and its engagement the highest, one of the lowest risks among the mining experts.
- All stakeholders, including mining experts, considered climate change's impact a major risk. The judgment of the mining experts on the importance of ESG risks was the most in line with the opinion of the local business sector from the previous study.

CRediT authorship contribution statement

A. Paat: Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **J. Majak:** Writing – review & editing, Writing – original draft, Investigation. **V. Karu:** Writing – review & editing, Writing – original draft, Project administration. **M. Hitch:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

Declaration of competing interest

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the paper's content.

It is to state that "No Competing Interests are at stake and there is No Conflict of Interest" with other people or organisations that could inappropriately influence or bias the paper's content.

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Appendix A. Questionnaire on ESG risks

Let us assume that the interviewed expert is closely related to a hypothetical phosphorite mining and processing company in Estonia's mining industry expert. Please rank the criteria in order of importance and the risks given under each criterion that you consider more important/least important for the successful operation of such a hypothetical company if you, as a mining expert, are an important link in its management.

Is it important to You, as an expert closely related to the company, to…

Governance risks:

1. …earn a profit?
2. …consider the effects of climate change on the company.
3. …receive government loans, tax incentives and other subsidies?
4. …make investments in local community infrastructure by the company (e.g. supporting sports facilities, etc.)?
5. …purchase products or services from local suppliers and partners (e.g. purchasing catering or cleaning services from a local company)?
6. …know the occurrence of corruption cases?
7. …pay taxes (e.g. social tax, environmental taxes, etc.)?

Environmental risks:

1. …know how many materials (equipment, wood, oils, etc.) are used to produce the final product?
2. …know what is the percentage of recycled materials used to produce the final product?
3. …know how much energy does the company consume and what is the share of renewable energy?
4. …know how much has the company reduced its energy consumption to produce the final product?
5. …know how much the company's water consumption is and how much it has reduced water consumption in its production process to produce the final product?
6. …know how much and what quality wastewater, including acidic mine water, does the company return to nature?
7. …know what is the company's impact on natural diversity and its actions for their protection or restoration (e.g., the decline of species or the change and fragmentation of habitats due to the company's activities and contribution to mitigation measures)?
8. …know how much does the company produce air emissions, and whether is anything being done to reduce their amount?
9. …know how much waste does the company generate from its operations, and how much of it can be reused or recycled by itself or by giving it to other companies?
10. …know what is the proportion of hazardous waste, including the so-called tailing waste generated during the mining and processing of phosphorite?
11. …know what were the company's environmental violations (i.e. the number of cases where the company's activities did not comply with environmental laws and what actions were taken to prevent a new violation)?
12. … know the assessment of the environmental activities of your subcontractors and partners (e.g. cooperation/non-cooperation with those who have, for example, significantly violated environmental laws)

Social risks:

1. …know what are the qualifications and salary levels of the company's employees?
2. …know what is the satisfaction level of employees in the company?
3. …know are company ensuring the working environment's safety, including an occupational health and safety management system?
4. …know what is the number of occupational accidents involving employees, including fatal cases?
5. …know is there company-provided training for employees?
6. …involve the local community in the company's plans and activities, including managing company activities that negatively affect the local community's living environment?
7. …conduct non-profit, joint activities (projects) with and for the local community (for example, supporting the construction of local recreation areas, hiking trails, kindergarten, etc.)?
8. …know the social activities of company`s subcontractors and partners (for example, cooperation/non-cooperation with those where women, gender, etc. arediscriminated)?
9. …support of politicians by company owners?
10. ….know the need for resettlement (forced expropriation) of residents and its actions? For example, when building a mine, it is necessary to acquire someone's real estate due to public interest, which must be compensated for.

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Appendix 4

Comparison of the importance of ESG risks in Papers II and III.

	Nr	Paper II questions	Paper II - average importance	Paper II Importance ranking (same as Art III)	Nr	Paper III questions	Paper III Importance ranking
		Is it important for you to know ...?				Is it important to You, as an expert closely related to the company, to...	
Governance	1	Does the company make a profit?	5.39	30	1	…earn a profit?	1
	2	Does the company take into account the effects of climate change in its operations?	6.24	9	2	…consider the effects of climate change on the company?	2
	3	Has the company received government loans, tax relief and other subsidies?	5.55	27	3	…receive government loans, tax incentives and other subsidies?	7
	4	What investments has the company made in the infrastructure of the local community?	5.84	20-22	4	…make investments in local community infrastructure by the company (e.g., supporting sports facilities, etc.)?	16
	5	What products or services does the company buy from local suppliers and partners?	5.84	20-22	5	…purchase products or services from local suppliers and partners (e.g., purchasing catering or cleaning services from a local company)?	15
	6	Have there been any cases of corruption in the company?	5.84	20-22	6	…know occurrence of corruption cases?	3
	7	How much does the company pay taxes (eg social tax, environmental taxes, etc.)?	6.05	16	7	…pay taxes (e.g., social tax, environmental taxes, etc.)?	4

	Nr	Paper II questions	Paper II - average importance	Paper II Importance ranking (same as Art III)	Nr	Paper III questions	Paper III Importance ranking
		Is it important for you to know ...?				Is it important to You, as an expert closely related to the company, to...	
Environmental	8	What are the company's main raw material components?	5.22	33	1	…know how many materials (equipment, wood, oils, etc.) are used to produce the final product?	23
	9	What is the percentage of recycled materials used in the company?	5.49	28	2	…know what is the percentage of recycled materials used to produce the final product?	22
	10	How much energy does the company consume and what is the share of renewable energy?	5.46	29	3	…know how much energy does the company consume and what is the share of renewable energy?	13
	11	What is the energy efficiency of the company?	5.58	26	4	…know how much has the company reduced its energy consumption to produce the final product?	10
	12	How much has the company reduced its energy consumption?	5.21	34	5	…know how much the company's water consumption is and how much it has reduced water consumption in its production process to produce the final product?	17
	13	How does a company use water as a shared resource with other users in the region?	6.20	11	6	…know how much and what quality wastewater, including acidic mine water, does the company return to nature?	9
	14	What is the company's water consumption?	5.96	18	7	…know what is the company's impact on natural diversity and its actions for their protection or restoration (e.g., the decline of species or the change and fragmentation of	21

						habitats due to the company's activities and contribution to mitigation measures)?	
	15	How much and what quality of wastewater does the company discharge back to the nature?	6.45	3	8	…know how much does the company produce air emissions, and whether is anything being done to reduce their amount?	14
	16	How much does the company reduce water consumption in its production process?	5.62	25	9	…know how much waste does the company generate from its operations, and how much of it can be reused or recycled by itself or by giving it to other companies?	11
	17	How much does the company divert acid mine water to the nature?	6.46	2	10	…know what is the proportion of hazardous waste, including the so-called tailing waste generated during the mining and processing of phosphorite?	6
Environmental	18	What is the impact of the company on protected areas?	6.41	5	11	…know what were the company's environmental violations (i.e. the number of cases where the company's activities did not comply with environmental laws and what actions were taken to prevent a new violation)?	8
	19	What is the company's activity in protecting or restoring protected areas?	6.24	9	12	… know the assessment of the environmental activities of your subcontractors and partners (e.g., cooperation/non-cooperation with those who have, for example, significantly violated environmental laws)	18
	20	What is the company's expected mining method (quarry or mine)?	6.23	10			
	21	How much does a company emit hazardous air emissions?	6.32	6-7.			

	22	Is the company doing anything to reduce its air emissions?	6.19	12			
	23	How much waste does the company generate as a result of its activities?	6.42	4			
	24	How much of the company's waste is reused, recovered and landfilled?	6.18	13			
	25	How much so-called tailings waste is created and reused during phosphorite extraction and processing steps?	6.16	14			
	26	How many environmental violations has the company had?	6.32	6-7.			
	27	Has the company assessed the environmental performance of its subcontractors and partners?	6.02	17			

	Nr	Paper II questions	Paper II - average importance	Paper II Importance ranking (same as Art III)	Nr	Paper III questions	Paper III Importance ranking
		Is it important for you to know ...?				Is it important to You, as an expert closely related to the company, to...	
Social	28	What employee qualifications level does the company need, and what is the remuneration of the employees?	4.94	37	1	...know what are the qualifications and salary levels of the company's employees?	19
	29	What is the satisfaction level of employees in the company?	4.93	38	2	...know what is the satisfaction level of employees in the company?	20
	30	Does the company have an occupational health and safety management system and how is a safe working environment ensured?	5.28	31-32	3	...know is the company ensuring the working environment's safety, including an occupational health and safety management system?	12
	31	How many employee-related accidents were in the company?	5.28	31-32	4	...know what is the number of occupational accidents involving employees, including fatal cases?	5
	32	What are the working conditions for the company's employees and do they have any adverse health effects?	5.68	24	5	...know is there company-provided training for employees?	24
	33	What training does the company offer to its employees?	4.24	39	6	...involve the local community in the company's plans and activities, including managing company activities that negatively affect the local community's living environment?	26

	34	How does the company identify and involve the local community in its plans and activities?	6.07	15	7	...conduct non-profit, joint activities (projects) with and for the local community (for example, supporting the construction of local recreation areas, hiking trails, kindergarten, etc)?	28
	35	What are the activities of the company that have a significant negative impact on the living environment of the local community?	6.50	1	8	...know the social activities of the company`s subcontractors and partners (for example, cooperation/non-cooperation with those where women, gender, etc, are discriminated)?	27
	36	What activities does the company do with the local community?	5.83	23	9	...support of politicians by company owners?	29
	37	Has the company assessed the social behavior of its subcontractors and partners?	5.05	36	10	....know the need for resettlement (forced expropriation) of residents and its actions? E.g., when building a mine, it is necessary to acquire someone’s real estate due to public interest, which must be compensated for.	25
	38	Have business owners supported politicians?	5.11	35			
	39	What are the land acquisition and resettlement operations (expropriation) of the population?	6.31	8			
	40	What is the preservation of cultural heritage objects as a result of the company's activities?	5.86	19			

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