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Analysis on the decision making process for the lithium development and policy implementation in Kazakhstan

카자흐스탄의 리튬 개발 및 정책수행을 위한 의사결정과정 분석

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Analysis on the decision making process for the lithium development and policy implementation in Kazakhstan

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이 논문을 공학석사 학위논문으로 제출함

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Abstract

Lithium is one of the strategic materials that can influence the sustainable development of the economy in the world. Currently, lithium-ion batteries are leading the market among all available battery technologies. They are widely used in portable electronic devices and electric vehicles. Kazakhstan has large reserves of rare earth metals and associated lithium, mainly concentrated in Eastern Kazakhstan. According to the US Geological Survey, at the beginning of 2013, the confirmed lithium reserves in the bowels of foreign countries show that even according to preliminary data of proven reserves, Kazakhstan is among the 10 world leaders. The previously conducted analysis of the proven reserves of rare earth metals, including lithium-containing metals in Kazakhstan, indicates the prospects and expediency of their development for the production of the constantly growing needs of the world market in lithium materials. Lithium production in the country is at the level of conversations, theoretical research, and single experimental developments. The Government must actively attract investments and conduct geological exploration to evaluate new deposits.

This study uses an analytical hierarchical process methodology to estimate and rank the factors for the lithium industry development in Kazakhstan. The methodology framework covers several major steps to answer the research question.

The research starts by conducting an extensive literature review of the related studies and then identifying the main influential factors for lithium development. The four main relevant criteria are: economic, technical, regulatory, and environmental. Some experts from the government and non-governmental sectors took part in the survey.

The results indicate that decision-makers from both sectors prioritize the economic criterion as the most important, followed by the technical criterion. Moreover, the regulatory and environmental criteria were ranked lower in importance. The present study also aligns with the National Plan "100 Steps" in emphasizing economic and technical aspects as the energy sector's development priority areas. By implementing policy implications, Kazakhstan can leverage FDI to accelerate the development of its lithium sector, enhance its global competitiveness, and establish itself as a key player in the lithium value chain.

Keywords: lithium industry, rare earth metals, analytical hierarchical process, Kazakhstan.

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Chapter 1. Introduction

This chapter describes the research background, problem identification and motivation, research objective, research questions, and its novelty.

1.1 Research background

Lithium-ion batteries (LIBs) dominate the market among all available battery technologies. This is due to their high energy intensity (specific and volumetric). LIB has much higher performance compared to other analogs (lead, Ni-Cd, and Ni-Mn) and is the leader in the market of portable electronics and electric transport (Tarascon, 2001). The main components of modern LIB are an anode (mainly graphite or lithium-containing oxide), a cathode (mixed oxides of lithium and other metals: LiCoO2, LiMn2O4, etc.) (Reddy, 2011; Armand & Tarascon, 2008), separated by a polymer separator, and an organic electrolyte. The electrochemical essence of the LIB determines the dependence of the lifetime, composition, and cost of the battery on the operating conditions. In this regard, these systems have different configurations and costs (IRENA, 2015).

Lithium-containing components (e.g., anode, cathode, and electrolyte salt) make up the central part of the cost of LIB. Therefore, intensive work is underway to find new materials with better performance and low cost. This requirement and the rapid development of the battery-powered devices market, especially electric and hybrid cars, and renewable energy, over the past 10 years has led to a sharp demand for higher-capacity materials for LIB (Pilot, 2010). These batteries are also in demand in markets related to military and space technology, medicine, and others. This led to the emergence of new cathode materials (e.g., LiFePO4, LiMnPO4, etc.) and their derivatives (Bakenov & Nakayama, 2007), anodic materials based on silicon, lithium titanate, and alloys (Bakenov & Taniguchi, 2010).

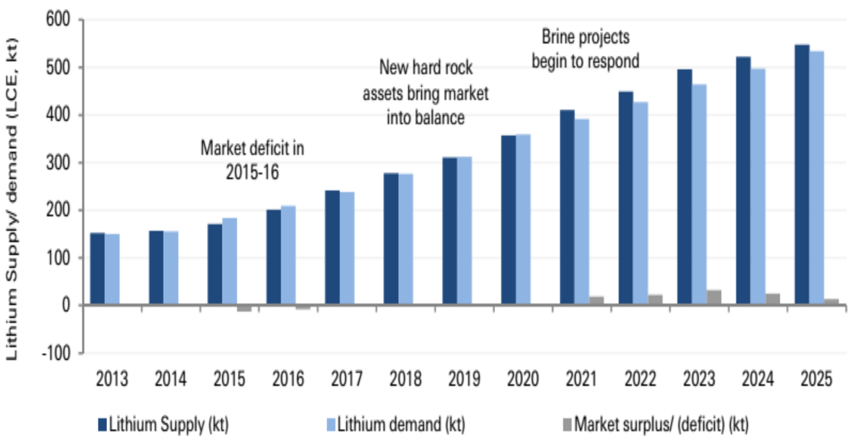
All this, as well as the development of technologies in portable electronics (phones and laptops/tablets) and electric transport, have led to lithium becoming a new strategic material capable of influencing the sustainable development of the world economy (Cho, 2012; Dudney, 2008). This has led to its high demand on the international market and increased prices. Interestingly, the demand for lithium is predicted to grow significantly over the coming years (Chen, 2013). The global demand for lithium compounds in 2016 exceeded 150,000 tons in terms of lithium carbonate. In 2020, it increased to approximately 300,000-320,000 tons, and by 2025 it will grow to 550,000 tons. This will mainly happen due to the mass introduction of electric vehicles and hybrids.

Contemporarily, there is no shortage of lithium and its compounds in the world. It is planned to increase the consumption of this metal in the production of lithium-ion batteries. The total metal production will amount to 238,000 tons in lithium carbonate (45,000 tons in terms of metal), owing to the implementation of several lithium projects.

Lithium carbonate is becoming the main marketable product. New lithium producers, both traditional and newcomers, will probably focus on the lithium carbonate market for LIB and will make steady profits in the next few years. Generally, a relatively uniform price increase is expected, and the average price in the long term will depend on the number of successful new projects. At the same time, the general trend of a sharp increase in lithium demand in the long term is beyond doubt for most analysts (Figure 1) (Reddy, 2011).

Figure 1. Lithium supply and demand forecast

(source: Deutsche Bank, 2011)



In this regard, new methods of lithium extraction, in addition to traditional ones, are of particular value. At the same time, the distribution of lithium reserves worldwide is uneven. Access to its stock plays a significant role and influences technological development.

Currently, lithium minerals are extracted mainly from pegmatite. There are reserves of mineral raw materials containing mainly spodumene and petalite, which are intensively explored and mined in Canada, Finland,

and other countries. Spodumene is the main commercial lithium mineral and contains about 8% lithium (in terms of Li2O oxide). About 50% of spodumene is mined in Australia and processed into lithium carbonate in China (Jaskula, 2012). There are other, less commercially popular lithium-containing minerals with a lower main component content.

Another type of lithium deposits are brines of some highly saline lakes. Chile and Argentina produce the largest part of the world's lithium from lake salts, with approximately 46% of the total lithium production (FMC, Rockwood, and S.Q.M.) (Murtazin, 2014 & Kan, 2016).

Lithium is widely used in the production of ceramics, special glass, batteries, high-temperature lubricants, continuous castings, polymers, aluminum alloys, and pharmaceuticals (Chen, 2013).

One of the main applications of spodumene is the production of lithium with a high degree of purity for lithium-ion batteries. Lithium obtained from spodumene has fewer impurities than lithium obtained from brines. These pollutants can impair battery performance, making spodumene the preferred source of raw materials for a lithium battery. In this regard, there is a growing interest in developing lithium reserves concentrated in the pegmatite deposits of spodumene, the main lithium-containing mineral suitable for industrial processing. Essentially, the problem with their development lies in the lack of effective technologies for obtaining lithium concentrates, which can significantly reduce the cost of obtaining lithium carbonate (Jaskula, 2012).

Lithium is used in many industries due to its unique high electrochemical potential, low thermal expansion coefficient, and catalytic properties. The glass and ceramic industries are the largest consumers of lithium, approximately 31% of total consumption, followed by batteries – 23%. Major automakers predict that the hybrid and fully electric vehicle sectors will grow steadily and reach a car market share of 10-30% by 2025. Consequently, the demand for lithium will increase by 100-200% over the same period. Electric car developers are constantly exploring new sources of lithium carbonate to reduce dependence on its main suppliers – Chile and China. To date, the prospect of an "explosion" in the global lithium market, related to the above, as well as the escalated raw material issue, is becoming real. The increased interest of investors in lithium products has led to dramatic changes in the lithium materials market. In July 2023, lithium metal prices reached $ 39.529/kg.[1]

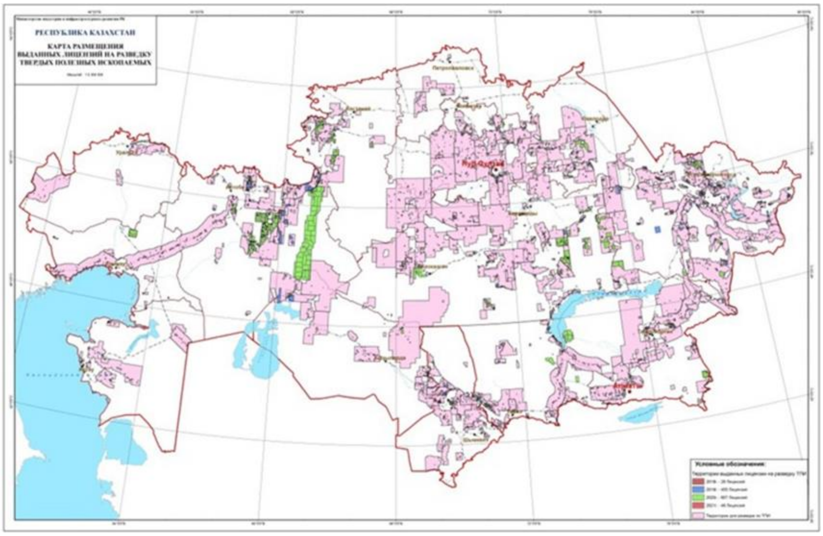
Kazakhstan has large reserves of rare earth metals and associated lithium, mainly concentrated in Eastern Kazakhstan. According to the degree of readiness for development and the costs of development, the lithium deposits of the East Kazakhstan region can be divided into two groups.

[1] https://www.dailymetalprice.com/metalpricecharts.php?c=li&u=kg&d=240

Figure 2. Map of placement of deposits of solid minerals in Kazakhstan

source: Ministry of Industry and Infrastructural Development of the Republic of Kazakhstan

(pink color - available territories for exploration, green color - issued licenses)



The first group includes lithium mineral deposits of the East Kazakhstan region. The Akhmetkino deposit (vein 25), which has been explored and whose reserves have been approved and in which more than 23,000 tons of lithium oxide and other valuable components are concentrated, should be considered promising. It is attractive that the infrastructure has been prepared at the field (a road has been built, a 10 kV line has been brought in, and a 100-meter tunnel has been pierced) (Kazakhstan mining report, 2014).

According to the US Geological Survey (USGS), confirmed lithium reserves in the bowels of foreign countries show that even according to preliminary data of proven reserves, Kazakhstan is among the 10 world leaders.

The second group is represented by technogenic deposits, which are "tails" formed due to the activities of the Belogorsky GOK during the Soviet period. This group of deposits requires minimal development costs among the groups under consideration. This group includes such processing plants as Belogorskaya with tailings reserves (in thousand tons): 1,560.3 (lithium content of 2,800 g/t), Belogorskoye Verkhne-Baymurzinskoye with reserves of 4260 (lithium content of 3200 g/t), Bakennoye with reserves of 1,372 (lithium content of 1,500 g/t), Ak-Kezen with reserves of 700 (lithium content 250 g/t), and so on. In total, 15,868,000 tons of reserves with a lithium content of 958.33 g/t.

According to the Belogorsky GOK, there are more than 32,000 tons of lithium in the dumps of processing plants. However, these data require careful rechecking, exploration, and approval of reserves.

The project aims to develop a technology for obtaining innovative electrode materials for modern lithium batteries with the creation of a full cycle of a production line from the extraction of lithium from domestic minerals and raw materials to high-tech products - cathode and anode materials of modern lithium-ion batteries.

The result is innovative cathode and anode materials of a new generation for modern LIB with significantly increased capacity and operation stability, obtained from lithium precursors - lithium carbonate of the battery grade based on domestic mineral and artificial raw materials.

The project is being implemented in scientific cooperation with a highly qualified research group of the Nazarbayev University School of Engineering and the Institute of Accumulators LLP, as well as with specialists of mining and metallurgical industries: the Scientific Center of Ulba Metallurgical Plant JSC, Belogorsky GOK LLP.

The development of scientific and technological bases for the production of products with a high degree of readiness for the end user according to the scheme:

Spodumene ores → Lithium concentrate → Lithium carbonate → Cathode materials → Batteries - will contribute to the development of a domestic high-tech lithium cluster and the creation of a new lithium industry in Kazakhstan, will become an important player in the global market of storage systems, energy sources and renewable energy, and electronics.

1.2 Problem identification, motivation, and novelty

President of Kazakhstan Kassym-Zhomart Tokayev said that Kazakhstan has lithium reserves but does not extract it. Hence, the country needs investments in exploration, field development, and production (President’s State of the Nation Address, 2022).

Meanwhile, the country considered lithium mining in 2019 and even conducted geological exploration in promising areas. There were plans to build a mining and processing plant near one of the lithium deposits. However, none of the projects came to fruition.

There are issues in the country regarding assessing lithium reserves, their quantity, and the depletion period. Full-scale studies to establish the exact reserves of lithium in Kazakhstan have not yet been conducted. No work was conducted to identify new lithium deposits or to determine the significant content of this element as a by-product in the products of raw materials processing.

In Kazakhstan, lithium mineralization is historically known in pegmatites of deposits in the East Kazakhstan region. Lithium mineralization has also been established in Aktobe, Kostanay, Karaganda, and Zhambyl regions and in the new Zhetysu region (The concept of the development of the geological industry, 2021).

During his visit to Zhetysu, the President touched upon the topic of lithium deposits and gave the geological service an order to intensify work in extracting lithium raw materials. Having serious plans for developing lithium deposits for several years, Kazakhstan has not mined this metal. The issue of restraining the development of deposits is open.

There are many factors why the state has not yet developed lithium mining, not to mention processing. Back in Soviet times, the main potential lithium deposits were classified. Perhaps some are still classified as “Secret.” Accordingly, the country had nothing to offer to investors. Over the past three years, work has been underway to declassify geological materials, and investors have already received exploration licenses. The following factors are the profitability of quarry development and further processing.

So far, lithium ores in pegmatites have been identified in Kazakhstan, but it still requires careful research. There are also many active and dried-up salt lakes in Kazakhstan, where it is possible to identify promising areas of rare elements, including lithium.

Currently, there is no prospecting and geological exploration for lithium from brines in Kazakhstan. It is necessary to activate the geological service and research institutes in this matter.

Projects for the extraction of lithium raw materials require large investments. In addition, today, a growing number of companies and investors want to develop lithium deposits in Kazakhstan. Everyone knows that Kazakhstan occupies a leading place in the world in terms of mineral resources. It can be said that it is one of the wealthiest countries in the world in terms of natural resources. To date, there are many requests from large and medium-sized foreign companies that are ready to extract and process lithium in Kazakhstan.

Some companies study lithium deposits in detail. Negotiations are underway with South Korean companies that are exploring lithium deposits. The final decision takes time, and the government (with the help of the state operator in attracting and supporting investors) helps successfully implement strategic projects.

Lithium reserves in Kazakhstan are not the largest. According to the USGS for 2021, the identified lithium resources worldwide amount to about 86 million tons. Bolivia has the largest reserves in the world — 21 million tons, followed by Argentina — 19.3 million tons, then Chile — 9.6 million tons, Australia — 6.4 million tons, China — 5.1 million tons, the Democratic Republic of the Congo — 3 million tons, Canada 2.9 million tons of lithium, and Germany 2.7 million tons.

The main sources of lithium for industrial extraction are localized pegmatites in hard rocks, and continental brines (aquifers with salt water).

Basically, there are two ways to extract lithium: ore and hydromineral. In the first case, the metal is extracted in mines or quarries from pegmatite minerals, while in the second, from underground brines. Most of the lithium is extracted from the clays of salt marshes. Lithium mining from salt marsh clays has already harmed the ecosystem where the metal is extracted through this method. Verily, this implies that lithium mining is harmful to nature.

The fact is that the extraction of lithium material requires a huge amount of water. Since most of the lithium deposits are located in arid highlands, there is a depletion of water reserves for the population. Due to the lack of moisture, the territories are deprived of pasture grass, which poses a threat to the existence of farms. Chemical effluents polluting rivers and reservoirs are another serious problem.

Lithium is used in smartphones and electric vehicles, but none of the above is produced in the country. In this regard, it can be argued that the Kazakh industry currently has no need for lithium.

Apart from electric vehicles, it is impossible to imagine any modern device without lithium batteries today. The role of lithium in the global economy is only increasing with the introduction of green energy. The acceleration of decarbonization in the world leads to an increase in demand for lithium for the production of energy storage batteries. European countries are increasing the generation of renewable sources, and for this, it is necessary to install electric energy storage devices that use lithium.

According to the USGS, the world's proven lithium reserves are estimated at 22 million tons, and the estimated reserves are 86 million tons. Everything depends on the growth of global consumption.

According to forecasts, most passenger cars will use lithium-ion batteries rather than gasoline engines in the next ten years. That is, a huge increase in lithium consumption is expected. The demand for lithium raw materials increases by 35% in just a year. According to current reserves, lithium will last for about 25 years, considering the annual increase in consumption.

Given the raw materials orientation of the economy of Kazakhstan and the importance of receiving foreign exchange earnings from the state, it has long been necessary to pay attention to rare earth metals as an additional significant income for the republic. All these metals are in demand by the green economy. The government is now looking for opportunities to increase the country's income, which means improving the social well-being of the citizens of Kazakhstan.

There are reserves of lithium, nickel, cobalt, and other rare earth metals in the bowels of Kazakhstan, which are in demand in developed countries. Another reason to think about their development may be the prospects of the petroleum products market. Euro-7 certification is underway now, and it is believed that these standards may stop the production of internal combustion engines. Many European countries do not want to produce such engines since 2035. Developed countries are already thinking about switching to electric cars. In this case, the materials needed to make batteries will be in substantial demand. In this regard, it is necessary to develop not only oil and gas production but also lithium. Rare earth metals could become a new locomotive of the country's economy in the future.

Kazakhstan can sell metal to Europe as a raw material, but it is much more profitable to try to produce batteries from it by order of European and Asian companies. For example, such automotive giants as Toyota, whose plant transfer to Kazakhstan is currently being considered, are interested in nickel and other materials for batteries.

Successful companies can be attracted as investors for geological exploration and construction of a mining and processing plant in Kazakhstan to extract metal and produce final products from it. This can bring huge profits to Kazakhstan. However, investors are needed for the country to enter the "club of lithium suppliers" on the world market. A national strategy is required to attract investors, which will prescribe attractive conditions for investors, such as a reduction or exemption from taxes. In the first stage, Kazakh companies could explore new raw materials. The experience of uranium mining could be used in the exploration and production of rare earth metals. As you know, Kazakhstan ranks first in the world in uranium mining.

The strategy should indicate what the state wants to obtain from this in 20-30 years, by 2040, to become one of the leading countries in lithium supply. Certainly, this should not be limited to lithium, as nickel and other rare earth metals are also in great demand in developed countries. One of the active suppliers of such metals is now China. The transition to a green economy will not be possible without raw materials. Based on this, it is possible to sign extensive agreements with the European Union, and attract investments, as was done with the oil and gas sector, which attracted almost $260 billion. It is necessary to create conditions for the investor to be protected. It is a long, tedious job, but correctly building a priority and strategy is the most important thing. It is necessary to attract a large pool of experts to openly discuss such a national strategy and not in a narrow circle.

In addition, it is necessary to pay more attention to geological exploration, as is done by such advanced countries in the field of raw materials extraction as Australia and Canada.

Kazakhstan should hurry up in developing new types of raw materials sector. For example, Africa is currently experiencing a technological and raw materials revolution. The raw material attractiveness of Kazakhstan may fall against this background since African countries have convenient access to the ocean. These countries have now actively extracted gas, oil, and other resources. This may become a challenge for Kazakhstan, and it will have to compete with Africa.

The value of lithium as a material for the manufacture of batteries is increasing; in fact, this material, along with other metals, can become a "second oil." If, in the 2000s, the country witnessed an oil boom, which largely supported the growth of Kazakhstan's economy, now we can expect a lithium-ion boom. However, Kazakhstan should not lag behind in this area, and, it is necessary to make the right accents and priorities because in 10 years, lithium offers on the world market will no longer be so relevant since other countries and manufacturers will have time to occupy this niche.

The state has been talking about the prospects of lithium mining and battery production for a long time, but nothing has been done in this direction by ministries and companies so far. The reserves of this material in the subsurface have not been fully explored, and now it is necessary to conduct this work so that in 10 years, Kazakhstan will not be among the outsiders. Production on a small scale could be organized now.

If we compare with the major players in this market, the declared lithium reserves in Kazakhstan, even at 100,000 tons, are not so large. For comparison: in Chile, they are measured in tens of millions of tons, but it must be borne in mind that this country is located on another continent. Next to Kazakhstan, other major players in the production of batteries include South Korea, Japan, and European countries that are preparing to switch to alternative energy sources and will switch completely to electric vehicles in five years. Now they are looking for a source of lithium metals that they could use in their production.

The primary lithium deposits known in Kazakhstan were explored back in Soviet times, and since not everyone understood the need for this metal then, they were preserved as a strategic reserve. Until 2015, no one was engaged in their exploration and development. The situation has changed, and Kazakhstani companies own all the explored deposits. Some are continuing exploration, while others are already preparing the necessary documentation to proceed to production. According to the Geological Survey of Kazakhstan, Kazakh companies can already obtain a license for lithium mining next year.

Kazakhstan companies will want to attract foreign investment, as it is not just money but technologies that are not available in the country. There are no specialists in Kazakhstan who could work at enterprises processing ore into lithium. Turning to technology partners, Kazakhstani companies are looking not for money but for experience and specialists. Regarding the prospects of such foreign investments in mining and production, it is worth noting that the world's largest companies producing batteries for electric vehicles, such as LG and Samsung, do not extract raw materials themselves and turn to competent companies - technological institutes, which, by their order, consider potential deposits for investment. Some companies are now considering one of the Kazakh deposits. They will turn to major market players for investments if they see its potential.

The prospects for the development of lithium are tremendous. According to data at the beginning of autumn 2022, the price of lithium carbonate on world markets averaged about $70,000 per ton. The sharp rise in prices for this metal is because Chinese companies are increasing the production of batteries and preparing to switch their vehicles to electricity. At the same time, since the Chinese are one of the monopolists in production, one should be wary of their investment proposals since they can actively impose their conditions. European countries that are interested in producing batteries for their market and may agree to build a plant in Kazakhstan that produces final products, and not just the purchase of raw materials, look more promising in this regard.

The President has repeatedly raised the issue of lithium development. It remains hoped that with the establishment of the National Geological Survey in Kazakhstan, the country will see shifts in the exploration of new lithium deposits.

To date, several studies have been devoted to identifying and ranking important criteria and factors for various sectors of the economy of different countries. However, it should be noted that no similar study has been conducted so far on analyzing and prioritizing lithium development factors in Kazakhstan. Thus, in this study, an attempt was made to identify and prioritize the factors that have the most critical impact on the development of lithium in Kazakhstan.

The purpose of the study is to identify the main factors of lithium development in Kazakhstan, as well as to assist government policy-makers in making decisions and planning more precise current steps for the implementation of lithium development policy.

Thus, the study will have a significant academic contribution by filling the research gap in this field through formulation and analyzing the main criteria and sub-criteria for industry development. Moreover, the study may be implemented in the case of other developing countries with similar economies.

Therefore, this study aims to analyze the main criteria for lithium development and policy implementation in Kazakhstan.

1.3 Objective and research questions

The research objective is to determine the main criteria for lithium development in Kazakhstan and to understand in which direction the policy should be implemented.

The research questions of the study are as follows:

- Which factors are influential for the lithium industry development in Kazakhstan?
- Which factors should be considered more in the decision-making process for the lithium industry development?

To this end, the research analyzes experts' opinions from a multi-dimensional viewpoint. Thus, the influential factors were analyzed and ranked according to experts' points of view. The analytical hierarchical process (AHP) was applied to this research. This method is considered a popular tool for decision-making based on subjective judgments.

Chapter 2. Literature Review

This study conducts a comprehensive examination of existing literature. Consequently, this section of the thesis comprises a literature review that focuses on the AHP methodology and previous research conducted in the field.

2.1 Studies related to methodology

There are no universally applicable guidelines for constructing decision-making models within the AHP framework. As multiple perspectives exist on a given matter, this introduces variability into the decision-making process. AHP addresses this by developing supplementary models to prioritize and reconcile diverse viewpoints (R. W. Saaty, 1987). Consequently, the method enables the consideration of "human factors" in decision preparation, which stands as a prominent advantage of AHP over other decision-making approaches.

Constructing an AHP framework is a highly intricate undertaking. Nevertheless, it results in a precise comprehension of the functioning of factors that impact decision-making. It illuminates the accuracy of evaluating potential solutions and assigning ratings that reflect the significance of these factors (Al Khalil, 2002). Notably, the process of calculating ratings in AHP is remarkably straightforward, setting this method apart from other decision-making approaches.

To facilitate decision-making, data collection predominantly relies on a pairwise comparison approach (T. L. Saaty, 1980). The outcomes of these comparisons may occasionally present contradictions. This method presents a valuable chance to detect inconsistencies within the data. However, it is necessary to make adjustments to minimize such discrepancies. The pairwise comparison procedure, along with the process of modifying comparison results to reduce inconsistencies, often consumes a significant amount of time (T. L. Saaty, 1977). Nonetheless, in the final analysis, decision-makers can be assured that the data employed holds sufficient significance.

The AHP method does not serve the purpose of data validation, which represents a notable drawback and partially restricts its application. However, this method is primarily utilized in situations where objective data is lacking, and decision-making is driven by individual preferences (Wang et al., 2008). Moreover, there are limited alternatives available for pairwise comparison procedures in data collection. If a dataset is evaluated by expert individuals and exhibits minimal inconsistencies, it is generally deemed to possess an acceptable level of consistency (Kahraman & Kaya, 2010).

The structure of the AHP methodology is independent of the specific field or domain in which decisions are being made. Hence, the AHP methodology is universally applicable and can be employed across various contexts. It offers a systematic approach to evaluate the decision-making process. Given that decision-making processes often require a significant amount of time, models built using the AHP method always provide a reference framework (T. L. Saaty, 1977). By utilizing AHP, a complex task can be divided into smaller, independent subtasks. Consequently, experts can work independently on localized tasks, contributing to the development of solutions. It is not necessary for these experts to possess knowledge about the nature of the decision, which aids in maintaining confidentiality. In particular, sensitive information regarding the decision-making process may be kept private (T. L. Saaty, 1980).

The AHP method offers a means to assess different options, but it lacks an inherent mechanism for interpreting the results. In simpler terms, it assumes that the decision-maker is already aware of the order or preference of potential solutions and makes conclusions based on the circumstances. This aspect should be acknowledged as a drawback of the method (T. L. Saaty, 1990). Indeed, the AHP method can function as a supplement to other approaches aimed at addressing loosely defined problems, where human experience and intuition are better suited than intricate mathematical computations. The AHP method offers convenient mechanisms for incorporating expert information into the resolution of diverse problems.

The AHP method captures the intuitive thought process of humans and offers a broader perspective compared to alternative methods. It not only offers a means to evaluate the most favored option but also enables a quantitative expression of the level of preference through ratings. This aids in a comprehensive and accurate determination of the decision-maker's priorities. Furthermore, by evaluating the inconsistency measure of the data utilized, it becomes possible to establish the level of confidence in the obtained outcome (T. L. Saaty, 1977). Following a thorough examination of the relevant literature, the AHP method was chosen and implemented in alignment with the primary objective of this research.

2.2 Previous studies related to research

Previous studies have utilized the AHP methodology to investigate various aspects of the lithium development industry. These studies have aimed to assess and prioritize different factors related to lithium production, market dynamics, and sustainability considerations.

One notable study conducted by (Zhang, Wang, He, 2019) applied the AHP method to evaluate the sustainability of lithium-ion battery recycling processes in China. The researchers considered criteria such as economic viability, environmental impact, and social acceptance to determine the most sustainable approach. The study provided valuable insights into the key factors influencing the sustainable development of the lithium-ion battery recycling industry.

In another study, (Pardo-Martinez, Rodriguez-Puerta, Santana, 2020) employed the AHP methodology to analyze the critical success factors for lithium production projects in Colombia. They identified and prioritized factors such as resource availability, production costs, technological feasibility, and environmental impact. The research shed light on the significant factors that influence the success of lithium production ventures.

Furthermore, (Li, Lu, Sun, 2020) conducted a study using the AHP approach to assess the market competitiveness of lithium producers in China. The researchers considered criteria such as production capacity, market share, technological innovation, and cost competitiveness. The study provided valuable insights into the relative strengths and weaknesses of different lithium producers in the Chinese market.

This study (Kim et al., 2019) examines the importance of determining the relative weight of indicators in raw material criticality assessment. The weight assigned to indicators can significantly impact the assessment outcomes, making it crucial to employ a scientifically rigorous and quantitative methodology for weight derivation. In this study, a fuzzy AHP was applied to establish a plausible weight for assessing raw material criticality in Korea. The research findings revealed significant changes in criticality compared to previous methods. Additionally, three stakeholder groups (government, industry, and research) were analyzed to explore the variations in perspectives, weights, and criticality. The results and discussions presented in this review provide valuable insights that can inform the development of policies to address raw material criticality concerns.

Another study (Gueye, Badri, & Boudreau-Trudel, 2021) explores the socioeconomic impact of mining in Canada, acknowledging both its positive and negative aspects. The evaluation of this impact faces challenges related to the selection of appropriate criteria and indicators for sustainability measurement, as well as limitations in minimizing subjectivity in expert judgments. It is crucial to consider the constraints imposed by legislation and standards governing mining activities. To address these issues, this study proposes a theoretical model for assessing the socioeconomic impact of mining in Canada. The model combines the analytic hierarchy process and fuzzy integrated judgment, two multi-criteria analysis methods. Through simulation, the model considers the subjectivity of expert judgments while reducing it and enabling sensitivity analysis. Furthermore, the model offers an overview of a mine's progress towards sustainable development during its transition. This theoretical framework contributes to a more effective evaluation of mining's socioeconomic impact and provides insights into the journey towards sustainable mining practices.

This literature review (Mammadli et al., 2022) focuses on the significance of minor critical minerals and metals in various applications. Despite their importance, these minor commodities are often overshadowed and dependent on the production of base metals and other major commodities. As a result, their supply is not always guaranteed, their availability decreases, and their criticality increases. While many researchers have addressed this issue, there is a lack of actual impact factors beyond economic considerations that should determine the production of these minor commodities. To address this gap, this study identified several parameters and developed a computational tool using a multi-criteria decision analysis model based on the AHP and Python. The novel methodology was applied to assess the production status of various commodities in a polymetallic deposit in

Chovdar, Azerbaijan. The evaluation provided quantifiable insights into the production potentials of multiple commodities in the deposit and highlighted the promising prospects of this tool for assessing polymetallic deposits and their co- and by-production of minor critical raw materials.

This study (Agusdinata et al., 2022) explores the profound impacts of critical minerals extraction on sustainable development goals (SDGs), particularly in the context of clean technologies. While life cycle sustainability assessment (LCSA) is commonly used to evaluate sustainability impacts, there is a lack of frameworks specifically designed for assessing SDGs in the extraction of "green minerals." To address this gap, the study proposes a mining-specific framework that identifies linkages between LCSA and SDGs and presents a process for integrating methods and data. The framework is applied to assess the LCSA performance and local-community level SDG impacts of a nickel mining project in Indonesia. By incorporating remote sensing, media sources, stakeholder data, and expert opinion, the study reveals that LCSA covers all 17 SDGs but only a subset of targets and indicators. The findings emphasize the importance of incorporating indigenous perspectives in both LCSA and SDG assessments and highlight priority areas for enhancing life cycle sustainability and SDG outcomes, such as combating corruption, preserving cultural heritage, and reducing greenhouse gas emissions. The framework proposed in this study can guide corporate social responsibility initiatives and inform consumer choices regarding low-carbon technologies.

Another study (Wang et al., 2022) focuses on the increasing importance of new technologies, particularly in mitigating climate change, with a specific emphasis on lithium as a key component in electric vehicle batteries. The study highlights the significance of considering the entire life cycle of batteries, starting with the extraction of lithium. To evaluate lithium extraction projects worldwide, the study employs two multi-criteria decision-making models. Firstly, the AHP assesses projects based on four main criteria: Political and Social Risk, Economic and Financial Risk, Operational and Technical Risk, and Environmental Risk. These criteria are further divided into sub-criteria, allowing for a comprehensive analysis of potential risks. Subsequently, data envelopment analysis (DEA) is utilized to create a final ranking of the projects. The DEA incorporates two inputs (Initial Capex, Annual Production Cost) and three outputs (Annual Output Value, Lithium Resources, AHP Risk Factor). The AHP Risk Factor represents the qualitative aspects derived from the AHP method, thus enhancing the quantitative DEA analysis. This integrated approach enables the inclusion of important qualitative factors in the overall assessment of lithium extraction projects.

These previous studies highlight the applicability of the AHP methodology in the analysis of various aspects of the lithium development industry, including sustainability assessment, critical success factors, and market competitiveness. By utilizing the AHP methodology, researchers have been able to prioritize and evaluate different factors, contributing to a deeper understanding of the industry and facilitating informed decision-making.

2.3 Why the AHP?

The AHP methodology is considered the most suitable approach for the development of the lithium industry in Kazakhstan due to several reasons. Firstly, the AHP method allows for a comprehensive evaluation of various criteria and factors that are critical for the development of the industry. This includes considering both qualitative and quantitative aspects such as political and social risks, economic viability, technical feasibility, environmental impact, and resource availability. By systematically comparing and prioritizing these criteria, the AHP methodology provides a structured framework for decision-making and strategy development in the lithium industry (T. L. Saaty, 1980).

Secondly, the AHP method offers a robust and transparent process for incorporating expert opinions and stakeholder perspectives. In the context of the lithium industry in Kazakhstan, it is essential to involve various stakeholders, including government authorities, industry experts, investors, and local communities. The AHP methodology enables the integration of diverse viewpoints and preferences through its systematic approach of pairwise comparisons and the derivation of weights for each criterion. This helps in aligning the strategic direction of the lithium industry with the interests and priorities of different stakeholders.

Furthermore, the AHP method facilitates sensitivity analysis and scenario evaluation, allowing decision-makers to assess the impact of different scenarios and policy options on the development of the lithium industry. This enables policymakers to make informed decisions and design effective policies to promote sustainable and inclusive growth in the industry (T. L. Saaty & Vargas, 2012).

The adoption of the AHP methodology for the development of the lithium industry in Kazakhstan has important policy implications. It provides a structured approach for formulating policies that address key challenges and leverage opportunities in the industry. By considering multiple criteria and stakeholder perspectives, policymakers can ensure a balanced and holistic approach to the development of the industry. Moreover, the AHP methodology supports evidence-based decision-making, enabling policymakers to allocate resources efficiently and effectively to promote the growth and competitiveness of the lithium sector.

Chapter 3. Methodology

This chapter of the dissertation research includes methodological framework, AHP hierarchy structure, selecting the criteria and sub-criteria, as well as their description, questionnaire presented to the study participants and the survey process itself.

3.1 Methodological Framework

The objective of this study is to make decision-making process for the lithium development in Kazakhstan by using the analytical hierarchy process (AHP) method.

The AHP method was proposed in the late 1970s by the American mathematician Thomas Saaty. The method consists in decomposing the problem into simpler components and step-by-step prioritization of the evaluated components using paired (pairwise) comparisons. At the first stage, the most important elements of the problem are identified. The second is the best way to verify observations, test and evaluate elements. And the final stage is the implementation of the development of the method of application of the solution and the assessment of its quality. The whole process is subject to review and reinterpretation until it is certain that the process has covered all the important characteristics necessary to present and solve the problem.

To answer the research question, several basic steps of the methodological framework were covered (Figure 3). In this regard, this study began with an extensive analysis of the literature review on previous studies, and then the main factors that influence the development of the lithium industry in Kazakhstan were identified. In addition, various government programs and reports were reviewed, which took approximately two months in the period from February to April. Based on the work done, the identified factors were divided into four main criteria: technical, economic, regulatory and environmental.

Preparation of a questionnaire for conducting a preliminary survey with the participation of government experts from the relevant areas of the Ministry of Industry and Infrastructure Development, Ministry of Ecology and Natural Resources, the Office of the Prime Minister of the Republic of Kazakhstan, as well as experts from the non-governmental sector of the Republican Association of Mining and Metallurgical Enterprises, was the next step of this study. In this regard, based on the feedback received from the results of the preliminary survey, the criteria and sub-criteria were changed and improved, as well as some adjustments were made.

The revised questionnaire was again sent to the above-mentioned governmental and non-governmental experts to obtain the final result of the review. In this regard, an analysis of the results was carried out and appropriate conclusions were made.

Further information on the stages of the methodology, description of the criteria, structure and process of the study are described in the following subsections of this chapter.

Figure 3. Methodological framework of research

3.2 AHP methodology

According to the described stages (R. W. Saaty, 1987; T. L. Saaty, 1990), the implementation of the AHP method requires the implementation of the following five points.

1. The first is the development of a hierarchical tree based on the problem or goal of interest, then the identification of the main criteria, and ultimately the definition of the sub-criteria of each main criterion.

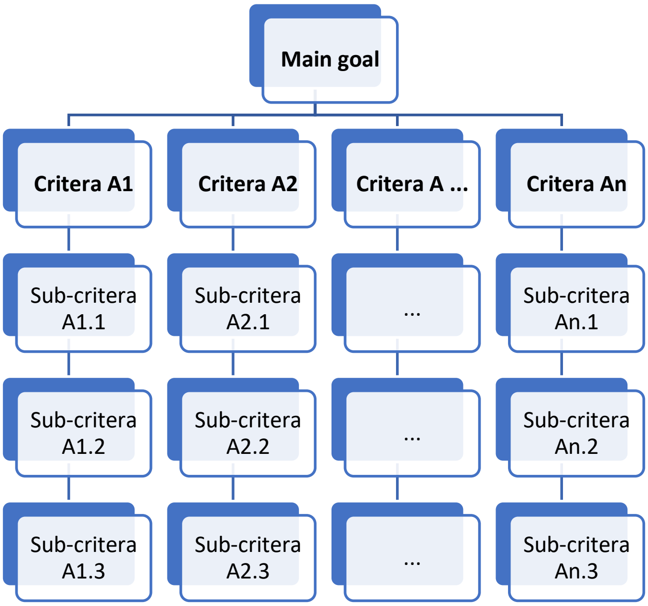
Step 1: The main purpose of the study is the development of lithium in Kazakhstan.

Step 2: At this stage, the main criteria that affect or may affect the development of lithium in Kazakhstan have been identified.

Step 3: At the final stage, the sub-criteria are defined and described, within each main criterion. As an example, the normative criterion is one of the main criteria that includes specific factors. In this regard, specific sub-criteria have been compiled and described for each main criterion of the study.

Summarizing the above, the main goal is the development of lithium in Kazakhstan. The following is a description of the main criteria and sub-criteria, which are described in detail in the next subsection. The structure of the hierarchical tree looks like in Figure 4.

Figure 4. The structure of the hierarchical tree



2. The second stage of the AHP method is the implementation of a pairwise comparison of individual hierarchy criteria based on a nine-point scale (T. L. Saaty, 2008). Experts participating in the study should familiarize themselves with the criteria by using numerical methods. Evaluation of each criterion should be carried out according to a nine-point scale (Table 1). The experts participating in the survey should evaluate the importance of each criterion with a coefficient ≥1, in addition, the highest score is no more than 9. It should be noted that information about paired (pairwise) comparison of all criteria can be represented as a comparison matrix (T. L. Saaty, 1977).

Table 1. AHP scale

Definition	Description	Scale
Option A and B have the same importance	Equally	1
Option A is moderately more important than option B	Moderately more	3
Option A is strongly more important than option B	Strongly more	5
Option A is very strongly more important than option B	Very strongly more	7
Option A is extremely more important than option	Extremely more	9
Intermediate evaluations	Intermediate values	2, 4, 6, 8

3. A pairwise comparison matrix has been developed. This matrix covered the results of each pairwise comparison between all criteria. In accordance with the purpose of the study, a matrix of pairwise comparison of criteria for each main criterion was also created. An example matrix is shown according to Table 2, where A_1, A_2, ..., A_n are the main factors that determine the object. To create a matrix from a pairwise comparison of criteria A and B using a score from 1 to 9, the result of comparing criteria B and A will be the inverse value. For example, when considering the matrix

element a_{ij}, when comparing these coefficients $_i$ with $_j$, then a_{ij} = b, and, therefore, when comparing $_j$ and $_i$, then a_{ij} = 1/b.

Table 2. AHP comparison matrix

source: (R. W. Saaty, 1987; T. L. Saaty, 1977)

	A_1	**A_2**	**…**	**A_n**
A_1	1	a_{12}		a_{1n}
A_2	a_{21}	1		a_{2n}
…			1	
A_n	a_{n1}	a_{n2}		1

4. Calculating the weighting coefficients for each criterion for both the main and sub-criteria is the next step. According to Equation (1),

$$Aw = \lambda max * w \quad , \qquad (1)$$

A is the comparison matrix, w - is the eigenvector or priority weight, λmax is the maximum eigenvalue.

The main rule for this comparison matrix is the inverse system. This matrix is an inverse symmetric matrix, and all numbers must correspond to a nine—point scale of relative importance. After structuring the matrix, it is necessary to create a normalized comparison matrix, according to the following Equation (2):

$$\bar{a}_{jk} = \frac{a_{jk}}{\sum_{l=1}^{m} a_{lk}} \quad , \qquad (2)$$

According to Equation 3, it is necessary to calculate the normalized eigenvector for each row. This represents the final weight of each main criterion in relation to the main goal, as well as the final weight of each sub-criterion in relation to the main criteria. Based on this, we can judge the relative importance of the criteria.

$$W_j = \frac{\sum_{i=1}^{m} \bar{a}_{jl}}{m} , \qquad (3)$$

5. The most important and final stage is the calculation of the consistency coefficient (CR), which informs about the degree of deviation from the consistency of the indicators. The resulting deviation must be less than or equal to 0.1 (10% discrepancy) in order to make an optimal decision. If the answers of interested experts have indicators of CR > 0.1, then they may be perceived as unreliable, and the author, with the participation of experts, needs to recheck the answers again. CR can be calculated according to Equation 4:

$$CR = \frac{CI}{RI} , \qquad (4)$$

where CI - is the consistency index, RI - is the standard values, according to a number of criteria (n) according to Table 3.

CI is calculated according to Equation 5:

$$CI = \frac{\lambda \max - 1}{n - 1} , \qquad (5)$$

Table 3. Random consistency index

Source: (R. W. Saaty, 1987)

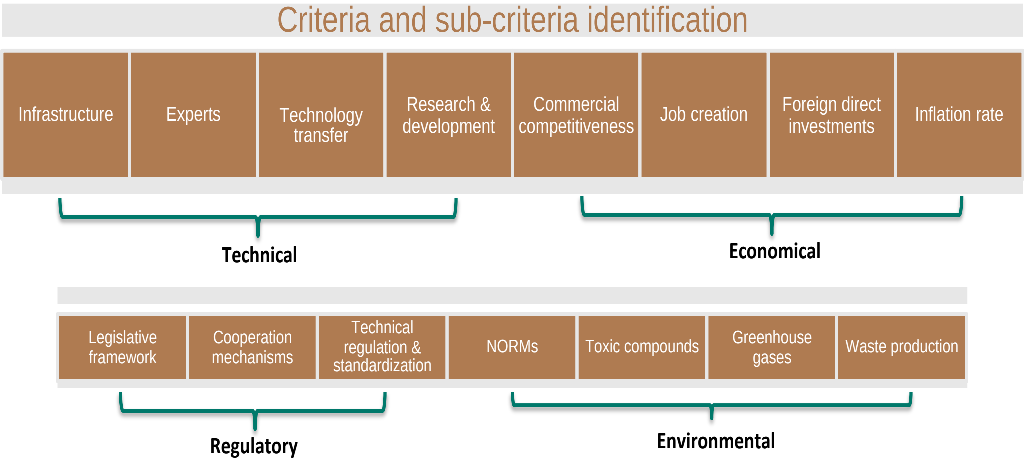
Number of criteria	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3.3 Description of criteria and sub-criteria

This subsection describes and explains the criteria used to evaluate the decision-making process. Criteria and sub—criteria are the most important factors that are necessary to assess the development of the industry from the point of view of government officials who are able to make a decision. It should be noted that the choice of correct and suitable criteria, as well as sub-criteria, affects the final result of the assessment. Therefore, the choice should be analyzed before the evaluation is carried out (Cavallaro & Ciraolo, 2005). The number of criteria, as well as sub-criteria, will depend on the data reviewed, the literature review and other documents.

According to the analysis and review of the literature, preliminary agreement with governmental and non-governmental experts, criteria and sub-criteria for the lithium development in Kazakhstan have been determined (Figure 5).

Figure 5. Main criteria and sub-criteria



3.3.1 Technical criteria

Technical criteria describe factors for lithium industry development in Kazakhstan and they are play a major role in the success of research. Important sub-criteria in this area are described in more detail below.

Infrastructure

The mining investment is an acquisition of a plant mining ore together with the processing plant producing concentrates of these metals as well as the deposits potentially viable for mining. Polymetallic ore deposits analyzed with different degrees of utilization and mining infrastructure which could be a subject of investment activities (Sobczyk et al., 2017).

To technological transfer development, the complexity of expanding transport and logistics infrastructure is an important issue as well (Kuznetsov et al., 2019).

Experts

The shortage of skilled labor in the mining industry is a critical business risk that countries like Canada and Australia are already facing (Wylie, 2013). Reasons for this include the unattractive working conditions in the mining sector, such as remote work locations and a stressful and demanding work environment that does not match the aspirations of the younger generation seeking a better work-life balance. An aging workforce is worsening the situation in many parts of the world, along with a decline in advanced degree graduates from the mining engineering field (Wang et al., 2022).

Technology transfer

The method of technology transfer occurs through the dynamics of technological developments in certain industrial sectors. Technological developments, for example, are growing faster in the information technology, telecommunications and banking sectors than in the mineral and textile technology sectors. On the other hand, the planned changes are made by the most influential parties when it comes to technology transfer. (Mauldin et al., 2021).

The model is aimed at strengthening the technology transfer process in developing countries. In this model a business environment consisting of certain techniques, expertise, and capability requirements related to technology transfer needs to be developed to strengthen the technology transfer process in developing countries. Moreover, a country's maturity in understanding and applying technology transfer influences its success rate in the technology transfer process (Waroonkun & Stewart, 2008).

Research & development

Innovation capability, which could be measured by the level of technological R&D, is one important factor affecting the development of this industry (Xu, 2015).

To the provinces with abundant resources, they should reasonably plan exploitation of mineral resources by adjusting the resource tax, mineral right and other measures. Besides, these provinces should increase investment in R&D to extend the industrial chain and strengthen supervision on the changes of the regional environment bearing capacity (Cui et al., 2019).

3.3.2 Economical criteria

From the literature review, four key sub-criteria that can affect for the lithium development in the area of economic were identified. These sub-criteria are described below in more detail.

Commercial competitiveness

Competition level in the exploration and mining industry and its development are of strategic importance for industrial development (Gayfullina, 2018; State program for 2015-2019).

Enterprise competitiveness refers to the enterprise in a certain period of time, relative to its competitors have the ability to support its survival and development advantage (Zhou et al., 2008), to expand that the enterprise in the competitive market environment, through the effective allocation of enterprise resources such as human, financial and material, more efficient (Liu et al., 2011). The competitiveness of an enterprise refers to the resources possessed by an enterprise in a competitive market environment through reasonable regulation and allocation, and finally reflects its strong or weak management ability relative to its competitors directly in three dimensions: profit and loss performance, market share, and social influence (Li et al., 2002).

Job creation

The mining industry is an important contributor to the economy of many countries, by offering jobs (Paraskevis et al., 2019). An estimated 30 million people are involved in large-scale mining, representing 1% of the world's workforce, with a further 13 million involved in small-scale mining. It is therefore likely that, including dependents, 250–300 million people rely on mining. Many other people are also directly or indirectly employed in the rest of the minerals supply chain. They are likely to be interested in good, safe and healthy working conditions, with opportunities for training and career development. These conditions can in turn improve motivation and productivity, lower labor absenteeism or turnover and result in fewer union disputes (Azapagic, 2004).

Foreign direct investments

Indeed, of great importance is the attraction of foreign direct investment in the areas of increasing competitiveness and economic efficiency in order to ensure a stable economic growth rate due to the existing potential. From the point of view of foreign investors, to determine the factors which sector to invest in and which affects the investment decision is relevant. What is important, this not only affects the economic growth and development of the region receiving the investment but also provides various advantages within the country or company in which the investment is attracted (Kobilov, 2020).

Inflation rate

Although inflation can drive up material prices, it also causes production costs to rise as mining companies have to pay higher wages and spend more money on raw materials and energy (Bouw, 2011). Besides, inflation may lead to a decrease in consumer spending as more money is needed to buy the same items. For this reason, inflation affects resource-based companies and is therefore another criterion (Wang et al., 2022).

3.3.3 Regulatory criteria

The third criterion consists of three sub-criteria in the area of regulatory risks, which are discussed individually in the coming part.

Legislative framework

It is also significant to evaluate the legislation status that governs the mining industry in a country and the specific legislation acts that may support or prohibit the production of specific commodities. The classification of a metal as strategic and critical not only for economic but also for political and strategic reasons may influence its production status from waste to a by-product or even co-product. It can also affect the social acceptance and amendment of legislation related to its production (Mammadli et al., 2022).

While businesses have little influence over changes in state legislation, they must comply with new regulations or face serious consequences. Examples of such changes include labor laws related to wage increases, changes in tax regulations, or changes in health and safety practices that can increase costs for businesses (Wang et al., 2022).

Cooperation mechanisms

Compared to the different cooperation mechanisms envisaged by the EU legislation, barriers to the implementation of the cooperation mechanism on joint projects between EU and developing countries include poor grid infrastructure (in order for the energy to be transferred into the community), geopolitical unrest, risks of limited public acceptance, existing legal limitations and complex financing schemes (Karakosta et al., 2013).

In order to support the development of cooperation mechanisms and implement a successful collaboration, the current and future situation of the host country need to be examined, so as to be able to develop the most appropriate energy policies (Papapostolou et al., 2016).

Technical regulation & standardization

Low level of technical regulation system, as well as industry standards, is among important challenges that needed to be decided (Kuznetsov et al., 2019). Through technology, the mining industry has overcome many obstacles. New options for increasing productivity are being generated by the evolving technology of the mining industry (Lööw et al., 2019).

A significant technological factor regards the quality standards that a product shall meet to be determined as a primary, co-, or by-product, or waste. If the end products do not meet the quality standards of the market or a specific customer, then their value is depreciated, and their feasible production may well be at risk. Low production efficiency can affect extraction costs, not to mention the quality standards (Mammadli et al., 2022).

3.3.4 Environmental criteria

The last criterion concerns the environmental risks associated with the process of field development and mining. Detailed sub-criteria are described below.

Naturally occurring radioactive materials (NORMs)

Starting from the exploration stage, and most importantly mining always has a significant impact on people and the environment, both positive and negative. The presence and content of naturally occurring radioactive materials (NORMs) in the bowels of the Earth's surface, as well as other negative toxic compounds, can entail great environmental risks and require special attention and careful monitoring (Tchounwou et al., 2012). In practice, such metals require a high degree of special treatment as end products or as waste. Usually, these wastes are contained in small concentrations and it is cheaper to process them as by-products.

Toxic compounds

Toxic compounds are the number of compounds that negatively affect the vital activity of the body. An additional factor interconnecting with the presence of NORMs and toxic compounds from the extraction of minerals and metals regards the treatment and disposal of wastes and tailings (Borden, 2011). Potentially toxic elements and compounds arising from the chemical additions in the process plant, should also be minimized. Isolated wastes should be managed consistent with their toxicity (Franks et al., 2011).

Greenhouse gases

While mining lithium in hard rock does not consume as much water and land as mining in salt flats, it does release a greater amount of CO2 emissions. In addition, in recent years, production has been switched in some cases from lithium carbonate to lithium hydroxide, as this material enables higher energy density in batteries (Grant et al., 2020). While this has a positive effect on battery life, it also causes more CO2 emissions. As decarbonization is an important policy goal for many countries, this poses a risk for certain extraction methods and lithium mines (Wang et al., 2022).

Waste production

Waste production – generation of waste that impacts the environment and community. The use of several methods in waste management and the extraction of metals from waste has been expanded in the concept of the circular economy and zero waste production.

Given the dynamic market of several minor metals, the advanced developments in processing technologies and the need for less waste production, even more producers are reconsidering the possibility of treasures hiding in their tailings (Mammadli et al., 2022).

In the case of lithium extraction from salt ponds, there is a risk that upper ground layers are contaminated by possible leakages in the processing ponds as well as during the disposal of the residual liquids (Sobczyk et al., 2021). This risk is explained in particular by the fact that the brine has to be enriched with hydrochloric acid in the course of lithium processing and may contain further toxic compounds.

Summarizing the above, Table 4 represents list of references with each criterion and sub-criterion.

Table 4. List of criteria and sub-criteria

Criteria	Sub-criteria	References
Technical	Infrastructure	Sobczyk et al., 2017; Kuznetsov et al., 2019
	Experts	Wylie, 2013; Wang et al., 2022
	Technology transfer	Mauldin et al., 2021; Waroonkun & Stewart, 2008

	R&D	Xu, 2015; Cui et al., 2019
Economical	Commercial competitiveness	Gayfullina, 2018; State program for 2015-2019; Zhou et al., 2008; Liu et al., 2011; Li et al., 2002
	Job creation	Paraskevis et al., 2019; Azapagic, 2004
	Foreign direct investments	Kobilov, 2020
	Inflation rate	Bouw, 2011; Wang et al., 2022
Regulatory	Legislative framework	Mammadli et al., 2022; Wang et al., 2022
	Cooperation mechanisms	Karakosta et al., 2013; Papapostolou et al., 2016
	Technical regulation & standardization	Kuznetsov et al., 2019; Lööw et al.,

		2019; Mammadli et al., 2022
Environmental	NORMs	Tchounwou et al., 2012
	Toxic compounds	Borden, 2011; Franks et al., 2011
	Greenhouse gases	Grant et al., 2020; Wang et al., 2022
	Waste production	Mammadli et al., 2022; Sobczyk et al., 2021

3.4 Hierarchical structure

This study analyzes the literature review to identify the main criteria, as well as their sub-criteria for lithium development in Kazakhstan. Criteria and sub-criteria are reflected in the hierarchical tree of the structure for their ranking. In this regard, according to the purpose of the study, 4 criteria are defined, and then sub-criteria. The hierarchical structure can be found according to Figure 6. The factors of the lithium development in Kazakhstan are classified according to 4 main criteria: Technical, Economical, Regulatory and Environmental. These criteria generally include 15 sub-criteria: 4 sub-criteria for technical criteria, 4 sub-criteria for economical sub-criteria, 3 sub-criteria for regulatory criteria, as well as 4 sub-criteria for environmental criteria.

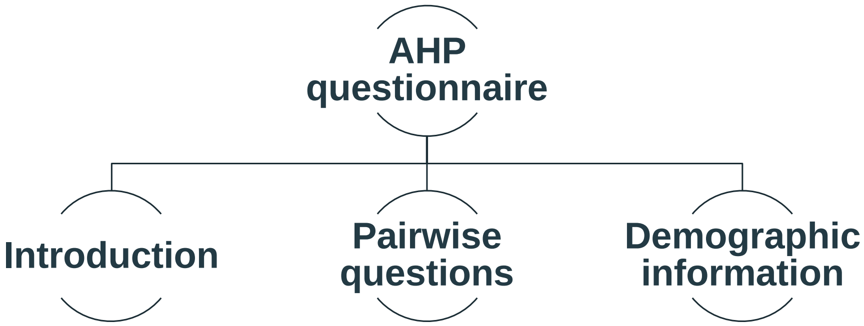
Figure 6. Hierarchy tree

3.5 Data collection

The AHP methodology was applied for the study in question in order to compile a questionnaire and collect data from interested experts in the mining and metallurgical sectors, as well as their analysis (R. W. Saaty, 1987, T. L. Saaty, 1990). An appropriate questionnaire was developed by analyzing the literature and discussing with experts in the sector under consideration (Appendix 1). Governmental and non-governmental experts participated in the survey, according to the questionnaire, presenting their expert opinions.

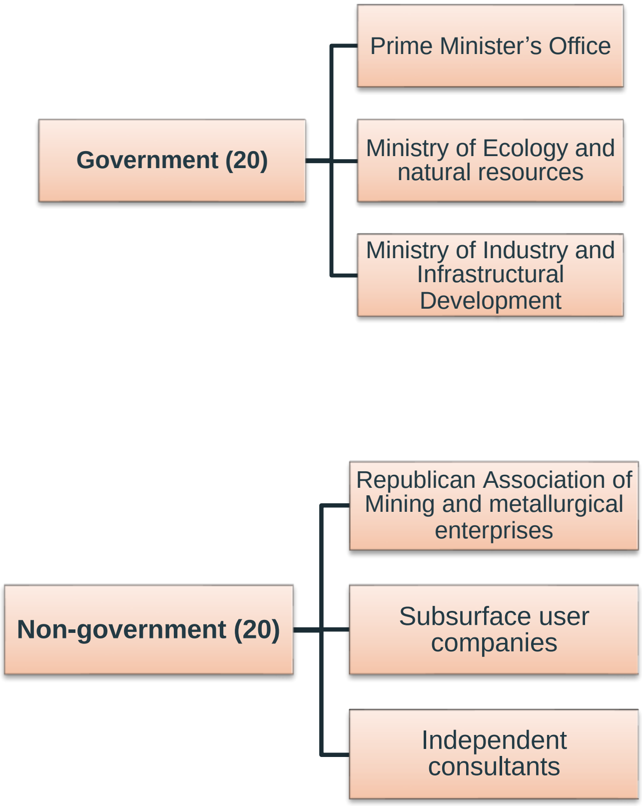
The questionnaire consists of three main parts. The first is an introduction explaining the purpose of the study. Second part includes pairwise questions were introduces to the respondents and an explanation on how to answer them. The final section consisted of questions about the respondents' general information Figure 7. Summarizing the above, the questionnaire consists of three sections – introduction, paired questions and general information about the respondents (age, education, place and work experience in the industry, etc.).

Figure 7. AHP questionnaire



The prepared questionnaire was compiled and sent using an information platform, requests by e-mail and telephone. Two main groups of respondents were selected as the most important persons in the mining and metallurgical industries, who play a key role in decision-making and policy implementation (Figure 8). A total of 40 expert opinions were received from both sectors, including 20 from the government and 20 from the non-governmental sectors. According to the results of the survey, the received answers and expert opinions were analyzed by comparison and counting.

Figure 8. Respondents



Chapter 4. Research Results

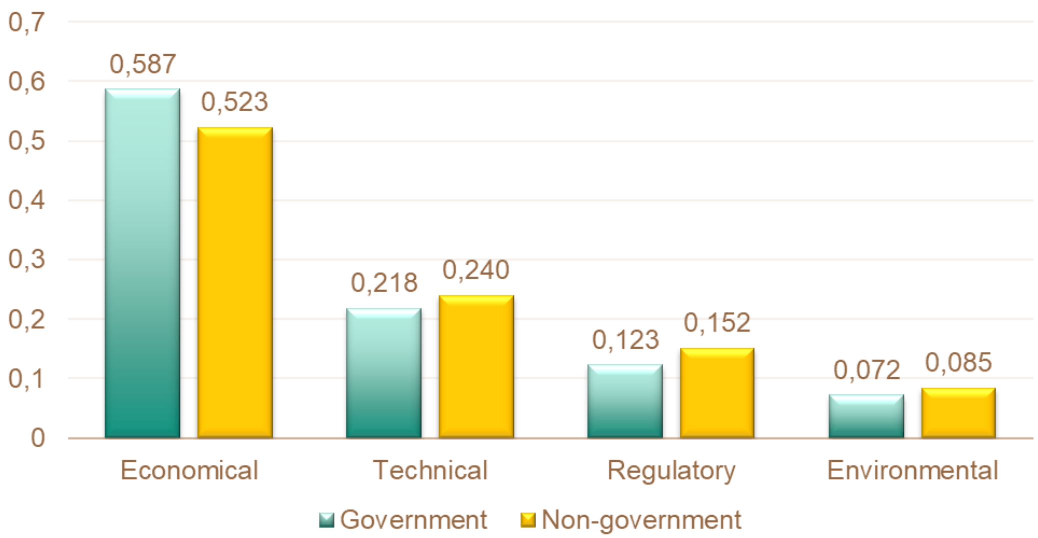
This chapter demonstrates the analysis of the results of the study: the consistency ratio, the weight of the main criteria and the corresponding sub-criteria, the result of the overall ranking, as well as the conclusion about the most significant factors using the AHP process.

4.1 Consistency Ratio of Main Criteria

According to (Wind & Saaty, 1980), the results of the study were evaluated in matrix form and used to evaluate the weights and ranks of each criterion and subcriteria. According to (Wang et al., 2011), if the consistency ratio (CR) is 0, the results of the pairwise comparison will be fully consistent, and if the consistency ratio (CR) exceeds 0.1 or 10%, the results of the pairwise comparison are not consistent.

According to the responses received and the analysis carried out, the consistency ratio (CR) for both expert groups is less than 0.1, which indicates favorable results and that the opinions of interested experts can be accepted. More detailed information about the results is provided below (Figure 9).

Figure 9. Graphic comparison of both groups' opinions on the main criteria



4.2 Estimated Weight of Main Criteria

The rating of the main criteria for lithium development in Kazakhstan, presented to both expert groups, is presented below. The submitted responses of experts from government sector on the main criteria are presented in Table 5, and the responses of experts from the non-governmental sector on the main criteria are presented in Table 6.

Table 5. Ranking of main criteria from Government experts

Criteria	Priority weight	Share	Rank
Economical	0.587	59 %	1
Technical	0.218	22 %	2
Regulatory	0.123	12 %	3
Environmental	0.072	7 %	4

Table 6. Ranking of main criteria from non-government experts

Criteria	Priority weight	Share	Rank
Economical	0.523	52 %	1
Technical	0.240	24 %	2
Regulatory	0.152	15 %	3
Environmental	0.085	9 %	4

4.3 Estimated Weight of Sub-Criteria

Tables 7 and 8 show the results of sub-criteria ranking within Economical criteria according to both experts group respondents.

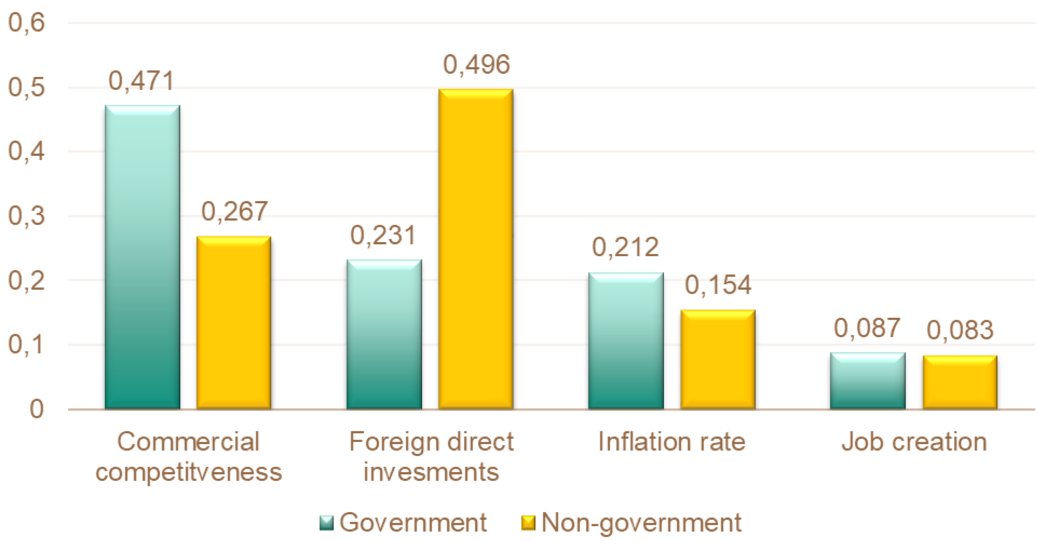
Table 7. Ranking of economic sub-criteria from Government experts

Criteria	Priority weight	Share	Rank
Commercial competitiveness	0.471	47 %	1
Foreign direct investments	0.231	23 %	2
Inflation rate	0.212	21 %	3
Job creation	0.087	9 %	4

Table 8. Ranking of economic sub-criteria from non-government experts

Criteria	Priority weight	Share	Rank
Foreign direct investments	0.496	50 %	1
Commercial competitiveness	0.267	27 %	2
Inflation rate	0.154	15 %	3
Job creation	0.083	8 %	4

Figure 10. Graphic comparison of both groups' opinions on Economic sub-criteria



Tables 9 and 10 show the results of sub-criteria ranking within Technical criteria according to both experts group respondents.

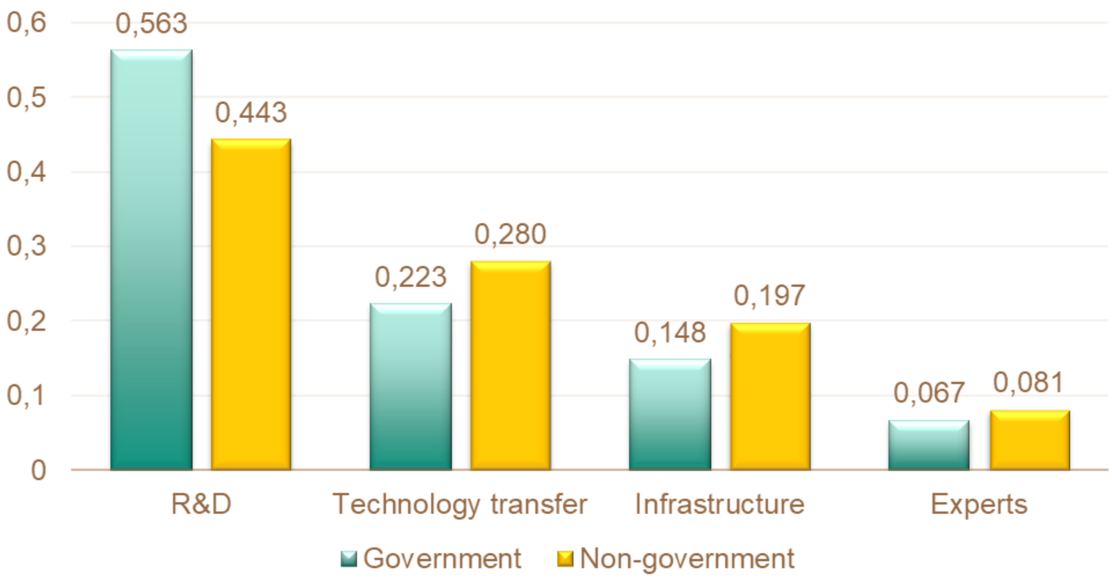
Table 9. Ranking of technical sub-criteria from Government experts

Criteria	**Priority weight**	**Share**	**Rank**
R&D	0.563	56 %	1
Technology transfer	0.223	22 %	2
Infrastructure	0.148	15 %	3
Experts	0.067	7 %	4

Table 10. Ranking of technical sub-criteria from non-government experts

Criteria	**Priority weight**	**Share**	**Rank**
R&D	0.443	44 %	1
Technology transfer	0.280	28 %	2
Infrastructure	0.197	20 %	3
Experts	0.081	8 %	4

Figure 11. Graphic comparison of both groups' opinions on Technical sub-criteria



Tables 11 and 12 show the results of sub-criteria ranking within Regulatory criteria according to both experts group respondents.

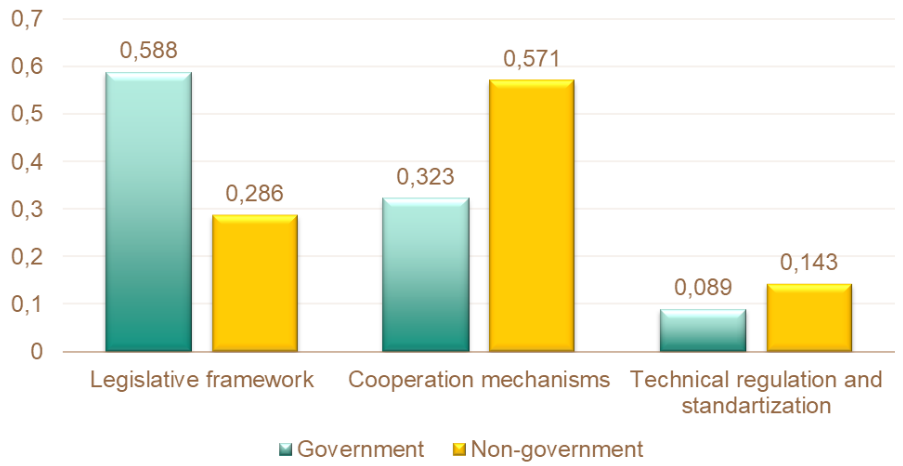
Table 11. Ranking of regulatory sub-criteria from Government experts

Criteria	**Priority weight**	**Share**	**Rank**
Legislative framework	0.588	59 %	1
Technical regulation & standardization	0.323	32 %	2
Cooperation mechanisms	0.089	9 %	3

Table 12. Ranking of regulatory sub-criteria from non-government experts

Criteria	Priority weight	Share	Rank
Cooperation mechanisms	0.571	57 %	1
Legislative framework	0.286	29 %	2
Technical regulation & standardization	0.143	14 %	3

Figure 12. Graphic comparison of both groups' opinions on Regulatory sub-criteria



Tables 13 and 14 show the results of sub-criteria ranking within Environmental criteria according to both experts group respondents.

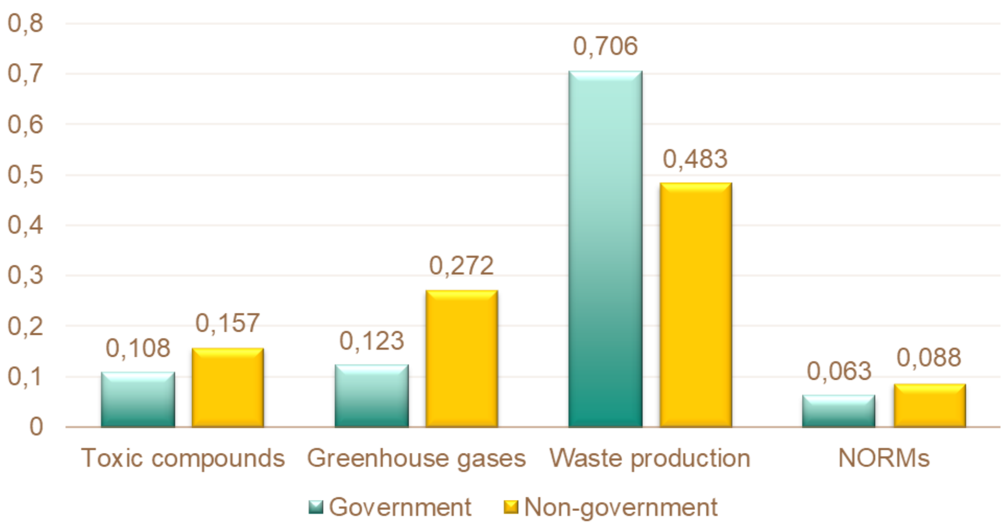
Table 13. Ranking of environmental sub-criteria from Government experts

Criteria	Priority weight	Share	Rank
Waste production	0.706	71 %	1
Greenhouse gases	0.123	12 %	2
Toxic compounds	0.108	11 %	3
NORMs	0.063	6 %	4

Table 14. Ranking of environmental sub-criteria from non-government experts

Criteria	Priority weight	Share	Rank
Waste production	0.483	48 %	1
Greenhouse gases	0.272	27 %	2
Toxic compounds	0.157	16 %	3
NORMs	0.088	9 %	4

Figure 13. Graphic comparison of both groups' opinions on Environmental sub-criteria



4.4 Overall ranking of sub-criteria

Results of the overall ranking of sub-criteria are presented in Table 15 and 16, as well as Figures 14 and 15 below. In addition, Figure 15 shows a comparison between both groups of experts' opinions.

Thus, Table 15 shows the results of overall ranking of sub-criteria according to government sector respondents.

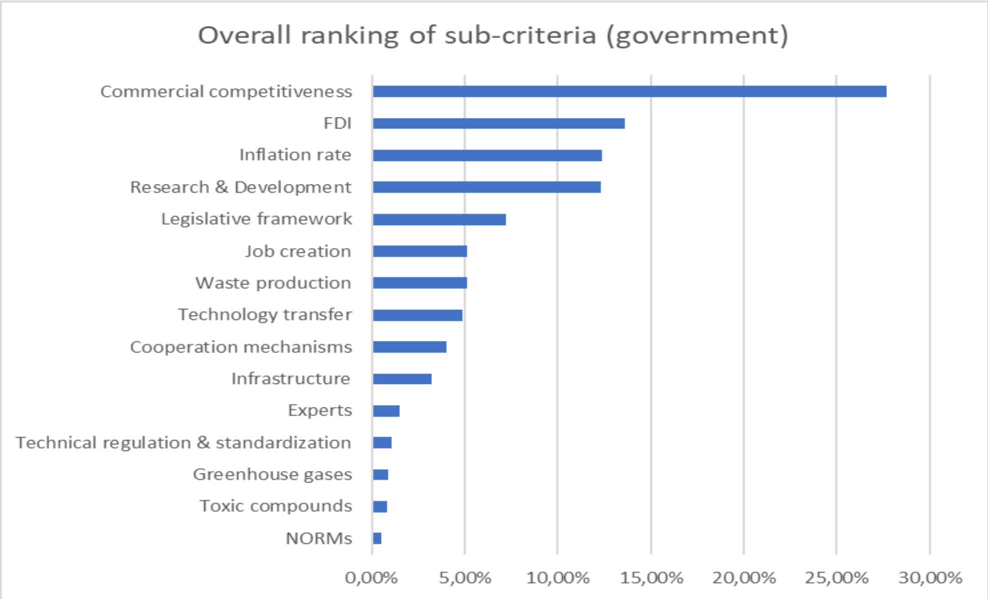
Table 15. Overall ranking of sub-criteria (government experts)

Criteria	**Share**	**Rank**
Commercial competitiveness	27.7%	1
Foreign direct investments	13.6%	2
Inflation rate	12.4%	3
R&D	12.3%	4
Legislative framework	7.2%	5
Job creation	5.1%	6
Waste production	5.1%	7
Technology transfer	4.9%	8
Cooperation mechanisms	4.0%	9
Infrastructure	3.2%	10
Experts	1.5%	11
Technical regulation & standardization	1.1%	12
Greenhouse gases	0.9%	13

Toxic compounds	0.8%	14
NORMs	0.5%	15

Figure 14 represents the graphical results of overall ranking of sub-criteria according to government sector respondents.

Figure 14. Overall ranking of sub-criteria (government experts)



The weight given to commercial competitiveness highlights its relevance in the assessment. Enhancing competitiveness through factors such as market dynamics, pricing strategies, and branding can positively impact economic growth, market share, and overall success. Foreign direct investments contribute to economic growth, employment opportunities, and technology transfer. Creating an attractive investment climate can encourage foreign investment inflows. The weight given to the inflation rate implies its impact on the assessment. Controlling inflation is essential for maintaining price stability, consumer purchasing power, and overall economic stability. Research and development contribute to innovation and technological advancement, leading to improved products, processes, and competitiveness. The weight suggests that investing in R&D can have a positive impact, albeit relatively lower compared to other factors. A robust legislative framework is crucial for establishing a favorable business environment, ensuring regulatory compliance, and promoting economic growth.

In conclusion, the weights assigned to each factor provide insights into their relative importance within the given assessment. Factors such as commercial competitiveness, foreign direct investments, inflation rate, research and development, and legislative framework are identified as significant drivers of the evaluation.

Table 16 shows the results of the overall ranking of sub-criteria according to non-government sector respondents.

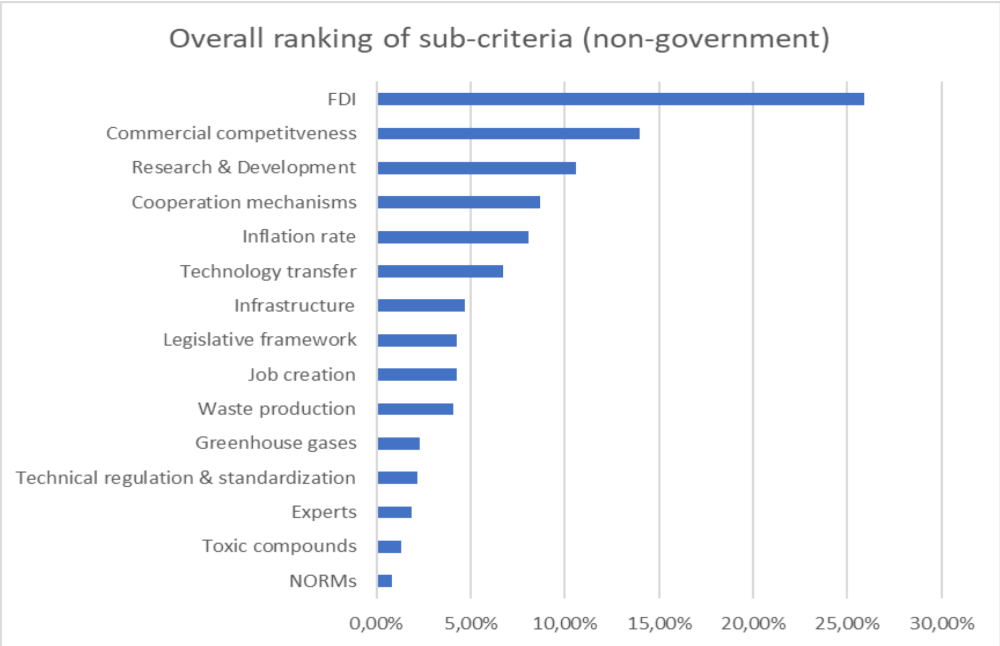
Table 16. Overall ranking of sub-criteria (non-government experts)

Criteria	**Share**	**Rank**
Foreign direct investments	25.9%	1
Commercial competitiveness	14.0%	2
R&D	10.6%	3
Cooperation mechanisms	8.7%	4
Inflation rate	8.1%	5
Technology transfer	6.7%	6

Infrastructure	4.7%	7
Legislative framework	4.3%	8
Job creation	4.3%	9
Waste production	4.1%	10
Greenhouse gases	2.3%	11
Technical regulation & standardization	2.2%	12
Experts	1.9%	13
Toxic compounds	1.3%	14
NORMs	0.8%	15

Figure 15 represents the graphical results of overall ranking of sub-criteria according to non- government sector respondents.

Figure 15. Overall ranking of sub-criteria (non-government experts)

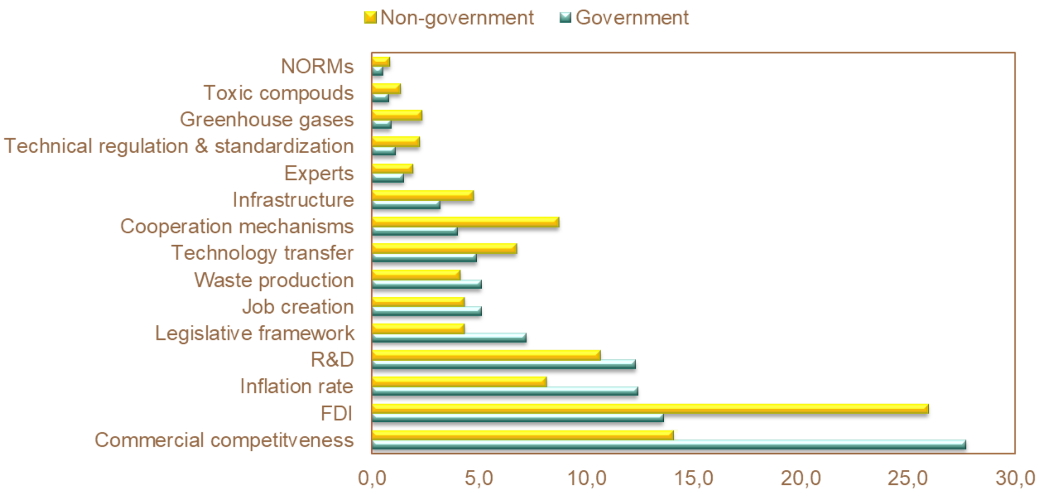


The weight assigned to foreign direct investments highlights its role in driving economic growth and development. Attracting foreign direct investments can stimulate job creation, and technology transfer, and enhance the competitiveness of the economy. The weight given to commercial competitiveness indicates its relevance in the evaluation. Improving commercial competitiveness through factors such as market positioning, product differentiation, and marketing strategies can drive market share and economic success. The weight given to research and development suggests its significance in the evaluation. Investing in research and development drives innovation, technological advancements, and fosters long-term economic growth. Effective cooperation mechanisms among stakeholders, such as public-private partnerships and collaboration between industries, can foster sustainable development and drive positive outcomes. The weight given to technology transfer indicates its influence in the assessment. Effective technology transfer mechanisms enable the adoption and diffusion of innovative technologies, leading to increased productivity, competitiveness, and economic growth.

Based on the weights assigned to each factor, it is evident that foreign direct investments, commercial competitiveness, research and development, cooperation mechanisms, and technology transfer are identified as highly significant factors in the evaluation. These factors play vital roles in driving sustainable development and economic growth. Overall, this analysis provides insights into the relative significance of each criterion and can guide decision-making processes towards achieving desirable outcomes.

Figure 16 below represents the graphical results of overall ranking of sub-criteria according to both government and non-government respondents.

Figure 16. Comparison of overall ranking of sub-criteria



Chapter 5. Conclusion

5.1 Key findings

The research results show differences in the views of experts from the governmental and non-governmental sectors. Based on the findings, it became clear that decision-makers from the government and non-government sectors estimate the weight of the economic criterion (59% and 52%, respectively) as the highest criterion for lithium development in Kazakhstan. This result corresponds to the conclusions of Mammadli et al. (2022) and Wang et al. (2022), who noted that the economic criterion is one of the most important criteria in the planning of mining, including lithium.

The second most important criterion is the technical criterion, with a priority weight of 22% and 24%, respectively. The importance of the technical criterion was also established in the study (Wang et al., 2022). The lack of necessary technological equipment and scientific research is a problem that the mining industry faces in many countries.

Regulatory (12% and 15%) and environmental (7% and 9%) criteria, according to the result from the governmental and non-governmental sectors experts, were placed in third and fourth place, respectively. These conclusions also correspond to the views of Mammadli et al. (2022) and Wang et al. (2022). The criteria were ranked almost identically but were classified as medium or low in terms of their regulatory and environmental indicators.

Based on this, it can be concluded that the economic criterion is the most important for government officials who can make decisions and implement policies and for non-government enterprises. According to Mammadli et al. (2022), economic parameters seem to play a crucial role in deciding on the production of minerals. The other three categories are equally less important in this case.

In the economical sub-criteria, commercial competitiveness and foreign direct investments are in the first and second places, respectively, ranking the most critical economical sub-criteria for lithium development. This also corresponds to the conclusion that the level of competition in the mining industry and its development is strategically vital for industrial development (Gayfullina, 2018). In addition, attracting foreign direct investment in the areas of increasing competitiveness and economic efficiency is of great importance. It is essential to determine the factors in which sector to invest and which influence the investment decision. What is important is that this not only affects the economic growth and development of the region receiving investments but also provides various advantages within the country or the company in which investments are attracted (Kobilov, 2020).

In the technical sub-criteria, R&D and technology transfer are in the first and second places, respectively, ranking the most important technical sub-criteria for lithium development.

This arrangement of criteria is also correlated with the National Plan "100 Steps"[2] (National Plan of 100 Steps). One of the points posits that economic and technical aspects should be priority areas of energy sector development.

In the case of regulatory sub-criteria, the legislative framework and the cooperation mechanisms are in the first and second places, respectively, in ranking the most important regulatory sub-criteria.

These approaches are also reflected in the National Plan "100 steps." The 75th step provides for the introduction of a simplified method of issuing licenses for all minerals, observing the best international practice by improving the legislative framework in the field of minerals. In addition, the 74th step provides for increasing transparency and predictability of subsoil use by introducing an international system of standards for mineral reserves to create favorable conditions for investment and competitiveness.

In the case of environmental sub-criteria, waste production is the most important for both groups of respondents. As part of the elimination of the consequences of the operation of facilities that have a negative impact on the environment, work should be conducted to bring land plots into a condition that ensures the safety of life and (or) human health, environmental protection and suitable for their further use for their intended purpose, as well as, depending on the nature of such facilities, post utilization of objects

[2] "The 100 concrete steps is the national plan for the implementation of five institutional reforms, such as – formation of a professional state apparatus; ensuring the rule of law; industrialization and economic growth; identity and unity; formation of an accountable state."

construction, elimination of consequences of subsurface use, closure of landfills and other places of storage and disposal of waste, including radioactive (Ecological Code of the Republic of Kazakhstan, 2021).

Notably, the management of the sector granting the right of subsurface use, replenishment of the mineral resource base, and regulation of the industrial sector in Kazakhstan belongs to the Ministry of Industry and Infrastructure Development. At the same time, environmental safety issues are within the competence of the Ministry of Ecology and Natural Resources. In this regard, decision-makers in these government sectors responded based on their experience.

5.2 Policy Implications

Based on the evaluation, the top-ranked criteria and sub-criteria were identified.

Considering the analysis findings, the following policy recommendations are suggested for developing the lithium industry in Kazakhstan. FDI, commercial competitiveness, inflation rate, and R&D are all important for lithium development in Kazakhstan for the following reasons:

FDI brings in the necessary capital and resources to develop and expand the lithium sector in Kazakhstan. The lithium industry requires substantial investment in mining operations, processing facilities, and infrastructure. FDI can provide the financial means to acquire advanced technologies, improve operational efficiency, and promote sustainable growth in the sector. As mentioned earlier, policy implications for FDI include creating an attractive investment environment, establishing clear mining and regulatory frameworks, and fostering public-private partnerships.

Enhancing commercial competitiveness is crucial for Kazakhstan's lithium development to compete effectively in the global market. This involves improving productivity, reducing production costs, and meeting international quality standards. Policy implications for promoting commercial competitiveness include investing in technology and innovation, fostering collaboration between industry and research institutions, and supporting entrepreneurship and business development.

Controlling inflation is vital for the stability of the economy and the attractiveness of the investment climate in Kazakhstan. High inflation rates can erode profitability and increase business costs, affecting the viability of lithium development projects. To address inflation, policy implications may include implementing sound monetary and fiscal policies, promoting price stability, and ensuring a favorable business environment with predictable regulations and low transaction costs.

Investing in R&D is crucial for the advancement of lithium technologies, product innovation, and process optimization. R&D can drive improvements in lithium extraction methods, battery technology, and energy storage systems. Policy implications for R&D in the lithium sector involve supporting research institutions, providing funding and incentives for R&D

activities, fostering collaboration between academia and industry, and promoting intellectual property protection.

By focusing on these aspects, Kazakhstan can attract FDI, enhance commercial competitiveness, manage inflation, and drive research and development, leading to the sustainable development of its lithium industry. This, in turn, can position Kazakhstan as a key player in the global lithium market, foster economic growth, create employment opportunities, and contribute to the country's transition towards a more sustainable and technology-driven economy.

5.3 Summary

The conclusion section of the study highlights the key findings and policy implications regarding the development of the lithium industry in Kazakhstan. The study analyzed the perspectives of experts from governmental and non-governmental sectors, considering criteria such as economic, technical, regulatory, and environmental aspects. The results indicate that decision-makers from both sectors prioritize the economic criterion as the most important, followed by the technical criterion. The regulatory and environmental criteria were ranked lower in importance. The study also aligns with the National Plan "100 Steps" in emphasizing economic and technical aspects as the energy sector's development priority areas. By implementing policy implications, Kazakhstan can leverage FDI to accelerate the development of its lithium sector, enhance its global competitiveness, and establish itself as a key player in the lithium value chain.

5.4 Limitations of the study

While the study provides valuable insights, it is important to acknowledge its limitations. Some potential limitations of the study include:

1. Sample Size: The research involved a relatively small sample size of 20 respondents from each sector. This limited sample may not fully represent the diverse range of perspectives and expertise within the lithium industry.

2. Generalizability: The findings are specific to the context of Kazakhstan and may not be directly applicable to other regions or countries with different socio-economic and environmental conditions.

3. Subjectivity: The study relies on the opinions and judgments of the experts participating in the research. The subjective nature of the assessment and the potential for bias in expert opinions may influence the results.

4. Exclusion of Other Stakeholders: The study primarily focuses on the perspectives of governmental and non-governmental experts, potentially overlooking the viewpoints of other important stakeholders such as local communities, environmental organizations, or international industry experts.

5. Timeframe: The conclusions are based on the information and data available at the time of the study. The dynamic nature of the lithium industry and evolving technological advancements may introduce changes and render some findings less relevant over time.

Considering these limitations when interpreting the results and applying the policy recommendations to real-world scenarios is crucial. Ultimately, further research and analysis incorporating a larger and more diverse sample, along with a comprehensive evaluation of external factors, may provide a more robust understanding of the development of the lithium industry in Kazakhstan.

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Appendix

Survey

Hello! How are you?

I am Azamat Assanov a master's student in the International Energy Policy Program at Seoul National University in South Korea, and I am taking this questionnaire for my master's degree research.

This research work uses the Analytic Hierarchy Process (AHP) methodology, and the questionnaire is based on the Pairwise Comparison method to determine "the main criteria for the lithium development in Kazakhstan and to understand in which direction the policy should be implemented".

If you have any feedback or questions about this questionnaire, please contact me at 2021-28242@snu.ac.kr and az.assanov@gmail.com. I am always happy to help you with any questions you may have.

This survey will take a total of 20 minutes to complete and I am thanking you for taking the time to complete it.

E-mail ___

Personal information

All personal information you provide and responses to questionnaires will be kept confidential and used for research purposes only. Once the data from the completed questionnaire has been analyzed and the results have been integrated into the research, it will be deleted immediately and will not be stored.

A working organization ___

Jurisdiction (office, department) ___

Position ___

Years of working in the energy or mineral resources industry ___

Contact phone number ___

E-mail address ___

Instructions: How to complete the Pairwise Comparison Questionnaire?

This pairwise comparison questionnaire is based on 4 main criteria and 15 sub-criteria.

Answering the questions in the questionnaire is not complicated, it is simple. I would like to ask you to give your opinion based on your experience about the relationship and relative importance of the two criteria.

For example: Let's say you have 2 criteria: Technical and Economical. Then, by comparing these 2 criteria, it will be determined which one is more important in terms of obstacles to the development of the lithium industry in Kazakhstan.

Below are four questions presented in the form of a 9-point scale of pairwise comparison of criteria A and B. It is necessary to select a numerical value of the scale based on the importance of one criterion in relation to another (Table 1).

Table 1. Selection scale for pair-wise comparison of criteria (A and B).

Explanation	Numeric scale
If option A and B have the same importance	1
If option A is moderately more important than option B	3
If option A is strongly more important than option B	5
If option A is very strongly more important than option B	7
If option A is extremely more important than option	9
You can also choose an even number for the intermediate score.	2, 4, 6, 8

Below is an example of a scale response. It is necessary to choose one of the numerical values of the scale according to your opinion.

Table 2. Example to do pair-wise comparison

Option A	Extremely		Very strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very strongly		Extremely	Option B

Economical	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technical

Meaning: Option A (Economical) is a very strongly significant criterion compared to option B (Technical)

Meaning: Option A (Economical) and option B (Technical) are equally important

Meaning: Option B (Technical) is a very strongly significant criterion compared to option A (Economical)

Question 1. Choice of main criteria

In this decision making of lithium development, which criteria are that you consider more important?

Please arrange the main criteria in order of importance from 1 (most important) to 3 (least important).

Table 3. Main criteria

Criteria	**Rank**
Economical	( )
Technical	( )
Regulatory	( )
Environmental	( )

Description of each criterion:

1. **Economical** – this criterion is used as a measurement of cost and benefit that can be affected on investment for lithium industry development and allow for incorporation of the benefits and costs incurred in implementing the project. Three sub-criteria were identified for economic criteria: commercial competitiveness, foreign direct investments, job creation and inflation rate.
2. **Technical** – this criterion is defining the technical relevance of the lithium industry development to be implemented, according to the scope established in the sub-criteria. Four sub-criteria were identified for technical criteria: research & development, technology transfer, infrastructure development, and skilled workers.
3. **Regulatory** – this criterion describes regulatory factors for lithium industry development. Three sub-criteria were identified for regulatory criteria: legislative framework, cooperation mechanisms, and technical regulation and standardization.
4. **Environmental** – this criterion is to incorporate the impact of the implementation of the project in the environment. Three sub-criteria were identified for environmental criteria: toxic compounds, greenhouse gases, NORMs and waste production.

In accordance with the mentioned criteria and using a scale from 1 to 9, please select the degree of importance of option A (left column) in relation to option B (right column).

Option A	Extremely		Very strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very strongly		Extremely	Option B
Technical	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economical
Technical	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Regulatory
Technical	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental
Economical	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Regulatory
Economical	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental
Regulatory	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental

Question 2. Choice of sub-criteria – Economical

Description of each sub-criteria:

1. **Commercial competitiveness** – this factor was mentioned as an important factor for many researchers. Competition level in the exploration and mining industry and its development are of strategic importance for industrial development. The foundation that enables to create a competitive world-class industry in the country is the existence of some important factors as related and supporting industries, the market, conditions, the strategy, and structure to achieve stable competitiveness. In addition, the main factors contributing to the industry development are proximity to

demand markets (market), access to raw materials and technology, and government incentives.

2. **Foreign direct investment** – investigating and acquiring the experience of countries with similar economies whose national wealth has benefited from the diversification of their economies is one of the steps needed to create a sustainable economy. For example, considering the current global integration processes, such successful global practices as the creation of large centralized state-owned corporations and foreign participation are considered as key factors. The importance of FDI for the development of industries, especially at the initial stage, is highly emphasized in many pieces of literature. The significance of the foreign direct investment for renewable energy development in terms of developing countries emphasized. Many countries have developed, as well as have been trying to develop various measures in order to attract FDI to the sector.
3. **Inflation rate** – another important criterion for many industries is the inflation rate. According to some researches, the country's ability to smooth out the large level of macroeconomic volatility caused by big fluctuations in export prices has been always considered a crucial factor for development. Otherwise, it might be much more complicated to support investments for non-

resource trade sectors that can be destroyed by big fluctuations in the real exchange rate.

4. **Job creation –** this factor is measuring the number of local jobs creating and local company participation.

In this decision making of lithium development, which sub-criteria are that you consider more important?

Please arrange the Economical sub-criteria in order of importance from 1 (most important) to 3 (least important).

Table 4. Economical sub-criteria

Sub-criteria	Rank
Commercial competitiveness	( )
Foreign direct investment	( )
Inflation rate	( )
Job creation	( )

Option A	Extremely		Very strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very strongly		Extremely	Option B
Commercial competitiveness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Foreign direct investment
Commercial competitiveness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Inflation rate
Commercial competitiveness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Job creation
Foreign direct investment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Inflation rate
Foreign direct investment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Job creation
Inflation rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Job creation

In accordance with the mentioned criteria and using a scale from 1 to 9, please select the degree of importance of option A (left column) in relation to option B (right column).

Question 3. Choice of sub-criteria – Technical

Description of each sub-criteria:

1. **Research & development** – some researches show that technological integration can develop only in a favorable innovation environment. Thus, innovation activities are one of the important factors for industry development.

2. **Technology transfer** – achieving success largely depends on solving the problems of technological backwardness. Ineffective technologies for exploration and mining is among key challenges for the industry development in the country.
3. **Infrastructure development** – moreover to technological transfer development, the complexity of expanding transport and logistics infrastructure is an important issue as well. In the case of Kazakhstan, insufficient transportation infrastructure is among key challenges for industry development.
4. **Experts** – human capital may be considered as additional to natural resources, and countries with an insufficient level of this capital will have more difficulties to maintain diversification of their economies and to improve the export technology border. Quality of human resources is very important and another challenge for Kazakhstan is an underqualified staff and major skill gaps in the sector.

In this decision making of lithium development, which sub-criteria are that you consider more important?

Please arrange the Technical sub-criteria in order of importance from 1 (most important) to 4 (least important).

Table 5. Technical sub-criteria

Sub-criteria	Rank

Research & development	( )
Technology transfer	( )
Infrastructure	( )
Experts	( )

In accordance with the mentioned criteria and using a scale from 1 to 9, please select the degree of importance of option A (left column) in relation to option B (right column).

Option A	Extremely		Very strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very strongly		Extremely	Option B
Research & development	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technology transfer
Research & development	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Infrastructure
Research & development	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Skilled workers
Technology transfer	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Infrastructure
Technology transfer	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Skilled workers
Infrastructure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Skilled workers

Question 4. Choice of sub-criteria – Regulatory

Description of each sub-criteria:

1. **Legislative framework** – external factors of strategic development of a subsoil use industry include regulatory factors such as the system of legislation. Thus, it is significant to note, that

the level of legislation framework in the context of the industry development should be considered.

2. **Cooperation mechanisms** – considering the current global integration processes, special attention should be paid to expanding the attraction of foreign direct investment, foreign venture, and the development of schemes for their introduction to the world market, encouraging the use of global business practices and partnership between the state and the private sector.
3. **Technical regulation & standardization** – low level of technical regulation system, as well as industry standards, is among important challenges that needed to be decided. For instance, in the case of China, the problems of industry development included the lack of harmonized standards for manufactured products, which hindered the development of trade.

In this decision making of lithium development, which sub-criteria are that you consider more important?

Please arrange the Regulatory sub-criteria in order of importance from 1 (most important) to 3 (least important).

Table 6. Regulatory sub-criteria

Sub-criteria	Rank
Legislative framework	( )
Cooperation mechanisms	( )

Technical regulation & standardization	( )

In accordance with the mentioned criteria and using a scale from 1 to 9, please select the degree of importance of option A (left column) in relation to option B (right column).

Option A	Extremely		Very strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very strongly		Extremely	Option B
Legislative framework	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Cooperation mechanisms
Legislative framework	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technical regulation & standardization
Cooperation mechanisms	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technical regulation & standardization

Question 5. Choice of sub-criteria – Environmental

Description of each sub-criteria:

1. **Toxic compounds –** the number of compounds that negatively affect the vital activity of the body.
2. **Greenhouse gases –** this factor is used to measure emissions of greenhouse gases produced by the project to be implemented.
3. **Waste production –** generation of waste that impacts the environment and community. The use of several methods in waste management and the extraction of metals from waste has been

expanded in the concept of the circular economy and zero waste production.

4. **NORMs -** mining will always impact people and the environment, either positively or negatively. The presence and content of naturally occurring radioactive materials (NORMs) and other toxic compounds can entail high environmental risks and may require particular attention and close monitoring.

In this decision making of lithium development, which sub-criteria are that you consider more important?

Please arrange the Environmental sub-criteria in order of importance from 1 (most important) to 3 (least important).

Table 7. Environmental sub-criteria

Sub-criteria	Rank
Toxic compounds	( )
Greenhouse gases	( )
Waste production	( )
NORMs	( )

In accordance with the mentioned criteria and using a scale from 1 to 9, please select the degree of importance of option A (left column) in relation to option B (right column).

Option A	Extremely		Very strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very strongly		Extremely	Option B
Toxic compounds	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Greenhouse gases
Toxic compounds	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste production
Toxic compounds	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	NORMs
Greenhouse gases	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste production
Greenhouse gases	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	NORMs
Waste production	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	NORMs

국문 요약

카자흐스탄의 리튬 개발 및 정책수행을 위한 의사결정과정 분석

아자맛

협동과정 기술경영경제정책전공

서울대학교 대학원

오늘날, 리튬은 세계 경제의 지속 가능한 발전에 영향을 미칠 수 있는 전략적 물질 중 하나이다. 리튬이온 배터리는 사용 가능한 모든 배터리 기술 중에서 시장을 선도하고 있으며, 휴대용 전자 장치와 전기 자동차에 널리 사용되고 있다.

카자흐스탄에는 다양한 희토류 금속과 리튬이 다량 매장되어 있으며, 주로 카자흐스탄 동부에 집중되어 있다. 2013 년 초 미국 지질조사국에 따르면 확인된 리튬 매장량은 비록 잠정적인 데이터이긴 하지만 카자흐스탄이 세계 10 대 리튬 보유국 중 하나임을 보여준다.

카자흐스탄 원자재의 확인 매장량, 광물 및 재료 구성, 다양한 국내 기업의 리튬 함유 폐기물에 대한 이전 분석은 지속적으로 성장하는 리튬 수요를 충족하기 위한 리튬 개발 전망과 타당성을 보여준다.

현재 카자흐스탄의 리튬 생산은 논의, 이론적 연구 및 시험 개발 수준이다. 정부는 적극적으로 투자를 유치하고 매장량을 평가하기 위한 지질 탐사를 수행해야 한다.

카자흐스탄의 리튬 산업 개발을 위한 요소 및 우선 순위를 추정하기 위해 계층화분석법 (AHP: Analytical Hierarchical Process) 방법론을 적용하였다. 방법론 프레임워크는 연구 질문에 답하기 위한 몇 가지 주요 단계를 포함한다.

연구는 관련 연구에 대한 광범위한 문헌 검토를 수행한 후 리튬 개발에 영향을 미치는 주요 요소를 파악하는 것으로 시작하였다. 네 가지 주요 요소는 경제, 기술, 규제 및 환경이다. 정부와 비정부 측의 일부 전문가들이 조사에 참여하였다.

연구 결과는 양측 의사결정자 모두 경제적 기준을 가장 중요하게 우선시하고 그 다음에 기술적 기준을 우선시한다는 것을 보여준다. 규제 및 환경 기준은 중요도에서 낮은 순위를 차지했다. 이 연구 결과는 또한 에너지 부문의 개발 우선 분야로서 경제적, 기술적 측면을 강조하는 국가 계획 "100 단계"와 일치한다. 정책적 함의를 이행함으로써 카자흐스탄은 외국인 직접 투자를 활용하여 리튬 개발을 가속화하고, 글로벌 경쟁력을 강화하며, 리튬 가치 사슬에서 핵심 플레이어로 자리매김할 수 있을 것이다.

키워드: 리튬 산업, 희토류 금속, 계층화분석법(AHP), 카자흐스탄.

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