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ARTICLE

AN ECONOMIC ANALYSIS MODEL FOR LITHIUM PRODUCTION BY DIRECT LITHIUM EXTRACTION (DLE) METHOD FROM A SINGLE WELL

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Abstract: The article presents an economic model enabling the assessment of the profitability of lithium extraction using the direct lithium extraction (DLE) method from geothermal brines from a single well. The model enables a preliminary simplified assessment of the profitability of DLE projects, which can be helpful in selecting the optimal locations for such projects and drilling production wells. The article also presents the critical role of lithium as a raw material for the decarbonization of the global economy, methods of its extraction, and the economic prospects of the market for this raw material. It also presents exemplary DLE projects in the world.

Keywords: lithium, brine, lithium geothermal brine, lithium direct extraction, LDE

1. Lithium as a critical raw material for energy transformation

Lithium is one of the critical materials in terms of the world's energy transformation towards climate-neutral economies as it is a raw material necessary for the production of batteries. The European Commission has listed lithium as one of 34 critical raw materials for its development [1]. Battery production is not only needed for the development of electromobility, but also for industrial energy storage, which is necessary for the further development and wider use of renewable energy sources in the energy sector. Unfortunately, in the case of industrial energy storage, their costs are still so high that they are of limited use in large energy applications. The currently dominant battery technology on the market is lithium-ion (Li-ion) batteries, which have gained great popularity in consumer and industrial applications. In turn, battery technologies are mainly used for the production of energy storage:

- lithium-ion (Li-ion) – the most popular technology today;
- lithium-iron-phosphate (LFP);
- lithium-nickel-cobalt-aluminum-oxide (NCA);
- lithium-manganese (LMO);
- lithium-cobalt (LCO);
- lithium-titanium (LTO).

The listed battery technologies use lithium as one of the main components. The value of the global lithium market [2] is estimated at about $9.86 billion (2024). It is estimated that by 2033 the global lithium market will increase several times and reach $28.45 billion. This means that from 2024 to 2033 the CAGR for the lithium market will be 12.50%. Lithium metal [2] is used in metallurgy (refining iron, nickel, copper and zinc). Lithium [2] is also used in the chemical industry for organic synthesis. For example, the reagent, n-butyl lithium, is one of the main initiators of polymerization processes in the production of synthetic rubber. Lithium is also [2] used in the pharmaceutical industry. Lithium metal is also an important element of various battery technologies. It is used as an anode in lithium batteries due to its low mass and high negative electrochemical potential. As mentioned earlier, the use of lithium in battery production makes it a key raw material for the success of the energy transformation.

The report [2] also presents forecasts for markets strongly linked to lithium production, whose products require this raw material for their production:

- lithium-ion Battery Recycling Global Market: USD 8.10 billion (2023), USD 10.26 billion (2024). Forecast: USD ~85.69 billion by 2033, CAGR of 26.6% from 2024 to 2033;
- lithium Iron Phosphate Battery Global Market: USD 12.7 billion (2022). Forecast: USD ~54.36 billion by 2032 with CAGR of 15.7%;
- lithium Titanate Batteries Global Market: USD 56 billion (2022). Forecast USD ~185.93 billion (2032) with CAGR of 12.8%;
- Fiber Batteries Global Market: USD 83.90 million (2023). Forecast: USD ~386.55 million (2032) with CAGR of 18.50%;
- Action Camera Global Market: USD 2.8 billion (2023). Forecast: USD ~6.39 billion (2033) with CAGR of 8.6% from 2024 to 2033;
- Industrial Batteries Global Market: USD 42.04 billion (2023). Forecast: USD 463.63 billion (2033) with CAGR of 27.02% from 2024 to 2033.

The countries that dominate lithium production [3] are China and Australia. China not only extracts lithium but also processes it into other products. Australia, on the other hand, mainly extracts lithium as a raw material and sells it on international markets. The fact that most of the supplies of raw materials (including lithium) recognized by the European Commission as critical for the development of the EU economy come from outside the EU was one of the reasons for the adoption on April 11, 2024 of Regulation 2024/1252 on critical raw materials (the so-called Critical Raw Materials Act), which assumes that by 2030:

- the extraction capacity of critical raw materials in the EU is to cover at least 10% of the annual consumption of strategic raw materials in the EU;
- the processing capacity of critical raw materials in the EU should be at least 40%;
- the recycling capacity of critical raw materials in the EU should be at least 15%.

In the case of lithium, this means that the EU and its member states will take a number of actions to increase lithium production within the EU and become independent from supplies from outside the EU.

Providing stable and cheap sources of lithium is also important for the development of the Polish economy. Poland is the second largest global producer of lithium-ion batteries for the electromobility sector. Paper [4] presents the location of projects from the electromobility sector in Poland divided into individual segments – production of batteries and components for them, production of electric vehicles, production of e-buses and centers for the development of EV-related technologies. In addition to LG Energy Solutions, other leading companies (e.g. Northvolt, Umicore, SK Innovation, Capchem, Guotai Huarong, BMZ, Mercedes-Benz Manufacturing Poland) from the battery sector are also investing in Poland.

In 2021, 540,000 tons of lithium were produced worldwide and according to the predictions of the World Economic Forum, by 2030 this number will have to increase to over 3 million tones. The demand for lithium may increase up to 8-fold by 2040 and 10-fold by 2050 – according to the forecasts of the International Energy Agency. The world could face a lithium shortage as early as 2025. According to BMI (one of the research units of the Fitch Solutions organization), this state of affairs will be mainly responsible for the high demand for this element in China, which will significantly exceed the supply. According [5] to a report published by BMI researchers, China's demand for lithium for electric vehicles will grow by approximately 20.4% each year from 2023 to 2032. However, at the same time, the supply of this element in China will increase only by 6%. BMI clearly states in its report that this percentage cannot cover even 1/3 of China's total lithium demand. Global lithium demand forecast divided into various industries was presented in paper [6].

2. Lithium production from geothermal brine

There are three main sources of lithium and methods of its production. The first method involves obtaining it from hard rocks, spodumene, and sedimentary rocks. This is an expensive method, requiring the construction of an open-pit mine and large investment outlays. Such an investment requires a large area of land, fulfilling many formalities and obtaining many permits, and it is also energy-intensive. The lithium produced is unlikely to be climate neutral – it depends on whether the energy supplying such a mine and the devices operating in it comes from zero-emission sources and whether the fleet of mining trucks has been fully electrified. Another method involves obtaining lithium from brines, which are stored in tanks for the natural evaporation (under the influence of the sun and temperature) of water from them. Both methods are not ecological and require a large area for their implementation, which is taken from nature or residents for the duration of lithium exploitation, and then it should be reclaimed, which means additional costs.

There is a third method, which is much more ecological and is considered the future of the lithium mining industry. It involves direct extraction of lithium from geothermal brines, which are extracted from the rock mass by drilling holes. The brine is first extracted to the surface using exploitation holes, in a special Direct Lithium Extraction (DLE) installation (lithium is recovered from it), and then it is re-injected into the rock mass using injection holes. The brine circulates in a closed circuit and is not released into the environment. If the entire installation is powered by electricity from renewable energy sources (RES), the lithium produced will be climate neutral. Such an investment does not require a large area for its operation. It only needs:

- spaces for production heads;
- spaces for injection heads;
- spaces for Direct Lithium Extraction (DLE) installations;
- possibilities of running pipelines connecting the above elements.

This investment is also much less cost-intensive than the two previous methods and, unlike them, has only a minimal impact on the natural environment.

There are already some companies in the world that are already involved in the extraction of lithium using the DLE method. One of the most famous places in the world where DLE projects are being developed is the Salton Sea in California, USA. This region is called Lithium Valley and various energy companies are investing in this area. The waters in this area are highly saline and rich in minerals. The lake is located on the San Andreas fault line and has a high amount of geothermal heat. Geothermal energy projects have been developed in this area for many years. In recent years, companies have attempted to extract mineral resources from the geothermal brine. It is estimated that the aquifers near the Salton Sea may contain enough lithium to meet almost 40% of the world's lithium demand. Using DLE technologies, some companies are now extracting lithium from the brine and recovering geothermal energy. Previously, lithium-rich brine was only a byproduct of geothermal energy production and the lithium in it was not exploited.

Europe also has deposits of lithium-rich brines. The publication [7] presents the results of the EuGeLi project, in which the well data for Western Europe were analyzed for the occurrence of lithium-rich brines. Four highly prospective areas in Western Europe were identified. It should be emphasized that the study did not perform analyses for the countries of Central and Eastern Europe.

In Poland, there are also areas containing deposits of geothermal brines rich in lithium [8] with concentrations reaching even above 200 mg/L. However, the Polish potential of geothermal brines containing lithium is still largely unmapped and requires extensive research.

DLE projects are no longer just academic considerations tested in laboratories. Such projects are already being implemented in various parts of the world and are being invested in by serious small and large investors. This is demonstrated by the four examples presented below.

Among the most well-known projects for lithium extraction from brines is the project in the Upper Rhine Valley, carried out by Vulcan Energy Resources Ltd, which is in the development phase. Vulcan has granted 16 licenses in the Upper Rhine Valley, for a total secured concession area of 1,790 km². Vulcan market capitalization is AUD 900 million (4 February 2025). Vulcan's [9] potential resources are 27.7 tones of LCE (Lithium Carbon Equivalent). Major investors are:

- stellantis corporation (5%);
- Hancok Prospecting Pty Ltd (6%);
- CIMIC Group (6%).

Another well-known DLE project is the project located 25 miles west of the town of Magnolia in southwestern Arkansas, owned by Standard Lithium Ltd. [10] with 1.4/0.4 million tones LCE (Lithium Carbon Equivalent). Estimated Indicated/Inferred Resource. The company has drilled over 400 boreholes and has planned +30,000 tons lithium hydroxide annual production which after conversion to LCE (by multiplying the conversion factor 0.88) is +26,400 tones of LCE. Company market capitalization is CAD 388.87 million (4 February 2025). Lithium avg. Grade of 437 mg/L. Equinor has joined Standard Lithium Ltd investors as a strategic partner.

Another DLE project is project Prairie Lithium Project owned by Arizona Lithium Ltd. with license area 390,000 acres, the size of the deposit estimated at 6.3 million tones LCE, depth 2.4 km, the thickness of the formation 140 m and lithium concentration 101–106 mg/L. Technical and economic feasibility study was presented in publication [11]. The Prairie project estimated at 4.1 million tones LCE was acquired by Arizona Lithium Ltd in December 2022 for CAD 70.6 million, where CAD 40 million was in cash.

In 2023, the private company Galvanic Energy sold licenses with an area of 120,000 acres in the Smackover geological formation rich in geothermal brine containing lithium with an estimated volume of 4 million tones LCE to ExxonMobil for an amount of over USD 100 million.

3. DLE well economic analysis – methods

In planning DLE projects, it is important to conduct an economic analysis for a single production well, as well as for the entire project. There are many factors that need to be taken into account, such as the cost of geological surveys, purchase or lease of the DLE installation, and drilling boreholes. Demand and possible price development scenarios should also be analyzed. One of the most expensive investment phases (apart from purchasing the DLE installation) is drilling boreholes. Therefore, this part of the economic analysis of DLE projects was focused on. An analysis was performed for an example geothermal brine deposit with a lithium concentration of 217 ppm located at a depth of 2 km. In order to be able to exploit such a deposit, it is necessary to drill a production hole 2,000 m deep. The average cost of drilling 1 meter of a hole in Poland is 10,000 PLN/m, which means that the hole will cost PLN 20 million, or about USD 5 million. There is a risk that despite promising lithium concentrations, the obtained brine flows may be too small. On the other hand, brine flows may be large, but the lithium concentration may be lower than assumed. It is necessary to analyze the profitability of a single borehole depending on the obtained brine flows and lithium concentrations in it. The annual lithium production from a single borehole is described by formula (1). For this purpose, the brine flow rate [l/s] should be multiplied by 3,600 (this is the number of seconds in 1 hour) and then multiplied by 24 hours. It is unlikely that DLE installations will operate 365 days a year, because such installations will usually require at least several days for service operations. Here, it was assumed that the number of operating days U will be 358, i.e. the total interruption in DLE operation will be 7 days, which seems to be a reasonable assumption. SE is the effective concentration, which is calculated by converting the concentration in parts per million to the concentration in mg/L and multiplying it by the lithium capture efficiency factor of the DLE installation, which is assumed to be 0.75 (i.e. 75%). In reality, the lithium capture efficiency of DLE installations can be much higher and exceed 90%, but it depends on the type of installation, the sorbent used, and the composition of the brine. The factor 10^{-9} is used to convert units expressed in milligram to tons. The last factor 5.323 is used to calculate lithium carbon equivalent (LCE). In the industry, lithium is sold in the form of several types of its compounds, which contain different concentrations of it. For standardization, lithium carbon equivalent (LCE) is used for billing and comparing lithium projects. In our case, we produce pure lithium. The factor 5.323 is used to convert the mass of pure lithium to the mass of lithium carbonate corresponding to the same amount of lithium. Figure 1 presents the calculated results of annual LCE production depending on the brine flow rate [l/s] and lithium concentration [ppm].

The annual incomings before tax are determined based on formula (2), which is a slight modification of formula (1). If the annual production obtained using formula (1) is multiplied by P, which is the market price of lithium (USD/tLCE), the annual pre-tax revenue from one well is obtained. This is expressed by formula (2). Since the analysis was originally performed at the turn of spring and summer 2024, the price from that period was assumed to be $P = 14{,}800$ USD/tLCE. There is one problem here that has not been taken into account. The DLE installation consumes energy and its operating cost is not zero. This can be taken into account in formula (3) by using as P the value of the market price USD/tLCE from which the cost of obtaining 1 ton of LCE has been subtracted. In the analyzed one, an updated value of P was assumed of 10,000 tLCE. After its substitution in formula (3), instead of annual income before taxation, the profit before taxation is obtained. Figure 2 shows the annual profit from one well depending on the brine inflow rate [l/s] and lithium concentration [ppm].

$$\begin{aligned} &\mathit{LCE\ Production} = \\ &= F \cdot 3600 \cdot 24 \cdot U \cdot SE \cdot 10^{-9} \cdot 5.323 \end{aligned} \tag{1}$$

$$\begin{aligned} &\mathit{Income\ before\ tax} = \\ &= F \cdot 3600 \cdot 24 \cdot U \cdot SE \cdot 10^{-9} \cdot P \cdot 5.323 \end{aligned} \tag{2}$$

where:

3,600 – number of seconds in 1 hour,
24 – number of hours during day,
F – flow rate [l/s],
U – the number of days a year the installation operates ($U = 358$),
SE – effective concentration (concentration ppm converted to mg/l using the DLE system conversion factor = 0.75),
10^{-9} – 1 mg is 10^{-9} tones,
P – market price per ton of LCE.

	PRODUCTION tons LCE/year											
	Concentration ppm											
F (Flow Rate) l/s	25	50	75	100	125	150	175	200	225	250	275	300
5	15.44	30.87	46.31	61.74	77.18	92.61	108.05	123.49	138.92	154.36	169.79	185.23
10	30.87	61.74	92.61	123.49	154.36	185.23	216.10	246.97	277.84	308.71	339.58	370.46
15	46.31	92.61	138.92	185.23	231.53	277.84	324.15	370.46	416.76	463.07	509.38	555.68
20	46.31	92.61	138.92	185.23	231.53	277.84	324.15	370.46	416.76	463.07	509.38	555.68
25	77.18	154.36	231.53	308.71	385.89	463.07	540.25	617.43	694.60	771.78	848.96	926.14
30	92.61	185.23	277.84	370.46	463.07	555.68	648.30	740.91	833.52	926.14	1,018.75	1,111.37
35	108.05	216.10	324.15	432.20	540.25	648.30	756.35	864.40	972.45	1,080.49	1,188.54	1,296.59
40	123.49	246.97	370.46	493.94	617.43	740.91	864.40	987.88	1,111.37	1,234.85	1,358.34	1,481.82
45	138.92	277.84	416.76	555.68	694.60	833.52	972.45	1,111.37	1,250.29	1,389.21	1,528.13	1,667.05
50	154.36	308.71	463.07	617.43	771.78	926.14	1,080.49	1,234.85	1,389.21	1,543.56	1,697.92	1,852.28
55	169.79	339.58	509.38	679.17	848.96	1,018.75	1,188.54	1,358.34	1,528.13	1,697.92	1,867.71	2,037.50
60	185.23	370.46	555.68	740.91	926.14	1,111.37	1,296.59	1,481.82	1,667.05	1,852.28	2,037.50	2,222.73
65	200.66	401.33	601.99	802.65	1,003.32	1,203.98	1,404.64	1,605.31	1,805.97	2,006.63	2,207.30	2,407.96
70	216.10	432.20	648.30	864.40	1,080.49	1,296.59	1,512.69	1,728.79	1,944.89	2,160.99	2,377.09	2,593.19
75	231.53	463.07	694.60	926.14	1,157.67	1,389.21	1,620.74	1,852.28	2,083.81	2,315.35	2,546.88	2,778.41
80	246.97	493.94	740.91	987.88	1,234.85	1,481.82	1,728.79	1,975.76	2,222.73	2,469.70	2,716.67	2,963.64
85	262.41	524.81	787.22	1,049.62	1,312.03	1,574.43	1,836.84	2,099.25	2,361.65	2,624.06	2,886.46	3,148.87
90	277.84	555.68	833.52	1,111.37	1,389.21	1,667.05	1,944.89	2,222.73	2,500.57	2,778.41	3,056.26	3,334.10
95	293.28	586.55	879.83	1,173.11	1,466.39	1,759.66	2,052.94	2,346.22	2,639.49	2,932.77	3,226.05	3,519.32
100	308.71	617.43	926.14	1,234.85	1,543.56	1,852.28	2,160.99	2,469.70	2,778.41	3,087.13	3,395.84	3,704.55

Fig. 1. Annual production of LCE by one borehole

	PROFIT in millions US$ annually											
	Concentration ppm											
F (Flow Rate) l/s	25	50	75	100	125	150	175	200	225	250	275	300
5	0.15	0.31	0.46	0.62	0.77	0.93	1.08	1.23	1.39	1.54	1.70	1.85
10	0.31	0.62	0.93	1.23	1.54	1.85	2.16	2.47	2.78	3.09	3.40	3.70
15	0.46	0.93	1.39	1.85	2.32	2.78	3.24	3.70	4.17	4.63	5.09	5.56
20	0.62	1.23	1.85	2.47	3.09	3.70	4.32	4.94	5.56	6.17	6.79	7.41
25	0.77	1.54	2.32	3.09	3.86	4.63	5.40	6.17	6.95	7.72	8.49	9.26
30	0.93	1.85	2.78	3.70	4.63	5.56	6.48	7.41	8.34	9.26	10.19	11.11
35	1.08	2.16	3.24	4.32	5.40	6.48	7.56	8.64	9.72	10.80	11.89	12.97
40	1.23	2.47	3.70	4.94	6.17	7.41	8.64	9.88	11.11	12.35	13.58	14.82
45	1.39	2.78	4.17	5.56	6.95	8.34	9.72	11.11	12.50	13.89	15.28	16.67
50	1.54	3.09	4.63	6.17	7.72	9.26	10.80	12.35	13.89	15.44	16.98	18.52
55	1.70	3.40	5.09	6.79	8.49	10.19	11.89	13.58	15.28	16.98	18.68	20.38
60	1.85	3.70	5.56	7.41	9.26	11.11	12.97	14.82	16.67	18.52	20.38	22.23
65	2.01	4.01	6.02	8.03	10.03	12.04	14.05	16.05	18.06	20.07	22.07	24.08
70	2.16	4.32	6.48	8.64	10.80	12.97	15.13	17.29	19.45	21.61	23.77	25.93
75	2.32	4.63	6.95	9.26	11.58	13.89	16.21	18.52	20.84	23.15	25.47	27.78
80	2.47	4.94	7.41	9.88	12.35	14.82	17.29	19.76	22.23	24.70	27.17	29.64
85	2.62	5.25	7.87	10.50	13.12	15.74	18.37	20.99	23.62	26.24	28.86	31.49
90	2.78	5.56	8.34	11.11	13.89	16.67	19.45	22.23	25.01	27.78	30.56	33.34
95	2.93	5.87	8.80	11.73	14.66	17.60	20.53	23.46	26.39	29.33	32.26	35.19
100	3.09	6.17	9.26	12.35	15.44	18.52	21.61	24.70	27.78	30.87	33.96	37.05

Payback time for the cost of drilling a borehole in years (cost of drilling a hole 5.01 million US$)

≤ 0.5	≤ 1	≤ 2	≤ 3	> 3

Fig. 2. Annual incomings from one borehole at assumed market price 14,800 USD/tLCE

4. Discussion

The economic model created is very simplified and certain technological and economic assumptions have been made in it. The model ignores the fact that an injection well must also be made in addition to the production well if the brine is to circulate in a closed circuit. It may also be necessary to make more and more complex holes than a simple vertical hole. There are at least several companies in the world that produce and sell DLE installations. However, the selection of the appropriate installation will significantly affect the economics of the project – starting with the efficiency of lithium extraction, the costs of lithium extraction, and ending with the cost of the installation itself. There are large stationary DLE installations (e.g. Sunresin), which resemble small production plants, their cost is high and the construction time is long. There are also small modular mobile installations (DLE) (e.g. International Battery Metals – up to 95% recovery rate), the cost of which is much lower and can be leased. Choosing leasing instead of purchasing a DLE installation can reduce the initial investment required to start production. This is not taken into account in the economic model. It also uses outdated lithium market prices (14,800 USD/tones of LCE) from the period at the turn of spring/summer 2024 when the presented modeling was conducted. Currently, the market price of lithium (USD/tones of LCE) is around 10,829 USD/tones of LCE. The model also does not take into account the cost of geological work to extract and recognize lithium-rich brine deposits, which may be significant. It is worth adding that the brine may contain other valuable elements, and it is also possible to recover heat from it, which further improves the economics of the project.

Despite many simplifications, the presented economic model provides a lot of valuable information. It shows that there is a large margin (lithium concentration [ppm], brine flow rate [l/s]) for which a single well should pay off. Analysis of the data in Figure 2 shows that the well will not pay off in less than 3 years only for extremely unfavorable cases. These data are a strong argument reducing the risk for a potential investor. Given good geological conditions and promising lithium concentrations in the brine, the well would have to be drilled very incorrectly to make it unprofitable and its cost would not be recovered within a few years.

5. Conclusions

Lithium is a critical raw material on which the success of the energy transformation depends. According to the data presented in the article, the lithium market is very promising and is a strongly growing market, which may experience a supply gap in the future. Unfortunately, the need to obtain lithium, e.g. for the production of batteries, is criticized by ecologists due to the previously used non-ecological methods of its extraction, which have had a negative impact on the natural environment. However, it is possible that in the future lithium will be obtained using ecological methods using the Direct Lithium Extraction (DLE) method from geothermal brines. There are already companies in the world that implement such projects on a large scale, as well as companies producing and selling DLE installations. The economic modeling carried out in the article shows that such projects are highly profitable. Unfortunately, there is a lack of data in Poland to be able to select the most promising regions where geothermal brines rich in lithium occur. Lithium is also an important raw material for Poland, which is the world's second largest producer of lithium-ion batteries, and electromobility in the country is developing.

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