Validation of local coal supply effectiveness in the hard-to-reach Arctic zones in Yakutia

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Abstract. The article discusses shipment of coal to the Arctic regions of Yakutia. High transportation costs increase almost three times the price of one ton of the solid fuel. Coal fields in the Arctic have social rather than commercial value. The key target of local coal mining is enhancement of energy preparedness of population rather than money making. The review of modern methodological approaches to assessing the efficiency of using local coal resources in hard-to-reach areas reveals a wide range of such approaches, their ambiguity and neglect of the Arctic activities peculiarities. The paper presents a new approach for evaluation of small coal opencasts operating in remote Polar regions in Yakutia. The approach is based on the economic and mathematical model of substitution of local coal for imported coal. The technical and economic indicators of a small coal mine is calculated in terms of Krasnorechensky deposit of thermal coal, and the effect of replacing imported coal by local coal in the Abyi district is evaluated. The results of the study show feasibility of in-house coal supply in the isolated and hard-to-reach areas of the Arctic by means of creation of small coal opencasts, which enhances the energy security and reduces the socio-economic tension.

1. Introduction

The Arctic areas in Yakutia feature extreme natural climate, under-developed infrastructure, localized population and land invasion as well as high dependence on imported fuel and energy sources. In 2018, these areas were supplied with 125 kt of coal from Dzhebariki-Khaya opencast, 80 kt of coal from Zyryansky opencast, 1.8 kt of coal from the Magadan Region (330 km along Kolyma federal road and 250 km along the Indigirka river) for the needs of municipal housing economy, with 22 kt of coal from SUEK mines and 59.1 kt of oil products for the needs of Deputatskaya Heat Power Plant of Sakhaenergo (Figure 1).

Coal shipment conditions are extremely difficult due to large distances between mining points and final consumers (to 2–3 km), complicated and long-term logistics (during 2.0–2.5 years, with a few transhipments), limited duration of different type transportation at small quantities of regional consumption (5–50 kt). As a consequence, both loss and shipment cost of fuel grows 3–8 times as compared with its initial cost at opencasts.

By the data of the State Committee for Price Policy—Regional Energy Commission in the Republic of Sakha (Yakutia), in 2018 the price of boiler and furnace fuels for hard-to-reach northern regions fluctuated from 2.3 to 18–22 thousand Rub/t (Verkhoyansk, Ust-Yansk, Abyi and Muoma districts) and the price of oil varied as 40–55 thousand Rub/t, and exceeded the world market prices by...
3–5 times and more. Percentage of coal in its cost structure at the consumption place is 11–18% in the hardest-to-reach areas (Abyi, Muoma, Ust-Yans and Verkhoyansk districts) and 37–50% in the other areas in the Arctic (Zhigan, Nizhnokolymsk, Srednekolymsk and Verkhnekolymsk districts) as is detailed in Figure 2.

**Figure 1.** Routes and average cost of coal shipment to consumption places, thousand Rub/t.

**Figure 2.** Structure of coal cost with regard to shipment and storage: (a) Abyi, Muoma, Ust-Yans and Verkhoyansk districts; (b) Zhigan, Nizhnokolymsk, Srednekolymsk and Verkhnekolymsk districts (by data of State Committee for Price Policy—Regional Energy Commission in the Republic of Sakha (Yakutia) in 2018).

For some areas, the coal shipment cost is so higher than its mining cost that local fuel production in the direct vicinity of the main consumption places can save budget cost and improve energy
preparedness.

2. Mathematical and economical models of coal supply
Considering strong impact of regional features, it is difficult to adapt the available Russian and foreign experience to the actual conditions of mining, haulage and combustion of solid fuel in the Arctic [1–8]. The review of Russian approaches to evaluation of local coal use efficiency shows that this problem has been addressed by such researchers as M. B. Ryazanov (small coal opencasts in Primorye) [1], N. P. Ivatanova and A. V. Karetnikov (local deposits in the Tula Region) [2], M. V. Kuklina (small opencasts in Buryatia) [3], I. Yu. Ivanova (small power industry in the decentralized power supply zone in the north–east of Russia) [4], N. A. Zhalsanova (remote areas in Transbaikal) [5], A. V. Zavarzin (regions with low density of population) [6], L. V. Chaika (rural areas in the Komi Republic) [7] and many other.

Ryazanov’s approach is directly connected with the fact that any coal mine, even in remote and hard-to-reach areas of the North, should be evaluated by its commercial effectiveness. The coal price established should cover both operating cost and capital expenses connected with mineral exploration. In the meanwhile, the government forgoes mechanisms of direct and indirect effects, and places small and very small coal properties to general coal fields of Central Russia. Another approach dictates an emphasis to be laid on the socio-economic factors in evaluation of small coal opencasts which supply the local needs and money making is not their key target.

The current approaches to power supply of Arctic Yakutia by expensive imported fuel and energy sources disable reasonable energy preparedness of the region and its industrial and business effectiveness. While holding large geological resources of solid fuel, the region suffers from deficiency of the local reserves in its energy budget.

The lack of integrated estimates of effectiveness reached by the process flows of coal production and shipment in the framework of the unified supply system in the north–east of Russia results in the irrational use of the available reserves in each chain of the process flows and in continuous cost escalation to ensure their functioning.

Coal fields located in adverse and remote areas of the Arctic can and should have social in a greater degree rather than commercial value [9] as development of these fields enhances the energy preparedness of these areas. Regarding small and very small coal opencasts in the Arctic zone, profit earning can be their secondary objective. Performance of mines at the edge of zero profitability or even unprofitability in the conditions of limited resources and reserves is quite feasible in the competitive environment [10].

Expedience of such small mining businesses is conditioned by the objective necessity of stimulation of the energy preparedness and self-sustainability of the region and creation of new jobs to reduce social tension. Thus, the newly proposed approach is based on the equal economy of local and imported coal expenses:

\[ E_{\text{loc}} \leq E_{\text{imp}} \]  \hspace{1cm} (1)

where \( E_{\text{loc}} \) are the total expenses connected with local coal, including mining, combustion and minimum distance haulage; \( E_{\text{imp}} \) are the total expenses connected with remote mining, multiling shipment, long-term host and intermediate storage and combustion of coal at local boiler plants.

The total expenses connected with local coal are given by:

\[ E_{\text{loc}} = E_{\text{min,loc}} + E_{\text{h,loc}} + E_{\text{comb,loc}} \]  \hspace{1cm} (2)

where \( E_{\text{min,loc}} \) are the expenses connected with local coal mining; \( E_{\text{h,loc}} \) are the expenses connected with coal haulage and storage; \( E_{\text{comb,loc}} \) are the expenses connected with fuel combustion at local boiler plants.

The total expenses connected with imported coal are given by:

\[ E_{\text{imp}} = E_{\text{purch,imp}} + E_{\text{h,imp}} + E_{\text{comb,imp}} \]  \hspace{1cm} (3)

where \( E_{\text{purch,imp}} \) is the expenses connected with coal purchasing from a remote supplier; \( E_{\text{h,imp}} \) are the expenses connected with haulage and storage of imported coal; \( E_{\text{comb,imp}} \) are the expenses connected with imported coal combustion at local boiler plants.
The imported coal expenses are calculated from the formula:

\[ E_{\text{imp}} = \sum_{i=1}^{k} Q_{\text{imp}} \times P_{\text{imp}} + E_{h_{st\_imp}} + E_{\text{comb\_imp}} \]  

(4)

where \( Q_{\text{imp}} \) is the coal volume purchased from a remote supplier, \( t \); \( P_{\text{imp}} \) is the supplier’s price of coal, Rub/t.

The expenses connected with local coal mining and use are calculated from the formula:

\[ E_{\text{loc}} = \sum_{j=1}^{n} Q_{\text{loc}} \times P_{\text{loc}} + E_{h_{st\_loc}} + E_{\text{comb\_loc}} \]  

(5)

where \( Q_{\text{loc}} \) is the coal volume produced in the Arctic region; \( P_{\text{loc}} \) is the price of coal produced in the Arctic region.

The economic evaluation assumes some limitations below:

- Calorific value of the fuel:
  \[ CV_{\text{loc}} \leq CV_{\text{imp}} \]
- Ash content \( A_d \) %:
  \[ A_d^{\text{loc}} \leq A_d^{\text{imp}} \]
- Wetness \( W_r \) %:
  \[ W_r^{\text{loc}} \leq W_r^{\text{imp}} \]
- Volatile yield \( V_{daf} \) %:
  \[ V_{daf}^{\text{loc}} \leq V_{daf}^{\text{imp}} \]

where \( CV_{\text{loc}}, A_d^{\text{loc}}, W_r^{\text{loc}}, V_{daf}^{\text{loc}} \) are the characteristics of local coal; \( CV_{\text{imp}}, A_d^{\text{imp}}, W_r^{\text{imp}}, V_{daf}^{\text{imp}} \) are the characteristics of imported coal.

The logic chart of the approach implementation in substitution of the imported coal by the local coal on the basis of the economic and mathematical model is presented in Figure 3.
Using the economic and mathematical model, we compare fuel supply of the Abyi district as a potential consumer from Sogolokh site of Krasnorechensk coal field nearby the navigable river Indigirka with the current coal supply from Zyryansky opencast in the Verkhnekolymsk district (refer to Figure 1). The effectiveness evaluation neglects expenditures connected with elimination of consequences of periodic force majeure (shallow water, early freeze-up, etc.) as well as the cost of deep dredging in the Kolyma and Indigirka riverbeds.

The calculations (see Table 1) show that the annual operating cost of local coal mining, at zero profitability and without regard to capital cost of coal extraction in Sogolokh site in the amount of 180–250 million Rub, will make up 2.2–2.6 thousand Rub/t. Given the payback period not longer than 8 years (average life of the main mining and haulage equipment), the total price of local coal for a local consumer will be not higher than 5.0–5.5 thousand Rub/t at the current imported coal price of 18.96 thousand Rub/t.

Table 1. Comparison of the current and proposed flow charts of coal mining, haulage and combustion

| Description                     | Current flow chart                                           | Proposed flow chart                                           |
|---------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|
| Coal supply flow                | Zyryansky opencast–Kolyma River–Laptev Sea–Indigirka River–Abyi boiler plants | Krasnorechensky opencast–Indigirka River–Abyi boiler plants |
| Consumed coal volume            | 15.75 kt at boiler plants at the Abyi district (2018)        | 15 kt for the Abyi district, up to 60 kt in case of total substitution of imported coal by local coal in three Indigirka districts in Yakutia |
| Total coal price for consumer, Rub/t | 18.96 thousand Rub/t—2018                                  | 5.0–5.5 thousand Rub/t (at an opencast at profitability of 10%—4.5–5.0 thousand Rub/t; intra-regional haulage—0.53 thousand Rub/t) |

The comparison points at the evident advantages of the proposed flow chart including construction of a new opencast at the Indigirka River nearby the actual and prospective consumers.

It is also important to bear in mind the quality of coal to be consumed. Highly metamorphic coals, either being mined or planned for production at the both opencasts discussed, belong to power-effective fuel. Coals have similar process properties, and their exchange cannot cause any troubles at boiler plants. Planned reequipment in the studied regions is advisable to be carried out with allowance for the new opencast coal as the main fuel. An additional argument in favor of the new opencast to be constructed is the average coal ash content $A_d$ which is 14.3% in Sogolokh site of Krasnorechensky deposit and 17% in Zyryansky opencast [11], while the more rational logistics reduces losses.

3. Conclusions
The efficiency evaluation of two fuel supply scenarios in the hard-to-reach Arctic areas in Yakutai, based on the proposed approach and economic and mathematical model, reveals the expediency of substituting imported coal for local coal. Local production of local solid fuel at small opencasts is advisable to be performed in coal field sites featured better quality of produced coal and located nearby potential consumers and navigable rivers.

The proposed flow chart simplifies shipment and improves energy preparedness of population. However, there are high risks connected with unprofitability of such small coal mining businesses in the remote Arctic regions. The governmental support and administrative control toward stimulation of such business activities in the Arctic zone can greatly facilitate construction and sustainability of small local opencasts. Creation of new coal mines in the maximum vicinity of the consumption points can and will reduce the time laps between mining and consumption of coal, decrease quantitative and qualitative loss of fuel, and immediately simplify conditions of coal haulage and storage.
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