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Energy potential of mining transport at mines of Kyrgyzstan located at high altitude

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Abstract. Review and Justify use of new alternative way of gold ore transportation on high altitude mining operations in Kyrgyzstan in prime purpose of the study. Glaciers of Kyrgyzstan are main source of fresh water supply in Central Asia. Local ecosystem preservation is important part of metal mining in Kyrgyzstan and specific needs of nomads should be taken in the account. Novelty of study is preliminary assessment of mine in Kyrgyzstan for potential gravity energy by loading and dumping point's GPS coordinates are taken on site and review of appropriate technologies for ore transportation in order to reduce carbon emissions. Aerial ropeway specific energy consumption formula and recuperating ropeway system from previous studies are reviewed and used in study. Improvement of existing mine operations by improving transportation practices should be further studied. The design and maintenance of haul roads may allow to reduce diesel fuel consumption by 10% and more. Preliminary potential energy for recuperation by aerial ropeway application in Jerooy and Jamgyr gold mines of Kyrgyzstan are identified. Energy recuperating aerial ropeway system with fuel cells can be strategically long-term preferred solution for mines in Kyrgyzstan located in high altitude.

1. Introduction

About 45% of all glaciers in Central Asia are situated on the territory of Kyrgyzstan. They are the major source of water-supply for rivers, and forecasts of their condition are of particular concern due to the effects of global climate change. Glaciers and snowfields on the mountain tops are of great importance in the regulation for water supply and regulation of natural features of the region. There are 8200 glaciers with total area of 8169, 4 square kilometers within Kyrgyzstan, occupying 4.2% of the country. Water resources of the glaciers of Kyrgyzstan are estimated at 650 km^3 [1].

17 deposits gold deposits are on the state balance nowadays which are: Kumtor, Jerooy, Jamgyr, Makmal, Soltonsary, Terekskoe, Kuru-Tegerek, Taldybulak Levoberezhny, Kurandzhailyau, Terekkan, Terek-Mezhplastovoe, Mironovskoe, Abshyr, Ishtamberdy, Dolpran, Perevalnoe, Chalkuiryuk-Akdzhylga. Officially registered reserves of gold are 1055.256t [2].

As 90% of country territory is located in mountain landscape. Number of gold deposits located above 3000 meters above sea level on visible proximity to glaciers and significant snow walls. Lower hills and valleys are valuable assets for local nomad for cattle and crop farming. Mineral mining in mountain countries like Kyrgyzstan typically has advantages that processing plants can be located bellow mine. This opens opportunity to use potential gravity energy of gold ore are being transported down to processing plant. The main purpose of this paper is to review and evaluate the latest technologies to reduce carbon emission to reduce impact of mining operation to environment.

According to the International Energy Agency mining companies should reduce their carbon emissions by 58% by 2050 compared with 2010 [3]. Meeting this target is going to be the big challenge considering that demand for minerals is growing as the population is growing. The globe is running out high grade deposits and mining low grade ore means task to move more tonnage to longer distances and increase mineral mining at remote locations such us mining in mountains at high altitude.

Nowadays there are solutions for significant reduction of carbon emission while transportation of materials from equipment manufacturers are available. Assessment of running mining operations for emission reduction opportunities must be one of the key elements in this initiative. As transportation costs can take 40-60% of overall mining costs improvement of haul road design and maintenance can reduce consumption diesel fuel and as well. If the rolling resistance is higher than that used during mine planning, the trucks are unable to achieve the expected productivity [4].

There are 4 types of hybrid technology under study by developers: 1. Battery hybrid powertrain; 2. Supercapacitor hybrid powertrain; 3. Hydraulic hybrid powertrain; 4. Compressed-air hybrid powertrain. The power saving of mining hybrid haul truck studied by Chun Jin and others in 2019 [5]. Recycling of lithium batteries are studied by Rahman and Afroz in 2016 [6]. Hydro-Pneumatic Energy Storage System for Hybrid Mining Trucks was studied by Yi and other in 2022 [7]. Niuric and others studied the trolley assist diesel-electric AC trucks in 2009 [8].

Mtu Rolls-Royce engineers' states 220 tonnes payload mining haul truck traveling downhill potentially can recuperate 22% of energy and on loaded downhill application up to 54% of energy can be recuperated. Fuel performance simulation on 220 tonns payload truck shows 29% less green-house gas emission for factory installed hybrid system [9].

The foregoing allows us to conclude that the research for alternative types of transportation of mining material in the development of high-altitude deposits is an actual problem.

The purpose of this research was to find and justify an alternative method of transporting minerals in the high-mountain mines of the Kyrgyz Republic, providing a reduction in energy consumption, a reduction in emissions of harmful gases, and an improvement in the technical and economic indicators of transportation of minerals.

Based on the analysis of existing operations in high-altitude mines, two technological schemes for transporting ore were selected for further study: the use of aerial ropeway and the use of dump trucks with diesel drives.

At the same time, the following main tasks were solved: ensuring cheaper transportation of ore, saving expensive diesel fuel, improving the environmental situation (reducing harmful emissions).

1.1. Related works

Climate change [1] and greenhouse gas emission assessment [10] is vital aspect of further development of energy profile [11] and mineral resource industry of Kyrgyzstan [2]. As transportation of materials is one of the main cost structures of mining operation decarbonization of this process [3] has strategical importance. Improving haul road maintenance and design [4] can be the first action to be considered by miners in their decarbonization plans. Mining trucks widely used in open pit mines have the potential to recover around 30% of potential energy [5] by hybrid trucks technologies. Increasing lithium battery capacity and availability makes feasible use of hybrid and electric trucks in mining industry [12]. Recycling of lithium batteries has great meaning for sustainable resource saving initiative. More than 90% of Cobalt (Co) can be extracted from composition of $CoSO_4$ [6]. Novel energy storage technologies for hybrid trucks is being studied such us the hydro-pneumatic hybrid truck with optimized scheme reduces its fuel consumption and carbon emission by 23.57 kg/day and 72.12 kg/day respectively compare with reverse dragging scheme [7]. For any open pit mines dipper than 150 meters trolley assist diesel-electric mining trucks can be seriously considered [8]. 54% of potential energy can be recuperated on system introduced by Mtu Rolls-Royce [9]. For mine located on mountain terrain conditions aerial rope way can be long term solution. Self-propelled wagons as one of the possible solutions [13] to increase productivity of rope ways can be considered depending on mine's conditions. Recuperation of potential gravity [14] energy can further increase return on investment in aerial rope ways in Kyrgyzstan mines.

1.2. Purpose
Transportation costs may reach 50-70% of overall mining costs. The present work aims to study status of ore transportation from mine sites to processing plans in mines located in Kyrgyzstan at high altitude mountain conditions and possibility to use alternative technologies in order to reduce costs of transportation as well as carbon emission and impact to environment.

To achieve this goal study covers two areas:

1. Review and asses modern alternative technologies for application on mine sites of Kyrgyzstan.
2. Identify potential energy and carbon emission savings while application various transportation technologies.

2. Research methodology
When conducting research, a comprehensive methodology was used, including the analysis of literary sources, the experience of mining operations in high altitude mountains, the study of the terrain of the Jerooy and Jamgyr mines of the Kyrgyz Republic, a technical and economic assessment of the proposed new technological and economic solutions.

The technology of transporting mining material by dump trucks with a diesel drive was adopted as the base for the research. As alternative schemes, the transportation of rock mass by aerial ropeway.

2.1. Methodology and analysis
Aerial ropeway application can be optimal solution for miners in Kyrgyzstan as long terms solution. It can help to reduce impact to glacier ecology and wildlife as well as increase safety for personal. Jerooy and Jamgyr gold mines have significant energy recuperation potential as ore processing plants are located at lower altitude than mine sites.

Table 1 shows the ore loading and dumping point's GPS locations that were taken on site.

Table 1. Ore loading and dumping points of Jerooy and Jamgyr mine sites.

Locations	Title	Jerooy mine data		Jamgyr mine data	
		Coordinates	Altitude	Coordinates	Altitude
Loading point – A	h_1	42°17'32"N 72°45'34"E	3150 m	42°11'13"N 71°32'59"E	3240 m
Dumping point - B	h_2	42°23'34"N 72°43'34"E	2062 m	42°10'32"N 71°31'45"E	2988 m

Table 2 shows potential energy data for related mine sites.

Table 2. Annual potential enegry data of Jerooy and Jamgyr mine sites.

Parameters	Title	Units of measure	Jerooy mine value	Jamgyr mine value
Ore transportation target per year	m	tonnes	1 300 000	150 000
Height of transportation	H	meter	1088	252
Acceleration of gravity	g	meters per second	9,81	9,81
Potential energy	E	Mega Joules	13 875 264	370 818

Potential energy is calculated by formula (1):

$$E = mg(h_1 - h_2). \tag{1}$$

2.2. Calculation methodology of energy consumption of ropeway

Specific energy consumption is the amount of energy consumed by a ropeway for transporting cargo. The specific energy consumption of the ropeway can be calculated by formula (2) [13]. Specific energy consumption for traditional design (with haul rope)

$$e_{HR} = 2\left(1 + k_m + \frac{q_T \lambda}{m_1}\right)(fL + H)\, g, \tag{2}$$

where k_m is the wagon loading coefficient, $k_m = m_0/m_1$; q_T is the distributed load taking into account the weight of rope and wagons; λ is the wagon hanging spacing; m_1 is the total weight of cargo; f is the resistance factor of wagon movement and haul rope; L is the track length in the plan; g is the acceleration of gravity; m_0 is the wagon weight (empty).

Specific energy consuption for ropeway carriyng loaded wagons down the hill can be calculated by formula (3):

$$e_{HR} = 2\left(1 + \frac{m_0}{m_1} + \frac{q_T \lambda}{m_1}\right)(fL + H)\, g. \tag{3}$$

3. Results and discussion

Jerroy and Jamgyr mine operations demonstarate sugnificant potential for energy recuperation. It is importante to evaluate ways to recuperate potential gravity energy and store it.

Figure 1 describes the way recuperative cableway system with fuel cells works [14]. Unit (10) serves for transportation of the load using a skyline (1), mainly for skidding, which uses gravity of the carriage and load to run an electric generator (8) with the help of a winding device (3) and a clutch (5), and voltage from electric generator (8) helps electrolysis of water in fuel cells (10), where oxygen and hydrogen and produced, and consequently they synthesize in fuel cells (10) into water when pulling an carriage up the hill, and at the same time, voltage is produced, and it is transmitted through the switch (13) into an electric motor (9), it runs the winding device (3) using a clutch (6) and it helps to move the carriage down the hill.

The recuperative cableway system with fuel cells can be a practical solution to recuperate energy of cargo traveling down the hill. As Lithium-Ion batteries become widely available at reasonable cost they can can be used as fuel cells in mentioned solution to store recuperated energy. Recycling of Lithium-Ion batteries are very important issue for environment. Recovery of valuable metals from used Lithium-Ion batteries are studied by Wang et al [12].

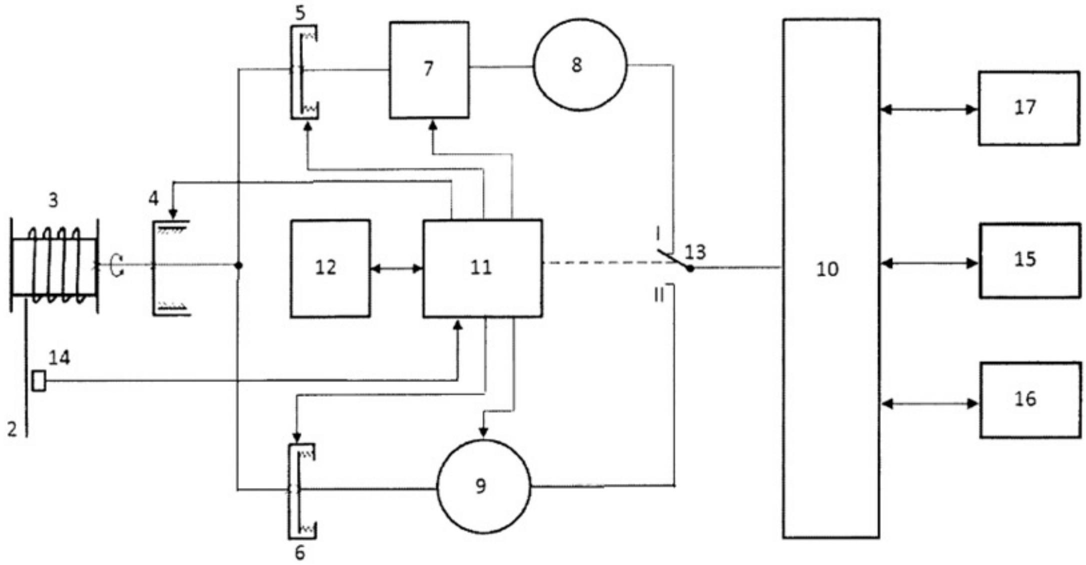

Figure 1. The recuperative cableway system with fuel cells.

The system for transportation of the load, mainly for downhill storage (1), is characterized obtaining energy for the system running from fuel cells (10).

According to claim 1, the system is characterized by the winding device (3) is connected with the electric generator (8) connected with fuel cells using electric conductors in the phase of gravitational approaching.

The system is characterized by that the fuel cell (10) is connected by electric conductors with the electric motor (9), which is connected to the winding device (3) in the phase of moving carriage down the hill.

Results of cycle timing study on site displayed productivity and CO_2 emission estimation because of common way of ore transportation by diesel engine driven truck on one of the gold mines in Kyrgyzstan (table 3).

CO_2 emission calculated by formula (4) [10]:

$$CO_2(t) = \sum VK, \tag{4}$$

where K is the Diesel fuel burn CO_2 emission coefficient CO_2 EF kg CO_2/l – 2.65; V is the Diesel fuel consumption.

Performance of arial ropeway implemented in Cerattepe copper mine in Turkiye described in [15]. Diesel equivalent consumption is estimated as per ration of 0.88 US gallons per 37.95 kWt/hour (table 4).

Specific equivalent fuel consumption of aerial ropeway per one ton at Cerattepe mine in 0.6 liters per ton. Whereas the same parameter for diesel driven dump truck is 2 liters per ton. Thus, CO_2 emission with aerial rope way is 3.3 times lower from fuel consumption point of view. Study does not consist of CO_2 emission and energy consumption for auxiliary processes such as maintenance and repair of equipment and haul road and ropeway.

The mining industry is increasing its electrification processes to meet global demand to reduce carbon emissions. As per International Energy Agency Kyrgyzstan has around 90% of total electricity generation in hydro-based making it one the county with highest shares of renewable electricity in the world. However only about 10% of hydro energy potential has been developed [11].

Table 3. Site performance results of ore transportation by on-high way truck in gold mine in Kyrgyzstan.

Parameters	Units of measure	Value
Payload of truck	tonnes	25
Engine power	kWt	295
Distance	kilometer	35
Average time per trip	hour	2.75
Average fuel consumption per trip	liter	50
Productivity per truck	tonnes per hour	9.09
Fuel consumption	liters per hour	18.18
Average operating time	motor hours	6500
Annual CO_2 emission	kilogram	311968.8
Horizontal length on plan	meters	11749
Vertical fall	meter	-1088
Established power per produced ton	kWt per tons per hour	32.45
Specific fuel consumption	liters per ton per kilometer	2

Table 4. Performance of arial ropeway implemented in Cerattepe copper mine.

Parameters	Units of measure	Value
Productivity	tonnes per hour	60
Motor power	kWt	414
Horizontal length on plan	meters	4471
Vertical fall	meters	-1515
Established power per produced tonn	kWt per tons per hour	6.9
Equivalent of diesel fuel consumption	liter per hour	36.38
Specific equivalent fuel consumption	liter per ton	0.6

4. Conclusions

In this research various drive systems of transportation technologies and their performance in open mine operations located in high altitudes in Kyrgyz Republic.

Main results and conclusions are in following:

1. Analyses of operational performance of aerial ropeway and diesel driven dump trucks shows that aerial ropeway in 3.3 times more energy efficient. Transportation path on aerial ropeway is 3-7 times shorter in compare with haul road for dump trucks operation.
2. Cycle timing study on various mines shows that equivalent diesel fuel consumption of aerial ropeway in high altitude mine conditions can be only 0.6 liters per ton, for transport systems with diesel driven dump truck can reach 2 liters per ton.

Considering amount of renewable energy share in electricity generation of Kyrgyzstan use of aerial ropeways in mining can be significant contribution to environment and local ecosystems.

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