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*Case Report*

# Study of Long-Distance Belt Conveying for Underground Copper Mines

**Natalia Suchorab-Matuszewska, Witold Kawalec * and Robert Król**

Department of Mining, Faculty of Geoengineering, Mining and Geology, Wroclaw University of Science and Technology, ul. Na Grobli 15, 50-421 Wroclaw, Poland

* witold.kawalec@pwr.edu.pl

**Abstract**

Efficient material handling is critical for mining productivity, safety energy and cost control. This paper analyzes the energy efficiency of five alternative designs for a 3 km inclined underground conveyor system for copper ore transport, considering route geometry, belt specifications, drive configurations, and operational parameters. Two main design approaches were examined: a single long conveyor and two shorter conveyors. Variants differed in belt tensile strength, use of intermediate drives, and system layout. Calculations results achieved by using dedicated QNK-TT software show differences in specific energy consumption index between variants for both average and peak capacities and highlight that high-capacity performance requires non-standard solutions: either higher belt strength or an intermediate drive system. The study shows that conveyor energy efficiency depends strongly on load level, with near-maximum throughput yielding the best performance. The authors conclude that conveyor system components selection should be based on a multi-criteria evaluation—including capacity margin, operational safety and maintenance complexity — rather than energy efficiency alone.

**Keywords:** long-distance belt conveyor; underground copper mine; specific energy consumption; energy efficiency

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## 1. Introduction

Efficient material handling is a key element in mining operations since its direct influence on productivity, safety and operating costs. As the mining industry moves towards deeper ore bodies extraction [1], there is a demand to develop reliable and cost-effective technologies such as long-distance transportation systems [2,3]. One of the representative examples of the long-conveyor system is the Sasol's Impumelelo coal conveyor in South Africa. The 27 km long conveyor's route is barely inclined - around 50 m of the elevation between the tail and head pulleys length. The conveyor is designed to transport up to 2 400 t/h at maximum belt speed 6.5 m/s. A specially selected ST 2000 belt with super low rolling resistance belt bottom cover was chosen to improve the energy efficiency. The relatively low operational belt tension was achieved with the unique drive layout - the conveyor is powered by 6 motors (4 x 1 000 kW and 2 x 500 kW) located in three positions: at the head, tail and booster station (intermediate drive station) and it is additionally equipped with mid-flight fixed tripper station [4]. Another noteworthy example is the Chuquicamata Underground Mine Project in Chile. The underground conveyor system overcomes 1 km of the elevation difference along the 7 km route with the belt speed of 7m/s. Despite the high capacity (11 000 t/h) the system consists of only 2 conveyors with the 8 x 5 000 kW of installed total drive power. It should be noted that the top-end tensile strength ST 10 000 belt was specially developed and installed, and the applied safety factor was decreased by 20% to 5.0 assuming the demanded fatigue strength of splice connection of 50% of the belt tensile strength was retained [5].

It was recognized that the long-distance conveyor systems are one of the most efficient methods for bulk material transportation over the great distances in the industrial sites [6–9]. Belt conveying enables to transport material along the curves, uphill or downhill, achieving high throughput capacity (up to tens thousand tonnes of material per hour) [10,11]. Advanced monitoring, remote diagnosis and automated operation enhance reliability of the system, its operational safety and maintenance in difficult mining conditions [12,13]. Additionally, long-distance belt conveyors are considered as environmentally friendly due to their low energy consumption, reduced noise and decreased emissions compared to truck-based transport [14–16]. It is important to point out that the term long-distance conveyor' lacks a strict definition in technical literature. In general, it is a material transport system characterized by an exceptionally long route that exceeds the capabilities of standard conveyor solutions. It needs a unique engineering approach, such as multiple drive stations and custom-designed components, with the special focus on especially designed conveyor belt [10,11,17,18].

The following diagram summarizes the most important aspects for an efficient, reliable and cost-effective conveyor (Figure 1).

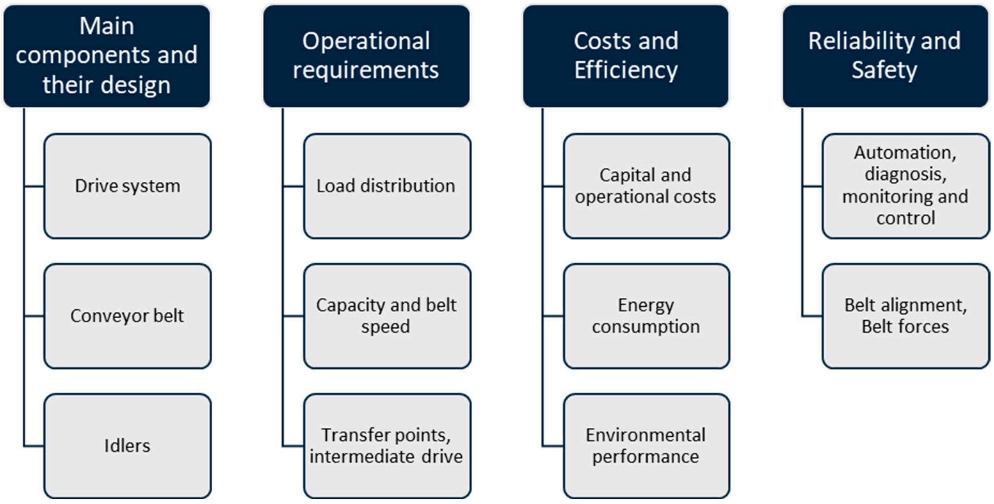


**Figure 1.** Diagram summarizing key aspects for designing an efficient, reliable, and cost-effective conveyor system

Each of the presented components contributes to the overall performance and sustainability of the conveyor system. Firstly, careful design and selection of main components mainly focuses on drive system configuration, power management and ensuring smooth operation over a long distance. The right belt material and strength selection are important for the belt tension (belt forces) and belt lifespan, while the proper idler design and spacing may significantly influence the rolling and indentation resistance [19–23]. Secondly, operational aspects relate to the variability of the mass and load distribution, that is crucial for conveyor dynamic states modelling, belt wear or energy efficiency [24,25]. Belt speed adjustment is essential for transportation stability and thus more sustainable conveyor operation [26–28]. At the same time, well-designed transfer points [29,30] or intermediate drive implementation [31–33] help to maintain consistent operation, avoid material spillage and reduce belt tension. Thirdly, optimizing costs and efficiency of conveyor transportation concerns its economic, energy and environmental performance. Both initial investment and long-term maintenance costs must be considered for economic viability. Component selection and system design minimizes energy consumption, reducing operational expenses. In addition, conveyors are more environmentally friendly as they emit less dust and noise and have a lower energy footprint during transportation process when compared to road or rail transport [34–37].

Finally, the implementation of robust reliability and safety systems is aimed at monitoring conveyor operation with a view to detecting abnormal operating conditions [38]. From maintenance point of view the integrated technologies such as vibration, magnetic, temperature or vision components [39–41] are crucial for non-destructive diagnosis of belt conveyor condition. Another important element is the intelligent detection of belt misalignment [42,43] as it detects, corrects and

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prevents improper belt handling. Above that, the issue of belt forces is a fundamental matter concerning the transfer of loads and stresses in the belt during conveyor operation [44,45]. It was recognized that the aspects crucial for controlling belt forces are as follows:

- proper management of load distribution – uneven load distribution leads to vibration, dynamic stresses in the belt and increased variations in belt tension. This can result in excessive energy consumption, belt wear damage or misalignment of the belt [46–48].
- soft start/stop systems smooth acceleration and stopping, reduce peaks in power transmission and sharp tension fluctuations as well as minimize vibrations. This ensures stable operation, protects the system from potential damage and saves energy [18,49,50].
- intermediate drive system distributes drive forces along the conveyor reducing the maximum belt tension and increasing transmitted friction force. This can improve operational reliability and reduce maintenance costs by minimizing the wear and tear on the belt and other component [18,31–33,46].
- implementation of effective tensioning device detects and adjusts belt tension in real-time under varying loads and speeds to prevent the belt from slippage. It helps to avoid excessive strain that leads to prolonging belt lifespan [51,52].
- proper belt selection – belt parameters e.g. tensile strength or elasticity modulus directly influences the belt tension and prevent from its permanent deformation. An equally important aspect is the belt construction (e.g. steel-cord or fabric), belt condition (e.g. wear level or renovation), the quality of belt splices and belt transition sections behavior [23,53–55].

This paper presents an analysis of the energy efficiency of long-distance inclined belt conveyors designed for an underground copper ore mine. Five alternative solutions were proposed and evaluated. The study includes an analysis of the main resistance components affecting conveyor performance, as well as the detailed impact of conveyor throughput on specific energy consumption. Furthermore, the total electrical energy consumed by each conveyor variant was calculated based on the assumed distribution of material load along the operational range. The aim of the article is to provide an engineering insight into the energy use of one of the key stages of the mining process – material transport. It highlights the importance of selecting belt conveyor equipment for ensuring the efficiency of the mining process.

## 2. Materials and Methods

The development of the new mining fields, located deeper and farther from the existing main haulage routes, are the typical situations of the underground ore mines. Then there is a need to arrange an efficient transport of the mined ore to shafts with regard to all aspects, described in the Figure 1. General design assumptions of the study project long-distance, underground belt conveying are summarized here:

- The analysed conveying route is straight, 3 km long, it consists of 2 segments: the first 2.7 km inclined at the angle 2°, the second (0.3 km long) is steeper (angle 7°), the average angle 2.5°.
- It is assumed that the conveyor line is supplied by the retention bunker to manage material flow, stabilize material stream along the route and provide temporary storage when the conveyor is not in operation.
- Designed system capacity is set to 2000 t/h (maximum) and 1000 t/h (average).
- Transported material is pre-crushed copper ore without large lumps (density 2.275 kg/m$^3$).
- The conveyor is supposed to work as the main transport line favorable operational conditions and minimal belt misalignment are assumed. A safety margin of over 30% of the maximum belt filling cross-section has been assumed to accommodate short-term throughput surges and prevent potential belt-tracking issues along the long-distance route.
- The steel-cord belt from a standard series (St 2000, St 2500, St 3150) is analyzed or optionally a dedicated higher-strength version of the belt may be used.
- Due to the length of the conveying route, two general solutions are analyzed: single long-distance conveyors (3 km long) and two standard conveyors (1.5 km each). The belt safety factor

for the long 3 km single flights is reduced from the standard 6.7 to 5.0 (based on the assumed implementation of belt splices inspection procedures and regular audits of the entire belt loop condition combined with the reduced number of belt lap cycles). For the last reason, the standard belt safety factor was retained for the shorter 1,5 km [56–58].

Technical parameters and design variants of conveyors

The technical parameters of these conveyors are based on the successfully used in the KGHM underground copper ore mines in Poland domestic Legmet heavy-duty conveyors series of standardized designs [59]:

- belt width of 1.2 m and a belt speed of 3.0 m/s,
- standard spacing for the upper idlers is 0.83 m, and for the bottom idlers, 2.5 m, with the upper fixed (non garland) idler sets forming a 30° trough angle and V-type bottom idlers
- rollers with an increased diameter of 159 mm (compared to the standard 133 mm).
- drive units range from 250 to 500 kW and implementation of variable frequency drives,
- belt tensioning: gravity take-up systems.

Calculations

Calculations of belt conveyors drive power demand were carried out in the QNK-TT domestic software that uses primary resistances to motion rather than the standard simplified friction coefficient method [60,61]. The components of the main resistance to motion are calculated precisely by analyzing energy dissipation in belt and transported material as well as interaction between belt and idlers. The software uses object-oriented modeling techniques, including a wide variety of conveyor equipment configurations and operating conditions. These calculations are based on scientifically validated formulas supported by extensive laboratory tests and industrial measurements [62–65].

The appropriate measure of efficiency of proposed belt conveyors variants is specific energy consumption indicator – SEC [66,67]. It describes the amount of energy needed to transport a mass unit of material over a distance of a length unit (here: W/(kg·m)). However, as pointed out in [35], for more complex conveying routes, e.g. inclined routes, the route specific energy consumption (SEC)—defined as the amount of energy required to transport a unit mass of material from point A to point B along the route—should be used for comparison (here: W/kg). This value depends on the actual inclination of the route, operational capacity, and the parameters of the given transportation configuration. Equations describing SEC indicators are shown below.

$$SEC = \frac{N_E}{Q_m \cdot L} \quad (1)$$

$$route\ SEC = SEC \cdot L \quad (2)$$

$N_E$ - the electric net power of the drive delivered to the conveyor, W;
$Q_m$ - actual mass capacity, kg/s;
L - length of the conveyor route, m.

## 3. Results

This section presents results of calculations performed for different belt conveyors construction variants in the real working conditions (Table 1). All five options are designed for an uphill conveyor route with a total length of 3,000 m and a vertical lift of 131 m (for Variants 1–4), or two shorter conveyors of 1,500 m and 53 m and 78 m elevation (inclination 2° and 3° respectively - Variant 5). Results show that not all variants are capable of achieving the target maximum throughput of 2,000 t/h.

Variant 1 represents the solution with a standard head drive system (4 × 500 kW) and a high-tensile strength St4000 belt, resulting in the highest belt force of 680 kN (88% of the maximum belt strength). For variants 2 and 3 the standard steel-cord belt rated 3150 kN/m (variant 2) and 2000 kN/m (variant 3) are proposed. The lower tensile strength of these belts limit the available maximum

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capacity to 1600 and 1000 tonnes per hour (respectively), which proves that the standard solution does not match the assumed requirements. Variant 4 introduces an additional intermediate drive (2 × 355 kW) in the top belt strand, effectively reducing belt force to 504 kN (83% of the maximum belt strength) while maintaining comparable power demand. Variant 5 replaces the single long conveyor with two shorter ones, which slightly lowers the total power demand (1 809 kW in total); however, the maximum belt force in the second conveyor reaches 99% of the installed belt's strength.

Both of the proposed long-distance variants that match the capacity requirements, include non-standard solutions: one involves a conveyor belt with increased tensile strength (Variant 1), and the other features a conveyor with an intermediate drive system (Variant 4). The higher (non standard) belt strength causes a need to apply a special layout of belt splices, which can only be made by highly qualified personnel. The intermediate drive system creates additional difficulties with the adjustment of belt tensioning that have to be addressed with the dedicated drive and take-up procedures control system. It has to be provided by the experienced supplier together with the specialized training of the mine staff responsible on maintenance of belt conveyors. One of the main challenges in implementing innovative solutions in mining operations is organizational resistance to change. Users of machinery systems often prefer standard machinery components because they are readily available in stock, well-known to the staff, and easier to assess in terms of quality and reliability. Introducing non-standard solutions - whether in the form of unconventional components or a novel system layout - can raise operational concerns [68,69]. For example, servicing conveyor belts with different tensile strength may lead to maintenance difficulties and requires alternative operating instructions, increasing the risk of errors. This preference for familiar, proven equipment comes not only from logistical convenience but also from a tendency to avoid the complexities and uncertainties associated with managing and maintaining non-standard configurations.

**Table 1.** Summary of proposed technological solutions

| No | Route length | Lift | Capacity | Required drive power | Drive system configuration | Maximum belt tension (% of belt tensile strength) | Belt type GTP-St Steel-cord for underground installation), rating (belt covers thickness) |
|---|---|---|---|---|---|---|---|
| | m | m | t/h | kW | - | N | - |
| 1 | 3 000 | 131 | 2 000 | 1 851 | head, 4x500 | 680 (88) | 4 000 (10+8) |
| 2 | 3 000 | 131 | 1 600 | 1 524 | head, 4x500 | 565 (93) | 3 150 (10+8) |
| 3 | 3 000 | 131 | 1 000 | 1 038 | head, 3x500 | 400 (105) | 2 000 (10+8) |
| 4 | 3 000 | 131 | 2 000 | 1 827 | **head, 4x355 + 2x355 intermediate in the top belt strand** | 504 (83) | 3150 (10+8) |
| 5 | 1 500<br>1 500 | 53<br>78 | 2 000<br>2 000 | 824<br>985 | head, 4x250x2 | 286 (79)<br>355 (99) | 2 500 (10+8) |

Conveyor resistance to motion as well as lifting transported bulk material directly influence its energy consumption. Therefore, the components of main resistance to moitin of the proposed conveyors have been analyzed. Figure 2 presents the components of primary resistances to motion in the top belt strand as a function of mass flow rate for conveyors named Variant 1. Five resistance components are calculated:

- idler rolling resistance,
- belt bending resistance,
- belt indentation rolling resistance,
- flexure resistance of bulk material,
- sliding resistance of a belt on idlers.

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In general, as the throughput increases the total resistance increases as well. For every component there is a relationship between its value and mass flow rate, although it is not strictly linear. The most significant contribution comes from belt indentation rolling resistance and idler rolling resistance [14,20,56,60,65,67]. This indicates potential for improvement in belt and idler selection – reducing their resistance will lower total conveyor resistance, required power and ultimately belt conveyor energy consumption.

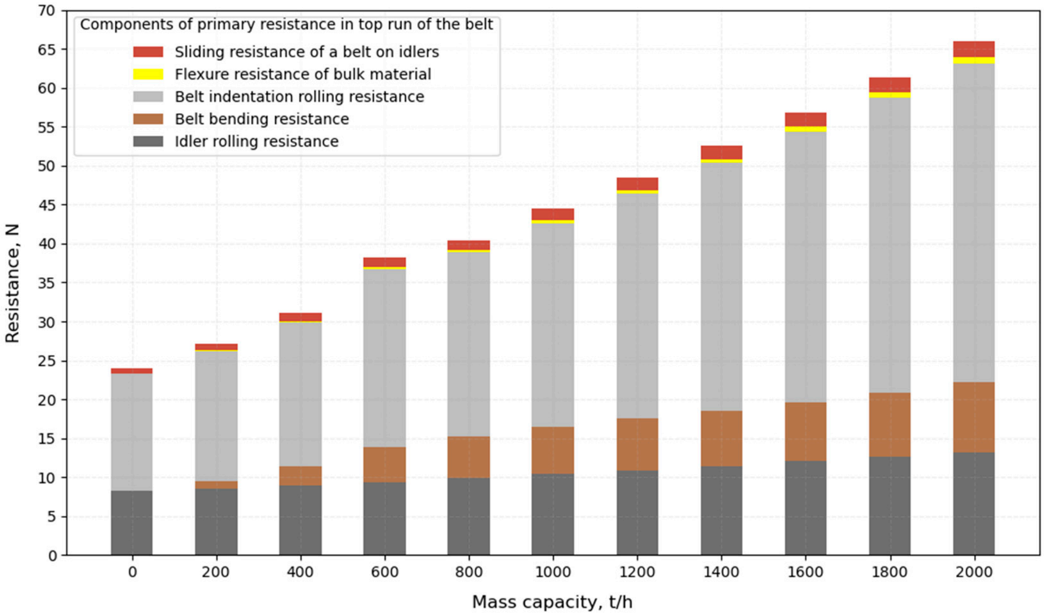


**Figure 2.** Cumulative plot of components of primary resistance in the top belt strand for Variant 1 (source: QNK-TT)

For the proposed design variants, the SEC index was calculated. Table 2 presents the SEC values both unit indicator and route indicator for two operating conditions: average and maximum capacity. This shows how each variant behaves under typical and peak loading scenarios, helping to assess how effectively each system utilizes energy over its transport route. All variants represent similar energy efficiency, due to the fact that they have been composed with the use of the same conveyor components except the differentiated belt strength (and – consequently – unitary mass of the belt) and drive layout. The standard strength steel-cord belt used for variants 2, 3 and 5 returns slightly lower SEC values in analyzed capacity scenarios (though the maximum capacity si not available for variants 2 and 3). Variant 4, which introduces an innovative intermediate drive, achieves an improvement in efficiency compared to Variant 1 - particularly at maximum capacity - demonstrating the benefits of redistributed drive power. Variant 1, using a high-strength belt for a single conveyor, shows higher SEC values but (together with the variant 4) represents the highest margin of the maximum belt force (table 1).

Because the differences in SEC values among these variants are not prevailing, it is important to consider investment and operational costs generated by each of the proposed solutions. In particular, the variant with two conveyors (Variant 5) will result in doubled investment costs of the main components such as drive units, brakes, and take-up devices must be installed for each conveyor separately. Moreover, any transfer point of conveyed bulk material requires a surveillance either directly by a dedicated staff or with the use of cameras and additional gauges to prevent possible operational failures.

**Table 2.** Energy efficiency for average and maximum capacity.

| No | Capacity 1 000 t/h | | Capacity 2 000 t/h | |
|---|---|---|---|---|
| | SEC | Route SEC | SEC | Route SEC |

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<table>
<tr><th></th><th>Ws/kgm</th><th colspan="2">$10^3$ Ws/kg</th><th>Ws/kgm</th><th colspan="2">$10^3$ Ws/kg</th></tr>
<tr><td>1</td><td>1.199</td><td colspan="2">3.60</td><td>0.969</td><td colspan="2">2.91</td></tr>
<tr><td>2</td><td>1.147</td><td colspan="2">3.44</td><td>none</td><td colspan="2">none</td></tr>
<tr><td>4</td><td>1.158</td><td colspan="2">3.47</td><td>0.952</td><td colspan="2">2.86</td></tr>
<tr><td rowspan="2">5</td><td>1.039</td><td>1.56</td><td rowspan="2">3.39</td><td>0.853</td><td>1.28</td><td rowspan="2">2.83</td></tr>
<tr><td>1.219</td><td>1.83</td><td>1.031</td><td>1.55</td></tr>
</table>

Figure 3 presents a comparison of specific energy consumption (SEC) as a function of mass capacity (in t/h) for three system configurations labeled as Variant 1, Variant 2, and Variant 4, because they represent the same route layout. Each variant is represented with calculated data points and a corresponding fitted curve based on a hyperbolic model. All variants show a decreasing trend in SEC as mass capacity increases. Variant 4 demonstrates the best performance in terms of efficiency, followed by Variant 2 and Variant 1. Given that the differences in SEC values between the variants are relatively small, the relationship is presented with two different mass capacity ranges. Moreover, since the considered system represents main haulage conveyor, which should not operate at low capacities, it was arbitrarily assumed that the analyzed capacity range would start from 700 t/h.

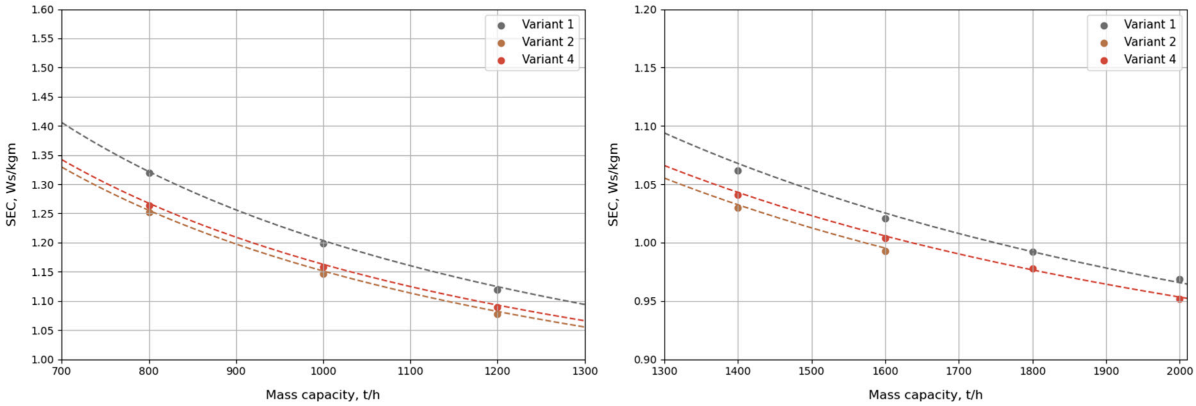


**Figure 3.** Relationship between SEC value and mass capacity

In the next step the route SEC for analyzed variants was calculated assuming on the basis of the measured distribution of mass capacity of conveyors used in KGHM PM S.A. underground copper mine for a main haulage conveyor [62] (Table 3). The results of the expected mean value of the energy consumed by the conveyors are presented in Figure 4.

**Table 3.** Assumed mass flow rate distribution

| Classes of capacity, t/h | Frequency |
|---|---|
| 200 | 0.196 |
| 400 | 0.022 |
| 600 | 0.036 |
| 800 | 0.097 |
| 1 000 | 0.383 |
| 1 200 | 0.234 |
| 1 400 | 0.029 |
| 1 600 | 0.003 |
| 1 800 | 0 |
| 2 000 | 0 |

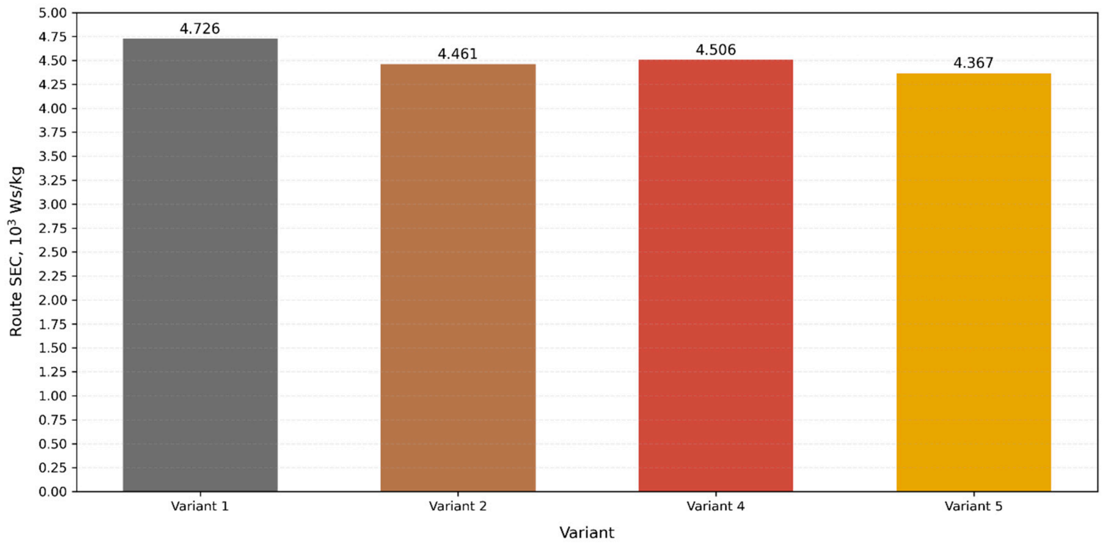


**Figure 4.** Route expected mean SEC values for analyzed variants

Figure 5 presents how much electric energy is required to transport 1 mln tonnes of bulk material for fixed mass flow rates from 200 to 2000 tonnes per hour. As shown in the bar chart, energy consumption significantly decreases as the mass capacity increases. For low throughputs (e.g. 200 t/h), the differences between variants are more significant - As the capacity increases, the total energy consumption levels off and the differences between the design variants become smaller. At high capacities (above 1400 t/h), all variants achieve similar energy consumption levels, indicating improved efficiency with higher loads.

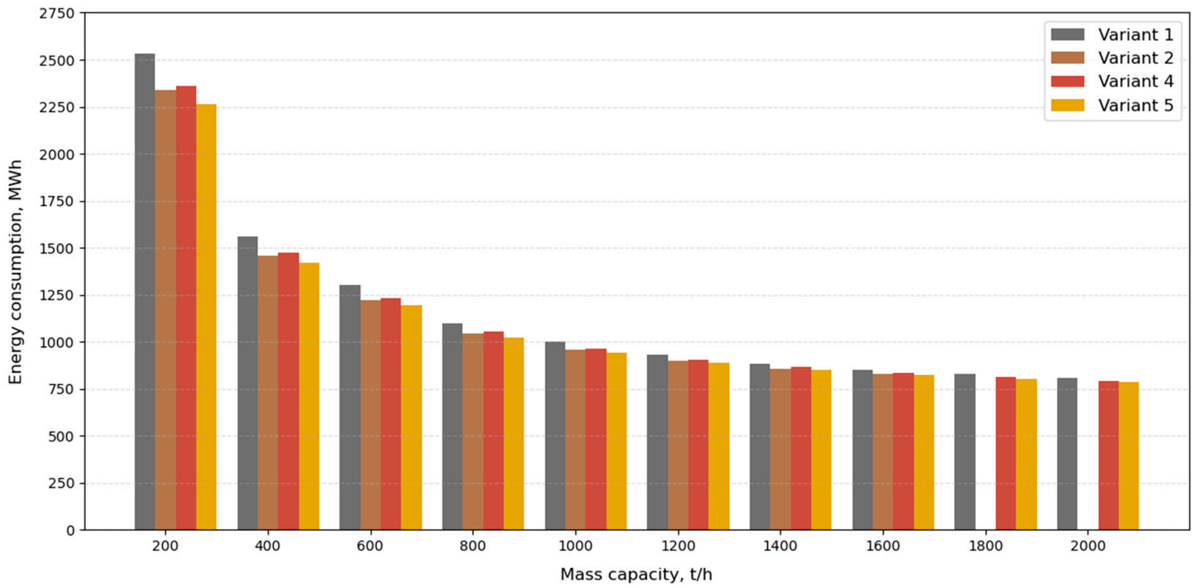


**Figure 5.** Electric Energy consumption for transportation 1 mln tonnes of copper ore at given mass capacity

In the next step, the percentage difference in energy consumption between four selected conveyor design variants was analyzed. These specific variants were selected because they meet the real achieved throughput capacity, making them suitable for real operational conditions (remembering that the variant 2 does not match the maximum capacity of 2000 t/h). The percentage difference in energy use was calculated based on the example histogram (Table 4).

**Table 4.** Percentage changes in electric energy consumption

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| | Variant 1 | Variant 2 | Variant 4 | Variant 5 |
|---|---|---|---|---|
| **Variant 1** | 0.00% | 5.63% | 4.67% | 7.61% |
| **Variant 2** | -5.96% | 0.00% | -1.01% | 2.10% |
| **Variant 4** | -4.90% | 1.00% | 0.00% | 3.08% |
| **Variant 5** | -8.23% | -2.14% | -3.18% | 0.00% |

The comparison shows that variant 1 is the least energy efficient solution. It consumes more energy than all other variants. Variant 2 performs better than Variant 1 (−5.96%), but slightly worse than Variant 5 (+2.10%) and slightly better than Variant 4 (−1.01%). Variant 4 is more efficient than Variants 1 and slightly less efficient than Variant 2 and 5.

## 4. Discussion

Based on energy efficiency index only variant 5 should be chosen as a preferred solution. However, the calculated differences are small and in practice can be negligible. Therefore, the choice of a transportation system must take into account a comprehensive, multi-criteria assessment. The following aspects should be considered equally:

- Energy efficiency – While this remains a key factor, the impact of secondary resistances (flexure resistances of bulk material on transfer points, bending resistances of belt on pulleys, friction resistances on scrapers and other belt cleaning devices) becomes less significant on longer routes.
- Operational safety – Reliability and safety under actual mining conditions must be prioritized. The rising availability of monitoring gauges and diagnostic systems working on-line [13,39,40,42,43,45], as well as the development of periodical advanced tests of selected belt conveyor components [12,23,41,51,58,65] allow both the designers and the users of belt conveyors to investigate and implement more sophisticated solutions (like the proposed variant 4) instead of simply reuse of well known designs (here: variant 5).
- Wear and maintenance – Shorter conveyors are subject to more frequent operational cycles, which leads to faster belt wear.
- Mass of moving elements – A lighter belt can be advantageous at lower capacity, whereas higher capacity requires a stronger (and therefore heavier) belt, which may increase energy use and maintenance complexity but provides the performance margin that cannot be neglected according to possible increases of the required mine output – the conveyor line maximum capacity should not become a bottleneck of the future development of the new mine area .
- Maintenance and monitoring – as mentioned in the previous chapter, any multiply -conveyor systems (instead of the single flight solutions) require supervision and maintenance of both the head station and the intermediate transfer point. Additionally, systems with intermediate drives may present challenges related to start-up and braking operations.

Therefore, the selection of the most appropriate conveyor system should be based on a holistic, multi-criteria evaluation rather than a single factor such as energy consumption.

## 5. Summary and Conclusions

The presented calculation results of the study alternative variants of underground long-distance belt conveyors for transporting copper ore are based on the requirements and technical constraints of the main haulage along the inclined route from the developed new mining fields in the KGHM mines in Poland. The accurate results of the required drive power with regard to the actual capacity and the different parameters of the analyzed conveyors have been done with the use of the dedicated, in-house developed software which allows to investigate the influence of the chosen conveyor components on its resistance to motion, hence - its energy consumption. Such analysis is not possible with the use of standard calculation methods.

The results have proved that there are no big differences of the energy efficiency among the analyzed variants. However, the careful comparison of them highlights the drawbacks of variants 2

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and 3 (limited maximum capacity) and of the variant 5 (limited belt force margin for the maximum capacity for the conveyor 5b with the bigger material lift).

The obtained results underline the strong dependency of the average energy use by belt conveying on the actual mass flow. Conveyors, like the other transportation modes, are the most efficient when fully loaded. The main haulage conveyors are planned to be fed through a bunker. The bunker can and should be used for forming an even load close to the maximum capacity masses in order to increase the energy efficiency of belt conveyors. The savings of energy which can be obtained with the use of energy oriented operational control of transported mass are beyond the results that could be achieved by only the selection of energy efficient belts.

The paper does not deal with the investment and maintenance costs, because these are not disclosed by the company. Therefore, it has been assumed that the used components are the same unlike the number of the necessary units (drive units, take-up devices). The variants utilize, however, belts of various tensile strength which costs of purchase and splicing could also be different. On the other hand, the suppliers can treat an installation for a special, long-distance conveyor as a flagship of their portfolio that proves the high level of the achieved technology. The agreed price of a special belt could be therefore advantageous for mine.

**Supplementary Materials:** The following supporting information can be downloaded at the website of this paper posted on Preprints.org. reports of the calculations of belt conveyors (QNK-TT), Excel spreadsheet with processed results

**Author Contributions:** Conceptualization, NSM, WK, RK; methodology, NSM, WK, RK.; software, WK.; validation, WK.; formal analysis, NSM, WK; investigation, NSM, WK.; resources, NSM WK, RK; data curation, NSM; writing—original draft preparation, NSM, WK.; writing—review and editing, NSM, WK, RK.; visualization, NSM.; supervision, RK.; project administration, RK; funding acquisition, RK. All authors have read and agreed to the published version of the manuscript.

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