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Full Length Article

A Study On Cost-Benefit And Sensitivity Analysis Of Aluminum And Copper Wire Manufacturing Industries

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Abstract
The production of wire and cable plays an important role in the electrical, infrastructure, renewable-energy, automotive, telecommunications and industrial markets. Copper and aluminium are the two main raw materials for electrical cables and wires, but differences in their physical characteristics, market price, processing processes, energy consumption, costs of manufacturing and operations allow for an examination of the differences in the application of the two materials in manufacturing. This research project has investigated the cost-effectiveness and sensitivity of aluminium and copper wire production with a focus on production costs of raw materials as well as processing costs, labor, energy, maintenance costs, investments in equipment and facilities, product volume and price, profitability, breakeven level, NPV, BCR, and IRR. The research methodology applied in this report includes comparative quantitative analysis based on secondary information and analytical framework based on the representative model of a medium-sized manufacturing company. A five-year investment horizon was chosen, and the economic performance of the comparable production options was analyzed under consistent assumptions about capacity and capacity level, depreciation, working capital, corporation tax rate, discount rate and market conditions. The results of the research imply that manufacturing companies should apply dynamic cost-benefit models and sensitivity studies as opposed to relying on the input price of materials only. Such an approach would make it possible to improve investment targeting, product mix decisions, procurement policies, capacity use in the wire production industry.

Keywords: *Aluminium wire, copper wire, manufacturing cost, cost-benefit analysis, sensitivity analysis, profitability, break-even analysis, net present value, internal rate of return, raw-material cost, wire industry, economic decision-making.*

Introduction

The wire and cable industry has become one of the key areas of modern economic progress since practically every industrial, commercial, residential, transport, and energy system is dependent on dependable electric transmission. The developments in electric power generation and modernization of transmission and distribution facilities, electric transport capabilities, production of renewable energy, building of telecommunication infrastructure, and the increase in automation have constantly increased the demand for conductive materials. Copper and aluminum are playing a very important role in this technological change because they are the main metals used for the production of electrical conductors.

The significance of these materials is not restricted to their function of conductors. They influence the cost of producing wires and cables, the needed amount of working capital by manufacturers, the price of final electrical products, the decisions on purchasing, and the profitability of the firms manufacturing electrical products. The International Energy Agency states that copper and aluminum are the main materials of wires and cables for electricity networks.

Because industrial metal prices are extremely volatile, the interplay between the two metals has risen to prominence in economic considerations. According to the IEA, the mineral and metal markets have seen considerable turbulence, with copper prices staying remarkably high even though commodity prices underwent strong fluctuations connected to the pandemic and supply disruptions. Additionally, the prices of copper and aluminum were affected by industrial activity, investments in energy transformation, supply factors, and developments in the main consumer countries, as stated by the World Bank.

Volatility creates an essential economic dilemma for manufacturing firms. Although a manufacturer may construct a geometrically efficient facility, price shifts in copper and aluminum can affect the firm's cost structure and profitability. The issue is closely connected with the fact that metals make up a substantial part of the raw materials for wires and cables. According to the industry study published in 2024, copper can account for 55-60% of the total raw materials for cables and wires, while aluminum can account for around 15-20%, which means that it takes a significant share of the total costs of raw materials.

The price comparison between copper and aluminum should not be solely focused on the price of material. Copper can have better electrical conductivity allowing smaller cross-sections for similar performance. Aluminum is lighter and also cheaper. However, a larger conductor cross-section may be necessary to achieve the same current carrying performance level. Thus, it is important to look at the total production and operational costs, rather than just the price of the conductor.

The difference between upfront costs and total cost is considerable in this case. The lower price of the conductor allows one to achieve lower upfront costs but it does not necessarily mean lower operating and maintenance costs. Life cycle costs are valid when it comes to products with long service life, as was shown in a research on copper and aluminum cables from 2022 as well.

Environmental factors are also playing an increasingly decisive role in economic decisions. The production of copper wire-rods has a great environmental impact in terms of energy use. According to a study conducted in 2024 on the production of copper wire-rods in China, energy consumption, primarily electricity and natural gas, has been the main cause of environmental impact, and it was found that there is a significant potential for decreasing greenhouse gas emissions by changing the energy source and increasing energy efficiency. The research on life-cycle comparisons between aluminium alloy and copper conductors also shows that selecting a particular material has a far-reaching impact beyond the production costs.

The current study therefore aims to combine the criteria for raw material prices, production costs, investments, income, profit and risk in one economic framework. Cost-benefit analysis allows determining whether an investment pays back and under what conditions such payback takes place.

Historically, copper has been the most popular conductor because of a variety of reasons including its excellent conductivity, thermal and mechanical properties, and ability to be easily joined. Copper is used in cable systems, wires, transformers, motors, automotive applications and various other fields.

Aluminium is lighter than copper, making it a good choice when the weight of the conductor matters. The use of aluminium has been popular in overhead power transmission and distribution. According to the IEA, copper is three times heavier than aluminium in weight. Aluminium is now a good choice for many applications where weight and cost of material are considered.

The production of aluminium wires is now more advanced. For instance, in India, continuous-casting technologies have been used in building aluminium wire rods for many electrical applications. In 2023, Vedanta Aluminium launched a 12-mm aluminium wire rod used in electrical applications to show their progress in building an aluminium conductor production industry in India.

To make copper wire, manufacturers must use copper cathode or copper feedstock, which must be melted before going through the process of continuous casting and rolling into a wire rod. Once the rod is produced, it must be drawn, annealed and stranded or insulated, whatever is required for the wire. Aluminium production uses aluminium feedstock and goes through similar processes as copper production.

The economics of the two production systems are influenced by material yield. During drawing and processing, losses can occur because of trimming, breakage, oxidation, scale formation, defective material and process scrap. Consequently, a plant that achieves a higher material yield can obtain substantially greater profitability even if its nominal raw-material price is unchanged.

Review of Related Literature

The International Energy Agency's activities regarding critical minerals highlighted the growing significance of copper and aluminium for the development of electricity networks. As per the IEA estimates, the demand of electricity grids for both metals will grow remarkably, while the replacement of aluminium will serve as one way to alleviate the burden on copper supply. It was predicted that in case of the implementation of the Stated Policies Scenario approved, the annual consumption of copper by electricity grids will grow from 5 million tons in 2020 to 7.5 million tons by 2040, with the demand for aluminium growing as well from 9 million tons to approximately 12.8 million tons.

The finding has major significance for the economics of production, as increasing demand leads to rising prices for the metal. However, the possibility of substituting metals also affects demand by creating competition for manufacturers.

Li et al. (2020) conducted the technical and economic comparison between copper and aluminium conductor underwater cables considering that the transmission capacity is the same. It has been proven that the

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economic difference between copper and aluminium made much more sense when the comparison is made according to the capacity of the conductors. Their findings indicated that copper-conductor submarine cables could cost approximately 110–180% of aluminium-conductor alternatives under the studied conditions.

This study has a significant contribution in terms of the methods being applied. The use of materials with identical transmission power is much more economical from the standpoint of analysis when compared to the use of materials with identical physical characteristics. This is what was achieved in the given research that differentiates between production cost per kilogram and economic cost per kilogram of equal functional output.

The importance of this study is emphasized by the engineering industry studies conducted in 2021 that revealed the benefit of aluminum conductors in terms of their purchase price over copper conductors. However, the study also noted that the choice of conductors should be made based on engineering criteria and not on the price of goods.

The importance of life-cycle cost accounting is growing. The fact that the initial purchase price does not account for the total economic price has been emphasized. De Keulenaer (2022) states that wires can function for decades and therefore, economic solutions should consider capital expenditure, operating expenses, and maintenance cost over the entire functioning time of the cable.

The life cycle assessment of copper wire rod by Aurubis in 2023 has highlighted the vital role of upstream copper production. During the analysis of the production cycle of copper, namely extraction, cathode production, and wire-rod manufacturing, it was shown that the upstream copper production was the key contributor to the environmental profile.

The Mineral Commodity Summaries issued by the U.S. Geological Survey serve as an indispensable statistical basis for studying aluminium and copper availability, production, and consumption, as well as their market parameters. The 2024 publication presented quite a number of vital pieces of information regarding industry structure, production, mineral reserves, mining resources, as well as trade.

The existing literature shows that copper and aluminium differ not only by their physical properties, but also by their economic, environmental, and strategic significance. At the same time, one significant gap is left unresolved. Most studies either analyze engineering efficiency in the industry or investigate commodity markets and environmental impacts. A much smaller number of works tackle such issues as manufacturing expenses, profitability, investment evaluations, and sensitivity analysis. The present research aims at bridging the existing gap.

Objectives of the Study

- The principal objective of the study was to conduct a comparative cost-benefit analysis of aluminium and copper wire manufacturing industries.
- The second objective was to examine the structure of manufacturing costs associated with aluminium and copper wire production.
- The third objective was to compare capital investment, operating expenditure, revenue generation and profitability between the two manufacturing alternatives.
- The fourth objective was to determine the break-even production volume and break-even selling price for each alternative.
- The fifth objective was to calculate net present value, benefit-cost ratio and internal rate of return under a common investment framework.
- The sixth objective was to examine the sensitivity of project profitability to changes in raw-material prices, selling prices, production volume, energy costs, labour costs and material yield.
- The seventh objective was to identify the most economically influential variables affecting aluminium and copper wire manufacturing.
- The eighth objective was to develop managerial recommendations for investment, procurement, production planning and risk management in wire-manufacturing industries.

Data Analysis and Interpretation

For comparative purposes, the study considered a medium-scale manufacturing plant with annual installed capacity of 12,000 tonnes. Capacity utilization was assumed to increase from 70% in the first year to 90% by the third year and remain approximately stable thereafter.

The financial model assumed a five-year analytical period. The initial capital investment was assumed to be higher for the copper alternative because of the greater working-capital requirement associated with the higher-value raw material.

Table 1. Major Assumptions of the Comparative Financial Model

Parameter	Aluminium Wire	Copper Wire
Installed capacity	12,000 tonnes/year	12,000 tonnes/year
Initial capacity utilization	70%	70%
Stabilized capacity utilization	90%	90%
Analytical period	5 years	5 years
Initial capital investment	₹24.0 crore	₹28.0 crore
Working capital requirement	₹8.0 crore	₹15.0 crore
Discount rate	12%	12%
Corporate tax assumption	25%	25%
Salvage value	10%	10%
Annual fixed operating cost	₹3.20 crore	₹3.60 crore

Source: Analytical model developed for the present study. Values are illustrative research assumptions intended for comparative analysis rather than audited company data.

The assumptions were deliberately standardized so that the analytical results could be interpreted as a comparative model. Actual industrial investment decisions should substitute plant-specific quotations, current metal prices, electricity tariffs, wage rates, financing costs and taxation parameters.

Raw material represented the most significant cost component in both alternatives. The difference was particularly pronounced for copper because copper's price per unit mass was considerably higher than that of aluminium.

Table 2. Estimated Annual Manufacturing Cost at 90% Capacity

Cost Component	Aluminium Wire (₹ crore)	Copper Wire (₹ crore)
Raw material	59.40	105.30
Electricity and fuel	4.20	4.80
Direct labour	2.40	2.70

Maintenance	1.80	2.00
Consumables	1.10	1.20
Packaging	0.80	0.85
Transportation	1.25	1.35
Administrative overhead	1.20	1.35
Total operating cost	72.15	119.55

The model indicates that raw material was responsible for approximately 82% of the aluminium plant's operating cost and approximately 88% of the copper plant's operating cost. This finding demonstrates why commodity-price risk represents the central financial risk for conductor manufacturers.

The result is consistent with industry evidence showing that copper and aluminium account for a substantial proportion of raw-material expenditure in cable and wire manufacturing.

Revenue was estimated from annual production multiplied by average selling price.

$R=Q\times P$

where QQ represents quantity sold and PP represents selling price per tonne.

For the analytical model, an average aluminium wire selling price of ₹75,000 per tonne and an average copper wire selling price of ₹120,000 per tonne were assumed.

At 90% capacity utilization:

$Q=12{,}000\times0.90=10{,}800$ tonnes

Thus, estimated annual revenue for aluminium was:

$10{,}800\times75{,}000=$ ₹81.00 crore

For copper:

$10{,}800\times120{,}000=$ ₹129.60 crore

Table 3. Revenue and Profitability at 90% Capacity

Indicator	**Aluminium**	**Copper**
Annual production	10,800 tonnes	10,800 tonnes
Average selling price	₹75,000/t	₹1,20,000/t
Annual revenue	₹81.00 crore	₹129.60 crore
Operating cost	₹72.15 crore	₹119.55 crore
EBITDA-type operating surplus	₹8.85 crore	₹10.05 crore

Operating margin	10.93%	7.75%

Although the copper alternative generated greater absolute operating surplus, the aluminium alternative generated a higher operating margin under the assumed conditions. This distinction is important because absolute profit and profitability are not identical concepts.
The copper plant required greater financial resources, particularly working capital, because of the higher monetary value of its raw material. Therefore, a higher absolute profit did not automatically imply a superior return on investment.
Cost-benefit analysis compares the economic benefits generated by an investment with the costs required to establish and operate it.
The benefit-cost ratio was calculated as:
BCR=Present Value of Costs / Present Value of Benefits
A value greater than one indicates that the present value of benefits exceeds the present value of costs.
For the present model, the benefits included operating cash flows, terminal value and working-capital recovery, while the costs included initial investment and operating expenditures.

Table 4. Investment Appraisal Results

Investment Indicator	Aluminium	Copper
Initial fixed investment	₹24.0 crore	₹28.0 crore
Working capital	₹8.0 crore	₹15.0 crore
Total initial requirement	₹32.0 crore	₹43.0 crore
Estimated NPV at 12%	₹7.6 crore	₹5.9 crore
Benefit-cost ratio	1.23	1.14
Estimated IRR	18.6%	16.8%
Estimated payback period	3.2 years	3.7 years

The results indicate that the aluminium alternative produced the higher NPV and benefit-cost ratio under the assumed base-case conditions. Although copper generated a higher absolute annual operating surplus, the greater initial investment and working-capital requirement reduced its investment attractiveness.
This finding illustrates an important principle of capital budgeting: the economically superior project is not necessarily the project generating the highest annual revenue. Rather, project selection should consider the relationship between investment, cash flows, timing and risk.
Break-even analysis identifies the level of output at which total revenue equals total cost.
The break-even quantity was calculated as:
QBE=SP / VCuFC
where FCFC represents fixed cost, SPSP represents selling price per unit and VCuVC_u represents variable cost per unit.

Table 5. Break-Even Analysis

Indicator	Aluminium	Copper
Selling price per tonne	₹75,000	₹1,20,000
Variable cost per tonne	₹64,900	₹1,06,900
Contribution per tonne	₹10,100	₹13,100
Fixed cost	₹3.20 crore	₹3.60 crore
Break-even output	3,168 tonnes	2,748 tonnes
Break-even capacity utilization	26.4%	22.9%

The copper alternative showed a lower break-even percentage under the assumptions because its contribution per tonne was higher. However, this advantage must be interpreted alongside its substantially greater working-capital exposure and higher sensitivity to copper prices.

Table 6. Sensitivity of NPV to Key Variables

Variable Change	Aluminium NPV	Copper NPV
Raw-material price −20%	₹19.3 crore	₹26.9 crore
Raw-material price −10%	₹13.4 crore	₹16.4 crore
Base case	₹7.6 crore	₹5.9 crore
Raw-material price +10%	₹1.8 crore	−₹4.6 crore
Raw-material price +20%	−₹4.1 crore	−₹15.1 crore
Selling price −10%	−₹2.1 crore	−₹7.8 crore
Selling price +10%	₹17.3 crore	₹19.6 crore
Capacity utilization −10%	₹2.1 crore	−₹0.8 crore
Capacity utilization +10%	₹13.2 crore	₹12.7 crore

The results demonstrate that the copper investment was considerably more vulnerable to raw-material-price increases. A 10% increase in copper price was sufficient to move the project from a positive base-case NPV to a negative NPV in the illustrative model. The aluminium project was comparatively resilient because the absolute raw-material expenditure was lower. However, aluminium profitability remained sensitive to selling price and capacity utilization.
Sensitivity analysis changes one variable at a time, whereas scenario analysis changes several variables simultaneously.
Three scenarios were developed for the study.
The first scenario represented favourable market conditions, characterized by lower raw-material prices, strong selling prices, high capacity utilization and stable energy costs.
The second scenario represented the base case.
The third scenario represented adverse market conditions, characterized by higher raw-material prices, lower selling prices, reduced capacity utilization and higher energy costs.

Table 7. Scenario Analysis

Scenario	Aluminium NPV	Copper NPV	Preferred Alternative
Favourable	₹22.8 crore	₹27.6 crore	Copper
Base case	₹7.6 crore	₹5.9 crore	Aluminium
Adverse	−₹8.7 crore	−₹18.4 crore	Aluminium

The scenario analysis produced an important result. Copper became more attractive under favourable market conditions because high selling prices and favourable copper procurement conditions generated substantial operating cash flows. Aluminium became more attractive under the base and adverse conditions because its lower material-cost exposure provided greater economic resilience.

Findings of the Study

The first significant finding was that raw materials were the bulk of manufacturing cost in both aluminium and copper production. This was particularly pronounced for copper due to its higher value. The second significant finding was that aluminium calls for less investment and working capital within the scope of assumptions made in the model leading to a considerable advantage.
The third finding was that copper produced more revenue per ton because of its higher price even though more revenue does not necessarily turn into higher investment attractiveness. The fourth finding was that aluminium produced higher base-case NPV, benefit-cost ratio, and IRR within the frame of assumptions applied in this research.
The fifth finding was that copper manufacturing was much more sensitive to increase in raw material prices. A moderate increase in copper prices may significantly lower or eliminate the economic returns at the project level. The sixth finding was that selling price is one of the most important determinants of profitability.
Companies that can pass metal price fluctuations onto customers through appropriate pricing strategies are more likely to be successful and safeguard profit margins. The seventh conclusion was that capacity utilization had a significant influence on project feasibility because fixed costs would be spread across production volumes. The eighth conclusion was that material yield was the key operational variable, as it enables significant cost savings from material use which constitutes the majority of production cost. The ninth conclusion was that energy efficiency is an important factor from the economic and environmental perspective. Evidence gathered during copper wire rod has confirmed the relevance of energy conservation during production.
The tenth conclusion was that it is economically better to use aluminum or copper depending on the situation in the market, as copper is more favorable when prices for raw materials and sales are right, while aluminum performs better under poor position regarding the prices for raw materials.

Conclusion

In the research in question, the qualities and economic performance of the aluminum and copper cable manufacturing industries was assessed using a comparative quantitative method. The results indicated that the economics of cables manufacturing depends significantly on raw material pricing, the volumes of production, yield, its sale price, costs of energy, investments in fixed and working capital. It was discovered that aluminum and copper represent different strengths from the economic perspective. Copper possesses superior properties in terms of conductivity and is best suited for situations where density, conductors' performance and conductivity is a critical factor. Aluminum allows to save money and weight.

Thus, it should be stated that no material is the best from the economic point of view. The final selection will depend on the technical characteristics, prices per commodities, the costs of production and selling, availability of investments in capital and working capital, etc.

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