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# How to Calculate Economic Evaluation in Industrial Chemical Plant Design: A Case Study of Gold Mining Using Amalgamation Method

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**ABSTRACT**

In the world of the chemical industry which continues to develop, factory design is the first step that determines the success of a project. However, to ensure that sustainability, efficiency and a positive impact on the economy can be achieved, economic evaluation is a critical aspect that must be considered carefully. Economic evaluation has a central role in the design stage of industrial chemical plants. However, until now, there is still no research that explains step by step how to calculate economic evaluations, especially in the field of industrial chemistry. Based on this, the aim of this article is to demonstrate how to calculate economic evaluations in chemical plant design. To provide a detailed understanding, we present a step-by-step example of calculating an economic evaluation of the design of a gold mining using amalgamation method. It is hoped that this article can have a significant impact by illustrating effective ways to optimize financial sustainability, make wise data-based decisions, and manage risk carefully in the design of industrial chemical plants through in-depth analysis using economic evaluation. Here, this article not only serves as an important basis for corporate decision-making, but also provides valuable guidance for the chemical industry in designing efficient and economically sustainable production facilities.



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## 1. INTRODUCTION

The chemical industry plays an important role in supporting global economic progress, providing essential raw materials for various sectors, from manufacturing to technology (Cannatelli & Ragauskas, 2017; Nagahata & Takeuchi, 2019). In an industrial era that continues to develop, chemical plant design is the starting point that determines the success of a project (Tugnoli *et al*., 2011). In addition, to face global challenges and demands for sustainability, designing industrial chemical plants is not just a form of engineering, but also a strategy that requires a solid economic foundation (Luo *et al*., 2022). However, amidst market dynamics and increasingly fierce competition, ensuring that the designed plant is not only technically efficient but also provides significant financial benefits is a challenge.

Economic evaluation in industrial chemistry includes an overall assessment of the investment, operational costs, and financial impact of the various decisions made to develop and operate a chemical production facility (Yadav *et al*., 2023). By understanding the economic application of each process step, we can form smarter strategies, optimize results, and reduce the risks associated with business decisions in the chemical industry (Hakeem *et al*., 2023). The benefits of economic evaluation are not limited to financial analysis alone but also include careful financial risk management. By understanding and mitigating risks, economic evaluations open opportunities to improve operational efficiencies, reduce efficiencies, and shape adaptive financial strategies (Fu *et al*., 2023). Another benefit of economic evaluation is that it provides guidance for intelligent resource allocation, ensuring that chemical plant projects can develop sustainably. Therefore, economic evaluation plays a key role in designing chemical plants.

Many reports regarding the successful economic evaluation of industrial chemical plant designs have been documented. The latest report on the economic evaluation of industrial chemical plant design is presented in **Table 1**. **Table 1** shows research that reports feasibility analysis such as capital required, sensitivity to prices of raw materials and worker salaries, taxes, and how much profit can be obtained. However, until now, there is only a little research that explains a step-by-step understanding of how economic evaluation procedures are in industrial chemical plants. Apart from that, students and researchers, especially in the fields of chemistry and industry, have difficulty finding relevant reading sources to explain economic evaluation in detail, even though this understanding is fundamental in learning in their field.

Therefore, the aim of this research is to demonstrate how to calculate economic evaluations in chemical plant design. Here, as an example, we present an economic evaluation of gold mining using the amalgamation method. Basically, the gold extraction process is by the amalgamation method using mercury. In the process, mercury is used to bind the gold from the ore as a stable amalgam. The amalgam is then heated until the mercury evaporates, and the mercury isolates the gold. Mercury is used in the mining process because it is easy to use, available, and cheap (Moody *et al*., 2020). In practice, mining gold using mercury only takes a short time. Therefore, this method is widely used in gold processing processes. Even so, it cannot be denied that gold extraction using mercury can cause a decrease in environmental quality due to land clearing for mining and disposal of tailings as residue from gold processing using certain chemicals, reducing health quality, low implementation of work safety and security, and causing social conflict. Based on this, we intend to carry out an economic analysis of gold mining using the amalgamation method. This can see the feasibility of gold mining from an economic perspective, which is the reason why gold extraction using the amalgamation method is widely used. Economic analysis was carried out using computational calculations. While various economic metrics, including profitability index,

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break-even point, payback period, cumulative net present value, internal rate of return, and gross profit margin are used to conduct technical feasibility analysis.

In this article, we will explore the importance of economic evaluation in an industrial context, highlighting the various methods and indicators used to measure the economic performance of a sector. Through the advantages of economic evaluation in industrial chemical plant design, this article is able to present a comprehensive and relevant view for readers, practitioners and stakeholders in the dynamic and changing world of the chemical industry.

**Table 1**. Previous research report on economic evaluation in the field of industrial chemistry.

| No | Materials | Product | Results | Ref |
|---|---|---|---|---|
| 1. | Rice husk, Bisphenol A-epichlorohydrin, and Aliphatic cyclo amine. | Resin-based brakepad with rice husk as reinforcement agent | The optimum and ideal circumstances for the manufacturing of brake pads were determined to be all characteristics that exhibited positive values, according to the economic factors in the economic evaluation. Nonetheless, the project's comparatively low IRR value makes it unappealing to investors. | Nandiyanto *et al.* (2021) |
| 2. | Titanyl nitrate, Glycine, and nitric acid. | $TiO_2$ Nanoparticles | Due to the process's ability to be executed with inexpensive equipment and already accessible technology, economic evaluation analysis offers information regarding the possibility of large-scale production. Also, this discovery offers a glimmer of hope for the prospect of producing $TiO_2$ in underdeveloped nations in order to boost earnings and draw in investors. | Ragadhita *et al.* (2019) |
| 3. | Rice husk, maize cobs, acid solution, and base solution. | Silica particles | According to a study of various agricultural wastes, rice husks are the best raw material with the highest demand, whereas maize cobs are the worst raw material. To validate the analysis, multiple economic conditions with varying raw material costs, utilities, labor, and sales costs, as well as taxes, were entered into the computation, and these conditions demonstrated a positive value for the production potential of silica particles. | Nandiyanto *et al.* (2020) |

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**Table 1 (Continue)**. Previous research report on economic evaluation in the field of industrial chemistry.

| No | Materials | Product | Results | Ref |
|---|---|---|---|---|
| 4. | Magnesium oxide, $NaHCO_3$, dan NaOH | Magnesium Oxide Nanoparticles | The findings of the investigation demonstrate that the precipitation approach can be used to produce magnesium oxide nanoparticles on an industrial scale. Furthermore, the Payback Period analysis demonstrates that the investment will be worthwhile after more than three years. | Febriani *et al*. (2020) |
| 5. | Chloroauric acid, sodium citrate, and sodium borohydride | Nano Gold | The economic analysis revealed that Nanogold manufacturing on an industrial scale can be economical under particular raw material conditions. This demonstrates that the break-even point, payback period, and gross profit margin can all be reached in less than 20 years. | Miftahurrahman *et al*. (2019) |
| 6. | Lanthanum (III), nickel (II) nitrate hexahydrate, glycine, distilled water, NaOH, $Na_2CO_3$ | $LaNi_5$ particles | Information from engineering study shows that potential CR and CPR projects can be completed with commercial machinery. The project is appropriate for large-scale production but appears less appealing to industrial investors, according to the economic study of GPM, PBP, BEP, CNPV, and PI, which produced good findings, but IRR and ROI produced negative results. | Nandiyanto *et al*. (2020) |
| 7. | $AlCl_3.6H_2O$, ammonium hydroxide solution, water, and ethanol | Al2O3 (Aluminum Oxide) Nanoparticles | The findings of this investigation demonstrated that the precipitation approach might be used in an industrial setting to produce Al2O3 nanoparticles. According to engineering theory, Al2O3 nanoparticles can provide an annual profit of $144.635,669 USD during a 20-year period. An economic assessment, based on projections of ideal and non-ideal conditions, such as tax increases, sales fluctuations, raw material prices, utility prices, and labor salaries, is conducted to make sure this project can be completed. | Kurniadianti *et al*. (2021) |

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**Table 1 (Continue)**. Previous research report on economic evaluation in the field of industrial chemistry.

| No | Materials | Product | Results | Ref |
|---|---|---|---|---|
| 8. | Sodium sulfide ($Na_2S$), zinc acetate dihydrate [$(CH3COO)_2Zn._2H_2O$], etanol and water | Zinc Sulfide Nanoparticles | The most effective method for creating zinc sulfide nanoparticles on an industrial scale, based on the economic analysis, is the ultrasonic precipitation-assisted approach. The return on investment expenses only lasts for two years, despite the fact that the earnings increase over a 20-year period. | Astuti *et al*. (2021) |
| 9. | Abultion indicumleaf extract, $Cu(NO_3)_2.3H_2O$, and distilled water. | Copper Oxide Nanoparticles | According to technical study, the total cost of production for producing 100 kg of CuO nanoparticles per day would be IDR 220,322,850.00, with a gross profit margin of IDR 16,721,250,000.00 year. The investment will turn a profit after more than three years, according to PBP study. This project's short return on investment makes it competitive by PBP capital market norms. | Putra *et al*. (2021) |
| 10. | Methyl palmitate, Methyl stearate, Methyl oleate, methyl linoleate, and Methyl linoleate | Edible Oil Waste | Economic analysis reveals that the manufacture of biodiesel from leftover vegetable oil is highly promising because the economic criteria examined yield good findings. Our results should offer a broad overview of the assessment and financial structure of industrial scale, particularly in the biodiesel production process. Biodiesel is typically utilized as a sustainable energy source to power vehicles such as trucks, trains, ships, and barges. | Nandiyanto *et al*. (2022) |

## 2. BASIC THEORY

### 2.1. Presentation of the Wastewater Treatment Plant

Economic evaluation in industrial chemistry is a systematic and holistic approach to assessing and analyzing the financial impact of decisions and projects related to production and operational activities in the chemical industry (Bunchner *et al*., 2018). In principle, this economic evaluation is an integral part of company management and operations, as well as utility arrangements which are used to analyze alternative uses of resources, physical assets,

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equipment used and the operations of a company. Then, these evaluations are compared and calculated to get the best choice economically (Justo & Moraes, 2010). In general, the economic evaluation designed for a factory is aimed at finding out whether the factory being designed meets the feasibility test or not to be established. Economic evaluation also determines whether the decision to invest in a project is appropriate from the point of view of economic benefits (Pouransari *et al*., 2014).

### 2.2. Economic Evaluation Parameters

The feasibility of a factory can be estimated and analyzed through economic evaluation calculations which are divided into three categories, namely basic economic evaluation parameters, production costs, and financial estimation factors (Nandiyanto, 2018). The explanation of each economic evaluation parameter is as follows:

#### 2.2.1. Basic parameters of economic evaluation

There are several basic economic evaluation parameters including raw materials, labor, and utilities. Below is a detailed explanation:

#### 2.2.1.1. Raw materials

Raw materials are the main components needed in the production process. These raw materials will be converted into final products that have sales value or generate profits. Therefore, prices and availability of raw materials need to be estimated. In projects dealing with chemicals, the raw materials approach should be based on stoichiometric calculations. One example of a stoichiometric calculation is a mass balance.

#### 2.2.1.1.1. Mass balance

When carrying out an economic analysis, the first thing that must be done is to carry out a mass balance calculation. The mass balance is a calculation of all materials that enter, accumulate, and leave within a certain time. This statement is by the law of conservation of mass, namely that mass cannot be destroyed or created. Here, as an example presented, mass balance in the context of silica manufacturing involves calculating the amount of material entering and leaving the production system or process. To perform detailed mass balance calculations, we need to know the main chemical reactions involved in making silica. Suppose we have a process for making silica from silicon dioxide ($SiO_2$). Here is the main reaction Eq. (1).

$$SiO2 + 2C \rightarrow Si + 2CO \quad (1)$$

In Eq. (1), $SiO_2$ (silicon dioxide) reacts with C (carbon) to produce Si (silicon) and CO (carbon monoxide). For example, we have 1 kg of silicon dioxide and 50 g of carbon. By using the stoichiometric coefficient from the reaction equation, we could calculate the amount of Si produced and the amount of carbon monoxide released. The steps for calculating the mass balance for making silica are as follows:

**(i) Step 1: Determine the stoichiometric coefficient**

From the reaction equation, it is known that 1 mol $2SiO_2$ reacts with 2 mol C. This means that the mole ratio of $2SiO_2$ to C is 1:2.

**(ii) Step 2: Convert to mol**

Convert the amount of ingredients to moles by dividing the mass of each by its molar mass

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- Mol $SiO_2$ = $\frac{10\ kg}{Massa\ molar\ SiO2}$
  = $\frac{1000\ g}{60{,}08\ g/mol}$ = 16,67 mol
- Mol C = $\frac{50\ g}{Massa\ molar\ C}$
  = $\frac{50\ g}{12\ g/mol}$ = 4.16 mol

**(iii) Step 3: Determining the number of moles reacting**

*SiO2 + 2C → Si + 2CO*

- Mol Si = $\frac{1}{1}$ × Mol $SiO_2$
  = $\frac{1}{1}$ = 16.67 mol
- Mol C = $\frac{2}{2}$ × Mol $CO_2$
  = 4.16 mol

**(iv) Step 4: Convert back to mass**

- Massa Si = Mol Si × Massa molar Si
  = 16.67 mol × 28 g/mol
  = 466.76 gram
- Massa C = Mol C × Massa molar C
  = 4.16 mol × 28 g/mol
  =116.48 gram

Based on mass balance calculations, it is found that the masses of Si and C are 466.79 and 116.48 gram, respectively.

#### 2.2.1.2. Sale

Sales are activities or actions related to the product sales process. Sales must be optimized with competitors' prices, product distribution demand, handling and packaging methods and advertising costs.

#### 2.2.1.3. Utility

Utilities are support systems to support projects. Utilities include water, electricity, heating and boiler system supplies, shelter, and so on. Utility estimates are often complicated depending on inflation and energy costs.

#### 2.2.1.4. Labor costs

Labor is an indicator that measures the level of relationship between wage productivity and work output minus inflation. This indicator is related to the weight of working funds that need to be used to run the project. Indeed, the increase in hourly wages is correlated with the increase in labor costs. If the workforce depends on technology, more technology will be used which will have an impact on reducing labor costs.

#### 2.2.1.5. Fabrication Costs

Manufacturing costs are costs related to production process costs, including raw materials, extensive loans, costs related to fine art work, depreciation, costs related to sales and maintenance, production costs can change but can be predicted from the start of the project, production cost estimation. In general, the major factors that can influence the amount of expenditure are as follows (Nandiyanto *et al*., 2019a):

**2.2.1.5.1. Operation time and speed of production capacity**

This factor has a direct influence on manufacturing costs. The longer the process operates, the greater the gross production costs that must be incurred. This is due to its relationship with labor costs, maintenance and depreciation. Therefore, a factory must optimize its time to achieve maximum production capacity from an economic perspective but with short operational time.

**2.2.1.5.2. Policy**

Policies can influence the size of a company, especially those related to exports, imports, taxation, credit, and so on. These policies include: (i) reducing costs (savings), (ii) work contracts with other companies, for example purchasing raw materials, sharing profits and sales, (iii) relations with labor organizations, for example demands for wage increases.

**2.2.1.5.3. Equipment factory**

The factory equipment used can affect manufacturing costs, especially those related to efficiency. Therefore, to avoid large costs, the equipment used must comply with standards. If the process uses used goods, the equipment must still be in good condition for use.

**2.2.2. Production cost**

A few indicators of production costs are fixed costs, variable costs, depreciation, total purchasement costs, total investment costs, cash flow, and discount factors. Following is the complete explanation:

**2.2.2.1. Fixed cost**

Fixed costs are the costs required to build the project. Fees are relatively stable and decided early in the process. Fixed costs include debt costs, taxes, and fixed maintenance costs.

**2.2.2.2. Variable cost**

Variable costs are the costs required to maintain processes in the factory. These costs can change, depending on the market, product demand, and domestic economic conditions. Variable costs include raw materials, utilities, labor, and sales costs.

**2.2.2.3. Depreciation**

Depreciation is an action prepared to maintain production maintenance. This depreciation expense aims to purchase new assets or replace old assets that are no longer productive. To achieve depreciation, profit funds are set aside. As a result, in the calculation process, a certain amount of depreciation funds is charged to production costs. Many methods are available to predict depreciation. However, the common method is direct calculation using the following Eq. (1):

$$d = \frac{(ac - sv)}{t} \quad (2)$$

where *d*, *ac*, *sv*, and *t* are depreciation costs, acquisition costs, salvage value, and asset life, respectively. To complete the calculation, depreciation costs are calculated annually.

#### 2.2.2.4. Total purchasement cost

Total purchasement cost (TPC) is the cost to estimate the equipment needed for the process to run. This TPC only estimates the price of the equipment without taking into account other costs.

#### 2.2.2.5. Total investment cost

Total investment costs (TIC) or total investment costs are capital for initial costs that must be provided at the start of production. This TIC cost is calculated based on total factory costs. In simple terms, TIC is the cost of building a factory and initial costs, namely the costs of maintenance and services related to equipment for factory installation. Therefore, the TIC value will be greater than TPC (Kazi *et al*., 2010).

This TIC estimate usually uses Lang Factor, in principle the process must be prepared in at least two steps, where the first step is around 40% in the first year and the second step is the remainder during the project construction process (See **Table 2**).

**Table 2.** Lang Factor to estimate total investment costs (Kazi *et al*., 2010).

| Component | Factor |
|---|---|
| **Total Plant cost (Equipment)** | |
| Purchased Equipment | 1.00 |
| Pipping | 0.50 |
| Electrical | 0.10 |
| Instrumentation | 0.20 |
| Utilities | 0.50 |
| Foundations | 0.10 |
| Insulations | 0.06 |
| Painting, fireproofing, safety | 0.05 |
| Yard Improvement | 0.08 |
| Environmental | 0.20 |
| Building | 0.08 |
| Land | 0.50 |
| **Total cost (Management services)** | |
| Construction engineering | 0.60 |
| Contractors fee | 0.30 |
| Contingency | 0.20 |
| **Starting-up fee** | |
| Off-site Facilities | 0.20 |
| Plant start-up | 0.07 |
| Working capital | 0.20 |

#### 2.2.2.6. Cash flow (CF)

Cash flow is a financial report that contains the financial impact of project operations, financial transactions and financial transaction activities in one period. CF informs whether the project is profitable (if CF is positive) or not (if CF is negative). The CF value can be obtained by subtracting “profit after tax” from “depreciation”.

#### 2.2.2.7. Discount factors

The discount factor rate (*i*) is the interest rate charged on cash flows to determine the present value of future cash flows. **Table 3** shows the discount factors for estimating

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production costs. The value *i* is defined as a number less than one and can be estimated using Eq. (3) as follows:

$$i = (1 + r)^{-n} \quad (3)$$

where, *r* and *n* are the discount factor and processing time respectively. To attract investors, the *r* value must be higher than the average interest rate of commercial banks.

**Table 3.** Discount factor for estimating production costs.

| Component | Factor | |
|---|---|---|
| **Raw Materials** | | |
| **Utilities** | | |
| **Loan Interest** | | |
| **Labor-related cost** | | |
| Payroll overhead | 30% | Of labor |
| Supervisory, misc, labor | 25% | Of labor |
| Laboratory charges | 12% | Of labor |
| **Capital-related cost** | | |
| Maintenance | 6% | Of plant cost |
| Operating supplies | 1.75% | Of plant cost |
| Environmental | 2.25% | Of plant cost |
| Local taxes, insurance | 4% | Of plant cost |
| Plant overhead cost | 3% | Of plant cost |
| Depreciation | 0.20% | Of plant cost |
| **Sales related cost** | | |
| Packaging | 1% | Of sales |
| Administration | 2% | Of sales |
| Distribution and Marketing | 2% | Of sales |
| Research and Development | 1% | Of sales |
| Patents and Royalties | 1% | Of sales |

### 2.2.3. Financial estimation factors

Several economic evaluation parameters are explained to inform material production potential, including gross profit margin, internal rate of return (IRR), payback period (PBP), net present value, and profitability index (PI). To ensure project feasibility, a project is estimated from ideal to worst-case conditions in terms of production, including labor, sales, raw materials, utilities, as well as external conditions (i.e. taxes and government policies). To support the evaluation analysis several important economic parameters must be considered including, capital costs, production costs, selling prices, and utilities. This parameter has a direct impact on project termination during the production process (Nandiyanto & Ragadhita, 2019b).

#### 2.2.3.1. Gross profit margin

Gross Profit Margin (GPM) is the first analysis to determine the level of profitability of a project. This analysis is estimated by subtracting the cost of products sold (revenue) from the cost of raw materials. GPM is also used to measure the efficiency with which a company uses materials and labor to produce and sell products to make a profit. Although, GPM value indicates the success rate of a chemical process, GPM cannot be used directly because the project involves other basic economic evaluation parameters and product costs. The formula for finding GPM can be seen in Eq. (4) and is as follows (Nandiyanto & Ragadhita, 2019b):

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GPM = Sales revenue – Production price (Raw materials) (4)

#### 2.2.3.2 Break-even point

Breakeven point (BEP) is the minimum number of products that must be sold at a certain price to cover total production costs. In short, BEP is an important factor to avoid the project experiencing losses. BEP states that the minimum capacity at which the factory does not make a profit has the same value as production costs. To calculate the BEP value, Eq. (5) is used as follows (Nandiyanto & Ragadhita, 2019b):

$$\text{BEP} = \frac{Total\ fixed\ cost}{sales - total\ variable\ cost} \times \text{total production for a year} \quad (5)$$

#### 2.2.3.3. Average rate of return

Average Rate of Return (ARR) is the total inflow over the investment period divided by the number of years in the investment's life. This value is important for predicting project conditions. If the ARR value is higher than the discount rate (average interest rate at commercial banks), this project is healthy and profitable. Although ARR can predict the health of a project, it does not guarantee that the cash inflow will be the same in a particular year. ARR can be estimated using Eq. (6), which is as follows:

$$\text{ARR} = \frac{Pax}{TIC} \quad (6)$$

#### 2.2.3.4. Net present value

Net present value (NPV) is the value obtained from a project that states expenses and income. The NPV calculation must consider the opportunity cost of social capital (as discount rate *i*). On the other hand, NPV can also be used to estimate expected future financial flows. To calculate NPV, several data are required, including TIC, operating costs, maintenance costs, and expected benefits (estimated in the proposed project and depending on the current discount rate). NPV is estimated using Eq. (7):

$$\text{NPV} = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t} - \ C_0 \quad (7)$$

#### 2.2.3.5. Cumulative net present value

Cumulative net present value (CNPV) is a calculation of the total NPV value, from the start of factory construction to the end of factory operations. CNPV can be obtained as the sum of cumulative financial flows each year. In addition, CNPV also calculates depreciation and salvage value (final depreciation value).

#### 2.2.3.6. Internal rate of return

Internal rate of return (IRR) is a method for estimating investments from interest rates (equating the present value of the investment), the CNPV value in the present and the CNPV value in the future. In short, when the interest rate or discount rate is set in the IRR value, the CNPV will be zero.

#### 2.2.3.7. Profitability index

Profitability index is a method used to identify the relationship between project costs and impacts. There are two types of PI. One of them is PI which is related to the profit-to-sales ratio. If PI is less than 1, the project is unprofitable. On the other hand, where PI is more than 1 it can be classified as a good project.

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#### 2.2.3.8. Payback period

Payback period, known as return of funds, is a calculation carried out to predict the length of time it will take for an investment to return the total initial expenditure. In short, PBP is calculated based on when CNPV reaches zero for the first time.

#### 2.2.3.9 Return on Investment

ROI (Return on Investment) in economic evaluation refers to a performance measure used to assess the extent to which an investment or business decision provides positive financial results. ROI is calculated by comparing the net profit obtained from an investment with the initial investment cost. Eq. (8) to calculate ROI is as follows:

$$\text{ROI} = \frac{profit}{TIC} \times 100 \quad (8)$$

### 2.3. Gold Mining

Mining is the activity of extracting mineral or metal resources from within the earth. This process involves finding locations with valuable mineral deposits, such as gold, coal, or other metals. Gold mining is the activity of extracting and processing gold from gold deposits or deposits. This process begins with the exploration stage to find locations with a high-potential gold content (Spiegel & Veiga, 2018). After the discovery of a gold deposit, gold mining is carried out which can be carried out using open-pit mining or underground mining methods, depending on the geological and economic characteristics of the deposit. Gold mining involves complex steps to extract and separate gold from rocks and other minerals (Zolnikov & Ortiz, 2018). In open-pit mining, soil containing gold is excavated and transported to the surface for further processing. On the other hand, underground mining involves channels or tunnels that access loose layers of gold located underground. After extracting the gold, a delivery process is carried out which includes transcription, synchronization, and flotation stages to separate the gold from other materials. The next process involves melting to form a gold mixture and then refining it to increase the purity of the gold (Yoshimura *et al*., 2021).

### 2.4 Gold Extraction Uses the Amalgamation Method

The type of gold mining that usually uses conventional technology is by amalgamation. Amalgamation is the most commonly used gold extraction method. Gold extraction process using the amalgamation method by mixing gold ore with mercury (Hg) or known as quicksilver (Nandiyanto *et al*., 2023).

This process involves mercury releasing gold which then forms amalgam, a compound of mercury and gold. The amalgam is then heated to evaporate the mercury, leaving behind pure gold. **Figure 1** shows the gold extraction process using the amalgamation method. To ensure the processing steps, the process flow diagram is also presented in **Figure 2**.

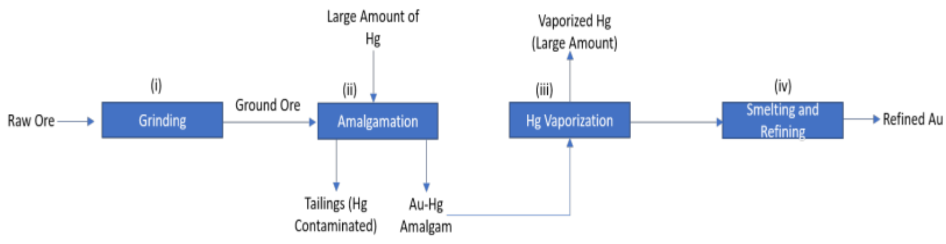


**Figure 1**. Gold extraction process using the amalgamation method adopted from Nandiyanto *et al*. (2023).

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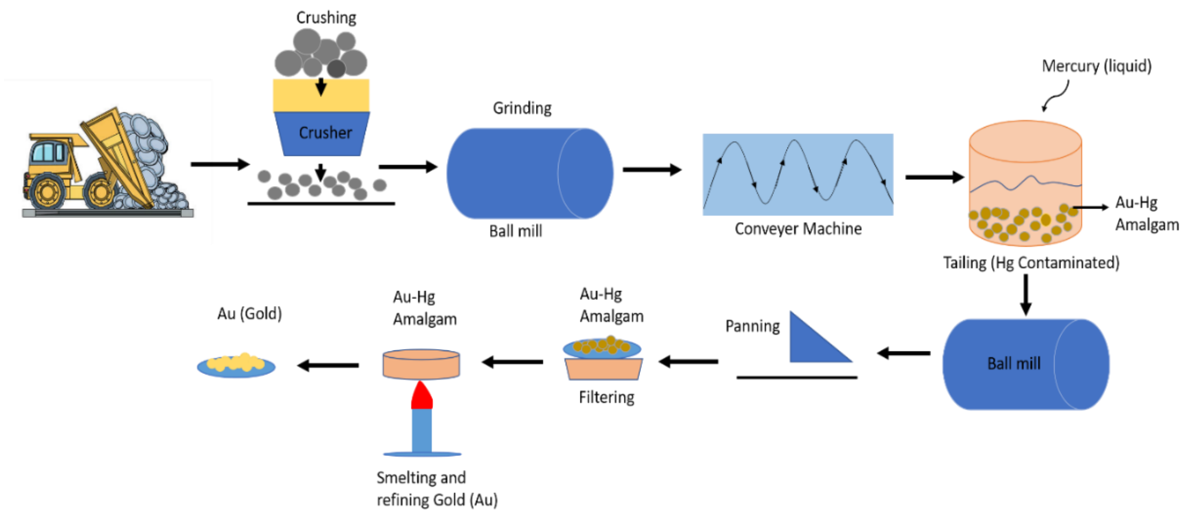


**Figure 2.** Process flow diagram to produce gold using amalgamation method.

The detailed explanation regarding gold extraction using the amalgamation method is as follows (Nandiyanto *et al*., 2023; Esdaile & Chalker, 2018):

(i) Rock crushing and grinding process. Natural rock extracted from mining holes, known as ore, is processed by grounding or crushing to produce smaller ore.

(ii) Mixing process with mercury. Ground ore that has been ground is mixed with mercury. Mercury forms compounds with gold, forming gold-mercury amalgam. This process is usually carried out in an amalgamation vat or other location. This amalgamation process aims to bind the gold.

(iii) Amalgam separation process. Once produced, the gold-mercury amalgam. Steps to separate amalgam from ore that does not contain gold. This can be done by a sieve process or gravity separation.

(iv) Smelting and refining of mercury. To remove gold metal from mercury, an evaporation process is carried out through combustion. Burning is usually carried out in an open process. Thus, the mercury that is still bound to the amalgam will evaporate into the air.

## 3. METHOD

In this article, an economic evaluation was carried out using a method based on an analysis of equipment prices, and the prices of specific equipment commercially available on online shopping sites. All price data was calculated using Microsoft Excel software to determine several economic evaluation parameter values used, namely CNPV, GPM, PBP, BEP, BEC, IRR, and PI. Then, various conditions are tested during the feasibility evaluation, including changes or sensitivity of raw materials.

## 4. RESULT AND DISCUSSION

### 4.1 Step 1: Plant Start Up to Establish Gold Mining using the Amalgamation Method

The initial step taken in carrying out an economic evaluation is a plant start up to establish a gold mine using the amalgamation method. Here, we calculate how much capital is used to run the entire equipment the first time. The capital used is its capital amounting to ±40,000 USD.

### 4.2. Step 2: Determining the Capacity and Duration of Production in Gold Mining using the Amalgamation Method

After estimating the capital that will be used, the second step is determining the capacity and duration of production. The length of the gold mining cycle process takes 8 hours, based on the literature from Hutchings and Kiely (2023). The number of workers required is 10 workers. Production is carried out in a year for 264 days in 7920 hours. Several steps must be taken:

(i) The initial step is determining production capacity. Previously, mass balance calculations were carried out. Based on the literature, 15 kg of stone contains 0.5 g of gold (Hutchings & Kiely, 2013). One process cycle takes 8 hours to produce 0.5 g of gold. The target production capacity for a day is 5 g, assuming 10 process cycles. Thus, in a year the amount of gold produced is 5 × 264 = 1320 g of gold in a year

(ii) After determining production capacity, determine the amount of mercury required. Based on the literature, the amount of mercury needed to produce 0.5 grams of gold requires 500 g of mercury for one process cycle. If calculated for 1 day for 10 process cycles required is 500 g × 10 = 5000 g = 5 kg. Thus, in a year the amount of mercury needed is 5kg × 264 = 1320 kg of mercury in a year.

(iii) After that, determine the duration of production. Here, the project plan is carried out for 20 years. This is done to see how easy it is to analyze project feasibility.

### 4.3. Step 3: Analyze the Equipment and Raw Materials Needed for Gold Mining using the Amalgamation Method

After determining the capacity and duration of production, the third step is to analyze the tools and materials needed for gold mining using the amalgamation method. All prices for tools and materials are obtained from online shopping sites. The description of the steps for analyzing the prices of tools and materials in gold mining using the amalgamation method is as follows:

(i) The first step is to determine the equipment and raw materials needed for gold mining using the amalgamation method. The tools needed include a ball mill, gold scales, hoe, shovel, hammer, large plastic tub measuring 71 cm, stone scales, toren tank, cloth, small basin, gold melting equipment and a practical gas stove. Meanwhile, the materials used are rock and mercury. After that, the tools and materials that have been determined are listed and recorded in Microsoft Excel as presented in **Tables 4** and **5**.

(ii) The next step is to determine the number of equipments and raw materials used. Here, the amount of material required is based on a mass balance calculation for production for a year. The amount of raw material used is based on determining production capacity and mass balance calculations. Then, the number of equipment and raw materials is listed and recorded in Microsoft Excel (as presented in **Tables 4** and **5**).

(iii) After that, the final step is to enter the prices of equipment and raw materials from online shopping sites into Microsoft Excel (See Tables 4 and 5). The online shopping site we use is Tokopedia: https://www.tokopedia.com/. Here, all prices for tools and materials are in USD. For the price of mercury, we calculated the price assuming mercury purchases during 1 year of production. Meanwhile, the price of rocks is 0.00 USD because natural resources are obtained. In searching for prices for equipments and raw materials on the Tokopedia online shopping site, there are several stages, namely, first open the link https://www.tokopedia.com/, then type the equipment and raw materials you are looking for in the search field. After finding all the prices of equipment and raw

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materials, they were converted into USD = 14,425 IDR and then recorded in Microsoft Excel as presented in **Tables 4** and **5**.

**Table 4.** Analysis of the price of equipment needed for gold mining using the amalgamation method.

| No | Item | Price (USD) | Unit/s | Total price (USD) |
|---|---|---|---|---|
| 1 | Ball Mill | 554.59 | 1 | 554.59 |
| 2 | Gold scales | 2.08 | 2 | 4.15 |
| 3 | Hoe | 2.77 | 3 | 8.31 |
| 4 | Shovel | 4.16 | 3 | 12.47 |
| 5 | Hammer | 3.47 | 3 | 10.39 |
| 6 | Large plastic tub Size 71 cm | 1.73 | 1 | 1.733 |
| 7 | Stone scales | 69.32 | 1 | 69.32 |
| 8 | Toren Tank | 27.73 | 1 | 27.73 |
| 9 | Cloth | 0.35 | 3 | 1.04 |
| 10 | Small basin for sifting for gold panning | 0.35 | 3 | 1.04 |
| 11 | Gold melting equipment | 0.35 | 3 | 1.04 |
| 12 | Practical Gas Burner (Cyclone Nozzle) | 1.39 | 3 | 4.16 |
| **Total** | | | | 696.01 |

**Table 5.** Analysis of the price of raw materials needed for gold mining using the amalgamation method.

| No | Item | Unit/kg (1 day) | Price (USD) | Price (USD)/ Year |
|---|---|---|---|---|
| 1 | Rock | 15 | 0.00 | 0.0000 |
| 2 | Mercury | 5 | 31.20 | 8,236.80 |
| **Total** | | | | 8,236.80 |

### 4.4. Step 4: Analyzing the Utilities Required by the Gold Mining Process using the Amalgamation Method

At this stage, an analysis of the many utilities used is carried out. Here the utilities used are a ball mill and a water supply unit. Below are several things that must be done in determining the utility of the gold mining process using the amalgamation method, namely:

(i) In the gold extraction process using the amalgamation method, a ball mill, and water are needed, the working time for both equipments takes 2 hours each.

(ii) Then, look at the equipment specifics for the power of the ball mill and the water supply unit. To see the specific power for ball mill and water power units, we look for the power specifications of the equipments in the online shop Tokopedia. We then entered and recorded the data into Microsoft Excel software as presented in **Table 6**.

(iii) After that, we looked for prices for electricity generation services (PLN) in Indonesia. Based on electricity generation services (PLN) in Indonesia, it is known that the price per kWH is 1,444.70 IDR. Then the price in rupiah is converted into USD. Where 1 USD = 14,425 IDR. Details of utility prices are shown in **Table 6**.

**Table 6.** Utility costs per year of gold production.

| No | Item | kWh | Hours | Unit/s | Cost (USD) /kWh | Cost (USD) /day | Cost (USD)/ Year |
|---|---|---|---|---|---|---|---|
| 1 | Ball mill | 37 | 2 | 1 | 0.10 | 3.70 | 978.28 |
| 2 | Water supply unit | 0.5 | 2 | 1 | 0.10 | 0.05 | 5.95 |
| | **Total** | | | | | 3.75 | 984.24 |

### 4.5. Step 5: Calculating Total Production Costs (TPC) Costs for Gold Mining using the Amalgamation Method

After the fourth step, analyzing the tools and materials needed, then calculating the estimated total production cost (TPC). Total production costs are all costs used during project operation. The total product cost consists of total manufacturing cost (TMC) and total investment cost (TIC). In detail, the steps to calculate total production costs (TPC) are as follows:

(i) The first step is to calculate the total investment cost (TIC). Here, calculate total investment costs using the Lang factor which is presented in **Table 2**. All total investment cost calculations are carried out using Microsoft Excel software as presented in Table 7. Lang factor is a simple technique for estimating investment costs for establishing a new project. This method is usually used for order-of-magnitude cost estimates. Fixed cost investment or total investment costs are calculated by multiplying the total costs required to purchase all major equipment by a factor. In calculating the total investment cost, it is used by converting IDR into USD, where 1 USD = 14,425 IDR. To calculate the total investment cost (TMC), it consists of equipment, management service, and starting-up free. A detailed explanation regarding the total investment cost (TIC) of equipment is as follows:

(a) Purchased equipment is the cost required to purchase equipment. For Lang Factor, it is 1. Based on the calculation results in **Table 4**, it is known that the costs required to purchase equipment are 696.01 USD.

(b) Piping is a piping system that carries fluid to several pieces of equipment. For Lang factor piping is 0.5. The formula for calculating piping is 0.5 × harga purchased equipment. Thus, the cost of piping items is 0.5 × 696.01 USD = 348.01 USD.

(c) Electrical is a system that uses electricity. For Lang factor electrical is 0.1. The formula for calculating electricity is 0.1 × purchased equipment. Thus, the cost of electrical items is 0.1 × 696.01 USD = 69.60 USD.

(d) Instrumentation is a tool used in measuring and controlling (control) process variables. For Lang factor instrumentation it is 0.2. The formula for calculating instrumentation is 0.2 × purchased equipment. Thus, the instrumentation cost 0.2× 696.01 USD = 139.20 USD.

(e) Utilities are systems used to support projects. For Lang Factor the utility is 0.5. The formula for calculating utilities is 0.5 × purchased equipment. Thus, the cost of the utilities item is 0.5 × 696.01 USD = 348.01 USD.

(f) Foundation is a fee to empower projects that are being run. For Lang Factor foundation it is 0.1. The formula for calculating the foundation is 0.1 × purchased equipment. Thus, the cost of the foundation item is .1 × 696.01 USD = 09.60 USD.

(g) Insulations are costs used for installation systems in the production process. Lang factor for insulation is 0.06. The formula for calculating insulation is 0.06 ×

purchased equipment. Thus, the cost of the foundation item is 0.06 × 696.01 USD = 41.76 USD.

(h) Painting, fireproofing, safety are systems of security anticipation tools used during the production process. Lang factor for painting, fireproofing, safety is 0.05. The formula for calculating painting, fireproofing, safety 0.05 × purchased equipment. Thus, the cost of the item painting, fireproofing, safety is 0.05 × 696.01 USD = 34.80 USD.

(i) Yard Improvement is the cost of improving land conditions and building roads in the factory area. Lang factor for yard improvement is 0.08. The formula for calculating yard improvement is 0.08 × purchased equipment. Thus, the cost of yard improvement is 0.08 × 696.01 USD = 55.58 USD.

(j) Environmental is the cost of maintaining environmental sustainability in the factory area and its surroundings. Lang factor for environmental is 0.2. The formula for calculating environmental is 0.2 × purchased equipment. Thus, environmental costs are 0.2 × 696.01 USD = 139.20 USD.

(k) Building is the material needed to construct buildings within the factory environment. Lang factor for building is 0.08. The formula for calculating Building is 0.08 × purchased equipment. Thus, the Building cost is 0.08 × 696.01 USD = 55.68 USD.

(l) Land is the cost of establishing land and building roads in the factory area. To calculate the Land formula it is 0.5. The formula for calculating environmental is adalah 0.08 × purchased equipment. Thus, the Building cost is 0.5 × 696.01 USD = 348.01 USD.

(m) All cost items for the total equipment cost investment are added up, resulting in a cost of 2,345.57 USD.

(ii) Next calculate the total production expenditure for management services. The following are detailed steps for calculating total production expenditure for management services, as follows:

(a) Constructions, engineering are costs used to pay for the construction of factory builders. Lang factor for constructions, engineering is 0.6. The formula for calculating construction, engineering is 0.6 × 696.01 USD = 417.61 USD

(b) Contractors fees are costs used to pay factory construction contractors. Lang factor for contractors is 0.3. The formula for calculating contractor fees is 0.3. The formula for calculating the contractor fee is 0.3 × purchased equipment. Thus, the contractor's fee is 0.3 × 696.01 USD = 208.80 USD.

(c) Contingency is the cost of accounting for environmental goods and services. Lang factor for contractors is 0.2. The formula for calculating contractor fees is 0.3. The formula for calculating the contractor fee is 0.2 × purchased equipment. Thus, the contractor's fee is 0.2 × 696.01 USD = 139.20 USD.

(d) All cost items for the total cost management services investment are added up, resulting in a cost of 765.62 USD.

(iii) After that, add up the total investment costs for equipment and management services. The total investment cost of equipment and management service is 3,111.18 USD. Here, the result of the total investment cost of equipment and management service is the total purchasement cost.

(iv) Then after that, to calculate the purchasement cost value. The formula calculates the purchasement cost value by subtracting the total purchasement cost - land. Thus the TPC value is 765.62 – 384.01 USD = 417.61 USD.

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(v) Next, calculate the total investment cost based on the starting-up fee. The details of the items in the total investment cost starting-up fee calculation are as follows:
  (a) Off-site facilities are the costs of facilities or areas located outside the main location of a project or installation. Lang factor for off-site facilities is 0.2. The formula for calculating off-site facilities is 0.2 × purchased equipment. Thus, off-site facilities are 0.2 × 696.01 USD = 139.20 USD.
  (b) Plant start-up is a cost that must be incurred when the factory starts operating or has started up. Lang factor for plant start-up is 0.07. The formula for calculating plant start-up is 0.07 × purchased equipment. Thus, plant start up is 0.07 × 696.01 USD = 48.72 USD.
  (c) Work capital is the costs required to carry out operations of a factory during a certain period of time normally. Lang factor for working capital is 0.2. The formula for calculating piping is 0.2 × purchased equipment. Thus, working capital is 0.2 × 696.01 USD = 48.72 USD.
  (d) All costs for the cost starting up-fee investment are added up to obtain a cost of 327.13 USD.
  (e) Next, the TIC is calculated using the formula, namely Total Production Cost (TPC) + starting up-fee. From the calculation results, the TIC value is 417.61 USD + 327.13 USD = 744.73 USD.

**Table 7.** Lang Factor to estimate total investment costs gold mining using the amalgamation method.

| Component | Factor | Price (USD) |
|---|---|---|
| **Total Plant cost (Equipment)** | | |
| Purchased Equipment | 1.00 | 696.01 |
| Pipping | 0.50 | 348.01 |
| Electrical | 0.10 | 69.60 |
| Instrumentation | 0.20 | 139.20 |
| Utilities | 0.50 | 348.01 |
| Foundations | 0.10 | 69.60 |
| Insulations | 0.06 | 41.76 |
| Painting, fireproofing, safety | 0.05 | 34.80 |
| Yard Improvement | 0.08 | 55.68 |
| Environmental | 0.20 | 139.20 |
| Building | 0.08 | 55.68 |
| Land | 0.50 | 348.01 |
| **Total cost (Management services)** | | 2,345.47 |
| Construction engineering | 0.60 | 417.61 |
| Contractors fee | 0.30 | 208.80 |
| Contingency | 0.20 | 139.20 |
| **Subtotal 2** | | 765.62 |
| **Total PC (=Equipment + management service)** | | 3,111.18 |
| **TPC (= Total PC – Land)** | | 417.61 |
| **Starting-up fee** | | |
| Off-site Facilities | 0.20 | 139.20 |
| Plant start-up | 0.07 | 48.72 |
| Working capital | 0.20 | 139.20 |
| **Subtotal 3** | | 327.13 |
| **TIC (=TPC + Starting up fee)** | | 744.73 |
| **TIC = (TPC-Land)** | | 396.73 |

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(iv) After calculating the total investment costs. Next is to calculate the total production costs. To calculate total production costs, use the total Lang factors presented in **Table 3**. **Table 8** shows the results of calculating total production costs using Microsoft Excel software. All costs for calculating total production costs are calculated by converting IDR to USD, where 1 USD = 14,425 IDR. Total production costs for gold mining using the amalgamation method consist of several cost items consisting of:

(a) raw materials are costs incurred to manufacture a production item. Based on the calculation results in **Table 5**, it is known that the price of raw materials for a year costs 8,236.80 USD.

(b) utilities are systems that support the project. Based on the calculation results in **Table 6**, it is known that the price of utilities for a year costs 984.24 USD.

(c) loan interest is the total cost of a loan and plays an important role in a borrower's decision to apply for or receive a loan. Here, we do not use production funds from loans.

(d) operating labor is the cost of workers or labor involved in the daily operations of a company, facility or project. In this study, the number of workers was 10 people. A worker's wages per day is 79,914.50 IDR and then converted into USD where, 1 USD = 14,425 IDR. Thus, the worker's wages in a day is 5.54 USD. Here, because there are 10 workers, the total wages paid for one day is 55.40 USD. Thus, the worker's wages that must be paid for a year is 14,625.60 USD.

(e) Labor-related costs consist of several overhead items such as salaries, supervisors, and laboratory costs. Meanwhile, the factors for calculating overhead salaries, supervisors, and laboratory costs are 30%, 25%, and 12% respectively. To calculate labor overhead wages, use the formula, namely 30% × the wages of 10 workers in a year. Thus, the worker's salary is 30% ×14,625.60 USD = 4,387.68 USD. Wages for supervisors are calculated using the formula, namely 25% ×the wages of 10 workers in a year. Thus, the supervisor's wages are 25% × 14,625.60 USD = 3,656.40 USD. Meanwhile, to calculate laboratory costs, use the formula, namely 12% × the wages of 10 workers per year. Thus, the worker's salary is 12% ×14,625.60 USD = 1,755.07 USD.

(f) Capital-related costs consist of several items, namely maintenance costs, operating supplies, environmental, depreciation, local taxes, insurance, and plant overhead costs. The factors for calculating maintenance, operating supplies, environmental, depreciation, local taxes, insurance, and plant overhead costs are 6%, 1.75%, 2.25%, 5%, 4%, and 3% respectively. To calculate maintenance, use the formula, namely 6% × TIC. Thus, maintenance is 6% × 396,730 USD = 23.80 USD. Operating supplies costs are calculated using the formula, namely 1.75% × TIC. Thus, operating supplies are 1.75% × 396,730 USD = 6.94 USD. Environmental costs are calculated using the formula, namely 2.25% × TIC. Thus, environmental costs are 2.25% × 396,730 USD = 8.93 USD. For depreciation costs, use the formula, namely 5% × TIC. Thus, environmental costs are 5% × 396,730 USD = 19.84 USD. Local taxes and insurance costs use the formula 4% × TIC. Thus, the cost of local taxes, insurance is 4% × 396,730 USD = 15.87 USD. And finally, to calculate Plant overhead costs, use the formula 3% × TIC. Thus, plant overhead costs are 3% × 396,730 USD = 11.90 USD.

(g) Sales related costs consist of several cost items, namely packaging, administration, distribution and marketing, research and development, and patents and royalties. The factors for calculating packaging, administration, distribution and marketing, research and development, and patents and royalties are 1%, 2%, 2%, 1%, and 1%.

First, we determine the selling price of gold. The price of 1 gram of gold is sold for 950,000 IDR converted into USD to 65.86 USD. The gold sales target in a day is 5 g. Thus, daily gold sales amounted to 329.29 USD. In a year it is estimated that the amount of gold sold is 1320 g. Thus, gold sales in a year amounted to 86,935.20 USD. The results of the gold sales calculation will be used in calculating sales related costs. To calculate packaging costs, use the formula 1% × gold sales in a year. However, because this research does not require packaging, the cost is 0.00 USD. Administrative costs are calculated using the formula, namely 2% × of gold sales in a year. Thus, the administration fee is 2% ×86,935.20 USD = 1,738.70 USD. Distribution and marketing costs are calculated using the formula, namely 2% ×of gold sales in a year. Thus, distribution and marketing are 2% ×s 86,935.20 USD = 1,738.70 USD. To calculate, research and development costs use the formula, namely 1% of gold sales in a year. Thus, research and development costs 1% \times 86,935.20 USD = 869.35 USD. Finally, calculate patents and royalities costs using the formula, namely 1% × gold sales in a year. Thus, the cost of patents and royalties 1% ×86,935.20 USD = 869.35 USD.

(v) After all items in manufacturing costs have been calculated. Next is to calculate the total manufacturing cost for a year by adding up all the items. Based on the results of the sum of manufacturing costs in a year it is 38,948.08 USD.

**Table 8.** Factor for estimating manufacturing costs gold mining using the amalgamation method.

| No | Item | Factor | | Price (per 1 day) | Price (per 5 day) | Price (per month) | Price (per month) |
|---|---|---|---|---|---|---|---|
| | Total Life Time | **20** | **Years** | | | | |
| 1 | Raw Materials | 7% | | 31.20 | 156.00 | 686.40 | 8,235.70 |
| 2 | Utilites | | | 3.76 | 18.78 | 82.63 | 984.24 |
| 3 | Loan Interest | | of loan | | | | |
| 4 | Operating Labor | 30% | | 55.40 | 277.00 | 1,218.80 | 14,625.60 |
| 5 | **Labor related cost** | 25% | | | | | |
| | a. Payroll overhead | 12% | of labor | 16.62 | 83.10 | 365.64 | 4,387.68 |
| | b. Supervisory, misc. labor | | of labor | 13.85 | 69.25 | 304.70 | 3,656.40 |
| | c. Laboratory charges | 6% | of labor | 6.65 | 33.24 | 146.26 | 1,755.07 |
| 6 | **Capital related cost** | 1.75% | | | | | |
| | a. maintenance | 2.25% | of (TPC-land) | 23.80 | 23.80 | 23.80 | 23.80 |
| | b. Operating supplies | 5% | of (TPC-land) | 6.94 | 6.94 | 6.94 | 6.94 |
| | c. Enviromental | 4% | of (TPC-land) | 8.93 | 8.93 | 8.93 | 8.93 |
| | d. Depreciation | 3% | of (TPC-land) | 19.84 | 19.84 | 19.84 | 19.84 |
| | e. Local taxes, insurance | | of (TPC-land) | 15.87 | 15.87 | 15.87 | 15.87 |
| | f. Plant overhead cost | 1% | of (TPC-land) | 11.90 | 11.90 | 11.90 | 11.90 |

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**Table 8 (Continue).** Factor for estimating manufacturing costs gold mining using the amalgamation method.

| No | Item | Factor | | Price (per 1 day) | Price (per 5 day) | Price (per month) | Price (per month) |
|---|---|---|---|---|---|---|---|
| 7 | **Sales related cost** | 2% | | | | | |
| | a. Packaging | 2% | of sale | 0.00 | 0.00 | 0.00 | 0.00 |
| | b. Administration | 1% | of sale | 6.59 | 32.93 | 144.89 | 1,738.70 |
| | c. Distribution and marketing | 1% | of sale | 6.59 | 32.93 | 144.89 | 1,738.70 |
| | d. Research and development | 7% | of sale | 3.29 | 16.47 | 72.45 | 869.35 |
| | e. Patents and royalties | | of sale | 3.29 | 16.47 | 72.45 | 869.35 |
| **Total Manufacturing Cost (TMC)** | | | | **234.51** | **823.44** | **3,326.38** | **38,948.08** |

### 4.6. Step 6: Calculating Gross Profit Margin (GMP) and Return on Investment (ROI)

In this step, Gross Profit Margin (GMP) and Return on Investment (ROI) are calculated to see the feasibility of the project. All calculations were carried out using Microsoft Excel software. The calculation is changed from IDR to USD, where 1 USD = 14,425 IDR. In detail, the steps to calculate gross profit margin and return on investment are described as follows:

(i) Before calculating GPM and ROI, first calculate the estimated profit. Profit is calculated using the formula, namely sales – manufacturing costs. Based on previous calculations, it was found that gold sales in a year were 86,935.20 USD while the total manufacturing cost was 38,948.08 USD. Thus, the estimated profit obtained is 86,935.20 USD - 38,948.08 USD = 47,987.12 USD. The details of the estimated profit calculation are presented in **Table 9**.

(ii) After calculating the estimated profit, the next step is to calculate the GMP. To calculate GMP by subtracting sales from the price of raw materials for a year. Based on previous calculations, it was found that sales for a year were 86,935.20 USD. Meanwhile, the purchase price of raw materials for one year is 8,235.70 USD. Thus, the GMP is 86,935.20 USD - 8,235.70 USD = 78,699.50 USD.

(iii) After that, the final step is to calculate ROI. The ROI calculation is carried out using equation (7), namely

$$\text{ROI} = \frac{profit}{TIC} \times 100$$

$$\text{ROI} = \frac{78{,}699.50}{744.73} \times 100$$

Thus, based on these calculations it is known that the ROI is 6,443.51 USD.

**Table 9.** Calculation of estimated profits.

| Component | Cost (USD) |
|---|---|
| Sales | 86,935.20 |
| Total Manufacturing cost | 47,987.12 |
| **Profit** | **47,987.12** |

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### 4.7. Step 7: Calculating Variable Costs, Fixed Costs, and Break Even Point (BEP) in Gold Mining using the Amalgamation Method

After calculating the Gross Profit Margin (GMP) and Return on Investment (ROI), this stage is carried out by calculating the cost, fixed cost and break even point (BEP) variables. **Table 10** shows the results of variable cost, fixed cost and BEP calculations. Calculations were carried out using Microsoft Excel software. All calculation costs are first converted from IDR to USD, where 1 USD = 14,425 IDR. In detail, the steps to determine variable costs, fixed costs, and break even point (BEP) are as follows:

(i) The first step is to calculate fixed costs. Fixed costs are expenses that the company will still pay regardless of the conditions. The nominal amount of fixed costs is the same, regardless of whether there is an increase or decrease in sales. Fixed costs consist of several items, namely loan interest, capital related costs, fixed costs + depreciation, depreciation, and fixed costs less depreciation. For loan interest, there are no estimated costs because you don't use a loan. The same thing also applies to fixed costs + depreciation and fixed costs less depreciation, there are no estimated costs. Depreciation costs have been calculated which are presented in Table 8, namely 19.84 USD. Meanwhile, capital related costs have been calculated in the previous calculation which is presented in Table 8. Based on the calculation results for each item in capital related costs, namely maintenance, operating supplies, environmental, depreciation, local taxes, insurance and plant overhead costs, all are added up. Thus, the capital cost related is 23.80 + 6.94 + 8.93 + 19.84 + 15.87 + 11.90 USD = 87.28 USD. Based on the sum of all items in fixed costs, it is obtained that it is 107.12 USD.

(ii) After that, the variable cost calculation is carried out. Variable costs are costs whose amount changes in proportion to changes in the volume of activity. Variable costs consist of several items, namely raw materials, utilities, operating labor, and sales related costs. All of these items have been calculated in the previous step, which can be seen in Table 8. The respective costs for raw materials, utilities, operating labor, and sales related costs are 8,236.80; 984.24; 14,625.60; 9,799.15; 5,216.11 USD. To calculate variable costs, it is done by adding up all the items in the variable costs. Thus, the variable costs are obtained at 8,236.80 + 984.24 + 14,625.60 + 9,799.15 + 5,216.11 = 38,861.90 USD.

(iii) Then, the next step is to calculate the estimated profit. There are several items used in calculating profit estimates, namely sales, production costs, investment, profit, profit on sales, and profit on investment. The costs for sales, manufacturing, profit, investment and profit have been calculated in the previous step which can be seen in Table 8. Based on the calculation results, it is known that the costs for sales, manufacturing, profit, investment and profit respectively are 86,935.20; 38,948.08; 744.73 and 47,987.12 USD. To calculate profit to sales, it is done by dividing sales by profit. Thus, the sales profit obtained is 86,935.20 divided by 47,987.12 USD = 1.81. Meanwhile, calculating profit to investment is done by dividing sales by investment. Thus, the investment profit obtained is 86,935.20 divided by 744.73 USD = 64.44 USD.

(iv) The final step is to calculate the break even point (BEP). The purpose of the break even point (BEP) is to determine the level of production or sales where total revenue is equal to total costs so that net profit is zero. In other words, to determine the minimum production quantity so that total costs and profits become zero. To calculate BEP, it is done by first determining the purchase price of gold per unit/g based on variable costs. For gold production in a year, it is obtained at 1320 units/g. Thus, determining the purchase price of gold is done by dividing the variable cost by the amount of gold

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produced in a year. Based on the calculation results, the purchase price for gold is 38, 861.90 USD divided by 1320 g/unit = 29.44 USD. After that, determine the selling price of gold per unit/g. The formula used to calculate the selling price of gold in a year divides sale by the amount of gold produced in a year. Thus, based on the results of these calculations, the selling price of gold in a year is 86,935.20 USD divided by 1320 g/unit = 65.86. Because all components have been calculated, BEP is then determined using equation (4), namely:

$$BEP = \frac{Total\ fixed\ cost}{sales - total\ variable\ cost} \times \text{total production for a year}$$

$$BEP = \frac{107.21}{86{,}935.20 - 38{,}861.90} \times 1320\ \text{g/unit}$$

BEP = 2.94 rounded to 3

Thus, based on calculations it is known that the minimum production amount is 3 g/total unit so that costs and profits become zero.

**Table 10**. Calculation of variable costs, fixed costs, and break even point (BEP).

| Component | Price (USD) |
|---|---|
| **Fixed cost** | |
| Loan Interest | 0.00 |
| Capital Related Cost | 87.28 |
| Depreciation | 19.84 |
| **Sub total fixed cost** | 107.12 |
| **Variable Cost** | |
| Raw material | 8,236.80 |
| Utilities | 984.24 |
| Operating Labour | 14,625.60 |
| Labor Related cost | 9,799.15 |
| Sales related cost | 6,085.46 |
| **Sub total variable cost** | 39,731.26 |
| Sales | 86,935.20 |
| Manufacturing cost | 39,817.44 |
| Investment | 744.73 |
| Profit | 47,117.76 |
| Profit to Sales | 1.85 |
| Provite to Investment | 63.27 |
| Unit/gram | 1320 |
| Fixed Cost | 107.12 |
| Variable Cost | 39,731.26 |
| Variable Cost | 30.10 |
| Sales | 86,935.20 |
| Sales | 65.86 |
| **BEP (gram)** | **3.00** |

### 4.8. Step 8: Calculating Cumulative Net Present Value (NPV) and Net Present Value (NPV)

In the final step of the economic evaluation, the cummulative net present value (CNPV) and net present value (NPV) are calculated. Calculation of total manufacturing costs using Microsoft Excel software. All costs for calculating total manufacturing costs are calculated by converting IDR to USD, where 1 USD = 14,425 IDR. **Table 11** presents the results of calculating cummulative net present value (CNPV) and net present value (NPV). There are several items needed to calculate cummulative net present value (CNPV) and net present value (NPV), namely year, production capacity, end of year number, investment-land, land, work capital, variable costs, fixed costs, sales, depreciation , pretas profit, taxable profit, income (10%),

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after tax profit, cash flow, cumulative cash flow, discount factor, net present value, cumulative net present value, CNPV/Investment, Interval Rate of return, and CNPV/TIC . Below is a description of the steps in calculating cummulative net present value (CNPV) and net present value (NPV):

(i) Before calculating the cummulative net present value (CNPV) and net present value (NPV), first determine how long production will take. In this research, the duration of production is 20 years (2021-2041).

(ii) After determining the production time, end of year number and production capacity are determined. For the end year number, for 2021 the 0th end of year number is calculated, 2021 is calculated as the 1st year, in 2022 the 2nd end of year number and so on until 2041 as the 20th end of year number. Meanwhile, the production capacity at the 0th, 1st and 2nd end of year numbers is each set at 0%. This is because this year is still the initial year of project development. Furthermore, after the end of the 4 to 20th years, production capacity was increased to 100%. Details of production time and end of year numbers are presented in **Table 11**.

(iii) Then, after determining the production duration, we determine the item's discount rate. In this study, a discount rate of 15% = 0.15 was used. After that, from determining the discount rate, here we calculate the discount factor (i) for the end of year number 1 using Eq. (3), namely:

$i = (1 + \mathrm{r})^{-n}$

$i = (1 + 0.15)^{-1}$

$i = (1 + 0.15)^{-1}$

$i = 0$

Thus, based on the calculation results, the discount rate for the end of the 1st year is 0. To calculate the discount rate for other end of year numbers, the same method is used as calculating the discount rate for the 1st end of year number.

(iv) To be able to calculate CNPV and NPV, it is also necessary to calculate investment-land items. Here, investment for land is made at the end of 1st and 2nd years with respective, percentages of 40% and 60% thus the total is 100%. The formula for calculating investment-land is the percentage at a certain end of year number × TIC. Thus, the investment-land for the 1st end of year number is 40% × 744.73 USD = 297.89 USD. To calculate investment-land for 2nd end of year number, use the same method as calculating investment-land for 1st end of year number. At in 0 years, because the project is still in the preparation and development stages, the investment-land is 0.00 USD. Meanwhile, at the end of year number in years 3 to 20 there is no need to recalculate investment land. Therefore, for investment land at the end of year number 3 to 19 is 0.00 USD. Investment-land details are presented in **Table 11**.

(v) The land calculation has been carried out in the previous step which is presented in **Table 7**. A project is estimated to be able to purchase land after the project runs at 1 st the end of year number. Therefore, the land calculation result of 348.01 is placed at the 1st end of year number. In detail, the land calculation results are presented in **Table 11**.

(vi) The working capital calculation item has been carried out in the previous step which is presented in **Table 7**. Because working capital is the costs required to carry out operations in a certain period of time normally. At the 1 st and 2nd of year numbers, working capital cannot be calculated because in those two years the project was still in the development process. Therefore, working capital costs only start at the 3rd end of year number. Thus, based on the calculation results in Table 7, the capital working at the 3rd end of year number is 139.20 USD. Detailed working capital calculations are presented in **Table 11**.

(vii) Fixed cost items have been calculated in the previous step which is presented in Table 7. Fixed costs are the same as variable costs, at the end of year number 0 to 2 there are still no costs incurred because the project is still in progress. development process. Based on the calculation results in **Table 7**, fixed costs start at the end of the 3rd year, namely 107.12 USD. At the end of 3 to 20th years, the fixed costs incurred are the same as the end of the 2th year. Details of fixed cost calculations can be seen in **Table 11**.

(viii) For the variable cost calculation item, it has been calculated in the previous step which is presented in **Table 7**. Here, the variable costs for the 0th, 1st, and 2nd end of the year have not yet been incurred because the project is still in progress. development process. Based on the calculation results in **Table 7,** variable costs start at the end of the 4th year, namely 39,731.26 USD. At the end of the 5 to 20th year, the variable costs incurred are the same as the 4th end of year number. The details of the variable cost calculation are shown in **Table 11**.

(ix) In pretax profit, costs have not been incurred at the end of the 0th to 2nd year. This is because the project is still at the development stage. The pretax profit calculation is carried out using the formula, namely: sales – (variable costs + fixed costs). Thus, pretax profit is 86,935.20 – (39,731.26 + 107.12) = 47,966.18 USD. Based on the results of these calculations, it is found that the pretax profit cost at at the end of the 3rd year is 47,966.18 USD. At the end of the 4th to 20th year, the pretax profit paid is the same as the end of year number 3. Details of pretax profit calculations are presented in **Table 11**.

(x) For taxable profits, nothing has been paid at the end of 0th to 2nd year. Because it is still in the project development stage. Therefore, new taxable profits can be paid in the 3rd to 20th year. The taxable profit formula used is pretax profit – depreciation. Thus, the taxable profit for end of the 3rd year is 47,966.18 – 19.84 USD = 47,946.34 USD. Taxable profit at the end of 4 to 20th years is the same as end of the 3rd year. Details of the taxable profit calculation are presented in **Table 11**.

(xi) In this study, the income tax paid was 10%. For income tax (10%), for end of year numbers 0 to 2 there is no income tax fee paid. This is because the project is still in the development stage. Therefore, income tax can only be paid at the end of the 3rd to 20 th years. The formula for calculating income tax is the percentage of income tax × taxable profit. Thus, income tax for end of 3rd year is 47,943.34 USD × 10% = 4,794.33 USD. The income tax paid for the end of the 4 to 20th years is the same as the end of the 3rd year. Detailed income tax calculations can be seen in **Table 11.**

(xii) After tax profit can only be calculated at the end of 3rd to 20th years. Because the project is estimated to be stable. The formula for calculating after tax profit is taxable profit – income tax (10%). Thus, after tax profit end of 3rd year is 47,946.34 – 4,794.33 = 43,152.01 USD. For after tax profit costs, end of year numbers 4 to 20 are the same as end of 3rd year. The detailed calculation of after tax profit is shown in **Table 11**.

(xiii) Cash flow can be calculated using the formula, namely after tax profit + Investment-land – working capital – land – depreciation. For example, cash flow at the end of year number 0 is 0.00 + 0.00 – 0.00 – 0.00 – 0.00 = 0.00 USD. Thus, the cash flow at the end of year number 0 is 0.00 USD. To calculate cash flow at the end of the 1 to 20 th year, use the same method as cash flow at the end of the 0 th year.

(xiv) In the study, the cumulative cash flow for the 0th end of year is 0.00 USD. Because it is still at the beginning of project construction. Cumulative cash flow is calculated using the formula, namely cash flow in a certain period + cumulative cash flow at the beginning of the period. Thus, to calculate the cumulative cash flow at the end of 1 st year is 0.00 USD + (-645.90 USD) = - 645.90 USD. To calculate cumulative cash flow at the 2nd to 20th end of year number, use the same method as calculating cumulative cash flow at the 1st end of year number. Details of cumulative cash flow can be seen in **Table 11**.

(xv) Net present value can be calculated using the formula, namely cash flow × discount factor. For example, to calculate the net present value at the end of 1th year is 645.90 USD × 0.870 = - 561.65 USD. The net present value calculation for the 2nd to 20th end of year uses the same method as when calculating the net present value for the 1st end of year number.

(xvi) Cumulative net present value for the 0th end of year number is 0.00 USD. Because it is still at the beginning of project construction. Cumulative net present value is calculated using the formula, namely net present value in a certain period + cummulative net present value at the beginning of the period. Thus, to calculate the net present value at the end of year number 1 is 0.00 USD + (-561.65 USD) = - 561.65 USD. To calculate cumulative cash flow at the end of 2nd to 20th year, use the same method as calculating the cumulative net present value at end of 1th year. Details of the cumulative net present value for the end of year number can be seen in **Table 11**.

CNVP/Investment can be calculated using the following Eq. (9):

$$\text{CNPV/Investment} = \frac{Cumulative\ net\ present\ value}{TIC - Land - Land} \tag{9}$$

For example, to calculate CNPV/Investment the 1st end of year number is

$$\text{CNPV/Investment} = \frac{-561.65}{396.78 - 348.01}$$

CNPV/Investment = -11.53 USD

Thus, the CNPV/Investment for the 1st end of year number is -11.53 USD. To calculate CNVP/Investment for the 2nd to 20th end of year number, use the same method as CNPV/Investment for the 1st end of year number.

(xvii) CNPV/TIC can be calculated using theEq. (10), namely:

$$\text{CNPV/TIC} = \frac{Cumulative\ net\ present\ value}{TIC \times 10} \tag{10}$$

For example, to calculate CNPV/TIC the 1st end of year number is

$$\text{CNPV/TIC} = \frac{-561.65}{744.73 \times 10} = \text{- 0.075 USD}$$

Thus, the CNPV/TIC for the 1st end of year number is - 0.075 USD. To calculate CNVP/TIC for the 2nd to 20th end of year number, use the same method as CNPV/TIC for the 1st end of year number. Complete calculation results are presented in Table 11. After calculating CNPV/TIC, the next step is to create a CNPV/TIC graph. **Figure 3** shows CNPV/TIC graph. Based on **Figure 3**, it is interpreted that in years 0 to 2 the project is still not profitable because it is still in the development stage. Then, in years 4 to 20th, the project starts to make a profit

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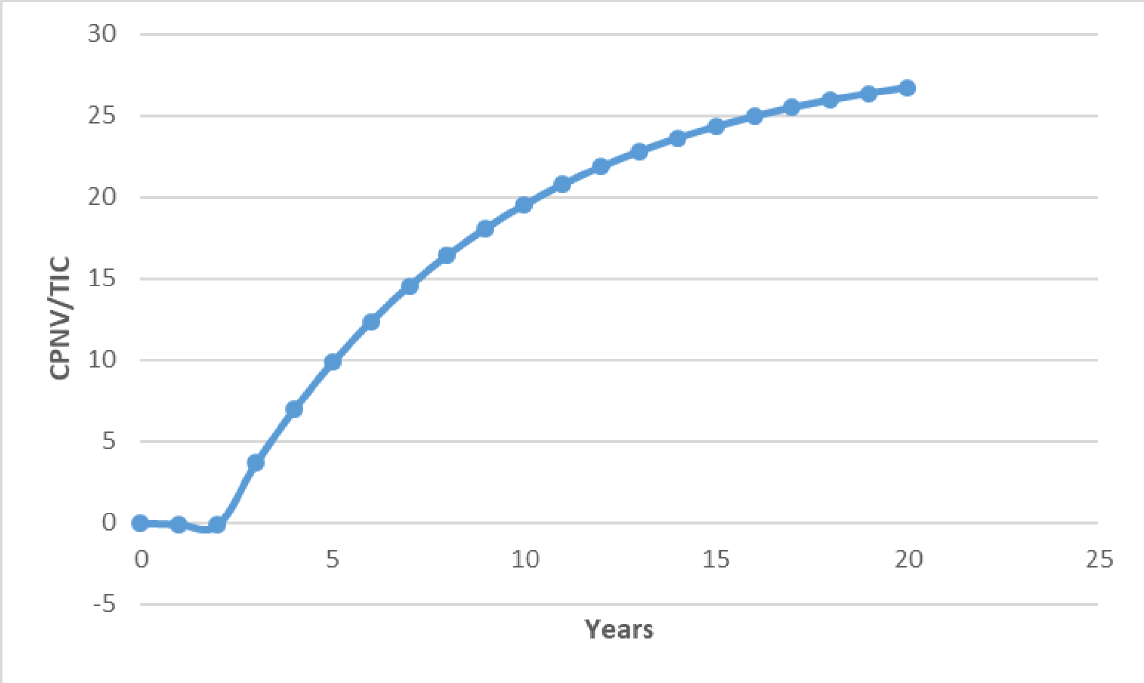


**Figure 3.** The CNPV/TIC graphics the lifetime for gold mining project.

**Table 11.** Analysis of CNPV calculations up to 20 years of production.

| Year | 2021 | 2022 | 2023 | 2024 | 2040 | 2041 |
|---|---|---|---|---|---|---|
| **Discount Rate** | 15% | 15% | 15% | 15% | 15% | 15% |
| **Production Capacity** | 0% | 0% | 0% | 100% | 100% | 100% |
| **End of year Number** | 0 | 1 | 2 | 3 | 19 | 20 |
| **Investment-Land** | 0.00 | 158.69 | 238.03 | 0.00 | 0.00 | 0.00 |
| **Discount rate** | 15% | 15% | 15% | 15% | 15% | 15% |
| **Land** | 0.00 | 297.89 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Working Capital** | 0.00 | 0.00 | 139.20 | 0.00 | 0.00 | 0.00 |
| **Variable Cost** | 0.00 | 0.00 | 0.00 | 39731.25 | 39731.25 | -39731.25 |
| **Fixed Cost** | 0.00 | 0.00 | 0.00 | 107.11 | 107.11 | 107.11 |
| **Sales** | 0.00 | 0.00 | 0.00 | 39817.43 | 39817.43 | 39817.43 |
| **Depreciation** | 0.00 | 0.00 | 0.00 | 19.83 | 19.83 | 19.83 |
| **Pretax Profit** | 0.00 | 0.00 | 0.00 | 79441.57 | 79441.57 | 79441.57 |
| **Taxable Profit** | 0.00 | 0.00 | 0.00 | 79421.73 | 79421.73 | 79421.73 |
| **Income Tax (10%)** | 0.00 | 0.00 | 0.00 | 7942.17 | 7942.1 | 7942.17 |
| **After Tax Profit** | 0.00 | 0.00 | 0.00 | 71479.56 | 71479.56 | 71479.56 |
| **Cash Flow** | 0.00 | -645,901 | -586,044 | 71499.40 | 71499.40 | 71499.40 |
| **Cumulative Cash Flow** | 0.00 | -645.901 | -1231.945 | 70615.464 | 1214605.89 | 1286105.293 |
| **Discounted Factor** | 0.00 | 0.87 | 0.756 | 0.658 | 0.070 | 0.061 |
| **Net Present Value** | 0.00 | -561.653 | -443.133 | 47012.017 | 5023.92 | 4368.63 |
| **Cumulative Net Present Value** | 0.00 | -561.653 | -1004.786 | 46286.163 | 326206.75 | 330575.38 |
| **CNPV/Investment** | 0.00 | -11.527 | -20.62 | 950.02 | 6695.40 | 6785.07 |
| **Interval Rate of Return** | 11.039 | | | | | |
| **CNPV/TIC** | 0 | -0.075 | -0.134 | 0.621511989 | 1.642 | 2.061 |

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## 5. CONCLUSION

In this article, economic evaluation has been explained which plays an important role in determining the feasibility and financial sustainability of chemical plant projects. A case study on gold mining using the amalgamation method (commonly known as conventional methods) highlight the complexity of the calculation steps involved, from investment costs to net income. The economic evaluation process requires an in-depth understanding of various factors. including operating costs, changes in raw material prices, and revenue estimates. By detailing the calculation steps and using metrics such as GPM, BEP, PBP, IRR, NPV, and CNPV, this article provides practical insight for professionals and engineers involved in designing chemical plants.

In addition, case studies evaluating gold mining using the amalgamation method show that GPM and profitability are positive. Apart from that, the CNPV/TIC value also shows the same thing. It is estimated that the gold mining project will make a profit in the 3-20th year. The results of economic evaluation have demonstrated that it is not just about calculating numbers, but also involves a deep understanding of risk, the time value of money, and the balance between initial investment and long-term profits. By taking inspiration from this case, it is hoped that researcher and students will be able to apply these concepts in the design of their own chemical plants. creating projects that are not only technically efficient but also provide optimal investment results and are economically sustainable.

## 6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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