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Economic Evaluation of Gold Nanoparticle (AuNP) Production Using Laser Ablation Synthesis Method

Salma Rahmadianti, Kanthi Pawening Tyas, Permata Maratussolihah, Gabriela Chelvina Santiuly Girsang, Asep Bayu Dani Nandiyanto
Department of Chemistry Education, Universitas Pendidikan Indonesia, Indonesia
nandiyanto@upi.edu

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Abstract
Gold nanoparticles are very useful in various fields such as photoacoustic imaging microscopy, biotechnology, optoelectronics, and biomedicine. So the production of gold nanoparticle synthesis needs to be developed to an industrial scale. The purpose of this study is to determine the feasibility of the gold nanoparticle synthesis project using the laser ablation method on large-scale based on economic aspects. Several economic evaluation parameters are analyzed to inform the potential production of AuNP, such as GPM (Gross Profit Margin), BEP (Break-Even Point), CNPV (Cumulative Net Present Value), PBP (Payback Period), and PI (Profitability Index). The results showed that the production of AuNP nanoparticles was so prospective. Technical analysis to produce 100 g of AuNP nanoparticles per day shows the total cost incurred by the production process is 2,323,180 USD per year. PBP analysis show that investment will be profitable after more than 2.2 years. This project can compete with PBP capital market standards because of the short investment returns. To ensure the feasibility of a project, the project is estimated from ideal conditions to the worst case in production, including labor, sales, raw materials, utilities, and external conditions.

***Keywords**: Gold nanoparticle; Laser ablation method; Economic evaluation*

Evaluasi Ekonomi dari Produksi Nanopartikel Emas (AuNP) Menggunakan Metode Sintesis Ablasi Laser

Abstrak
Nanopartikel emas sangat berguna dalam berbagai bidang seperti *microscopy photoacoustic imaging,* bioteknologi, optoelektronika, dan biomedis. Sehingga produksi sintesis nanopartikel emas perlu dikembangkan hingga skala industri. Tujuan dari penelitian ini adalah untuk mengetahui kelayakan proyek sintesis nanopartikel emas menggunakan metode ablasi laser dalam skala besar berdasarkan aspek ekonomi. Beberapa parameter evaluasi ekonomi dianalisis untuk mendapatkan informasi mengenai potensi produksi AuNP, seperti GPM (Gross Profit Margin), BEP (Break-Even Point), CNPV (Cumulative Net Present Value), PBP (Payback Period), dan PI (Profitability Index).). Hasil penelitian menunjukkan bahwa produksi nanopartikel AuNP sangat prospektif. Analisis teknis untuk menghasilkan 100 g nanopartikel AuNP per hari menunjukkan bahwa total biaya yang dikeluarkan untuk proses produksi adalah 2,323,180 USD per tahun. Analisis PBP menunjukkan bahwa investasi akan menguntungkan setelah lebih dari 2,2 tahun. Proyek ini dapat bersaing dengan standar pasar modal PBP karena keuntungan investasi dapat diperoleh dalam waktu yang singkat. Untuk memastikan kelayakan suatu proyek, proyek diasumsikan ke dalam kondisi ideal hingga kondisi terburuk ketika produksi, termasuk upah tenaga kerja, penjualan, bahan baku, utilitas, dan pajak pendapatan.

Kata kunci: Nanopartikel emas, Metode Ablasi Laser, Evaluasi ekonomi

1. Introduction

Nanoparticles are metal or polymer particles in a scale of 1-100 nm [1,2]. Metal nanoparticles, especially gold nanoparticles, have abundant uses in the fields of photoacoustic microscopy imaging [3], biotechnology, optoelectronics, and biomedicine [2,4]. These various uses are due to gold nanoparticles having properties such as biocompatibility [5], large surface bioconjugation, optical properties related to plasmon resonance (PR) [4], and unique electrical and magnetic properties [2]. With the widespread use of gold nanoparticles, it is necessary to develop large-scale production [6], because the interactions between particles and the formation of gold nanoparticles have an important role in determining the properties of gold nanoparticles [7].

The gold nanoparticle synthesis method is divided into 2 types, the "bottom up" method and the "top down" method [8]. “Bottom up” methods include, nanospheric lithography [9], biomolecular templating [10], chemical reduction [11], thermal reduction [12] or photochemistry [13], electrochemistry [14], and sonochemistry [15]. This method involves assembling the atoms resulting from the reduction of ions into the desired nanostructure. Top down methods include photolithography [16], electron beam lithography [17], and laser ablation [18]. This method involves the removal part of the material from a lump of material to obtain the desired nanostructure. Both types of methods can produce gold nanoparticles with the desired shape and size, but each type of method has its drawbacks, poor monodispersity will occur if using the "bottom up" method while if the "top down" method will produce a lot of waste. The laser ablation method uses a gold plate as a raw material. The process of synthesizing gold nanoparticles using the laser ablation method is shown in Figure 1. This method was chosen because it is relatively simple and effective for the formation of large amounts of nanoparticles [19], besides that the laser ablation method does not use harmful chemicals, but rather Haider et al. [20] use water, which will not pollute the environment. However, the yield of most laboratory scale syntheses is about 1 g per batch, and this is much less than the quantity required for commercial scale production [6].

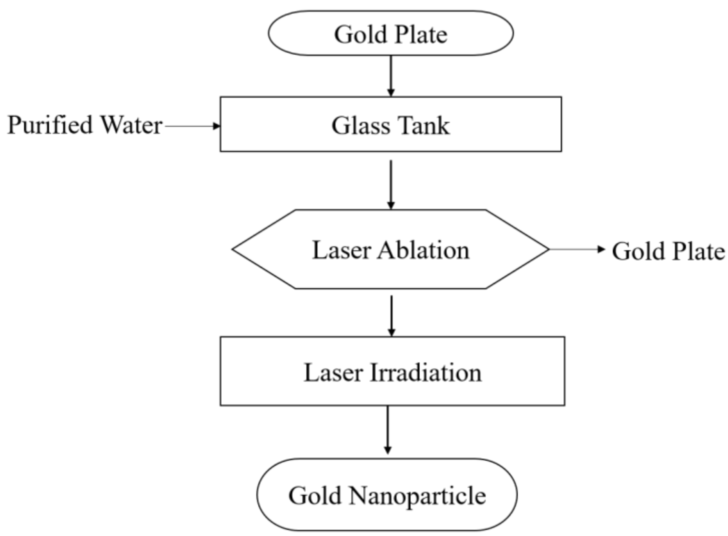

Figure 1. Synthesis process of AuNP nanoparticles using laser ablation method.

The purpose of this study was to determine the feasibility of the project based on the economic aspect. This paper was created because there are no paper that discuss the economic evaluation of the laser ablation synthesis method in the manufacture of gold nanoparticles. The economic aspect is reviewed in the development of laser ablation method as a gold nanoparticle synthesis method on an industrial scale. The research uses a method in the form of calculating several economic parameters on the parameters of ideal conditions and on variations in external economic factors such as raw material prices, utility prices, sales prices, worker wages, and taxes.

2. Research Method

To confirm the economic evaluation of this project, several economic parameters were calculated based on the literature [21,22], as follows:

a. GPM (Gross Profit Margin): To predict the level of profitability of a project. It is calculated by subtracting the cost of selling the product from the cost of raw materials.
b. BEP (Break-Even Point): To find out the minimum number of products that must be sold at a certain price to cover the total cost of production. It is calculated by dividing the fixed costs against the difference between the selling price and the variable costs.
c. CNPV (Cumulative Net Present Value) To predict the condition of the project as a function of the year of production. Obtained by adding the NPV from the beginning of the project establishment. NPV is a value that expresses the expenses and income of a business.
d. PBP (Payback Period): To estimate the possible years of profit. PBP is calculated when CNPV is at zero for the first time, it can be seen on the graph between CNPV/TIC (y-axis) and year (x-axis). PBP is indicated by a point parallel to the x axis.
e. PI (Profitability Index): To identify the impact of project costs. It is calculated by dividing the CNPV by the total investment cost (TIC). If the PI is less than one, then the project can be classified as an unprofitable project and if the PI is more than one then the project can be classified as a profitable project.

In calculating these parameters, data on equipment and raw materials are needed. The data was developed according to an industrial scale [20,22]. The price data is obtained from several available online stores. The calculation of these economic parameters assumes the following ideal conditions:

a. 1 USD is equivalent to 15000 IDR, The
b. Price of raw material for 1 99.95% 5 gram gold plate is 4023817 IDR
c. Salary for 10 people is 15,000 USD per year
d. The utility fee to be paid per year is 264.96 USD
e. Income tax 10%
f. Discount rate 15%
g. AuNP selling price is 90 USD/1 gram
h. Synthesis is carried out 20 times a day The
i. Project operates for 20 years

Furthermore, the economic evaluation of this project is carried out by varying raw materials, sales, tax values, utilities, and labor salaries in some conditions. Variations in raw materials, sales, labor salaries, and utilities were carried out at 80, 90, 100, 110, and 120%. Tax variations are carried out at 10, 25, 50, 75, and 100%.

3. Result and Discussion

3.1. Engineering Perspective

Figure 2 shows the process of making AuNP nanoparticles using laser ablation method for large-scale production. Gold nanoparticles were formed using an Nd:YAG laser (LOTIS TII, LS2134) by ablating a 99.99% pure gold plate of weight 5 g which was placed in a glass tank with 300 ml of purified water. After the laser ablation, the gold plate was removed from the solution and the prepared colloids were irradiated using the same Nd:YAG laser for 3 or 5 min. For characterizing nanoparticles, extinction spectra were taken using the UV-Vis Spectrophotometer. On the other hand, studying the size and shape distributions of the nanoparticles was carried out using the transmission electron microscopy (TEM) [20,22]. Table 1 describes the description of the AuNP production process flow diagram.

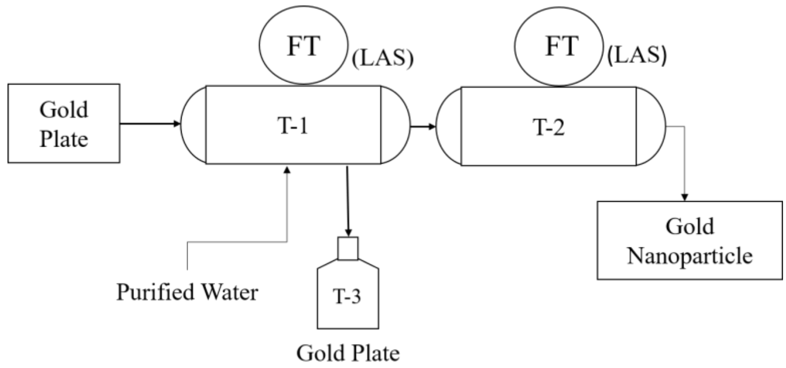

Figure 2. Process flow diagram of AuNP.

Table 1. Process flow diagram of AuNP

No	Symbol	Information
1	FT	Flow Transmitter
2	LAS	Laser
3	T-1	Tank-1
4	T-2	Tank-2
5	T-3	Tank-3

From an engineering point of view, the total cost for purchasing raw materials for one year is 1,615 USD. Sales in one year were 2,700,000 USD. The profit earned was 376,820 USD. The price for the analysis of equipment costs is 13,938 USD. The TIC must be less than 59,096.78 USD. This project requires a small investment fund. The project life span is 20 years, resulting in AuNP nanoparticles with CNPV / TIC reaching 17.09%, in the 9th year, and PBP has been reached in the 2.2 year.

3.2. Economic Evaluation

3.2.1. Ideal Conditions

Figure 3 shows a graph of the relationship between lifetime (year) on the x-axis and the value of CNPV/TIC on the y-axis. The CNPV/TIC value shows the Profitability Index (PI). If the PI value of a project is less than 1, the project can be classified as unprofitable and the project can be classified as profitable if the PI value is more than 1 (Zahra et al., 2020) [22]. In the graph it can be seen that the CNPV/TIC (%) is less than 1 in the 1st year and the 2nd year. This is due to the initial cost of purchasing nanoparticle production equipment.

The lowest CNVP/TIC value occurred in the 2nd year with a value of -0.845204551%. However, in the 3rd year to the 9th year, this project can be considered to be profitable because it has increased the value of CNPV/TIC to more than 1. In the 2nd year, there is an increase in income, which is the Payback Period (PBP). Based on Table 2, CNVP/TIC is negative from the 1st year to the 2nd year. Then the CNVP value increased to positive in the 3rd year with a value of 2.90487611% and continued to increase until the 9th year with a value of 17.09699147%. Therefore, the production of gold nanoparticles (AuNP) using the laser ablation method can be considered to be profitable because it only takes 2 years to restore the initial capital costs.

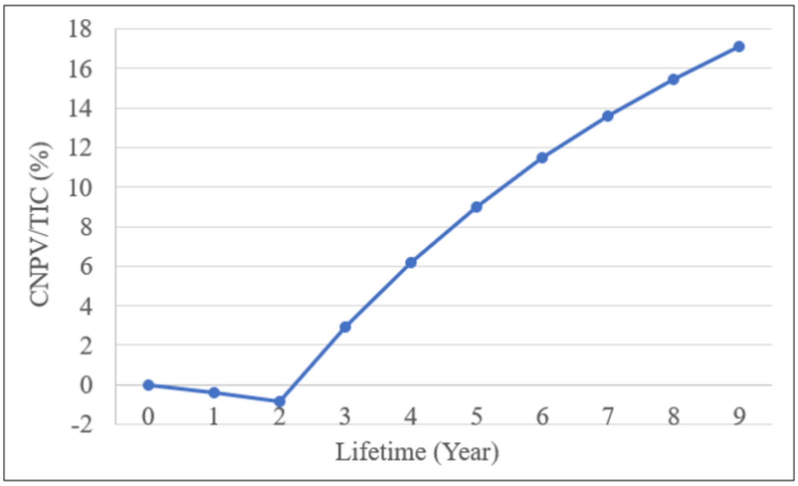

Figure 3. CNPV/TIC graph for lifetime year under ideal conditions

Table 2. Annual CNPV in ideal conditions.

CNPV/TIC	Year
0	0
-0,409351928	1
-0,8452045511	2
2.90487611	3
6.165815815	4
9.001415558	5
11.46715447	6
13.61127525	7
15.47572811	8
17.09699147	9

3.2.2. The Effect of External Conditions

One of the external factors that affect the success of a project is an income tax provided by the country to finance various public expenditures. Figure 4 shows a graph of the relationship between CNPV/TIC values for 9 years and tax variations, where the y-axis is CNPV/TIC (%) and the x-axis is age (years). An Increased tax every year will affect the CNPV value and if the tax increases, it will result in lower profits. This is related to the PBP because the higher tax income, the PBP will be much greater than the ideal condition.

When the income tax is 10%, the income successfully return the initial capital cost in year 2.2; 25% tax in year 2.3; 50% tax in the 2.5 year; 75% tax on year 2.8 and 100% tax on year 3.2. The profit of the project will continue to increase when it reaches the PBP point until the 9th year. The CNPV/TIC values at year 9 for 10, 25, 50, 75 and 100% were found to be 17.01; 16.47; 15.44; 14.41 and 13.37% respectively.

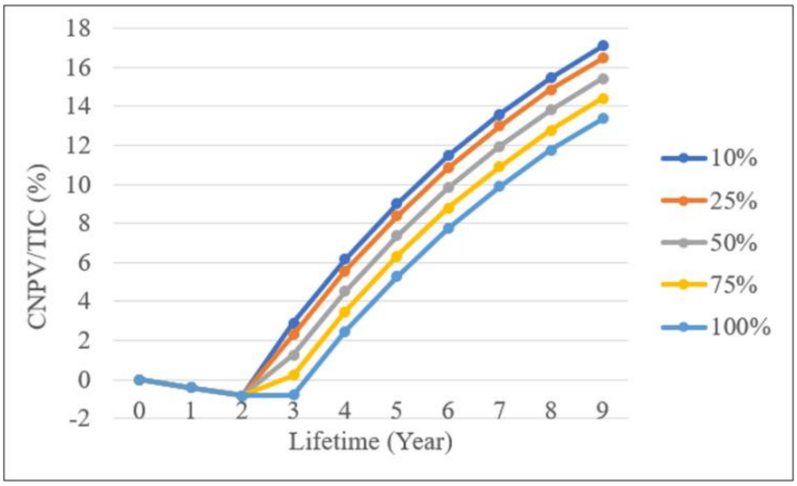

Figure 4. Graph of CNPV/TIC for tax variations

3.2.3. Change in Sales

Figure 5 shows a graph of the relationship between CNPV/TIC with various sales variations. The y-axis is CNPV/TIC (%) and the x-axis is lifetime (year). The analysis wa carried out by increasing and decreasing the sales by 10% and 20%, which is the ideal sales is 100%. When sales are decreased by 10% and 20%, the percentage of sales is 90% and 80%, respectively. When the sales are increased by 10% and 20%, the percentage of sales becomes 110% and 120%, respectively. The CNPV/TIC value in the 1st and 2nd years with variations in sales is the same, because the project is still developed. The effect of sales on CNPV/TIC can be obtained after the project has been running for 2 years. The higher sales, the more profit you will get. However, if there are conditions that cause the sales of the product to decrease, the project's profit will decrease.

Based on the PBP analysis, the return on investment will occur when the sales is 120, 110, 100 and 90% in years 2 to 3, while the 80% sales price variation will not reach PBP. PBP at 80% sales variation will not be achieved until year 9. However, the gap in profit generated for each year will decrease as sales decreases and the company will losses when sales are less than 20% of ideal conditions. On the other hand, the profit in every year will increase as sales increase from ideal conditions. The value of CNPV/TIC in the 9th year for each variation of 120, 110, 100, 90 and 80% is 41.16; 29.13; 17.01; 5.06 and -6.96%.

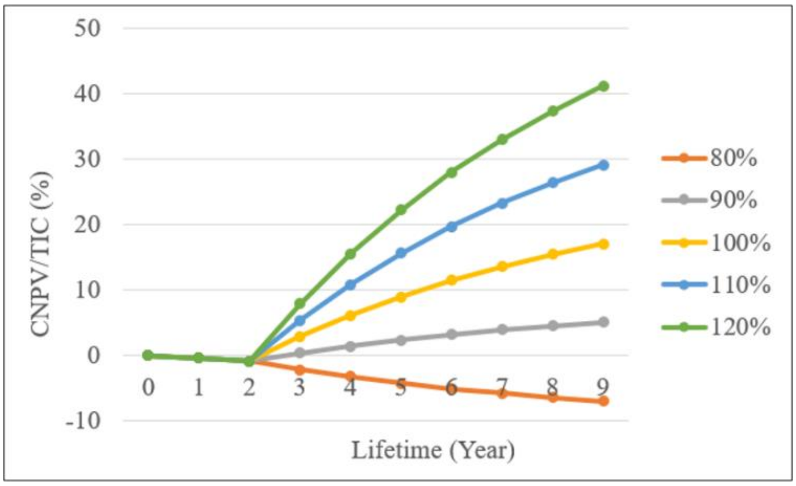

Figure 5. Graph of CNPV for sales variations

3.2.4. Change in variable cost (raw material, utility, labor salary)

Factors such as raw materials, utilities and labor salary can affect the success of a project. Figure 6 shows a graph of the relationship between CNPV/TIC with variations in raw material prices. The y-axis is CNPV/TIC (%) and the x-axis is lifetime (year). The ideal raw material price is 100%. Analysis of variation of raw materials was carried out by increasing and decreasing the price of these raw materials by 10% and 20% from ideal conditions. The variations of the raw materials used in this analysis were 80, 90, 100, 110 and 120%. The value of CNPV/TIC was constant in the initial conditions of the project (0-2 years) because the project was still in the developed. Variations in raw materials begin to affect the value of CNPV/TIC after the second year of project implementation. A decrease in raw materials will increase profits and an increase in raw material prices will reduce project profits.

The value of CNPV/TIC in the 9th year for variations of 80, 90, 100, 110 and 120% raw materials are 32.57; 24.83; 17.09; 9.36 and 1.62%. PBP values obtained from each variation of raw materials 80, 90, 100, 110 and 120% are in year 2.2; 2,3; 2,4; 2.5; and 3.2. The payback period (2.2 year) with the largest profit (CNPV/TIC = 32.57%) can be obtained from the variation of 80% raw material prices.

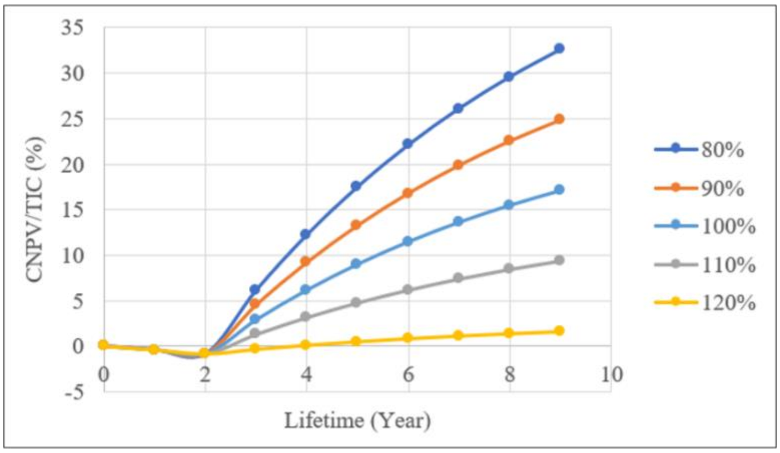

Figure 6. Graph of CNPV for raw material variations

Figure 7 shows a graph of the relationship between CNPV/TIC and utility price variations. The y-axis is CNPV/TIC (%) and the x-axis is lifetime (year). The analysis is carried out by increasing and decreasing the utility prices by 10 and 20% from the ideal price. The ideal value of utility is 100%. The utility price variations used are 80, 90, 100, 110 and 120%.

The CNPV/TIC value from year 0 to year 2 is constant because the project is still developed. The effect of utility on the value of CNPV/TIC can be seen after 2 years. The results show that there is no significant effect on variations in utility prices. The project can still go on and make a profit. The value of CNPV/TIC from year 9 for utility variations of 80, 90, 100, 110 and 120% is 17.10; 17.10; 17.10; 17, 09 and 17.09%. PBP results from utility variations of 80, 90, 100, 110 and 120% can be obtained in year 2.2. The payback period (2.2 year) with the largest profit (CNPV/TIC = 17,10%) can be obtained from the 80% utility price variation.

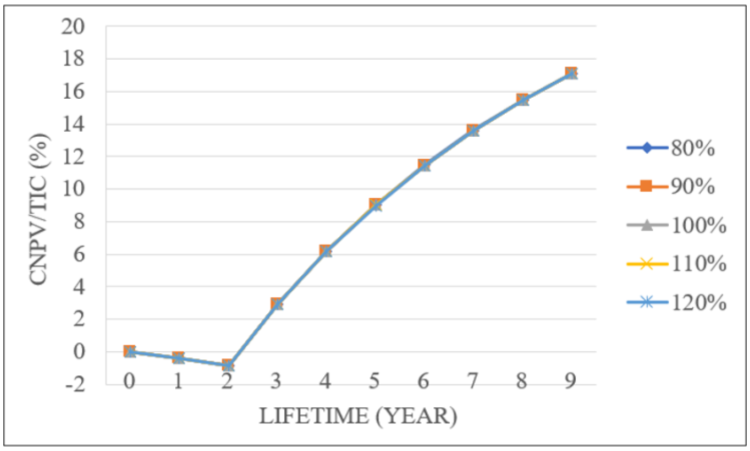

Figure 7. Graph of CNPV for utilities variations

Figure 8 shows a graph of the relationship between CNPV/TIC and variations in labor salary. The y-axis is CNPV/TIC (%) and the x-axis is lifetime (year). The analysis is carried out by increasing and decreasing the labor salary by 10% and 20% from ideal conditions. The ideal labor salary is 100%. Variations in the labor salary used are 80, 90, 100, 110 and 120%. In year 0 to year 2, the value of CNVP/TIC is constant because the project is still being developed. The effect of variations in labor salary will be seen after the 2nd year. The greater the salary of labor, the profit will decrease and vice versa. The value of CNPV/TIC in the 9th year for labor salary variations of 80, 90, 100, 110, 120% is 21.89; 19.49; 17.09; 14.69 and 12.29%. The PBP values for each variation labor salary of 80, 90, 100, 110 and 120% were achieved in year 2.2. The payback period (2.2 year) with the largest profit (CNPV/TIC = 21.89%) can be obtained from the 80% variation in labor salary.

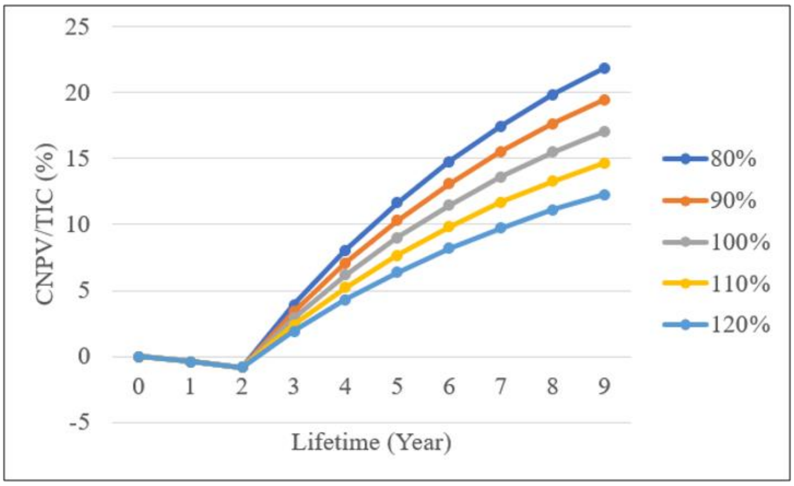

Figure 8. Graph of CNPV for utilities variations

4. Conclusion

Based on the above analysis, the production of gold nanoparticles using the laser ablation method is very profitable. PBP analysis shows that the investment will be profitable after 2.2 years. This short investment is very promising in the future. The laser ablation method was chosen because it is relatively simple and effective for the formation of large amounts of nanoparticles. According to the results of the economic evaluation analysis, it can be concluded that this project is feasible to run.

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