Improving the economy of community's gold mining sector in Indonesia with the usage of efficient and clean technology in gold extracting process

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Abstract. In many studies, most of community's gold mining (CGM) activities are considered as trigger of mercury pollution, and are synonymous with poverty. Mercury pollution is related with the type of technology used. Generally CGM activities use the Trommel & Mercury (TM) method, using mercury, a toxic liquid metal that is functioned to capture gold in the amalgamation process. From this type of technology, there are also indications of losses from: inefficient time, energy, and exploitation of natural resources (gold recovery is only 60%). The economic dimension in mining is including the feasibility of the gold mining business and miner's income. This paper examines the TM gold extraction method, that compared to the simulated non-mercury method, then analyzes their comparison in environmental and economic aspects. The research location was in area of CGM in Cineam District, West Java Province, Indonesia. The non-mercury Density Borax (DB) method was chosen as an alternative technology, to be compiled to the TM Method. The research method is descriptive analytic. Literature study and observation are data collection methods, supported by in-depth interviews. The results: the environmental dimension in the form of non-mercury gold extraction technology that is efficient can increase economic benefits and also could reduce the negative impact of mining on people and the environment.
Key Words: community gold mining, mercury contamination, miner's income, efficiency, sustainable mining practices.

Introduction. Small Scale Gold Mining (SSGM) or Community Gold Mining (CGM) is a complex phenomenon in most countries that have mineral resources. In many studies, most CGM activities are considered as trigger for environmental quality degradation and mercury pollution (UNIDO 2004). Mercury pollution is related with the type of technology (Zulkarnain et al 2008). Generally, CGM activities use trommel, a cylindrical shaped material crusher that rotates around, and is driven by a machine. In this research is called the Trommel & Mercury (TM) method (Balasubramanian 2017). The problem arises from of the usage of mercury (a toxic liquid metal which aims to capture gold) without proper handling (Abbas et al 2017). Around 1,400 tons year^{-1} of mercury are used by the CGM sector, making CGM the world largest consumer of mercury. Whitehouse et al (2006) mentioned that the amount of 120 Tonnes of Mercury was used in a year, just from a single province in Indonesia. Most of those mercury is coming from small scale gold mining activity.Health risks from mercury contamination are well known today in many countries (Appel & Na-Oy 2012). In TM method, mercury contamination originates from the combustion slurry of mixed metal and mercury from the amalgamation process, at the smelting stage (Koster-Rasmussen et al 2016) (Figure 1). Mercury vapors can easily and directly enter the human body, from the respiratory process (AMAP/UNEP 2013). That is why CGM miners usually contain higher levels of mercury in their body parts than ordinary people (Siallagan 2010).

Other environmental impact arises from the combustion of solar fossil fuels for trommel engines. Generally, TM processing units work 24 hours full, burning solar, a liquid diesel machine fuel, causing air pollution, and releasing carbon emissions that affect global warming and greenhouse gas (GHG) conditions, also causing energy waste and increasing production costs (Koster-Rasmussen et al 2016; Balasubramanian 2017). There are also indications of losses in the TM method from: inefficient time and energy: 4-12 hours of work time (Appel & Jønsson 2010), and waste in exploitation of natural resources; the gold recovery is limited to a maximum: 60% (Koster-Rasmussen et al 2016; Zulkarnain et al 2008).

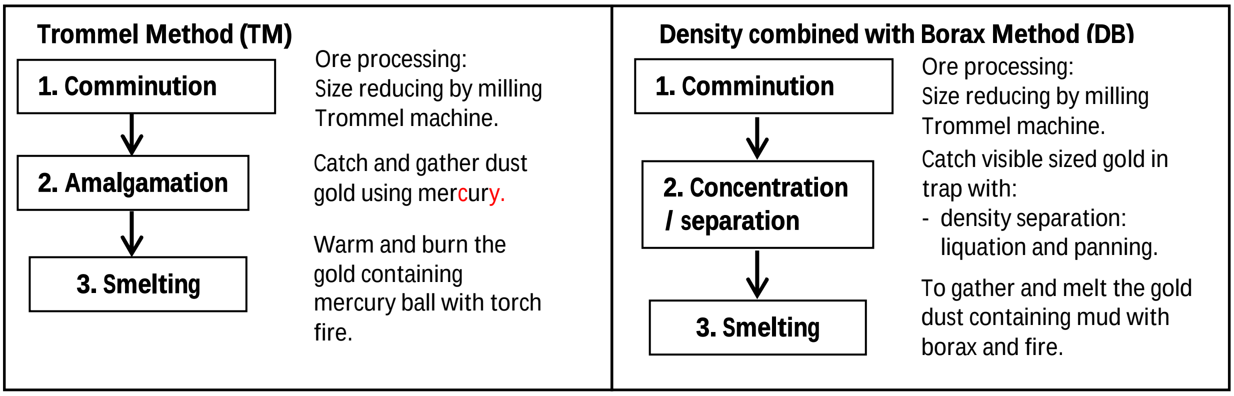

Figure 1. Diagram of CGM operation in gold production, Trommel Method (TM) (left) and Density Borax (DB) method (right).

People's gold miners are also identified with poverty (Buxton 2013; Labonne 2014), this part is included in the sustainability; economic dimension. A search has been carried out in this study, to find writings related to economic aspects in theme: feasibility of a people's gold mining business and the miner's income, but has not yet figured one. So that, in this research the economic aspects of the people's gold mining business are conducted. This economic dimension is closely related to the environmental and social dimensions, because the main reason for the continuesly and increase of the number of people who’s got involved in the people's gold mining sector is economic motivation and social inequality (Dansereau 2005; Erwiza 2005; Alisjahbana 2005; Zulkarnain et al 2008; Erwiza 2016). All of these negative impacts are not in accordance to the 5 pillars of Sustainable Mining Practices (SMP) (Laurence 2011), which is the principle of sustainable mining, recognized by the United Nations. SMP urges that a sustainable mining must be able to have a positive impacts on the 5 pillars: economic – ecology/environment - efficiency - work safety and health and the social community (Kumar 2014). We believe that the efficient technological interventions and replacing the mercury amalgamation process with an efficient gold capture method will have a significant impact on the environment and economic goals.

One of the oldest gold mining sites in Indonesia exists in Tasikmalaya District, in Cineam Sub-District, West Java Province. Mining activity there has been started since 1950 (www.tasikmalaya.go.id). The number of miners there significantly increased in 1997-1998 as the monetary crisis occurred, which caused numbers of unemployment, from massive dismissal of employment (Resosudarmo et al 2009). Most of them work at CGM sites, are using TM mercury processing method, unlicensed, which their locations are widely spread and remote. This condition caused difficulty for the Government to monitor, thus affecting the environment from uncontrolled mercury use. Mercury and other heavy metal content in soil and water samples coming from this mining site area, have exceeded the treshold of maximum content for heavy metal content, in local safety protocol (Widhiyatna 2005).

The aim of this paper is to examine the Trommel Mercury (TM) method, then to explain the description of technological interventions carried out by miners at the research site, in the effort to reduce the cost of production, and then, subsequently to simulate the use of the non-mercury Density Borax (DB) method, to then formulate numerical economic valuation data on stages of its gold production system into the economic dimension in the form of a simple business feasibility calculation and the miner's income. The focus is on the material processing stage. The other meaning is to conduct green economy based small scale/community gold mining, according to the 5 pillars of SMP (Laurence 2011; Kumar 2014). In general, this study is an effort to achieve more economic benefits, which are carried out in an environmentally protected condition, according to the principles of Ecological Economics theory (Constanza 1989).

Material and Method

Description of the study site. The research location was in the CGM area in Pasir Mukti Village, Cineam Sub-District, Tasikmalaya District, West Java Province, Indonesia (Figure 2). The number of residents of Pasir Mukti Village is around 2500 people, more than 15% of its residents work as gold miners. The number of gold mining pit in Cineam Sub-District is estimated at hundreds of pit and there are thousands of TM processing units. This study used a mixed methods approach, with the main method of Descriptive Analytical research (Silalahi 2009; Sugiyono 2008), and the research object was the gold production unit system, at local TM processing unit.

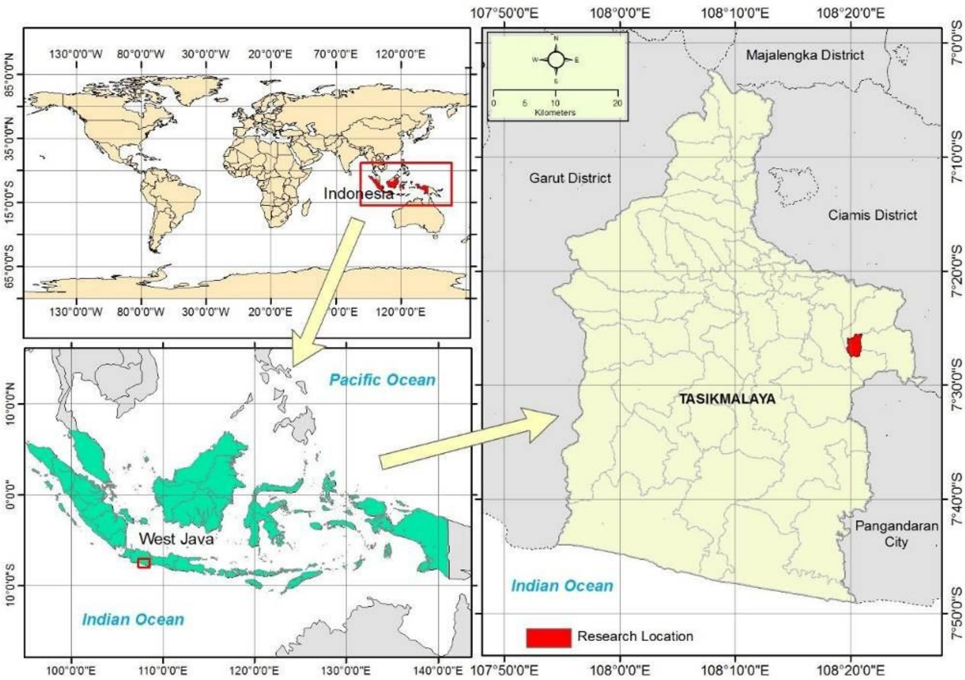

Figure 2. Research Location: Pasir Mukti Village, Cineam Sub-District, Tasikmalaya District, West Java Province, Indonesia.

Data collection was carried out according to periods of time, starting from the period before 1998, the period 1999-2001, and the period 2002-2018. Primarily data collection at the study site was conducted from August 2018 to January 2019, using the method of observation, in-depth interviews and questionnaires. For the period before 2018, the data were collected by in-depth interview method with data sources from the local miner's figures, and also supported by a literature study. The periodic data is then compiled to obtain performance data on technological and waste aspects. This gold production system data then being evaluated on each component in economy valuation, and calculated using the economic feasibility formula as well the calculation of the miner's income. The final stage, the calculation results is displayed in a graph, then the efficiency and aspects of waste are being compared. The waste aspects discussed are related to mercury and air pollution.

An alternative method of non-mercury material processing for gold extraction used in simulations is the Gravity Borax Method (GBM). This method has been used by small scale gold miners in Philippine for more than 30 years (Appel & Na-Oy 2012). The machine and tools are identic to the TM method, except GBM does not use toxic mercury. GBM Principle; Borax is combined with a gold trap, using the principle of gravity (Perez et al 2007). In this study it's called the Density Borax (DB) method, its working principle uses the power of water to push ore material through a gold trap (Appel & Jønsson 2010). Gold particle will be trapped at the bottom of the trap, while other materials such as iron, mud and sand will be washed away by the flow of water. This occurs because the density of gold is higher (Balasubramanian 2017). Borax is cheap and easy to find, and more gold is obtained through its use. Koster-Rasmussen et al (2016) found that the gold yield from the DB method was 14-16% more than those from the TM method use.

Data collecting. The results of interviews with local miners figures, initially some of the CGM miners of Pasir Mukti and surrounding areas used diesel fossil fuel driven engines (Heru 2018). This is allegedly because the TM processing location is near the mine pit, which is far from the settlement, so there was no electricity. The number of miners in a team is assumed to be 5-10 people for one pit. A cycle of gold production system is comprised of: an amount of material, water used, chemical use, machine use/TM machine, waste, energy use and gold result, working duration in 24 hours. Working time in a cycle of TM production was around by 4-8 hours, the average time = 6 hours. The content of gold at that time in nature was continued to decline. In 1999-2001, a technological innovation emerged, in energy efficiency. Solar fuel usage was successfully reduced by up to 50%, from a reduction in TM working time. Technological interventions that cause these efficiencies were the treatment of ore materials. The material is heated before being put into drum. So that when a hot material is doused with water, it will break easily and be reduced to flour, causing faster working time to reduce the size of the material at the comminution stage.

In 2002, it began to be widely used electrical energy for drum drive machines. This condition has continuesly to present day. DB method was implied in simulation at 2019. Matriculation of comparison of gold production systems following the time period of the year: < 1998, 1999-2001, 2002-2018 and 2019 simulation when the DB method was applied. To simplify the calculation, assumptions of numeric data for each gold production components were used in a working time called a processing cycle, in 24 hours; same type, amount and gold content of material processed = 400 kilograms, 1000 liters of water per set of TM processing units, 5 sets of TM processing units, and the average gold production yield of 3 grams per cycle. These data refer to the result of observations at the TM processing location in 2018 (Table 1).

Table 1

Gold production system of Trommel Method (TM), and Density Borax (DB) method

Components	*Period*			
	< 1998	*1999-2001*	*2002-2018*	*2019*
Method	TM	TM	TM	DB
Energy type	Solar fuel	Solar fuel	Electric	Electric
Amount	100 litters	50 litters	10.5 KWh	10.5 KWh
Time use	4-8 hours/24 hours. Average 6 hours	2-4 hours/24 hours. Average 3 hours	2-4 hours/24 hours. Average 3 hours	2-4 hours/24 hours. Average 3 hours
Cycle per 24 h	4	8	8	8

The daily needs data of residents at study site was obtained from the questionnaire, which is the majority 44% of 96 village community respondents answered; their daily needs of Rp. 50,000 (US$ 3.5) - Rp.75,000 (US$ 5.3) (Table 2). Slovin formula (Sugiyono 2008) was used to set the number of correspondens/sampels; from the population of 2500 habitants of Pasir Mukti village:

$$n = \frac{N}{1 + N.e^2}$$

where: n = number of sample;
N = population;
e = estimation error (0.1 or 10% used).

Table 2

Questionnaire with respondents of the Pasir Mukti Village habitants; daily needs

No	*Amount of daily needs*	*Frequency (N)*	*Percentage (%)*
	Pasir Mukti village community, Cineam sub district, District Tasikmalaya, Indonesia	Sample: 96	100
1	Rp. 0-50,000 (US$ 3.5)	12	13
2	Rp. 50,000 (US$ 3.5) - Rp. 75,000 (US$ 5.3)	43	44
3	Rp. 75,000 (US$ 5.3) - Rp. 100,000 (US$ 7)	41	43
4	> Rp. 100,000 (US$ 7)	-	-

***Data processing**.* Microsoft Office Excel was used as a tool to calculate, and display goals. Data requirements were primary quantitative that is numerical data from the observations and in-depth interviews on the gold production system. All of this data is also part of the production cost data component, and the economic valuation of each component of gold production is carried out, to obtain the value of capital. The monetary unit uses the Rupiah, with US$ as a comparative currency. The assumed exchange rates used in this study are: Rp. 14,000 per US$ 1. A simple formulation for calculating the profit consists of gold sales and total costs (TC). There are two components associated with TC: fixed costs (FC) and variable costs (VC). Defined, to simplify the calculation, all cost components are determined as fixed cost (FC). Profit figures, obtained from the difference between the sale of gold and total costs (TC). The formulas are:

$$TC = FC + VC$$

where: TC = total cost;
FC = fixed cost;
VC = variable cost.

$$\text{Profit} = \text{Sale of gold} - TC$$

Results and Discussion. This section consists of: 1) compilation of the Trommel Method with the Density Borax Method; and 2) cost analysis. In the compilation section, the production system component data discussed is: energy use, chemical use, production time, waste and gold yield. The component data is used as material for calculation of production costs (Noetstaller 1994) (Figure 3). The second part: cost analysis explains the economic calculations of gold mining business with data from the compilation of production systems of each period.

The compilation of the gold production system and economic valuation uses the TM and DB methods in periods

Energy use. Innovation in the treatment of ore materials in 1999 led to a faster working time to reduce the size of the material at the comminution stage can save by 50% the energy component. From the former consumption of 20 liters of fossil energy solar fuel/TM processing unit/6 hours of work (average of working time range 4-8 hours/cycle), reduced by it's half: 10 liters of solar fuel, and 2-4 hours/cycle (Table 3). The impact is that the miner's profits were increased. For economic calculations, the price of solar fuel assumes Rp. 8,000/liter (US$ 57 cent). In 2002, a number of miners switched to use electric energy. The TM processing unit has being relocated to residential areas, miners used village electricity. This change causes the miners' profits to continue increased. The environmental impact of air pollution due to solar fuel burning for 24 hour/day was reduced. The engine that uses electricity was water jet pump or dynamo. The electricity consumption is Rp. 15,000/set (US$ 1.07) per set processing units, then a total of 5 sets processing units = Rp. 75,000 (US$ 5.3)/cycle.

Table 3

Comparison of gold production system and production cost (data processing, 2019)

Period (year)	*Method*	*Process duration/ cycle (hour)*	*FC (Rupiah)*				*Total cost (Rupiah)*
			Energy	*Water*	*Material transport*	*Chemical*	
< 1998	Trommel Mercury (TM)	4-8	Solar Fuel 20 ltr x 5 units x @Rp. 8,000 (US$ 57 cent)/ltr = Rp. 800,000 (US$ 57.1)	0	Rp. 100,000 (US$ 7.14)	Mercury 10% used: 500grams = Rp. 500,000 (US$ 35.7)	Rp. 1,400,000 (US$ 100)
1999-2001	Trommel Mercury (TM)	2-4	Solar Fuel 10 ltr x 5 units x @Rp. 8,000 (US$ 57 cent)/ltr = Rp. 400,000 (US$ 28.5)	0	Rp. 100,000 (US$ 7.14)	Mercury: Rp. 500,000 (US$ 35.7)	Rp. 1,000,000 (US$ 71.4)
2002-2018	Trommel Mercury (TM)	2-4	Electric @Rp. 15,000 (US$ 1.07)/cycle x 5 units = Rp. 75,000 (US$ 5.3)	0	Rp. 100,000 (US$ 7.14)	Mercury: Rp. 500,000 (US$ 35.7)	Rp. 675,000 (US$ 48.2)
2019	Density Borax (DB)	2-4	Electric @Rp. 15,000 (US$ 1.07)/cycle x 5 units = Rp. 75,000 (US$ 5.3)	0	Rp. 100,000 (US$ 7.14)	Borax set: Rp. 375,000 (US$ 26.7)	Rp. 550,000 (US$ 39.2)

Chemical use. The results of calculations and compilation on the production system can be seen in Table 3. At 1 TM processing location, it is assumed to consist of 10 drums/trommel. The average Mercury that is poured into a drum = 50-100 grams, assuming the constant number is 100 grams. So for 5 sets of TM processing units used in the production system of 400 kgs of material amounting to 5000 grams/cycle. However, according to our observations, the amount of mercury that is used is equivalent to and burned below 10%, but in the calculation, the assumption of 10% mercury is used. Rest of the mercury, which did not being amalgamated, is taken and reused by miners. So the total amount 10% of mercury used is 500grams, with an average assumption price of 1 million Rupiah (US$ 71.4)/kg. The value of mercury purchase = Rp.500,000 (US$ 35.7). In many parts of the world, the amount of mercury used varies, because there is no specific standard. Borax used in the simulation in 2019 is assumed to be 1000 grams in total on 5 sets of processing units, with an assumed price of Rp. 250,000 (US$ 17.8), including additional costs for other materials such as soap, magnetic powder and so on, the total Borax set cost is Rp. 375,000 (US$ 26.7).

Time use. The working time at TM method material processing at the research location is quite efficient, compared to the processing time at other regions, initially in the period before 1998 = 4-8 hours/cycle in 24 hours (Table 3). The use of material heating technology could reduce time work up to 50% to 2-4 hours/cycle. That is, if initially within 24 hours of processing can be done 3-6x cycles, then after the intervention of material heating; processing time became 6-12x cycles. This condition could potentially increase profits, in the same work time per 24 hours. From observations, it is also noted that usually a cycle of material processing could be repeated to 2-3x, to get a smaller optimum grain size.

Gold production. The gold production of TM method at the observation site was about 3 grams in a production cycle (2-4 hours). There were 5 sets of TM processing units working within 24 hours (Table 4). The yield of gold varies, it depends naturally on the gold content in material, and also depends on the effectiveness of the processing method used (Perez et al 2007). In the same TM production time duration, the DB method can produce more gold (Koster-Rasmussen et al 2016). This result, according to Balasubramanian (2017) could be achieved due to the high effectiveness of gold separations using the gold trap, and also the role of Borax in supporting the process of unification of metals (Appel & Na-Oy 2012). For easy calculation of economic analysis, an addition in 10% of the gold yield on the DB method is used, compared to the gold production of the TM method = 3.3 gram.

Waste and disposal. The results of the observation and in-depth interviews with the figure of the miners (Heru 2018), in the period up to 1998, ore processing activities to extract gold in it produce waste mud, water, smoke containing mercury and smoke from burning solar. The period of 2002, waste in the form of mud, water, smoke containing mercury without smoke burning solar, because at that time, miners had begun to use electric energy drum propulsion.

Cost analisys. A comparison results of the TM and DB method calculations are displayed in Table 4. The cost of each components are grouped as Fixed Cost (FC). From Table 4, TC for the TM method for the period before 1998 was Rp. 1,400,000 (US$ 100), TC for the TM method for the period 1999-2001 was Rp. 1,000,000 (US$ 71.4), TC for the TM method for the period 2002-2018 amounting to Rp. 675,000 (US$ 48.2), and TC from the DB method amounting to Rp. 550,000 (US$ 39.2). The price of gold is used here assuming a flat of Rp. 550,000 (US$ 39.2) per gram, the price at the CGM mining site, used to calculate the economic value of gold from the sale (sale of gold) (Table 4). This price is reduced from normal gold rate in Indonesia in 2018 (around Rp. 700,000 or US$ 50/gram), because of the discount factors around 25% from: local gold content in material around 70-80% (assuming 20% discount) and 5% discount allocated for trader's profit. The gold production figure is determined at 3 grams for the TM method, and 3.3 grams for the DB method (10% addition).

Table 4

Matriculation of gold profit simulation

Period in years	*Methods and type of energy*	*Gold yield (gram)*	*Sale of gold @ Rp. 550,000 (US$ 35.7)*	*Total cost*	*Profit*
< 1998	TM solar fuel	3	Rp. 1,650,000 (US$ 117.8)	Rp. 1,400,000 (US$ 100)	Rp. 250,000 (US$ 17.8)
1999-2001	TM solar fuel	3	Rp. 1,650,000 (US$ 117.8)	Rp. 1,000,000 (US$ 71.4)	Rp. 650,000 (US$ 46.4)
2002-2018	TM electric	3	Rp. 1,650,000 (US$ 117.8)	Rp.675,000 (US$ 48.2)	Rp. 975,000 (US$ 69.6)
2019	DB electric	3.3	Rp. 1,815,000 (US$ 129.6)	Rp.550,000 (US$ 39.2)	Rp. 1,265,000 (US$ 90.3)

In TM method, for the period before 1998, a sale of gold of Rp. 1,650,000 (US$ 117.8) was obtained. The sale of gold figure is also the same for the TM method calculation results for the period 1999-2001 and the TM period for 2002-2018, according to the 3 gram gold production results. In the 2019 period, when the DB method was intervened, a gold production of 3.3 gram resulted in a sale of gold of Rp. 1,815,000 (US$ 129.6). From numeric simulation, the profit from TM method for the period before 1998 was Rp. 250,000 (US$ 17.8), the profit from using the TM method for the period 1999-2001 was Rp. 650,000 (US$ 46.4), profit from using the TM method for the period 2002-2018 was Rp. 975,000 (US$ 69.6), and profit from material processing using the DB method when intervened in 2019 were Rp. 1,265,000 (US$ 90.3) (Table 4).

Economic aspect. The calculation results have shown that in the same electrical energy usage, the 2019 period that simulated the use of the DB method can generate a profit of Rp. 2,265,000 (US$ 90.3) or 33% more than the TM method: Rp. 975,000 (US$ 69.6). This figure is obtained from the efficiency of the chemical component, namely the replacement of mercury with cheaper borax, and the component: sale of gold production which increased 10% to 3.3 gram. Increased profits are proportional to the decrease in TC and increase in sales of gold (Figure 3).

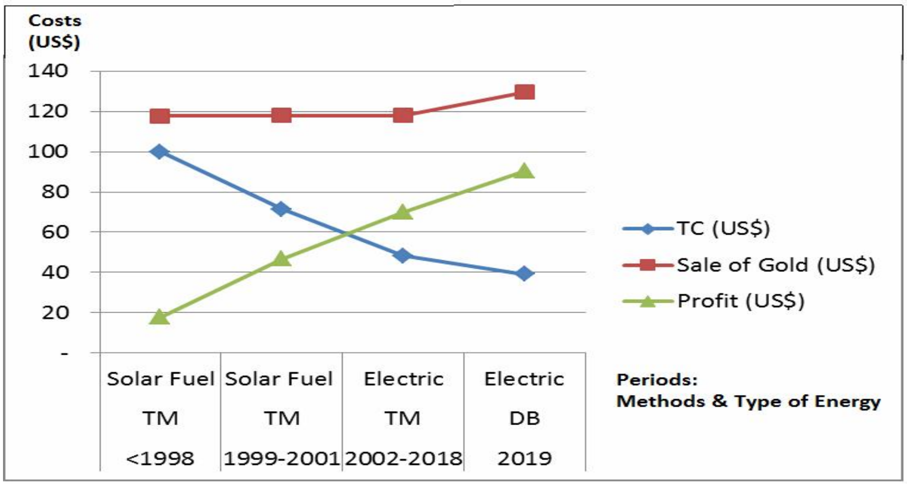

Figure 3. Graph of total cost (TC), sale of gold and profit in a time line, Trommel Mercury (TM) method and Density Borax (DB) method.

The main components of TC that have the greatest value are: chemicals and energy. In the period before 1998 the energy component was the highest part of working capital (57.1%). During the period 1999-2001 there was a change, with the largest amount of capital costs being the chemical component (50%). For the period 2002-2018, the value of capital costs for the purchase of chemicals is 74%. In the period of 2019 when the DB method was simulated, the cost of purchasing chemical components by 68%. This condition could be achieved from the absence of mercury purchase, same condition as the implication of DB method in CGM sites in Mozambiq (Stoffersen 2018) (Figure 4).

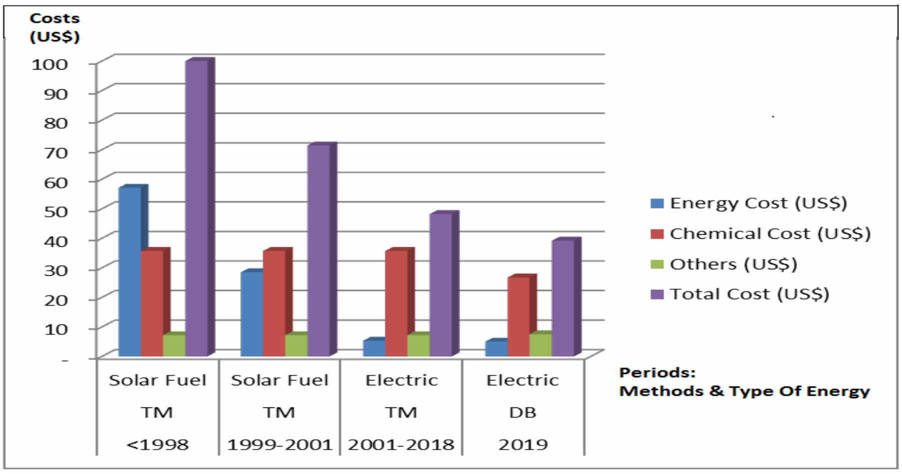

Figure 4. Ratio of cost for: chemical, energy and other capital cost components compared to TC.

In Table 4, we could see the profit of each method and each period: Rp. 250,000/US$ 17.8 (period < 1998), Rp. 650,000/US$ 46.4 (period 1999-2001), Rp. 975,000/US$ 69.6 (period 2002-2018) and Rp. 1,265,000/US$ 90.3 (period 2019). This data then is used to simulate the wage of Miner. For information, at research location CGM Pasir Mukti, a team usually has 3-15 workers. Assuming there are 10 Miners in 1 team for 1 pit, the money earned per single Miner per processing cycle : in the period of 1998 amounting to Rp. 25,000 (US$ 1.78), period 1999-2001: Rp. 65,000 (US$ 4.64), 2002-2018 period: Rp. 97,500 (US$ 6.96), and simulation for the 2019 period: Rp. 126,500 (US$ 9.03). So if we compare these data simulation to data of daily needs of local people (Table 2), in the period 1998, the income of miners was below the daily average needs of local resident's; which is the amount of Rp. 50,000 (US$ 3.5) – Rp. 75,000 (US$ 5.3). In assumption this simulation did not accomodate the other factors such: inflation of gold price – currency rate – chemical price and fuel price, this condition can be categorized as poverty. Income of miners in other periods: 1999-2001, 2002-2018 and 2019 = adequate or sufficient for the daily needs of the people of Pasir Mukti Village or not categorized as poverty. Thus it can be notified that the results of research simulations at the CGM Pasir Mukti village location have refuted the theory of Labonne (2014) and Buxton (2013) that people's gold mining is identic to poverty.

Environment aspect*.* Technology aspect in gold extraction consists of energy, time, water use, production and waste components. During the period 1999-2018, there were several technological interventions implemented by the miners at CGM Pasir Mukti, Tasikmalaya in an effort to improve benefit, by the efficiency at production cost. Among them: material heating before it is processed, then transformation of energy use from solar fossil energy into electrical. And in 2019, the simulation of non-mercury DB method use. All these technological interventions have driven changes in the value of technological components: energy, time, water use, gold yields and waste. These changes then impacted the environmental aspects, such: material wastes and chemical wates on land and waters, as well on air quality. The type of energy use has an impact on the GHG system, and also negatively affects the process of global warming / global warming. According to BMKG (2018), Indonesian Agency for Meteorology and Geophysics, the air quality is the air content that has certain pollutants related to human health.

In this research, aspects of waste / environmental impact discussed are pollutants of CO_2, specifically related to carbon emissions. The calculation is carried out on the aspect of environmental impact, specifically on the impact of mining activities on the air. The results of the calculation of the conversion of energy used in scope of a small scale industry of material processing for gold extraction with 5 sets of processing units, part of 1 group of miners on 1 mine pit. Pollutants that are recorded are the burning of solar fuel and the use of electrical energy in the material processing unit, which is associated with the GHG effect and global warming. This data then being calculated, resulting the potential carbon emissions released. The calculation of carbon pollution from solar combustion results is used to obtain CO_2 emission figures. Calculation of carbon emissions is generally done for period: 1 year. The formulas for calculating the emission of fuel use are:

CO_2 tons e for fossil energy fuels =
amount of fossil fuels (liters) x Conversion factor (Solar) x GWP / 1000

CO_2 tons e for electricity energy fuel
total electricity consumption (KWh) x conversion factor (kg / KWh) / 1000

The global warming potential (GWP) figures are based on the / International Panel on Climate Change (IPCC 2003) output list, the GWP value for solar fuel = 1. Burning solar fuel produces CO_2 gas, the value of carbon emissions is obtained from the conversion factor of Defra / Department for Environment, Food and Rural Affairs (Defra 2010) of the United Kingdom, amounting to 2.6413 kgs / liter solar fuel. The use of electrical energy at the processing site does not cause direct environmental effects of smoke air pollution. However, the use of electrical energy still has a value of its conversion factor to carbon emissions, namely from the burning of fuel or coal in energy production in the power plant. Loaded in the Decree of the Minister of Energy and Mineral Resources number 3783/21 / 600.5 / 2008 (Ministry of Mining Indonesia 2008), which is 0.891 kgs / KWh. Calculations of carbon emissions can be found in Table 5.

Table 5

Comparative data on energy and chemical use and results of calculation for the amount of carbon emissions

Components	Period			
	< 1998	1999-2001	2002-2018	2019
Method	TM	TM	TM	DB
Energy	Solar fuel 100 litters	Solar fuel 50 litters	Electric 10.5 KWh	Electric 10.5 KWh
Pollution	Smoke	Smoke	Non smoke	Non smoke
Emission	2.6413 kg L^{-1}	2.6413 kg L^{-1}	0.891 kg kWh^{-1}	0.891 kg kWh^{-1}
Time use	4-8 hours/24 hours. Average 6 hours	2-4 hours/24 hours. Average 3 hours	2-4 hours/24 hours. Average 3 hours	2-4 hours/24 hours. Average 3 hours
Cycle per 24 hours	4	8	8	8
Emision per processing cycle	0.26413 kg	0.132065 kg	0.138668 kg	0.138668 kg
Emision per 24 hours	1.58478 kg	1.05652 kg	1.09346 kgs	1.09346 kg
Emision per year (365 days)	0.578 ton	0.385 ton	0.399 ton	0.399 ton

In the period before 1998, the amount of solar fuel used in one cycle (4-8 hours) of 400 kgs material processing using TM processing method = 100 liters of solar fuel (Table 5). Then the value of carbon emissions produced in one material processing cycle for 4-8 hours amounted to: 100 liters x 2.6413 kgs/liter x 1/1000 = 0.26413 kgs/cycle (4-8 hours). Assuming the processing time is set in average of 6 hours, and processing is done in full 24 hours, then there are 4 processing cycles in 24 hours, therefor the total energy = 4 x 0.26413 kgs = 1.58478 kgs / 24 hours. Within 1 year the carbon emissions were generated at = 1.58478kgs x 365 days = 578.44447 kgs or 0.578 tons of CO_2 emissions / year. In the period 1999-2001 which still uses the TM method, the amount of solar used per processing cycle was half: 50 liters, so the CO_2 carbon emissions were: 0.132065 kgs/processing cycle. Processing time is shorter by 50% to 2-4 hours/cycle, assuming the average processing time is 3 hours, then there are 8x processing cycles in 24 hours, the total amount of emissions = 8 x 0.132065 = 1.05652 kgs / 24 hours. The number of tons e emissions in 1 year = 1.05652 kgs x 365 days = 385.62 kgs or 0.385 tons of emissions/year. The 2002-2018 periods also uses the TM method, but miners have used electrical energy, producing daily carbon emissions of: (10.5 KWh x 132.065 kgs /KWh) / 1000 = 0.138668 kgs per 400 kg material processing cycle. Total emissions = 8 x 0.138668 = 1.09346 kgs / 24 hours or 0.399 tons / year. The 2019 period is simulated with the same number of KWh electricity as the 2002-2018 periods.

Mercury that is used per processing location TM = 500 grams. In the full 24 hours of material processing, with an average assumption of 4 hours/cycle with a total of 400 kgs of material, there are 6x processing cycles. Then the amount of mercury used and then burned in smelting stage = 500 grams x 6 cycles/24 hours = 3000 grams of mercury / 24 hours, or 1,095,000 grams / year. The interview results show that there are 4000 sets of TM processing units in the research location and its surroundings (Heru 2018). A massive number of mercury released and carbon emissions will be obtained that is valid enough if research and calculations are done using numerical data for all TM processing units on site. From this TM's units massive numbers, the potency of mercury waste to poison Miners and the living things around is increased (Pressly 2013), and potential carbon emission released to nature is also massive (AMAP/UNEP 2013). For this reason, more comprehensive research at same location is needed.

In brief, starting from the initial period, prior to 1998, mining activities at CGM Pasir Mukti in sample 1 of the Mining groups with 5 sets of TM material processing units, obtained the value of the use of mercury burned at 1,095,000 grams annualy and annual carbon emissions of = 0.578 tons. In the period 1999-2001 the amount of carbon emissions released into the air for 1 year was reduced to 0.385 tons, presumably caused by the reduction in the amount of solar fuel used due to innovations in material processing technology at that time. Next, in 2002 a massive evolution of energy use for drum drives engines, from the use of solar fossil fuels to electricity. This is significant energy efficiency. In the periods of 2002-2018, the amount of carbon emissions from the use of electrical energy = 0.399 tons per year. Then in the period 2019, the calculation was simulated for non-mercury method: DB, the carbon emission rate is as large as those produced in the period 2002-2018. The technology innovations that local miners have done are undirectly conformed to the United Nation energy efficiency program (UN Foundation 2007).

Conclusions. The usage of TM methods that consumes solar fuel and mercury chemical plays a major role in the degradation of environmental quality as well the health and safety. Through technological interventions, there are several advantages and benefits to the environmental aspects as well the economic aspects. Local miners did the innovations on processing methods: material heating and transformation of energy use from solar fuel to electric. The usage of DB method as a material processing method for gold extraction in a simulation, can keep the environment safe from mercury contamination. The DB method can also reduce leakage of natural resources through the increased of gold production. The usage of DB method can also increase the economic benefits for miners from the increasing gold yield and the efficiency of production costs. In simulation, the calculation on gold mining business at the CGM location in Pasir Mukti Village, Cineam District, Tasikmalaya Regency, Indonesia shows that this community business is feasible, also could meet the daily needs of the local village community. This study supports that the Density Borax (DB)/GBM method is most appropriate to replace the Trommel Mercury (TM) method and encourages Indonesian Government to implify widely the DB method.

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