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RICHARD SARFO

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TITLE

THE HISTORICAL DEVELOPMENT OF THE ILLEGAL MINING SECTOR IN GHANA: SYSTEM DYNAMIC MODELLING APPROACH TO FORMALIZING THE SECTOR

AKNOWLEDGEMENT

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ABSTRACT

Illegal gold mining is arguably the most challenging national issue in Ghana today. This unbridled rush for gold has unleashed inestimable damages to the economy of Ghana including child labor, environmental stress, loss of tax revenue, and health crises in mining communities. As a limit to growth commodity, gold in Ghana will eventually become exhausted, either sooner or later. The ideal condition will therefore be to formalize the sector in a practically sustainable way. This thesis considers how the small-scale mines in Ghana can be formalized using the self-organized type of governance. In this system of governance, the indigenous miners are actively involved in creating and enforcing rules that govern the sector. When this happens, resource boundaries and resource users are clearly specified, effectively excluding foreigner from partaking in small-scale mining activities. Using a system dynamics model as an analytical tool, results show what amount of tax is needed to sustain the small-scale mining sector whilst ensuring a thorough care for the environment by the miners themselves. A win-win result ensues as the sector will provide a good measure of income to investors, greatly reduce the unemployment rate, whilst government will be able to receive a modest income as revenue from tax for the future of the mining sector.

CONTENTS

1.0 INTRODUCTION AND BACKGROUND

1.1 Introduction

This study seeks to address one the most (if not the most) challenging issue on the soils of Ghana today. The challenge in question is the illegal mining activities which is bedeviling the Artisanal and Small-Scale Mining sector of the country. Like a bad and never healing sore, this issue of illegal mining popularly known as galamsey (a compound word which literally means "gather and sell") has been tormenting government, concerned citizens and policy makers alike, especially since the hike in gold price in 2008.

The study commences by revealing how the government of Ghana has attempted to sanitize the Small-Scale Mining sector with various interventions and how the sector has responded to these measures. Then, it highlights some challenges confronting the nation due to the galamsey menace at hand. It further discusses the system of management that would probably be ideal for a sustainable management of the gold resource, which is the Self-Organized regime. This regime clearly defines users and boundaries of the resource making it easy to limit the influx of foreigners into the sector (Ostrom, 1999). It also ensures that, the indigenous people are actively involved in designing rules that govern the management of the resource. As revealed in settings where this style of management has been tested, the users will most likely respect the rules and ensure the smooth functioning of the rules since they have a hand in enacting these regulations. It is evident from the study that, the unbridled nature of returns on investment is the motivation behind this menace and an introduction of reasonable tax would likely provide win-win results for both the government and the illegal miners.

1.2 Background

As one of the earliest and most important industries in human history, mining has been a core part of our lives until today. Any mineral that is taken from beneath the earth surface, that is, the act of poking into the earth (surface or underground) to extract minerals, is mining (Amponsah, 2011). About 100 million people in the world depend on small-scale mining for a living (World-Bank, 2013). There are no uncertainties about the importance of mining resources such as gold, diamond,

manganese. Their availability in a country can contribute significantly to economic growth and development.

Ghana is blessed with enough of natural mineral resources, especially gold. Truth about this matter is reflected on how this country was formerly known as – Gold coast – due to the large deposit of gold on its shores. Usually the second largest gold producer in Africa (behind South Africa), recent reports indicates that Ghana has been the largest gold producing country in Africa since 2019. (Smith, 2019) and places itself at the 7th position on the list of world gold producers (Holmes, 2020).

But operational challenges such as finances, robust institutions and legal framework for managing the sector was very initially confronting. This resulted in a no new mine being opened for about four decades until 1980.(Tienhaara, 2006). However, a flood gate of mines creation was opened when the government intervened with policies such as the Economic Recovery Program (ERP) in 1983. (Hilson, 2004). Among the objectives for the Economic Recovery Program included the enticement of investors into the mining sector, alongside some other key areas to help boost the general economy of the country (Addy, 1998).

Evidence of the success story of this intervention is a matter of records. When referencing information disclosed by the Ghana mineral commission, Aryee recounted that, the mining industry received about US$4 billion of private investment capital. This money, among other things, were purported for mineral exploration, setting up of new mines and also for the improving those already in place (Aryee, 2001). Among the then existing mining companies whose transformation became clearly noticeable was Ashanti Goldfields Company. According to Nikoi (NIKOI, 2015), Ashanti goldfields mines was a small entity prior to the ERP reform. Soon after its implementation, Ashanti Goldfield Company became a universal mining giant, being counted as one of the multinational gold companies and appeared on the list of six international financial markets. Some 237 mining companies joined the pool of mines from when the reform was introduced until 1998. (Aryee, 2001).

The reformation also catalyzed the mining sector's contribution to domestic export dividends. From less than 20% in the mid-1980s, the sector's contribution to export earnings ramped up to

40% in 1992 and has been the best performing sector of the country since. (Aryee, 2001). Thus far, the mining sector has come of age by means of the strategic investments made.

Furthermore, a gist of the value of the small-scale artisanal mining sector is evident in the total workforce is employs. Today, this sector locally known as Galamsey (a composite word derived from 'gather' and 'sell') employs about one million people and supports just about 4.5 million more (about 15% of the Ghanaian population) (McQuilken & Hilson , 2016). Artisanal and Small-scale Mines contributes to more than 60 percent of Ghana's total mining labor force (Leudi, 2019). In 2013, gold exports from ASM operators accounted for 34 percent of Ghana's total gold export, which equaled the total contribution of the three largest multinational companies in the country. (Abdulai, 2017). It is indeed a great anchor to the mining and mineral sector and a key ingredient to the entire economy of the nation at large.

1.2 Problem Identification

Mining activities in Ghana can be grouped into small-scale and large-scale mining. Small-scale mining usually requires less capital investment and mostly undertaken by a group of handicraft workers. It is important to note that, while foreigners are the main actors of the large-scale mining sector in Ghana, small-scale mining activities are statutorily restricted to only Ghanaians. (Leudi, 2019).

However, despite the high degree of sanity in the mining sector as a result of the interventions discussed above, one of the most noteworthy policy challenges in Ghana today spins around the question of how best to formalize and maximize the benefits of the Artisanal and Small-Scale Mining (ASM) sector while concurrently curtailing the disturbing setbacks bedeviling it.

Although Ghana has had a formalized process for engaging in ASM on legal basis since the late 1980s, an estimated 85 percent of small-scale miners in the country operate on illegal basis. (Abdulai, 2017) Popularly known as galamsey, illegal mining has had significant adverse implications in Ghana, including but not limited to the following.

Notably among the many challenges posed by illegal artisanal mining in loss of revenue. While the extent of galamsey has been difficult to measure, it is estimated to have cost the country about

$2.2 billion in 2016 in uncollected tax alone (Bird, 2017). Similarly, illegal gold exports to the UAE – often reported to be carried in hand luggage on planes – have raised worrying concerns. Just in 2017 alone, the President of the country, Nana Akufo-Addo, observed a $5 billion discrepancy between trade statistics and actual gold exports. (Nwokolo, 2019). There are widespread claims that gold is mostly smuggled to China and India. (Lewis, et al., 2019). This means that, the informal nature of the sector is costing the country billions of US dollars each year.

Again, when referencing Ampomah (Executive Secretary of the Water Resource Commission), Mubarik asserted that, illegal mining activities accounts for about 60% of water pollution in Ghana (Mubarik, 2017). Arguably, it is claimed to be the most worrying challenge confronting water bodies in Ghana is galamsey. (Amagyei, 2017). Streams, lakes and rivers alike in small-scale mining zones are hugely polluted by mercury and other machineries used in digging for gold. The consequence of this incalculable damage to rivers and other water bodies is reflected in the most current anti-galamsey protest called "operation halt galamsey" spearheaded by the president of the nation. In this operation any suspected excavator and or other mining equipment are set ablaze by the military crackdown team when they chance upon them around water bodies. This recounts the gravity of pollution illegal mining has done to water bodies in the nation. (Ackaah-Kwarteng, 2021)

For example, major river bodies such as Pra, Birim and Offin rivers that are primary source of fresh water supply for most part of the nation (Ashanti, Eastern and Central regions respectively) has undergone severe polluted (Alhassan, 2014). Some galamsey operators also invade the main intake points of the Ghana Water Company (GWC) of these primary water bodies to undertake their activities, thereby blocking the supply of water. Others also divert these water course for mining purposes. The intensity of the problem is summed up in the comment made by Carl Fiati, the Director for Natural Resources and the Environmental Protection Agency (EPA). Allotey (Allotey, 2018) quoted Carl Fiati on the danger illegal mining activities poses on water supply saying "*We anticipated this problem long time ago that it's going to come a time when we continue the way we are going as a country, we are going to destroy all our water bodies and import water for drinking*," Mr. Fiati added. '*Already, some major water treatment plants have been shut done due to toxicity of water quality and water levels. Notably among them are the Abessim and Kyebi*

water treatment plants.' (Allotey, 2018). The immeasurable effect of illegal mining on the water bodies in the nation has rightly been tagged as 'the dangerous couple' by Plá, (Plá, 2020). Aquatic lives too are in serious danger and many species are at a brink of extinction, to say the least, due to the continue growing intensity of water pollution by illegal mining activities.

Closely linked to the water crises is health predicaments. For example, cyanide which is a core ingredient for gold extraction can enter nearby streams and other water bodies close by and eventually victimizes those who depend on it. A study has revealed that cyanide spills from a mine has appeared in the water supplies of adjacent homes. (Koberstein, 2005). Evidence from galamsey communities indicate high occurrence of lung illnesses among people who have direct or indirect relationship with galamsey. In Konongo and Odumase in the Ashanti Region, for instance, a strange lung disease killed over 100 persons. – majority being illegal miners – between 2010 and 2013 (Alhassan, 2014). According to doctors, this mysterious lung infection (chronic obstructive airway) is connected to the use of mercury by those who work in galamsey mines. (Alhassan, 2014). Uncovered pits serve as a bleeding grounds for mosquitoes too. Hence malaria is very common and constantly on the rise in these communities. (Castellanos, et al., 2016).

Also, many hundreds of children work in the small-scale gold mines in risky conditions, despite both Ghanaian and international law frowning on child labor. Most children are aged 15 to 17, but younger children are fully present in illegal mines sites too. The youngest child interviewed by Human Rights Watch was 9 years old. (Kippenberg, 2015). One common, yet dangerous means of gold processing is by means of mercury. Children working with gold are often exposed to high levels of mercury. Mercury is known to attacks the central nervous system and can cause lifelong disability, including brain damage, digestive and immune systems, lungs and kidneys and even death (WHO, 2017). It is sad to say that the country is sacrificing its precious future as well as the lives of the future leaders for a terrible life now.

Mining affected the education of children in many fronts. Too much time is being spent by most children working at galamsey concessions, which later results in making school attendance impossible (Azumah, 2018). Classroom work is hugely affected since children are almost always exhausted before class lessons begins in the morning. As noted, and reported by Amagyei, child (school going aged children) involvement in illegal mining activities has led to a significant

decrease of performance they put up in the Basic Education Certificate Examination (B.E.C.E). He further commented on the fast-paced rising rate of school drop-out in recent years in communities where galamsey activities are carried out. (Amagyei, 2017).

Again, another severely affected component of the environment by galamsey activities are vegetation cover, arable lands, and the ecosystem in general in Ghana (Eshun, 2017). As observed by Novoa, the recent growing rate of galamsey-driven deforestation is very disturbing. The nation has lost as much as 15,819 hectares of arable land and forest just in three years, from 2015 to 2018. All other species and lives residing in this depleted zone are threatened and displaced consequently. (Novoa, 2020). It is reported to cost an estimated $250 million to recover lands and waterbodies destroyed by galamsey in Ghana's Western region of the nation. (Nwokolo, 2019) . Zooming in on the effect of illegal mines on the environment, it is critical to reflect on how topsoil needed for agricultural production has been under threat. Heavy and modern mining equipment are causing a great deal of harm to the topsoil that support our agriculture production. (Agbesi, 2017). The illegal 'galamsey' activities however contribute in no small measure to hunger being experienced in some farming communities engaged in producing cash crops such as cocoa, oil palm, coconut, and oranges in Ghana. (Agbesi, 2017). Since it takes several years for soil to regain its fertility, only time can estimate the length of the famine which has already set in galamsey communities when it becomes fully ripe.

Furthermore, galamsey is also a death trap for miners and unsuspecting farmers within the mining communities, as they sometimes find themselves drawn to huge pits which are often left uncovered or unclaimed. (Eshun, 2017). Famous among the many incidences is what happened on November 12, 2009, in Dompoase, Ashanti Region of Ghana. A collapse occurred in an illegal, privately owned gold mine. Up to 30 miners were prospecting the mine when it collapsed due to a landslide. At least 18 workers were killed in the collapse, including 14 women and the owner of the mine. (Wikipedia, 2011). The most recent one occurred in 26th of May 2021, where more than forty illegal miners were trapped in a collapsed galamsey pit in Breman, a mining community in the Upper Denkyira West District of the Central Region. Sources indicate that, three dead bodies have been retrieved so far with others numbering around forty still yet to be retrieved. (MyJoyOnline, 2021).

Furthermore, one notable export commodity Ghana produces is cocoa. Sources indicate that, Ghana is the world's second largest cocoa exporter, and contributes about 20 percent of the world's supply. (Abbadi, et al., 2019). More than 70 percent of cocoa beans come from West Africa from Ivory Coast, Ghana, Nigeria and Cameroon. pro besides, Ghana and Ivory Coast alone produce fifty percent of the world's cocoa supply (Shahbandeh, 2021). Cocoa contributes enormously to the economy of Ghana. It closely follows mineral as the second foreign exchange earning of the country, supporting about four million lives in Ghana. (Shereen Abbadi, 2019). Since the record-setting amount of cocoa production, (over one million tons in 2011), cocoa production has on a downward trend, with a drop to 740,000 tons in 2015. This decline rate in cocoa production in Ghana is attributed to increasingly increasing growth rate assumed by illegal mining activities. (Taylor, 2018). "*Galamsey is the biggest threat to cocoa production*," Pomasi Ismael, the chairman of a cocoa buyers' collective, as quoted by BloombergLaw.com. (BloombergLaw.com, 2018).

Like a bad and never healing sore, this nuisance has been a big blow to today's economy of Ghana, and it has all the features of a potential catastrophe for the future. As a result, illegal ASM operators are labeled as a 'menace', 'threat', 'problem', 'challenge', and 'nuisance' (Abdulai, 2017) whose presence should be 'flushed out' with maximum force (Hilson, 2014) The government in response to this has come out with a lot of dynamic policies to curtail this menace among which includes clamping down on galamsey concessions, easing licensing protocols and increasing surveillance of illegal mining activities by means of the drone technology. It is unfortunate to know that these policy measures have not lived up to their billing.

1.3 Research Challenges

Most of the activities engaged by galamsey are under the shadow since this whole sector is deemed illegal. Hence, there is not enough concrete data about their activities. For example, many people engaged in this act do not want to speak up or give any sort of information due to security reasons. The second challenge has to do with my inability to travel to galamsey sites and communities for collecting primary data for this study due to corona travel restrictions. So I depended largely on secondary data and sometimes guided assumptions for this study.

1.4 Research Objectives and Research Questions

The objective for this research is to find out why illegal gold mining in Ghana continues to flourish and how can this menace be regularized. To achieve this objective, the following questions would be answered.

b. Why does the illegal mining sector continue to flourish despite the government's intervention policies?

c. Which robust policy can formalize the Artisanal Small-Scale Mining sector?

d. How does formalization of the sector help to reduce the environmental challenges associated with the illegal mining sector?

1.5 Data Collection

Due to travelling restrictions as a result of corona virus pandemic, the researcher could not take a trip for primary data collection. Hence, the study was primarily conducted with data from published research database (newspaper reports, written interviews and expert knowledge of key participants in the system and also from numerical data the written). Where data seemed conflicting, the researcher called to personnel in Ghana who are noted to have insight in the illegal mining operations for clarity.

1.6 Research Methodology

With the above research questions and objectives in mind, a research method that comes handy is System dynamic. *System Dynamics is a perspective and a set of conceptualize tools that enables us to understand the structure and dynamics of complex systems. It is also a rigorous modelling modeling method that enables us to build formal computer simulations of complex systems and use them to design more effective policies and organizations.* (Sterman, 2000). The approach commences with identifying and defining a dynamic problem, hypothesizing and analyzing the problem, followed by modeling stages, to building confidence in the model and its proposed policy(s). (SDS, 2021). System dynamic method of problem-solving focuses on using available information and realistic data to build a quantitative model capable of typically referencing the behavior of the problem at hand. Discernments from this built model is then used to create a new

policy strategy or update existing ones. Dynamic theoretical framework is the foundation of the system dynamic modelling method. This means that connections involved are built on causality, feedback systems and delay structures, model boundaries, and a unit of time (Deckers, 2017). The conceptual framework is based on data collected from literature, interviews, and observations. According to Turner, system dynamic modeling is a distinctive approach for probing into the challenges associated with natural resources due to their inherent complicated behavior is system dynamics modelling technique. (Turner, et al., 2016).

1.7 Research Ethics

A great deal of integrity was employed for the construction of model and analyzing it. The modelling process fully adheres to the standard set by the system dynamic society. Though this thesis was conducted primarily on secondary data, quotes and references used were given the needed ethical consideration they deserve. Insights and conclusions derived from this study are reported with all honesty.

CHAPTER TWO HYPOTHESIS

2.1 THEOROTICAL FRAMEWORK

2.1.1 What Is Tragedy of The Commons?

The tragedy of the commons is an economic dilemma in which every person has a good reason to have a fair share of a resource, but at the expense of every other individual -- with no way to prevent anyone from consuming. (Boyle, 2020). This tragedy is usually associated with common pool resources. Common-pool resources as defined by Ostrom is characterized by complexity of prohibition and create limited amounts of resource units so that one person's use take away from the remaining amount of the resource others can obtain. (Ostrom, 1999). Examples of common resources include irrigation systems, fishing grounds, pastures, forests, water or the atmosphere, and other mineral resources like gold, diamond and bauxite.

Sustainable management of a non-renewable natural resources has been a vastly disputed subject among researchers and policy makers, including governments and ordinary citizens alike (Hardin, 1968). Our quest to effectively manage minerals from getting into extinction or from being abusively used has led to a wide range of managerial strategies. Prominent among these strategies include privatization (Sethi & Somanathan, 1996), government control (Sethi & Somanathan, 1996) and self-organized regimes – when resources are self-regulated by indigenous users (Ostrom, 1999).

Self-organize management strategies have shown themselves to be broadly successful while the other two forms of managerial strategies, government control and privatization, have failed in some instances (Isaza, 2013).

In his publication, "State Policy and Pasture Degradation in Inner Asia", Sneath (Sneath, 1998) contrasted the efficacy of self-organized group-property regime and central government management based on the results of these two management strategies of grassland management in China, Mongolia and Russia. It became evident from the results that, the resources managed by government (China and Russia) shows more degradation compared to that managed by group-property institutions (Mongolia).

Both China and Russia on their part adapted state-owned approach whereas Mongolia adopted Agricultural-cooperatives approach in which the indigenous people mutually engage in farming operations as a group. By restructuring the managerial style, China in recent times has adopted privatization by giving portion of the agricultural land to individuals. Eventual results indicated that, whilst only one-tenth of the Mongolian pastureland got degraded, only about a quarter of the Russian pastural land remained. Also, less than three-quarters of the Chinese section has survived degraded. The lax in both privatization and government-controlled management strategies are exposed in here.

Superiority of the Self-Organized regime is also obvious in the South Indian's irrigation system study conducted by Bardhan. (Bardhan, 1999). He studied about quality of irrigation systems managed separately by both by the government and the locals. Results of his study revealed that, overall well-being of canals managed by the government is considerably lower compared to the one the farmers themselves. He also reported that, among the 480 farmers interviewed, the farmers were more compliant to rules governing the use of the irrigation system when they took part in formulating those laws as opposed to when the law was imposed on them by a higher authority. Another key highlight of his study was that, among the communities considered, there was frequent violation of rules where government agency decides the laws and farmers contribution to the local village fund was very little.

In a study entitled 'An institutional approach to the study of forest resources' Poteete and Ostrom came to a conclusion that is consistent with Bardhan's study. (Poteete & Ostrom, 2002). In the study an assessment was made between the kinds of organizational strategies involved in forest management. They concluded from their research that when indigenous people, who have the mandate to formulate regulations, have adequate knowledge about the state of a resource (forest in their case and any other common pool resource), and perceive a potential sustainable profit to overshadow the perceived cost for maintenance, there is a higher chance of forming effective mechanisms to take care of the resource in a more sustainable way.

These examples contribute to the believe that local common pool resource users are capable of effectively managing the resources they depend on if they are given the chance to formulate regulations or are actively involved in formulating them.

2.1.2 Threats to Self-Organized Regimes

However, self-organized regimes, just as any other managerial strategies, are not without setbacks.

With mutual trust (a key foundation of self-organized regimes) under threat due to rapid settlements, this system of management will sooner or later get dissolved in areas where migration rate is high. (Baland & Platteau, 1996).

Another threat has to with the government's quest to enforce or ensure uniformity of rules on all sectors in the country. When it so happens, it may be difficult for the government to exclude the governing of common pool resources in her unified scheme of governance. This will mean that the self-organized approach to the resource management has to change and may consequently lead to the collapse of the regime.

Mode and principles of procedure can be challenged when in transition within generations. With the rapid change of technology which proportionally affects the way we do things it is possible that the agreed principles of governance accepted by one generation may be derided by another.

4) turning to external sources of help too frequently.

international aid that does not take account of indigenous knowledge and institutions.

Again, upsurge in dishonesty and other forms of devious conduct is another threat to this system of management. When members or appropriators at a point in time tend to maximize their own economic self-interest at the expense of the other partners, the entire system will suffer.

Despite these challenges, Ostrom still expresses her confidence in self-organize regimes by placing emphasis on learning from success stories of the past achievers. She also advocates for a high level of effective communication, information and trust that are comprehensive and deep beyond the norm, but not beyond what is rational. *There is much to learn from successful efforts as well as from failures*, she added (Ostrom, 1999).

2.1.3 Why Is Gold Mining Considered a Tragedy of The Commons?

Gold is a highly sought-after and highly regarded precious metal. It is indispensable due to its natural marvelous luster and radiant glistening appearance. Is it a prime commodity for the jewel industries, finances and investing enterprises, sporting associations, electronics and computer companies, dentistry and medicine as well as aerospace. (Sepanek, 2012). But it is also a limited resource, and there will sooner or later come a time when there would be none available to be extracted. (Harper, 2020). Its finite volume (limited resource), and the fact that it could likely be found anywhere and accessed by anyone makes it fall into the domain of common pool resource. (Rassios, 2019).

By drawing on the works of Ostrom, Adams (Adams, et al., 2001) has the following to say about the key characteristics of a common pool resource.

1. the physical exclusion of potential users from common pool resources is difficult.

2. their consumption is rivalrous or subtractable; that is, increased consumption by one agent implies that less is available for others.

Gold extraction could strongly be aligned to these characteristics. As elaborated at the problem identification section of this paper, illegal mining activities have caused a loss of billions of dollars in revenue due to tax invasion (Leudi, 2019) to Ghana. It has also accelerated the depletion of agricultural lands and forest reserves (Agbesi, 2017), causing a growing concern about food security in communities where mining takes place (ACET, 2017), partly because of reduced food production (Alhassan, 2014) and also usage of farmlands for mining activities (Eriksen, 2014). Its implication continues to raise an ugly head on the water, health, forest reserves, aquatic life, pupil's school attendance, child labor concerns, and a host of others social vices (Eshun, 2018). Apparently, these effects of illegal gold mining activities which engulfs everyone else, especially the many innocent ones, clearly make it an undeniable candidate of tragedy of the commons (Hardin, 1968).

Accordingly, when miners in the illegal gold mining business ignore the outcome their actions have on the entire community, a 'tragedy of the commons' is then experienced (Eshun, 2018).

Thus, the price (negative effect of the greedy few) of illegal mining activities are apportioned to everyone.

The possibility of a common pool resource to be governed by a self-regime management depends on certain characteristics. Describing these characteristics in her study “Revisiting the Commons: Local Lessons, Global Challenges”, Elinor Ostrom’s (1999) speculation includes the following,

1. Possible Improvement: that is, there is clear evidence to believe that the resource conditions are not at a point of deterioration such that it is unprofitable or a waste of time to manage the resource.

2. Indicators: that is, there is a dependable statistic of the state of the resource that could be fetched or assessed at a reasonably low cost.

3. When there is a consistent way of forecasting the flow of the resource.

4. Geographical scope of the resource is another indicator. This allows users to generally develop precise knowledge of elements that exist within (inside or outside) their domain.

To a larger extend, gold minerals have all the above characteristics. Hence, it is safe to say that it qualifies for the self-organized management style. Appropriately, the above indicators address the shape and scope of gold deposit in Ghana. There is still enough deposit of gold minerals available. According to ghanatrade.org (2020), gold still remains the major exported commodity of Ghana. Due to its wide availability, finite volume and its open access nature, gold resource/deposits in Ghana could fittingly be described as a common pool resource and can equally be formalized by means of a self-organized regime. For a sustainable and win-win condition (between government and locals), small scale mining activities in Ghana should be governed by the locals and monitored by the government.

2.1.4 Why Is Ghana Experiencing This Tragedy?

Scaling up how tragic the small-scale mining sector in Ghana has become, it has been obvious that Hardin's ideology (Hardin, 1968) of resource management that encourages central government to take control of all common-pool resources is only next to failure in Ghana.

Over the years, the government has tried varied policies for formulizing this sector but with little to no positive impact. In the publication entitled *'The Rise of the Fourth Estate: The Media, Environmental Policy, and the Fight against Illegal Mining in Ghana'* Kpienbaareh declares the following interventions as already employed by the government of Ghana; the establishment of a Galamsey court, demarcation of land plots suitable for Artisanal and Small-Scale Mining activities, provision of alternative livelihoods for those engaged in galamsey and galamsey communities, and decentralization of the Artisanal Small-Scale Mining (ASM) licensing regime among others. (Kpienbaareh, et al., 2020). But yet the big question still remains, is galamsey menace in Ghana a policy impasse? (Liege, 2021).

The reality is, government-controlled strategy and interventions have done very little to address the challenges at hand. It is safe to say that the solution to this menace does not absolutely lie in the hands of the government. In other words, the government-controlled approach of management does not provide the remedy to the pervasive illegalities confronting the small-scale mining sector, especially in Ghana where government officials are claimed to be involved in this exploitation (Eshun, 2018).

But is this menace bedeviling the sector really inescapable? Ghana is locked up in this situation hugely due its managerial strategy in action. Without including the resource users in formulating policies to govern this sector will continue to pose this challenge. A new system of governance is obviously necessary, and Self-organized managerial strategy is recommended, due to its vast success story for managing similar commons in other locations. (Ostrom, 1999).

Illegal mining has always been a concern but the astronomical rise in the number of galamsey mines in Ghana is traceable to rise in gold price in world marked in 2008. (Botchwey & Crawford, 2019). This hike in gold price enticed many investors, both local and foreigners alike, to suffocate the mining sector. The protection enjoyed by galamseyers enjoyed from state and government

officials coupled with profitability of the gold resource escalated the rise in the number of investors consequently soaring the number of mines. (Botchwey, et al., 2018). The high level of mechanization and up-to-date technology introduced onto the various mining sites resulted in huge environmental degradation, to both land and water. (Adjei, et al., 2012).

3. CHAPTER THREE MODEL DESCRIPTION

3.1 PROBLEM DESCRIPTION & MODEL DESCRIPTION

3.1.1 Introduction and Model Overview

This model represents the mining industry in Ghana. The stock and flow diagram are the system dynamic approach to conceptualizing the realities pertaining to the illegal mining industry in Ghana. For the purpose of clarity, the model is grouped into four sectors: The Mining Sector, The Gold Reserves Sector, The Environment Sector and The Mining Benefit Sector. These sectors serve as the scope and boundary of this study. Each individual sector captures a specific reality of the mining industry that worth looking into in order to fully comprehend the dynamic behavior associated with the industry. This serves as the foundation of any justifications and insights this research provides. This is captured in figure one below.

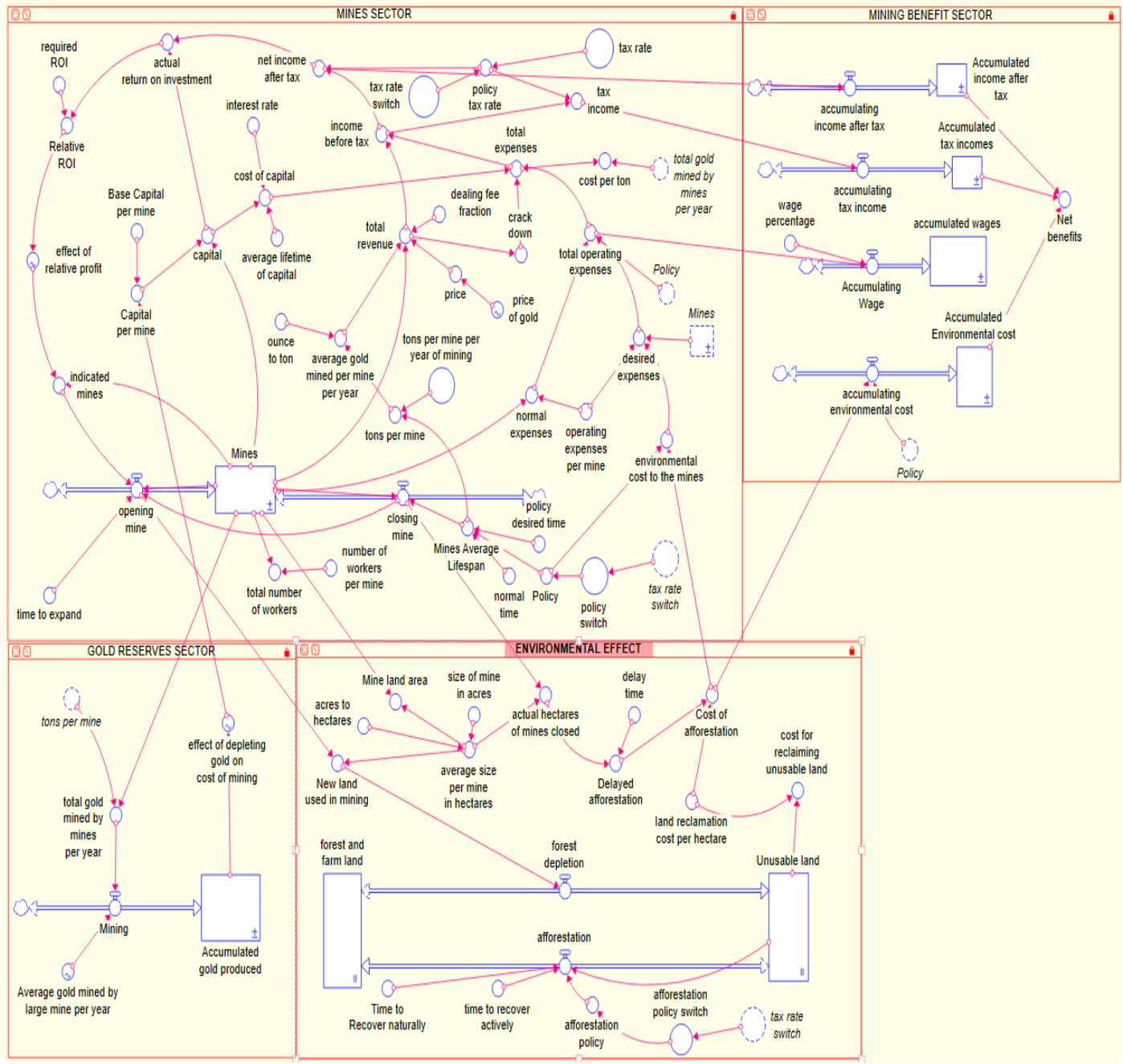


Figure 1- Overview of Model

3.1.2 The Mining Sector

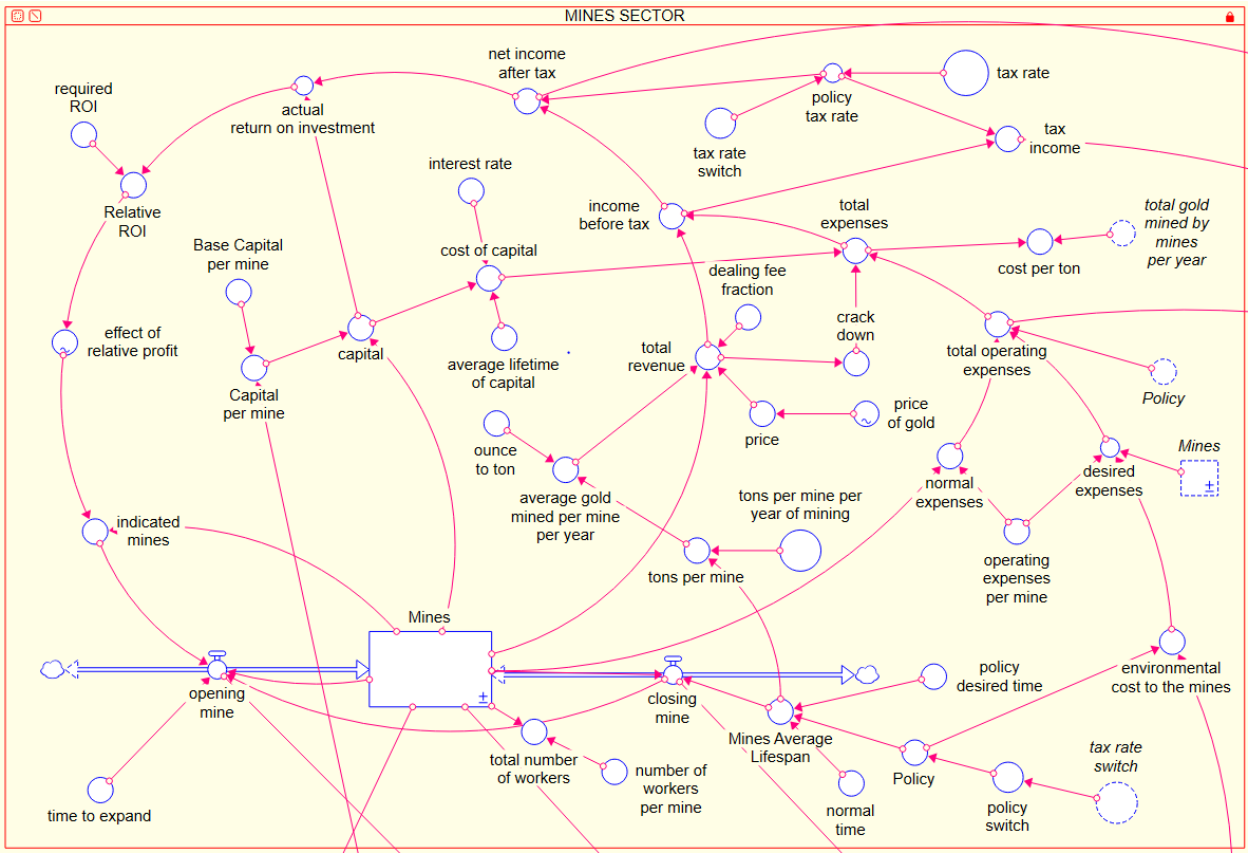


Figure 2 - Mining Sector

This part of the model captures the mining sector. The mining sector represents the main sector of the model. It describes the interaction between the number of mines and the profit nature of the business. The rise in number of mines is shaped by the profitability nature of the industry. Unrestrained increase in revenue and income owing to the steady increase in price of gold is internalized due to the lack of tax or similar regulation that confront the income of miners. With this reality at hand, a high relative return on investment is observed which influences the number of new investors that stream into the industry every year. The mechanism is self-reinforcing, explaining the reason behind the growth of the number of mines in this industry.

3.1.2A Profit Reinforcing Loop

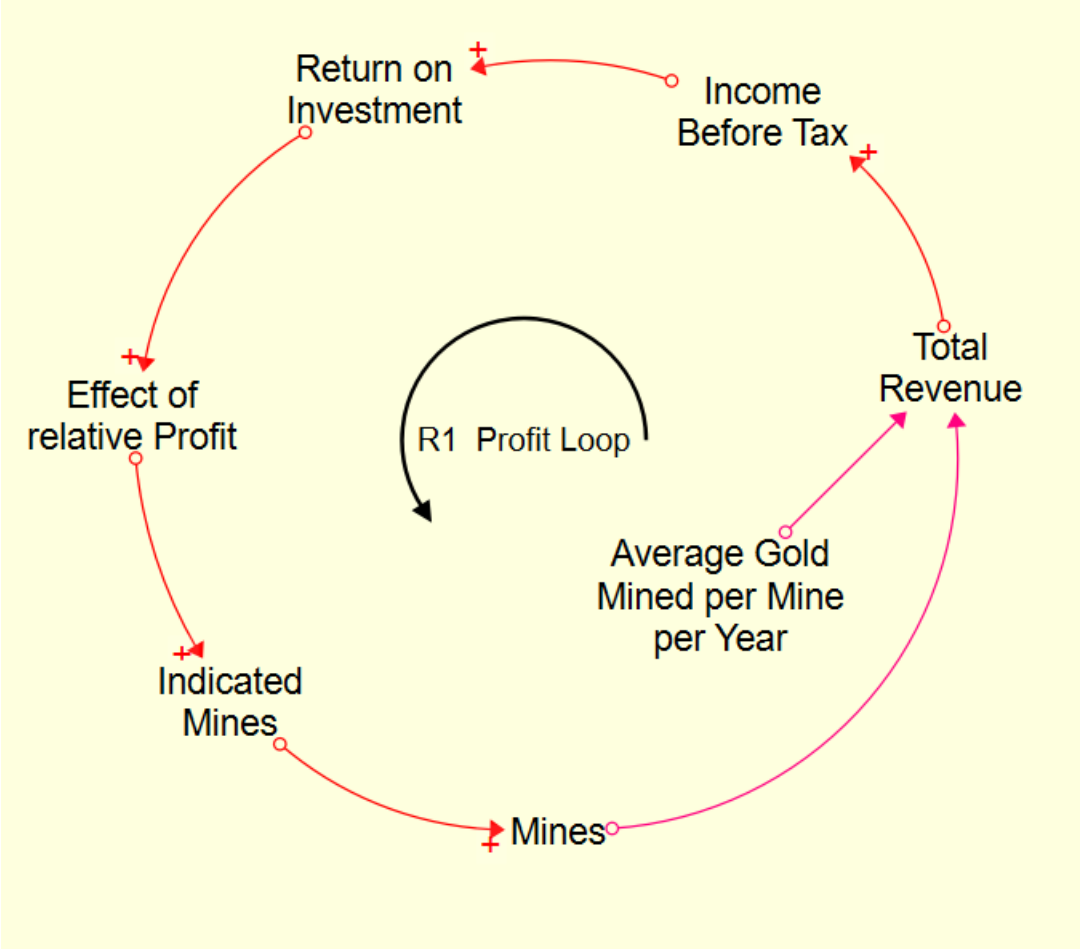


Figure 3 Reinforcing Loop one

This is the main and dominant loop of the sector. As discussed above, increase in number of mines proportionally increases the amount of money resulting from total revenue. With increased amount in revenue, and with no tax impeding the revenue growth, a high level of return on investment is realized. With open-secret knowledge about the high return on investment, a number of new investors are lured into the venture consequently. This influences the growth in the number on mines the following year, reinventing the wheel.

3.1.2B Capital Balancing Loop

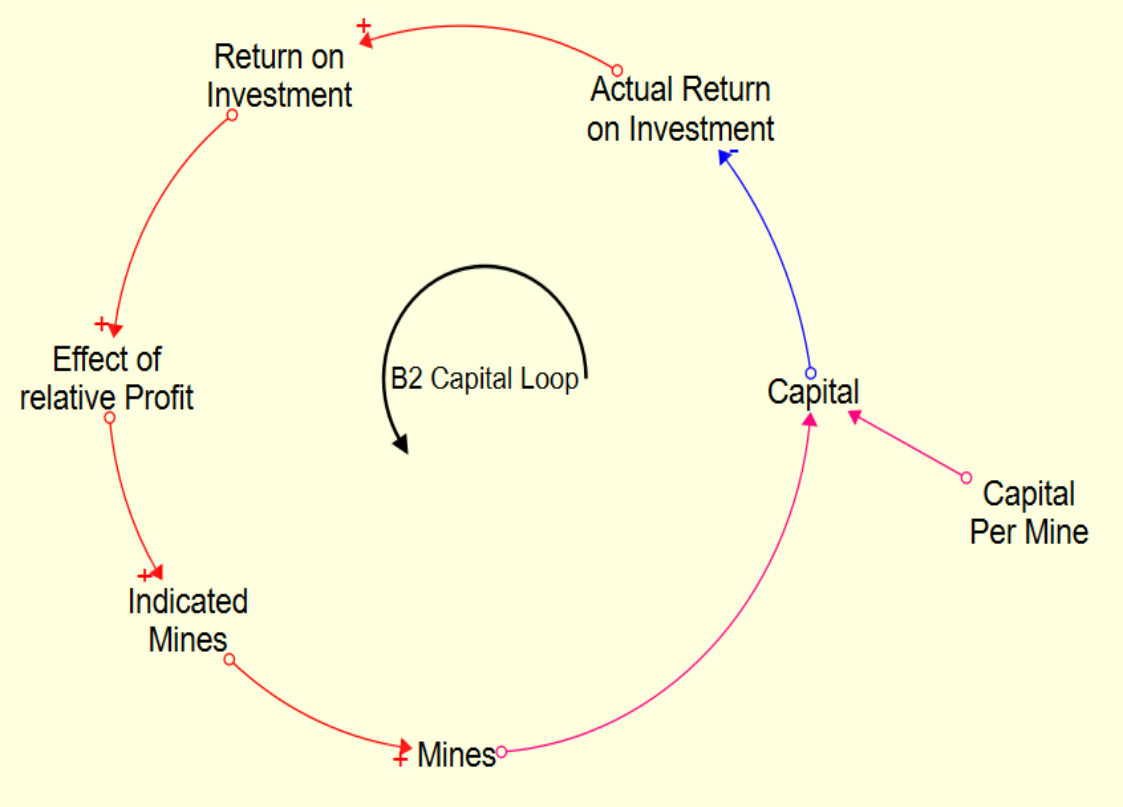


Figure 4 Capital Balancing Loop

The other balancing loop that provides a measure of impediment to the steady growth in the number of mines in this sector is the capital. When the number of mines increases, large capital is required to operate the sector. With any increase in the amount required as capital, the actual return on investment is reduced. This serves as a disincentive to potential investment affecting marginally the opening of new mines the following year. The loop is a self-balancing one.

3.1.2C Expenses Balancing Loop

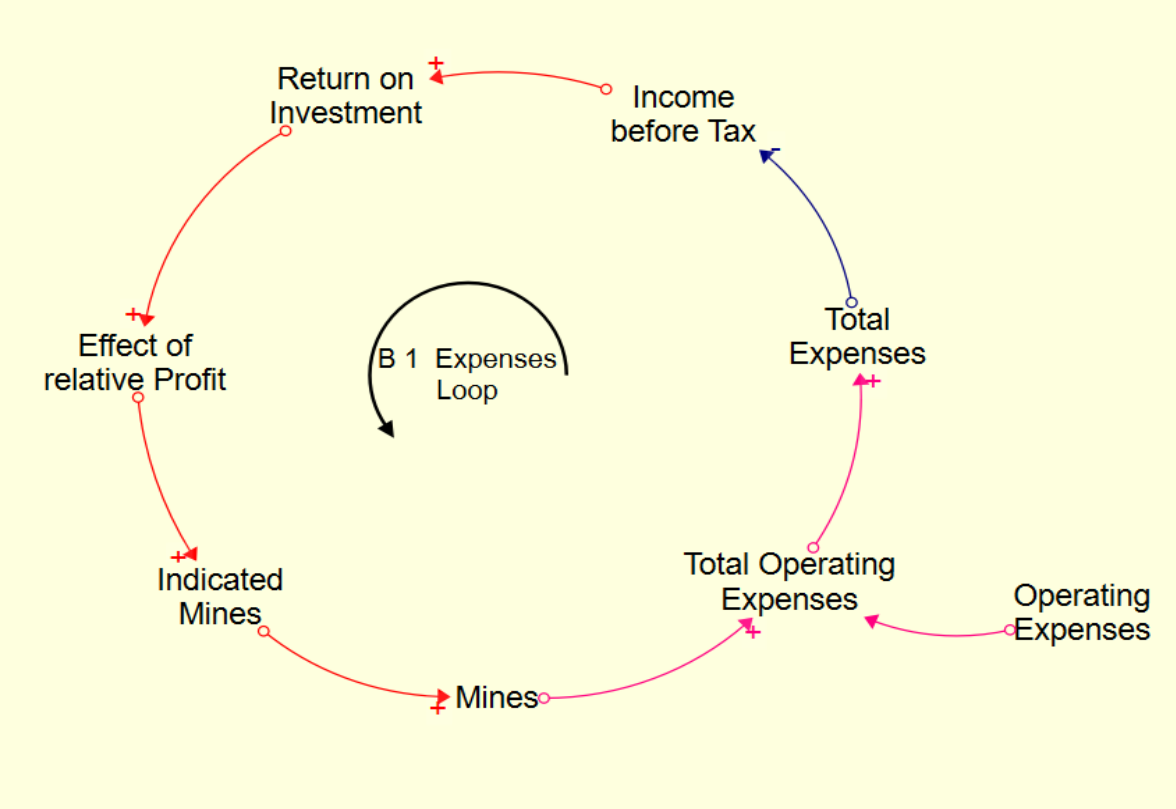


Figure 5 Expenses Balancing Loop

However, there is a limiting factor which slightly slows down the growth of the number of mines in the industry. This comes partly in the form of the expenses. Increasing in number of mines indicates that operating expenses is increased. With increased operating and other expenses, the level of income is reduced. This affects the return on investment and proportionally affects the number of new mines formed the following year. The mechanism is a self-balancing one accounting for why the illegal mines do not grow relentlessly.

3.1.2D Interacting Loops of Mining Sector

As discussed above, the mining sector is comprised of the four loops above: two balancing loops and two reinforcing loops. The balancing loops provide only a minute measure of restraint to the increasing drive of the number of mines. However, the reinforcing loops remain the dominant loop

for this sector accounting for the reason why the number of illegal mines keeps soaring. The main reinforcing loop comprising of mines – total revenue – income before tax – return on investment – indicated mines and mines is the strongest reinforcing dominating the sector. However, the other reinforcing loop comprising of the mines and the indicated mines also a reasonable degree of influence on the sector.

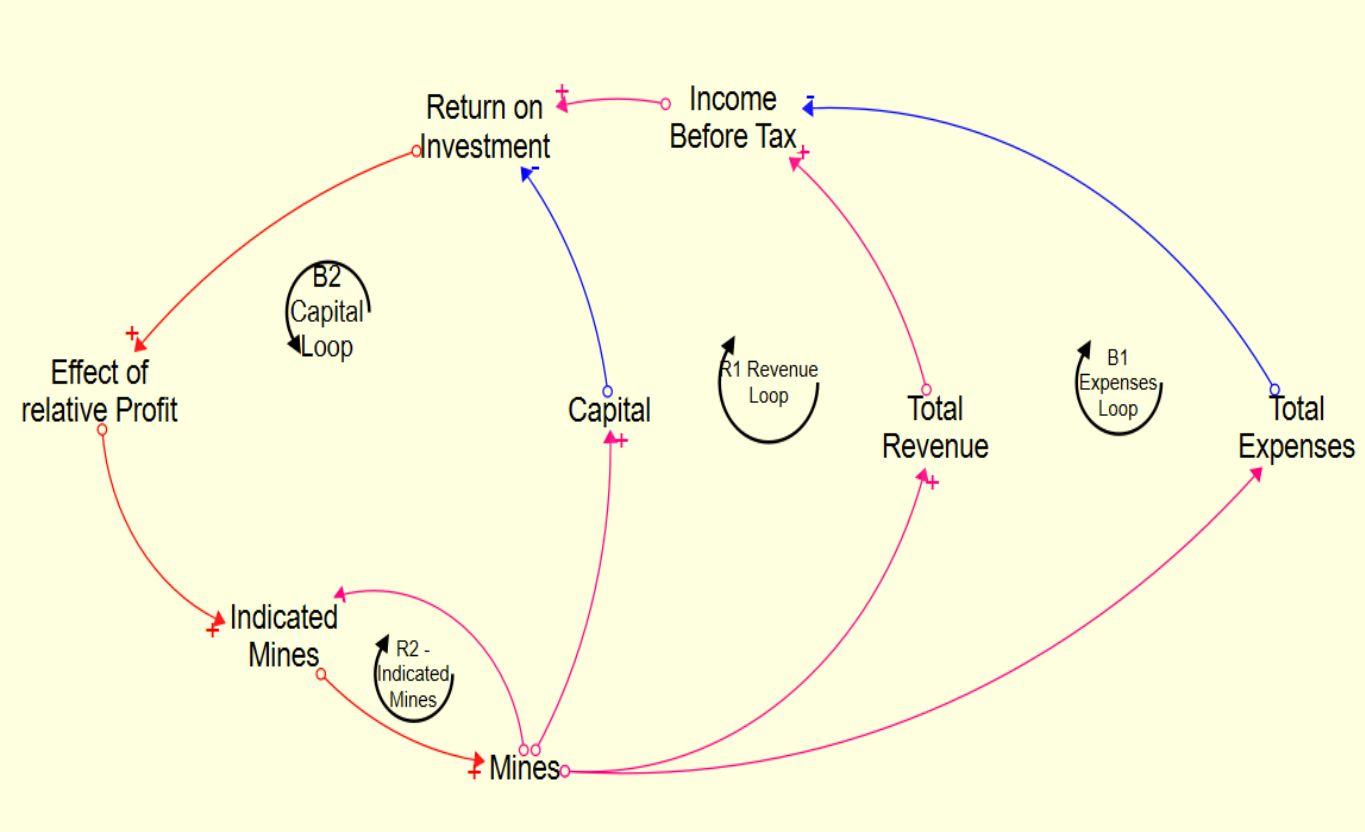


Figure 6 - Dominating Reinforcing Loop in Mining Sector

3.1.3 The Gold Reserves Sector

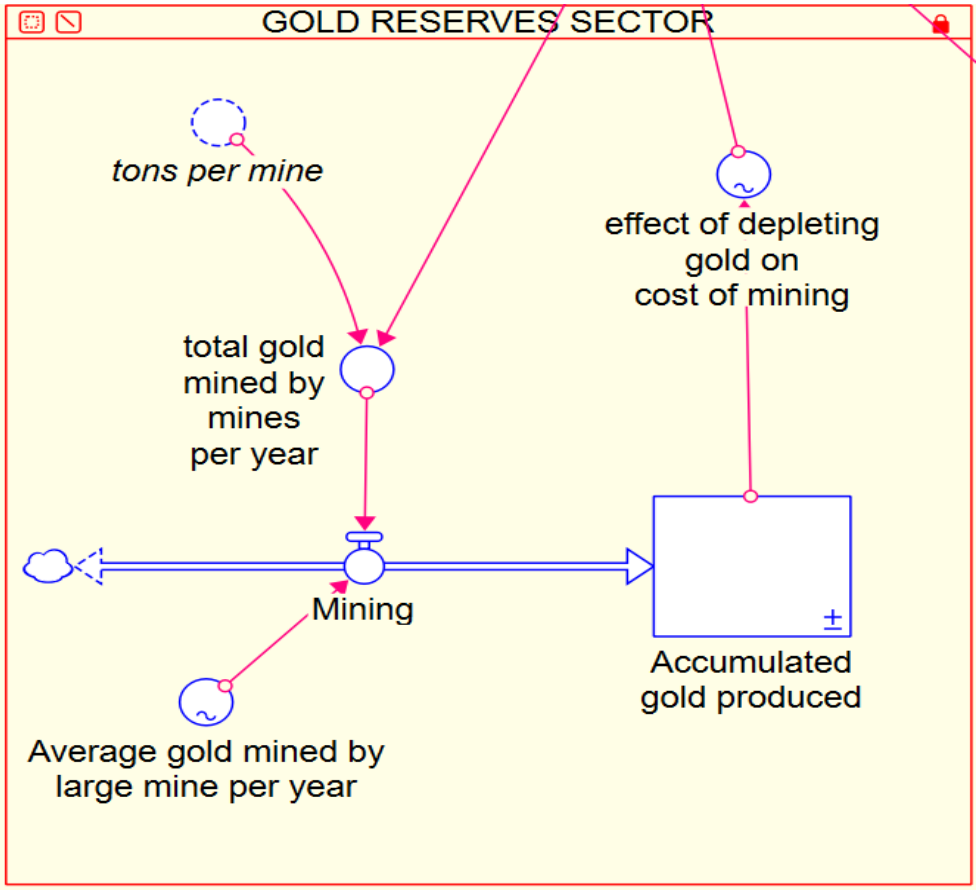


Figure 7 Gold Reserve Sector

This sector describes the relationship between the gold reserve remaining and the capital required to start up a mining business. This sector consists of the 'Accumulated gold produced' stock, with its flow of 'Mining'. 'Average gold mined by large mines per year', 'total gold mined by mines per year', 'tons per mine' and 'effect of depleting gold on cost of mining' are the variables making up this sector.

Tons per mines represents the total volume of gold (in tons) produced by each mine company annually. The 'total gold mined by mines per year' is a product of 'tons per mine' and the 'number of mines'. This therefore describes the total volume (in tons) of gold produced by the small-scale mines sector every year. 'Average gold mined by large mine per year' represents the total volume

of gold that the large mines in Ghana produce yearly. Therefore, what is produced by the large mines together with what is produced by the small-scale mines constitute the total gold produced or mined in Ghana on a yearly basis. The two together make up the variable named 'Mining'. The total amount of gold mined each year by both large-scale and small-scale mines accumulates in the Accumulate gold produced stock. The more gold the two types of mines produce each year, the more the volume of the accumulated gold produced. The more the accumulated gold produced, the lesser the remaining gold reserve in Ghana becomes since the total volume of gold in Ghana is a fixed number.

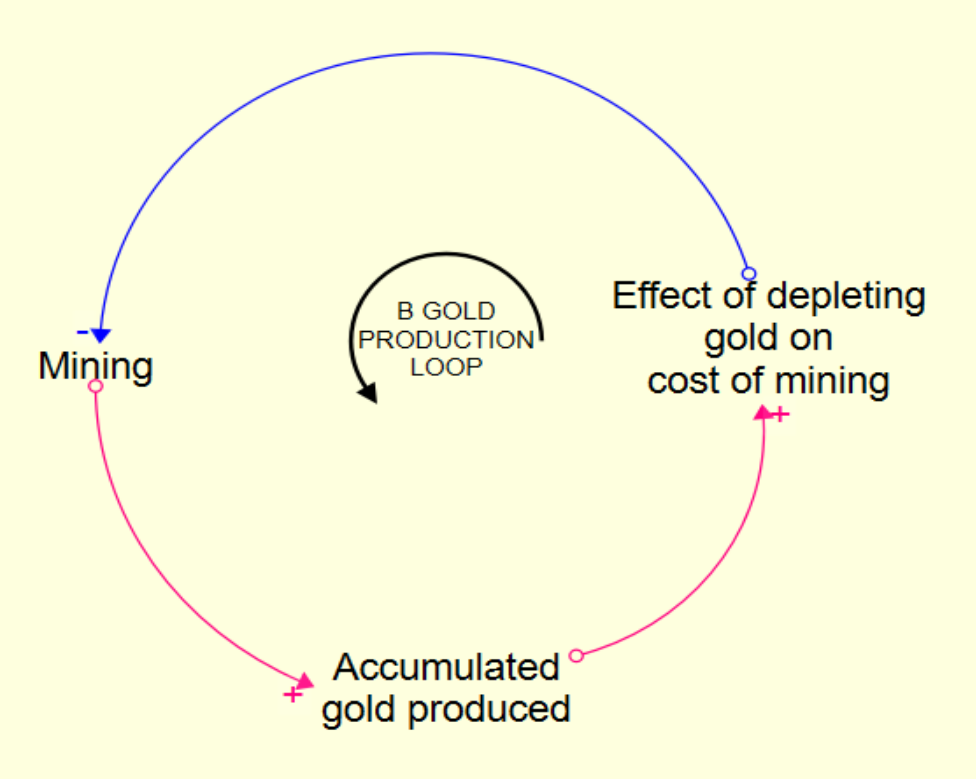


Figure 8 Gold Production Effect

As indicated by the causal loop diagram above, with less gold reserves remaining, it becomes increasingly difficult to mine a new gold, which means that the cost of gold mining sees a steady increase. With increasing cost in mining, the rate of mining consequently decreases. This describes the function of the 'effect of depleting gold on cost of mining' variable. This sector is a self-balancing one.

3.1.4 The Environmental Effect Sector

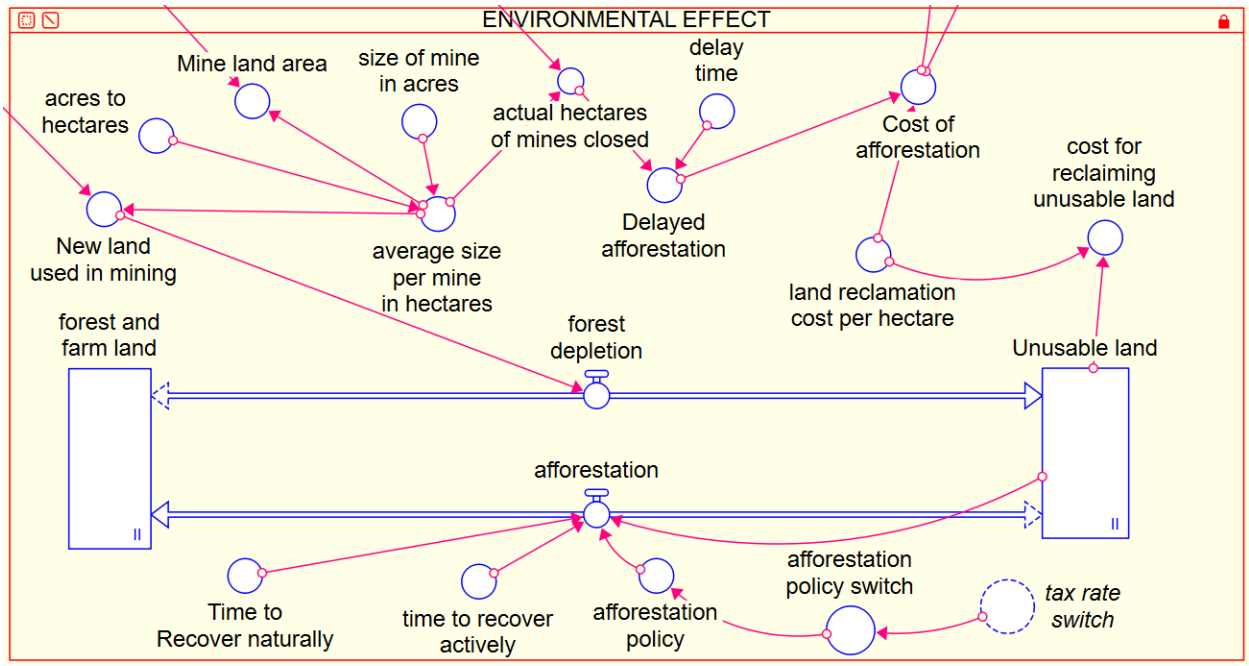


Figure 9 Environmental Effect Sector

This sector represents the relationship between the illegal mining activities and the environment. Mining activities inadvertently impacts the landscape and ecology of the environment within which they are situated. The mechanism involving the creation of new mines, its effect on the environment and how much it costs to reinstate the degraded land are what this sector demonstrates.

Noteworthy elements in this sector include new land used in mining, forest and farmland, forest depletion, cost of afforestation, land reclamation cost per hectare, cost of reclaiming unusable land, Unusable land, afforestation and time to recover naturally.

The forest and farmland stock represents the total land mass, including water bodies, where mining activities can be carried out. This land mass depreciates whenever a new mine (New land used in

mining) is created. The new land mine, due to its degradation, then become unusable land because it is neither good for farming nor any other productive course. The process by which creation of new mine turns a forest land into an unusable land is described by the forest depletion flow.

When no active afforestation intervention is carried out, the unusable land on itself will begin to regrow into forest land after a number of years. This process is called ‘afforestation’ and the estimated number of years of regrowth is termed as ‘time to recover naturally’ in this sector.

It is important to note that, the unusable land degraded by the galamseyers will be abandoned, awaiting the government to reclaim or regrow the land. This is because the miners are mining under the watch of the law and hence, they are not held accountable for the mess they cause. The extent of mess done to the environment, in monetary terms, is dependent on how much it cost to reclaim one hectare of land and the chunk of hectares degraded. This is activity is described by the variables land reclamation cost per hectare and cost of reclaiming unusable land.

3.1.5 The Mining Benefit Sector

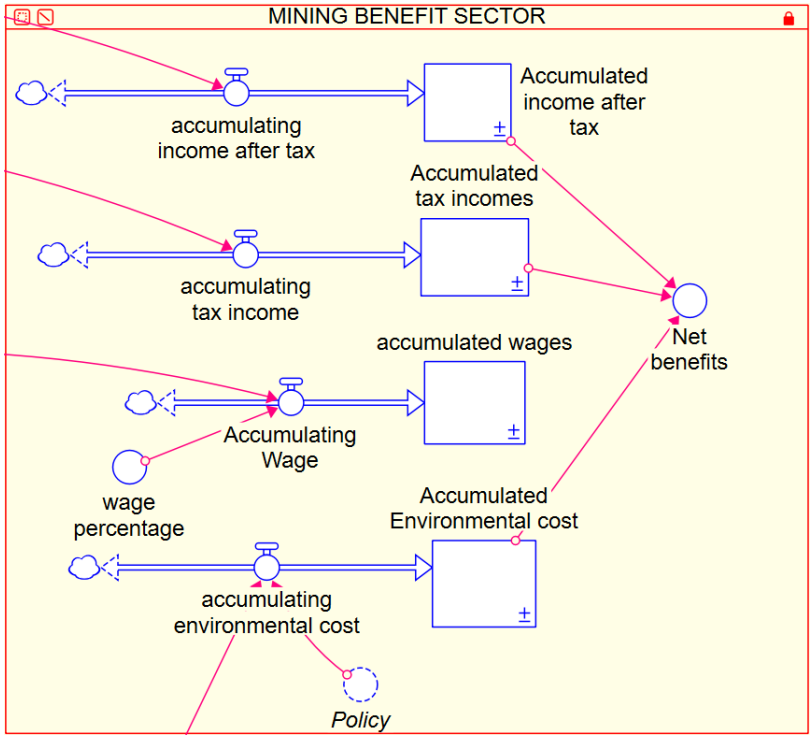


Figure 10 Mine Benefit Sector

This sector shows the financial statistics and implications by the illegal mining business on the economy of Ghana. It describes how the respective (wages, tax for the government, income for the miners, as well as the cost of mining on the environment) disciplines build up or accumulate throughout the period under discussion. It describes how much money is obtained by the miners, the government, the workers on a yearly basis and how they accumulate into huge sums of money eventually. It also highlights the environmental implications in monetary terms by this illegal activity.

It finally talks about the net benefit of the mining activity. Net benefit represents the overall financial gains from the sector taking into account both the positives and the negatives aspects.

3.2 Model Interlacing Causal Loop Diagram

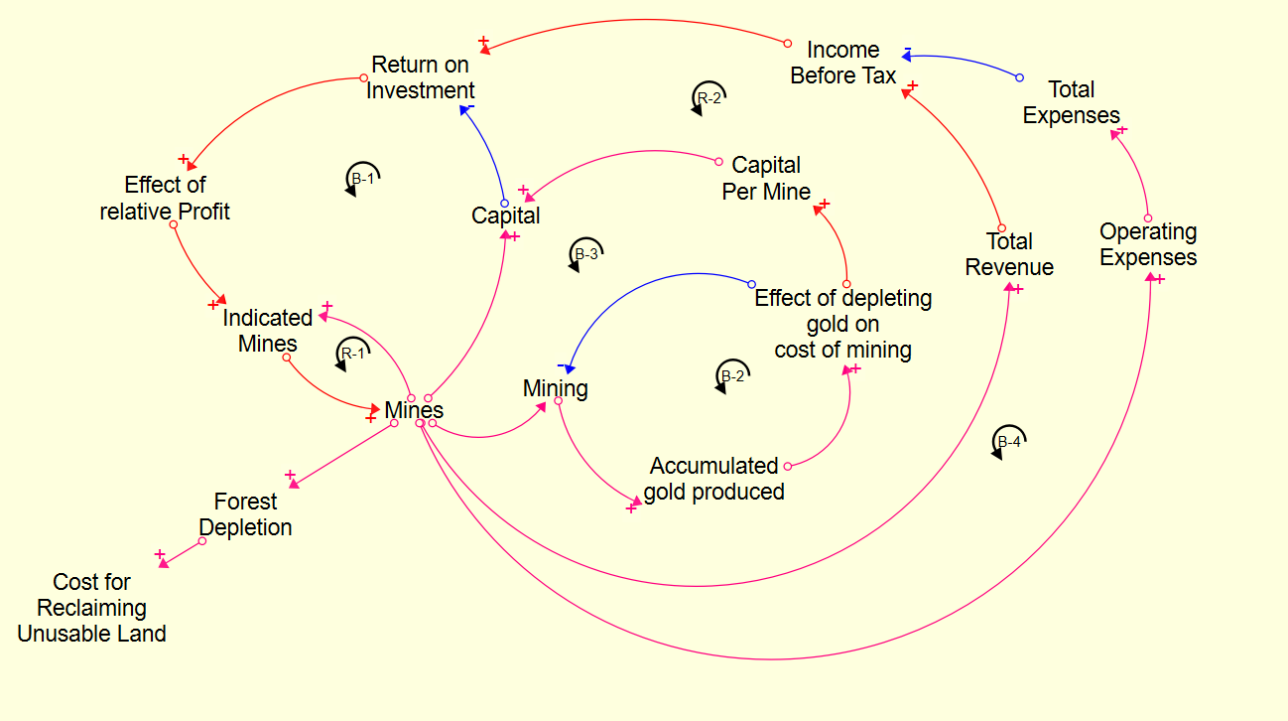


Figure 11- The Entire Sector's CLD

The figure above presents a general overview of how the elements within the illegal mining business interact with one another. It all begins with mining being at the center of all the

activities. When a mining business is established, capital is needed to fund it. So the more the number of mines, the more the funding capital required. With increased capital, the return on investment on capital is reduced which slightly decreases the establishment of new mines the following year. This is represented by the loop B-1.

Also, the more the number of mines, the more mining activities are carried out. This increases the amount of gold produced or dug. With more gold dug, it will require more capital (in the form of sophisticated mining equipment and new technologies) to mine the next tons of gold. This increases the cost of capital per mine and ultimately the entire capital invested in the mining business. When capital for mining is high, new investors are deterred from investing in the mining business the following year. This partially inhibits the growth of the mining sector. This is represented by the loop B-2.

Another growth inhibiting element of the sector comes in the form of expenses. Excessive expenses somewhat deter new investor from joining the pool of illegal miners. This is what is demonstrated by the loop B-3. With increases in number of mines, much is required to take care of the operating and other expenses the business incurs. This affects the income level of miners. With reduced income level, return on investment is also reduced making mining less attractive to onlookers or potential investors.

However, entire sector is driven by how much revenue is made each year by the mines. As the number of mines grow, the amount of revenue realized is proportionally increased. With no tax or resource rent paid by the miners, their income level increases, maximizing the return on the investment they make. With high return on investment, a lot more investors are enticed into the mining business the following year. When this happens, more new mines are formed each year increasing dramatically the total number of mines in existence. This is a self-reinforcing one and it is represented by the loop R-2.

It is noteworthy of mentioning that, when new mine is formed, farm or forest land suffers. When this happens, forest and farmland depletion is accelerated. This explains why depletion of forest reserves and farmlands in Ghana has been on ascendancy. Much money is required for land reclamation anytime a new mine is formed.

It is a simple formulation that matches mines to indicated mines over the mine start delay time of two years. The number mines are expected to grow to the level of the indicated new mines every two years. This is represented by loop R-1.

3. 3 Parameter Validation

Parameter	Value	Unit	Description	Source
Relative ROI	0.1	1/Year	this refers to the percentage of the total amount invested that an investor would need to earn each year in profit to make it a worthwhile investment	Assumption
Time to expand	2	Years	This accounts for the time taken for investor to fully get a mine site operational	(Leudi, 2019)
Land reclamation cost per hectare	11000	USD/Year	this refers to the amount of money required to reclaim one hectare of degraded land. It is estimated at $1100, a figure gotten from s researched source.	(GhanaWeb, 2017)
Base capital per mine	8000	USD/Year	the refers to the base capital per mine at the beginning of the simulation	Assumption
Mine lifespan	3	Years	This represents the average lifespan of a mine when it is mined illegally. The average mine of a galamsey mine	(Leudi, 2019)
Average lifetime of capital	20	Years	this refers to the average time it takes for machines, money and	(Assore, 2020)

			other equipment invested initially into the mines to become no more usable.	
Dealing fee fraction	20	Dmnl	this represents gold transaction cost. This refers to the fraction of the revenue lost when miners sell gold to dealers or middlemen	(Lawson, 2015)
Tons per mine per year of mining	0.00117	tons/mine/year	this refers to the volume of Tons of gold produced by each mine on a yearly basis It is measured in ounce/mine/year	(Leudi, 2019)

3.4 Time Horizon

The duration or period of time within which the model is calibrated from 2004 until 2070. The reason for this choice is as follows.

1. 2004 because that is when a reliable data for reference mode is reliably available. 2004 is reasonable since it allows for the build-up of a meaningful reference mode without any hinderance to insights the model can give.
2. 2070 is a reasonable ending point since it allows enough time for the full projected course of the mining industry under the scenarios tested in this model.

3.5 Level of Aggregation

This model is about the small-scale mining sector in Ghana. It zooms in on illegal aspect of the small-scale mines specifically. It does not compare illegal small-scale mines to large mines, neither does it compare the illegal mining business in Ghana to a similar business in another country. However, the insights and conclusions from the model can be applied to similar illegal mining business in a different setting.

3.6 Model Boundary

The model focuses on the illegal small-scale mining sector and how capital for setting up a new mine is affected by how much gold reserves is available. Again, it shows the stress illegal mines causes to the environment within which it is situated as well as everyone else living around the mining communities. It also focuses on the financial burden it leaves on the shoulders of the government, when mined pits or sites are abandoned upon their depletion of forest. It further reflects on the benefit of the sector in terms of the amount of money paid as wages to those employed by the sector.

3.7 Integration Method And DT

The integration method used for this model is Euler's method of integration. The DT is the default DT of 1/32. The model is sensitive to a DT value of ¼. Smaller DTs are however not sensitive to the model behavior.

3.8 Model Validation

To establish the validity of this model, the following wide variety of tests are carried out.

3.8.1 Boundary Adequacy

The model has a well-defined boundary. The essential concepts for tackling the galamsey crisis under the considered boundary are well represented in the model. The problem on hand affects the mining sector of the nation, the financial aspects in terms of tax invasion, the environment degradation harming the farm, water bodies and forest reserves. All these aspects are captured by the model.

3.8.2 Structure Assessment

As described in the introduction section and the model description section of this paper, the model was developed according to the real world information about the illegal mining business in Ghana. Based on Forrester and Senge's (Forrester & Senge, 1980) structural assessment validity requirement, this model has not contradicted knowledge about the real world structure it represents.

3.8.3 Dimensional Consistency

All parameters have real world meaning and use equations with coherent dimensions. Additionally, there are no unreasonable variables added to the model forcing dimensional consistency.

3.8.4 Parameter Assessment

Parameters chosen for this model are reasonable and fall within the parameter boundaries of the real world system. They were gathered from the pool of experts' studies and other related credible sources, and some were assumed due to the research challenges that confronted data gathering, as discussed in the research challenges part of this study. Estimated parameters as a matter of clarity do not substantially stray from the ideal world values, however, some of these variables seem to be very sensitive as really needing further testing and validation to give the model further credibility. The assumed variables include effect of depleting gold on cost of mining, effect of relative profit, dealing fee fraction, tons per mine per year, relative ROI, and time to expand.

3.8.5 Extreme Condition

With extreme conditions, we talk about equations which orchestrates the behavior the model produces. It specifically talks about how vigorous these equations are especially under extreme circumstances. By and large, each equation formulated in this model has been exposed to extreme conditions by using variety of modelling formulae. Where necessary, a MIN function is used to avoid the equations to take unwarranted figures.

3.8.6 Integration Error

There is no integration error in the model since the model is not sensitive to time step or numerical integration method. Euler integration method is used and a default dt of 1/32 was chosen. Change in dt below this does not affect the results the model produces.

3.8.7 Behavior Reproduction

Behavior reproduction focuses on how chiefly the model mimics the behavior of the reference mode. To a bigger degree, the model is able to reproduce the behavior of the reference mode that

is represents. In other words, the model largely replicates the behavior that the illegal mining has shown until 2018.

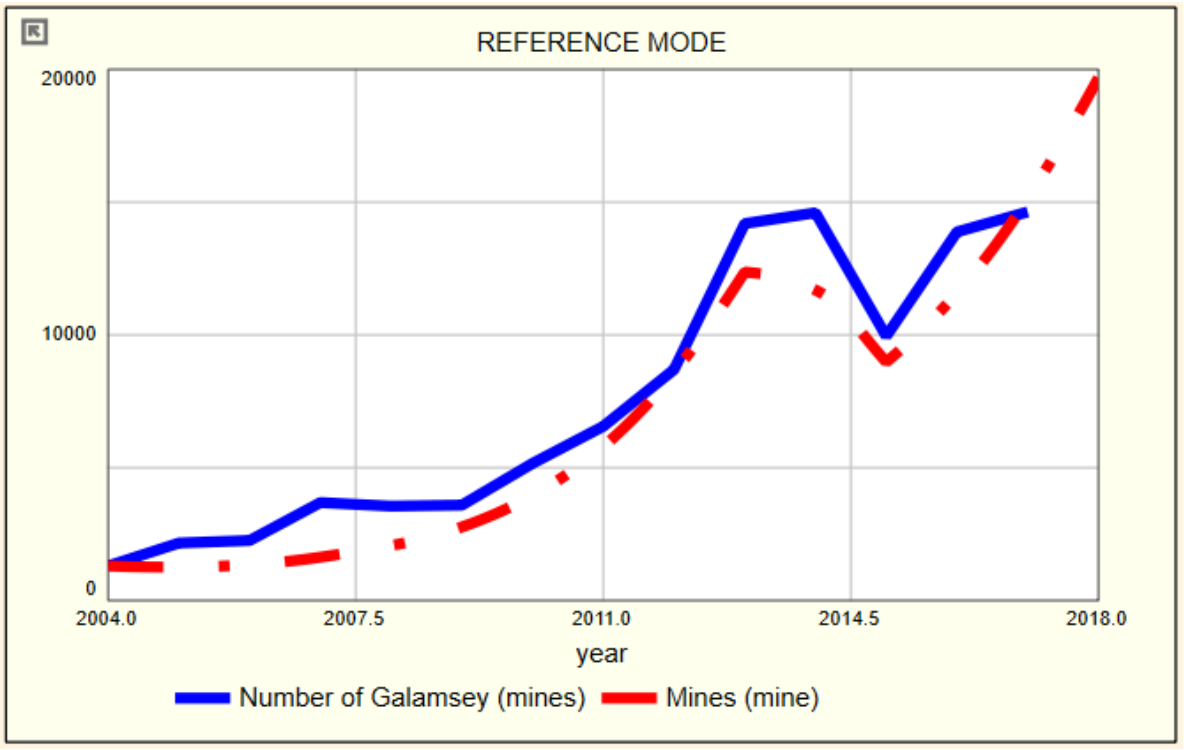


Figure 12 Model Behavior and Reference Behavior

Figure 12 represents the behavior assessment of the model in relation to the reference mode. The blue color (Number of galamsey) is the actual behavior the mining sector in Ghana shows. The red dash line (Mines) also represents the behavior the model produces. As seen by the two lines, the red one mimics the behavior of the blue one. This indicates the validity of the behavior assessment of the model.

3.8.9 Family Member

Due to the fact that the theoretical framework upon which the model is build is applicable to other settings experiencing similar challenges, the model could generally be useful for similar challenges experienced in other settings.

3.8.10 Surprise Behavior

The model does not produce any surprise behavior or make known any previously unobserved behavior. Rather, it successfully predicts a novel approach to solving the illegal mining at hand. That is, by using tax to regulate the sector when policy switch is activated.

3.8.11 System Improvement

By means of the model, the mining sector in Ghana has received a win-win approach (between miners and government) of regularizing the business. With the suggested policy, the environmental challenges associated with this sector would be largely resolved. Moreover, revenue in terms of tax would be obtained by the government for other developmental works.

4.0 CHAPTER FOUR – ANALYSIS

4.1 Introduction

The focus of this chapter is to analyze the behavior of the model and its striking reflections on the real world's scenarios. Simulation is constructed from parameters based on actual data about illegal mining activities. It describes the happenings in the sector based on the usual pattern of how business is conducted by the illegal miners. It zooms in specifically on how the growth of number of mines affects the revenue, farm and forest lands as well as the amount of money the government will need to restore degraded abandoned mine sites. The scenarios discussed in the section are the base case scenarios without the intervention of the proposed policy for the mining sector.

4.1.1 SCENARIO ONE: ILLEGAL MINING BUSINESS AS USUAL UNTIL 2018.

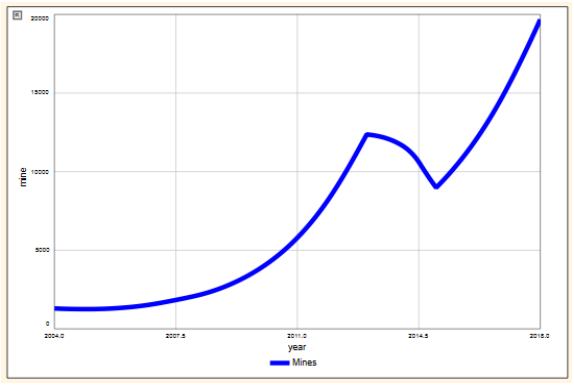


Figure 13 Mines in 2018

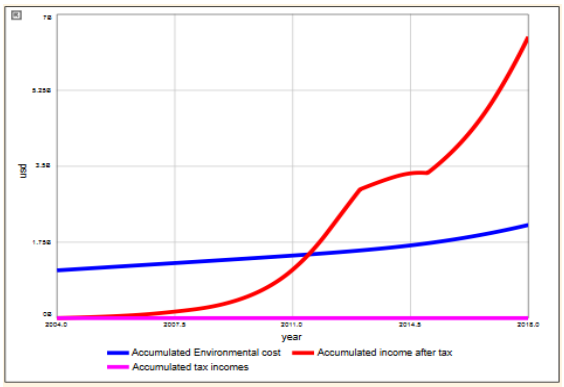


Figure 14 Miners Income in 2018

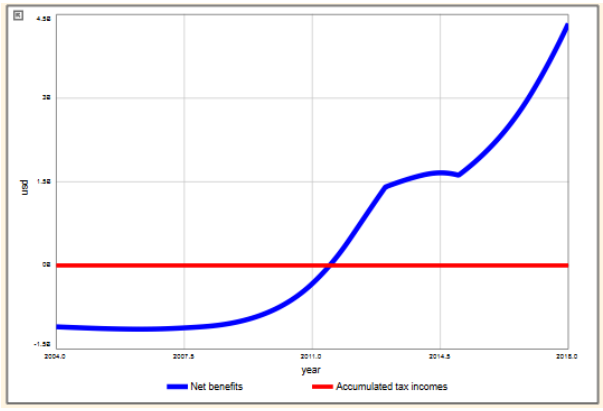


Figure 16 Net Benefit in 2018

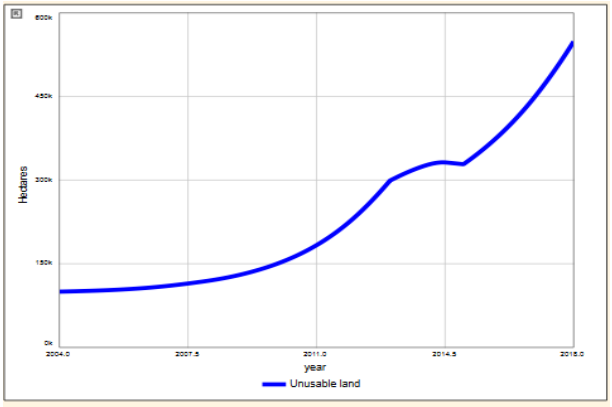


Figure 15 Degraded Land in 2018

The figures above show the steady growth in the number of mines in the illegal mining business in Ghana since 2004 - the starting point of this simulation - to 2018. Figure 14 represents the number of mines. It shows an increasing growth rate until around 2013 where it slows down momentarily. The slowing down of growth is due to the crackdown intervention employed by the government of Ghana in that year. A measure of policy success was seen until about 2015 where illegal mining became fully active again and the increasing growth rate resurfaces until 2018. This is what the graph portrays.

The next figure (figure 15) shows the benefits the sector accrues. It is obvious that the accumulated income after tax freely mimics the behavior of the growth of number of mines without any interruption. This indicates how beneficial the illegal mining business is as it grows. This is partly because of absence of tax or any other resource rent payment. The whole business is of course under the shadow of illegalities. At the end of the year 2018, the sector is enriched with some about 6 billion USD due to its free ride (no tax) nature.

The miners are enriching themselves at the expense of everyone else. This explains why the accumulated tax income is 0 USD throughout the year under consideration. A little wonder why the government has been trying out several conditions including cracking down to halt the operations of these illegal miners. The accumulated environmental cost however increases so long as there is an active mine in place. This indicates how the country is losing out on this illegal business. The cost for restoring the environment is left on the shoulders of the country to carry that burden.

Figure 16 zooms in on the benefit the sector provides. The so called benefit is even realized after 2011. This is evident by the net benefit line (blue) transiting from negative to positive value. It is so-called-benefit because the government is still left with debt and does not share in the income internalized by the sector. The net benefit still hitting below positive values is an indication of the incalculable revenue and environmental loss due to this illegal business in the mining sector. The situation is what it is hugely due to the absence of tax as depicted by the red line which remains at zero throughout the period under review. However, the government does benefit in the sense that, local people are employed which lifts part of the burden of mass employment she must carry. The effect of this sector is glaring in the figure 17 which represents the growth rate of degraded

farmland and forest reserves. A closer look at this graph reveals the striking similarity between the identity of its behavior and that of the growth of mines. It is safe to say that growth of illegal mines is parallel to the growth of forest degradation which remains as a sole burden of the nation. By 2018, there is about 500K hectares of land greedily consumed by the illegal mining sector as depicted by the graph of figure 17.

4.1.2 SCENARIO TWO: BUSINESS AS USUAL UNTIL 2021 (TODAY)

This part of the chapter focuses on the present situation of the illegal mining business in Ghana since 2004. Special attention is given the business between dealings between 2018 and 2021.

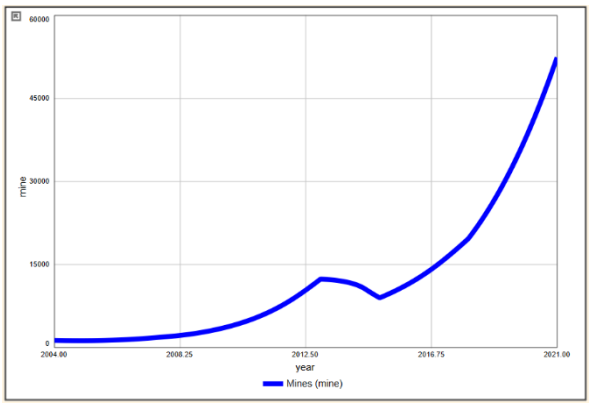


Figure 18 Mines in 2021.

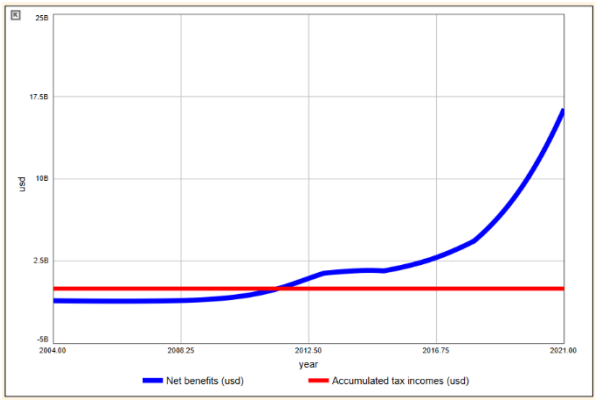


Figure 17 Mines Benefit in 2021

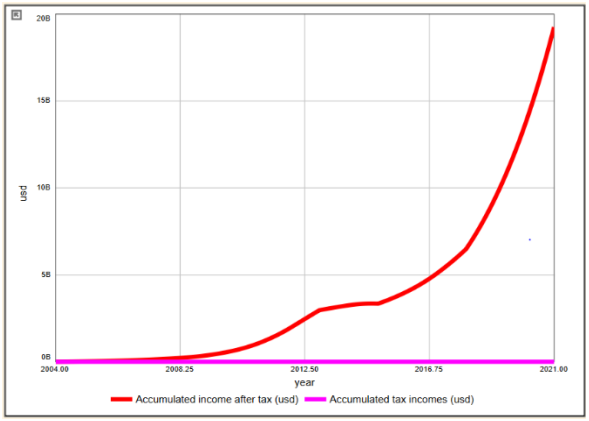


Figure 20 Environmental Cost in 2021

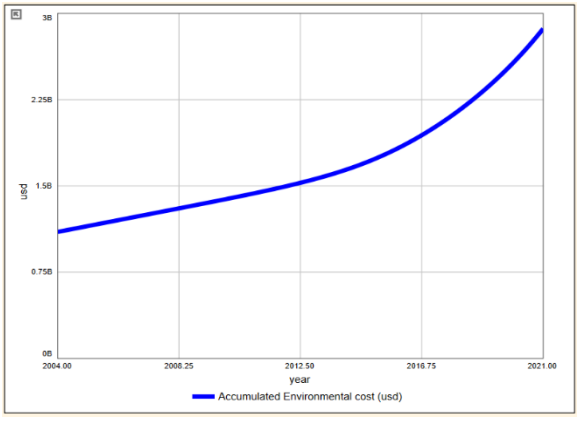


Figure 19 Miners Income in 2021

Mine's characteristics in 2021 follow the pattern it has assumed all the while. The upward trajectory of the number of mines is still experienced in 2021, just as in 218. Interestingly, the rate of growth of the number is increasing at a faster tempo more than before. The same speed in growth of number of mines is assumed by the miners' income graph which is also increasing more swiftly. This tells how beneficial the business is to the miners. It is again worthy of mention that, this unbridled growth in number of mines and miners' income for that matter is due to the absence of tax collection. This is indicated by the accumulated tax income being zero during the period under discussion. With no tax in place, the net benefit (depicted by the mines benefit graph) also mimics the behavior of the miner's income. The reason being that, when the number of mines grow, the miners' income grows proportionally, which increases the net benefit at the same rate due to absence of tax collection.

So, with about 50,000 mines in place in 2021, a projected income of about 20 billion USD is being raked in by the miners with about 17 billion USD net profit internalized. But what makes matters worse is the fact that the main drivers of this illegal business are foreigners who take away all benefits accrued from this venture away from the shores of Ghana. Meanwhile as depicted by the environmental cost figure, about 2.8 billion USD damage done to the environment is deserted.

4.1.3 SCENARIO THREE: BUSINESS AS USUAL UNTIL 2030 (IMMEDIATE FUTURE)

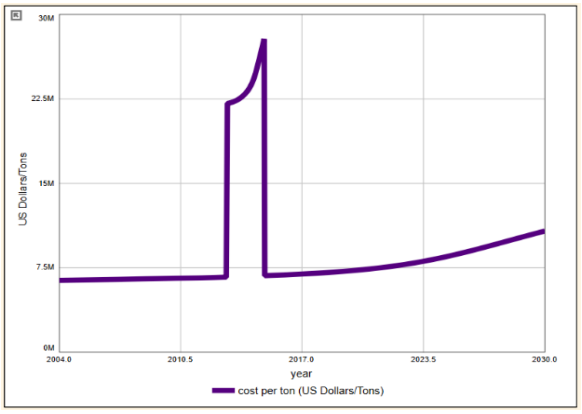


Figure 21 Cost of Producing a Ton of Gold by 2030

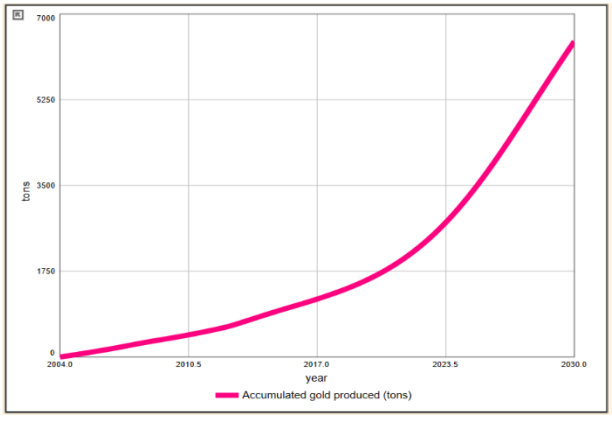


Figure 22 - Accumulated gold produced by 2030.

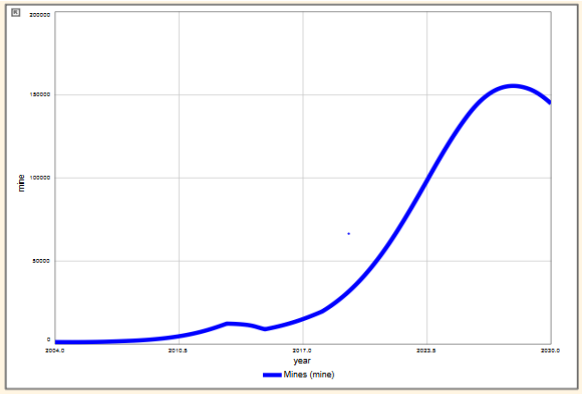


Figure 24 Number of Mines in 2030

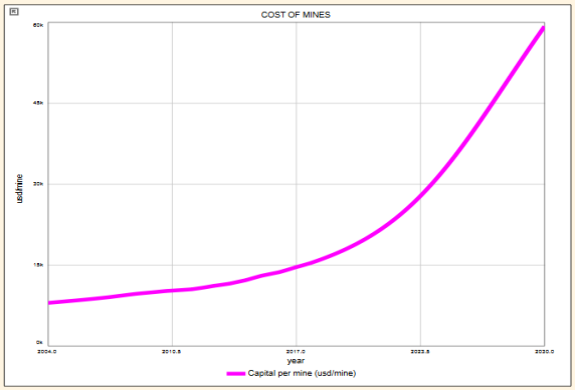


Figure 23 Capital for Managing a Mine in 2030

To begin with, the figure 22 which represents cost of producing a ton of gold shows an interesting behavior with the huge spike that shows up between 2013 and 2015. This was due to the crackdown policy employed by the government within those years. The crackdown made it extremely difficult to mine a ton of gold due to the high risk involved in operations then. This resulted in a drop in the number of mines within the crackdown period. But this policy was resisted, and mining operations resumed as usual from 2015 onwards.

The growth of number of mines is proportional to the volume of gold produced by the sector. With increased accumulated gold production, much more capital is required to stay in operation due to scarcity or limited reserve of gold deposits. Initially, the rise in cost of gold has only a marginal impact on the rising number of mines since the return on investment was still overwhelmingly profitable. But with the cost of production becoming a bit more expensive (about 7 million USD per ton) beginning 2024, there is an evident decrease in the rising number of mines. This is what is depicted by each of the graphs above from 2021 until around 2028.

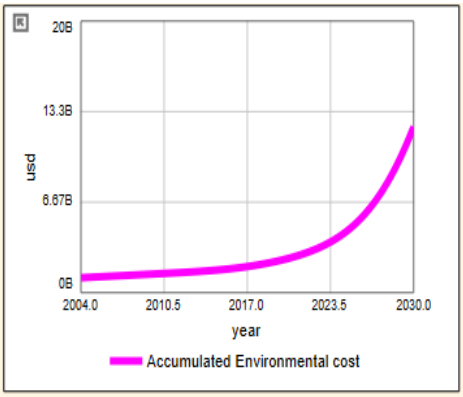


Figure 25 Environmental Cost in 2030

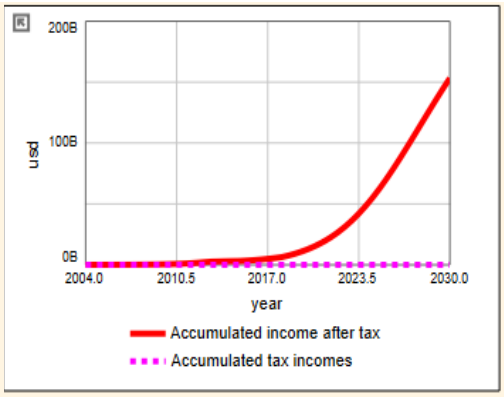


Figure 26 Miners Income in 2030

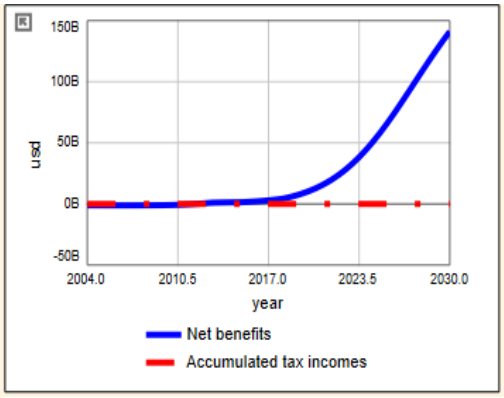


Figure 27 Net Benefit in 2030

With the cost of gold production still increasing after 2028, the number of mines begins to see a decline since the capital involved in setting up a gold mine is on the high. This in turn affects the accumulated income after tax and consequently the net benefit internalized by the sector. So as indicated by the two graphs just above, the rate of growth of the accumulated income after tax as well as the net profit generated by the sector starts to grow slowly after the year 2028.

However, it is quite disturbing to see how the environmental cost keeps accumulating despite the decrease in the growth rate of the number of mines. This is because, irrespective of the decrease in growth rate of the number of mines, the remaining number of mines keeps causing harm to the environment by means of their daily mining operations.

4.1.4 SCENARIO FOUR: BUSINESS AS USUAL UNTIL 2070 (DISTANT FUTURE)

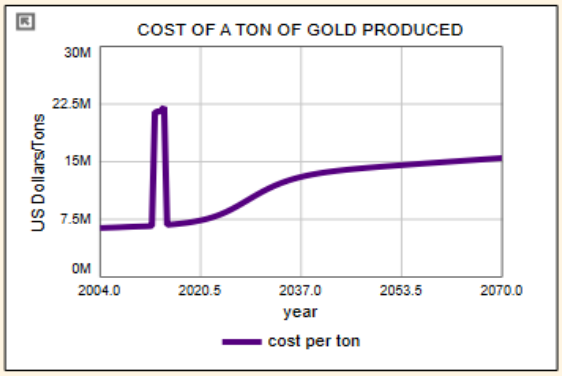


Figure 28 Cost of Producing a ton of gold by 2070.

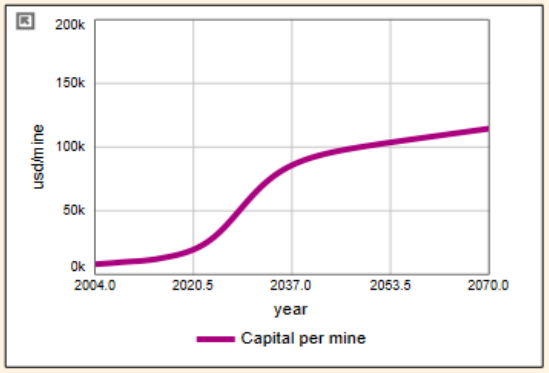


Figure 29 Cost of Managing a Mine by 2070

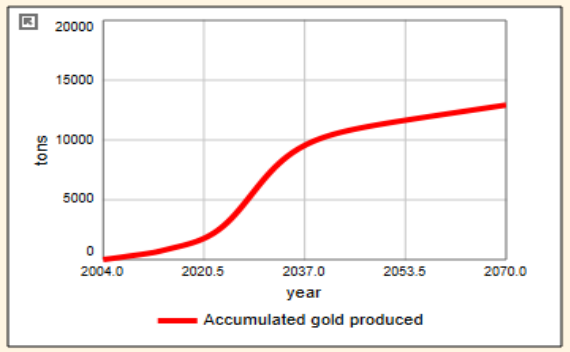


Figure 31 Total Volume of Gold Produced by 2070

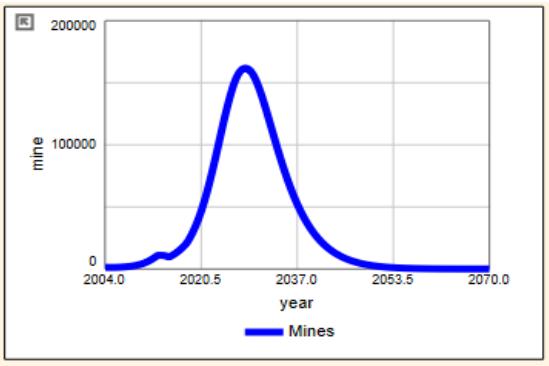


Figure 30 Number of Mines by 2070

Well, the cost for producing a ton of gold will continue to rise after 2030 but in a decreasing manner. This is because, the increasing rate of gold accumulation is slowed down due to the decreasingly decreasing growth rate of the number of mines. The consequence of this is reflected by the figure above which shows the number of mines.

However, beginning around 2034, the number of mines starts to reduce at a decreasing speed. This is due to the fact that, mining activities are reduced (due to less mines remaining) which has reduced the increasing rate of gold accumulation. Hence, irrespective of the fact that cost of gold production continues to increase, it rather increases in a decreasing rate this time. This slows down the rate at which the number of mines reduce at an increasing speed. So as shown by the graphs

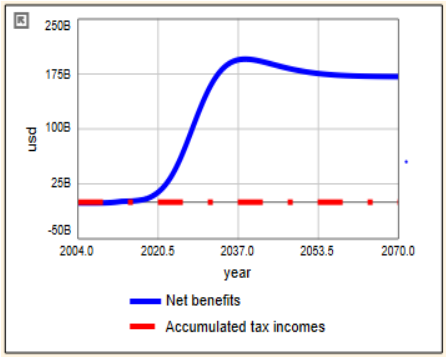


Figure 33 Net Benefit by 2070

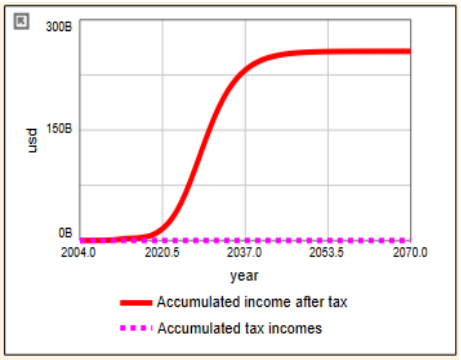


Figure 34 Miners' Income by 2070

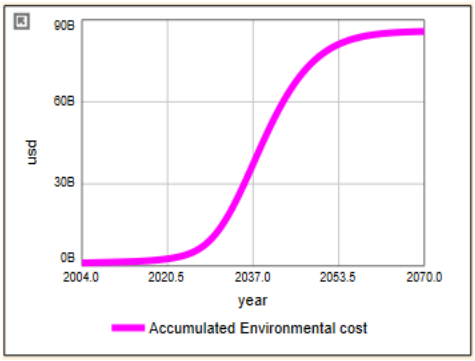


Figure 32 Environmental Cost by 2070

above, the accumulated gold produced will thereafter slow down the speed of growth, slowing down the growth rate of capital required to start a new mine or stay in operation. With this situation the at hand, the decline rate of the number of mines will continue to decrease decreasingly until the collapse of entire business around the year of 2070.

With the number of mines seeing a sharp decline from 2028, the accumulated income after tax begin to slow down in its growth. This is because despite the reduced number of mines, the remaining mines continue to realize a measure of income in their operations. But more and more mines continue to fall out of operation dwindling the speedy growth rate of the accumulated income after tax. By 2036 when the declining rate of the number of mines is intensified, the accumulated income after tax grows more slowly. This is because the intensive decline rate in mines is proportional to intensified loss of income, hence the income volume (in the shape of accumulated income after tax) increases more swiftly.

Net benefit also responds proportionally to the growth rate of the number of mines. As number of mines started to grow decreasingly in 2028, the increasingly increasing growth rate of the net benefit begins to slow down until 2036. With less mines continuing to remain, less and less income is realized each year. This is why the accumulated income after tax grows decreasingly.

Interestlingly, the environmental cost continues to grow more aggressively until 2036 when the it begins to slow down in its growth due to the sharp decline in the number of mines. Less mines remaining means less environmental cost is internalized, resulting in its decreased growth rate. As number of mines declines more sharply, the environmental cost grows more slowly.

But with enivronmental cost still active and the accumulated income after tax almost stagnated at 2040, the net benefit begins to see a measure of decrease from that year on.

4.2 DISCUSSION OF ANALYSIS

The uncomfortable reality is, at the point of the mines collapsing, the following scenarios are likely to happen.

1. The whopping majority of the income gotten from mines is taken away from the shores of the country since the mains drivers in this illegal business are foreigners.
2. Farmers might have given their farmland for galamsey concessions and hence they do not have any more farms to return to after the collapse of the mining industry. Unemployment and hunger will in mining communities and the nation at large will intensify.
3. Extreme loss of revenue to the state since the foreigner will carry along the income accrued from the illegal business out of the shores of Ghana. Even if 70% of accumulated income is used in wages for workers, a lot of money is set to leave the country.
4. Incalculable environmental problem. The many farmlands and forest reserves depleted are abandoned to be reclaimed by the nation at the expense of GDP generated. Losing this life-changing mineral in exchange of abandoned degraded farmlands and forest reserves really calls for an urgent measures and interventions. For this reason, this study proposes a policy to intervene this menace form rolling its complete ugly head on the nation.

5.0 CHAPTER FIVE: POLICY

5.1 INTRODUCTION

On this chapter, the study focuses on the behavior the mining sector will assume when it is formalized. It describes the happenings in the sector based on the usual pattern of how business is conducted by the illegal miners but with regulations agreed upon by both the government and the miners. It zooms in explicitly on how the proposed policy will affect growth of number of mines, the revenue, farm and forest lands, as well as the amount of money the government will need to restore degraded abandoned mine sites.

The suggested policy for the illegal mining business in Ghana is tax. Introduction of tax has the potential to replace more adequately the crackdown policy the government implemented. Different tax rates produce uniquely interesting income margins for both the government and the miners. Each rate certainly creates win-win results between the government and the miners, giving this policy a competitive superiority over the crackdown.

When the policy is activated in 2021 the following scenarios are triggered.

1. Mines' lifespan is moved from 3 to 10 year. Ideally, a small-scale legal mine has an average of ten years lifespan. The hit and run approach assumed by the illegal miners is the reason why the average mines lifespan is reduced to three years.
2. Amount of gold mined per mine per year increases. The more they stay on a piece of land mining for gold, the better they are able to fully exhaust gold deposits on that piece of land. This will proportionally increase the volume of gold produced since more time is dedicated to mining.
3. Burden of the environment is shifted to the miners. The policy ensures that, miners have a detailed plan for restoring the environment after the mining operation is expired. This will ensure that, the miners themselves will reclaim the degraded land (as part of their expenses)
4. Afforestation is actively carried out in 10 years rather than waiting for the forest to be restored naturally in 50 years.

5.1.1 SCENARIO ONE: IF TAX IS INTRODUCED IN 2021.

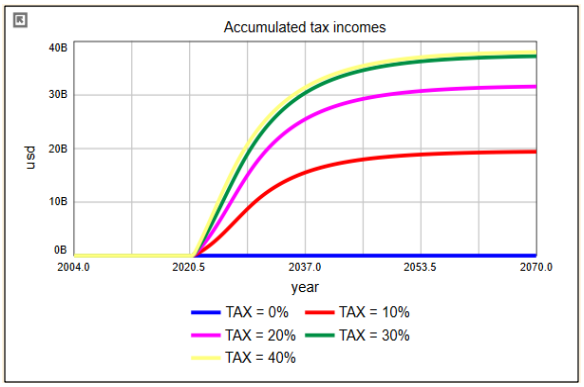


Figure 35 Income from tax in 2070

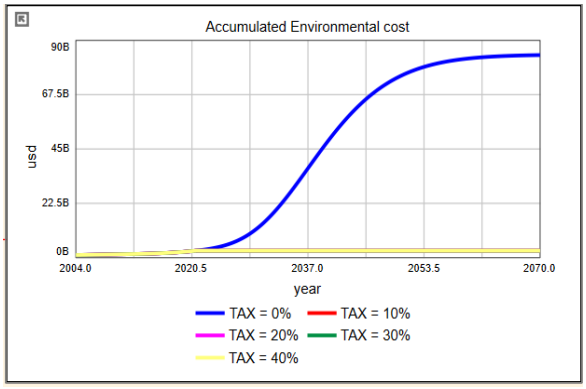


Figure 36 Environmental cost after policy in 2070

When policy is activated in 2021, the burden of the environmental cost is shifted from the government to the miners to care for. So throughout the entire lifespan of the mining sector, the government has no worries about the environment cost except the backlog before the policy was implemented.

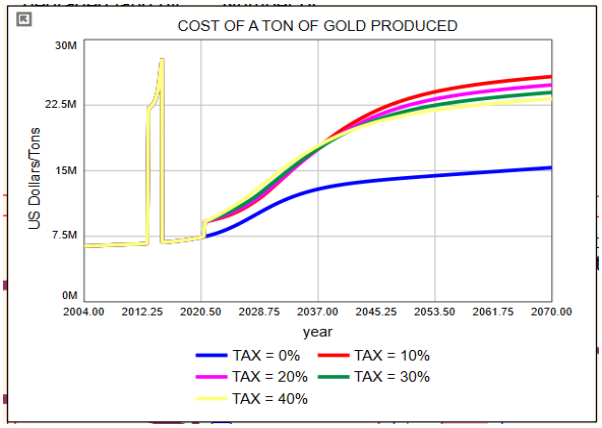


Figure 38 Cost of producing a ton of gold after policy in 2070

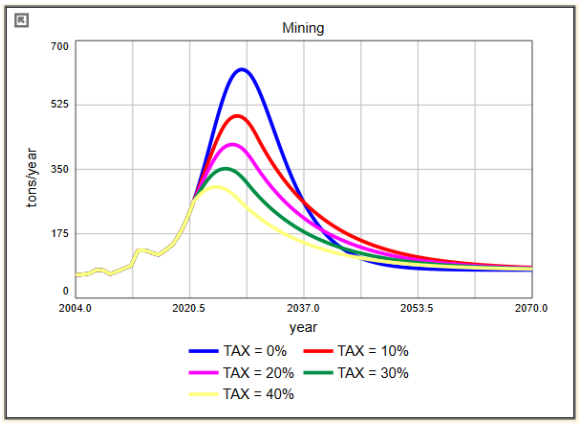


Figure 39 Rate of gold mining after policy in 2070

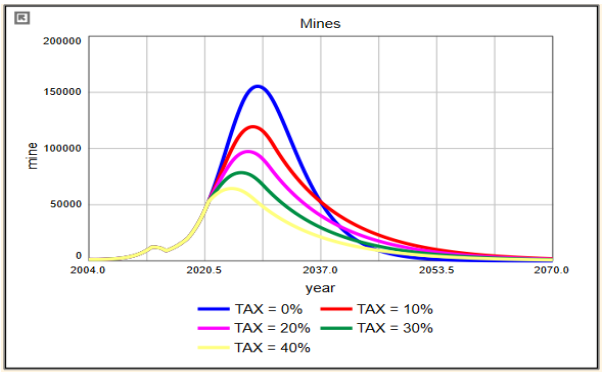


Figure 40 Nature of number of mines after policy in 2070

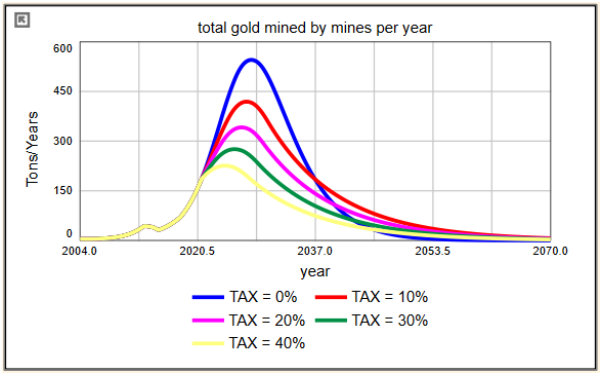


Figure 41 Volume of Gold produced after policy in 2070.

Besides, whenever the policy is activated (Tax not equal to zero), there is a sure hope that, not only the environmental stress is subsided but also there is a measure of good income for the government for other developmental projects thereafter.

With environmental cost now a burden of the miners, the cost of producing a ton of gold will increase due to increase in expenses. It will increase proportional with the percentage of the tax charged. The higher the tax percentage, the lower the income after tax for the miners. This means less money is available to mining. This makes mining more expensive. But when the tax percentage is low, however, there will be a comparatively more income after tax since expenses is reduced. With excess money at hand due to less tax, more mining activities could be carried out increasing the number of mines being established.

The lesser the tax rate, the lesser the tax income the government will get, but the more the income after tax obtained by the miners. This situation is true on the reverse.

However, as the number of mines increases, gold mining will increase, increasing the accumulated volume of gold produced. When more and more gold is produced, less and less gold reserve will remain, making it extra expensive to produce a ton of gold the next time due to gold scarcity. When cost of gold production is very high, the cost per capital for a mine or managing a mine site will be costly. This decreases the number of mines.

Also, with a higher tax rate in place, this means more expenses is paid or better still, a higher cost of gold production is seen. This triggers less and less gold to be produced the next time. This means that, there will be ample gold reserves ready to be harvested the next time. With more gold reserves available, the cost of mining will decrease which triggers the increased in growth of number of mines. In other words, when cost of gold production is increased (due to increase in tax rate) initially, the cost of gold production will eventually become lower due to much gold reserves that will be available for mining in the future, and vice versa.

So the steeper the rise in mining activity, the steeper the volume in the amount of gold produced, and the steeper the rise in number of mines. Soon thereafter, less gold will be available, quickly decreasing the rate of gold mining and consistently decreasing the number of mines.

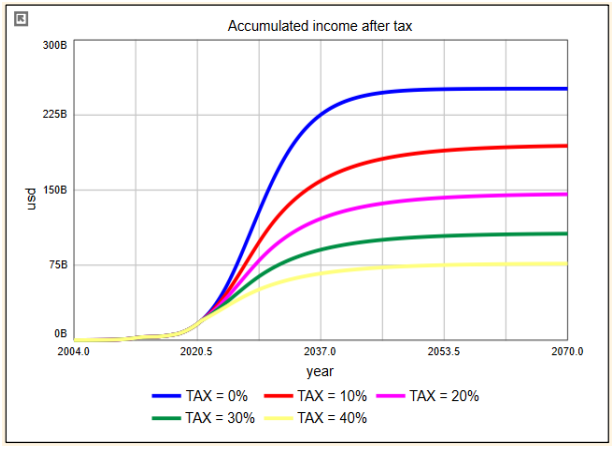


Figure 42 accumulated income for miners after policy in 2070.

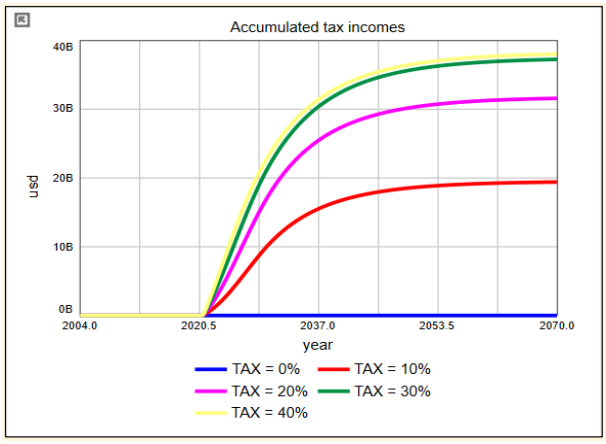


Figure 43 Accumulated government income after policy in 2070.

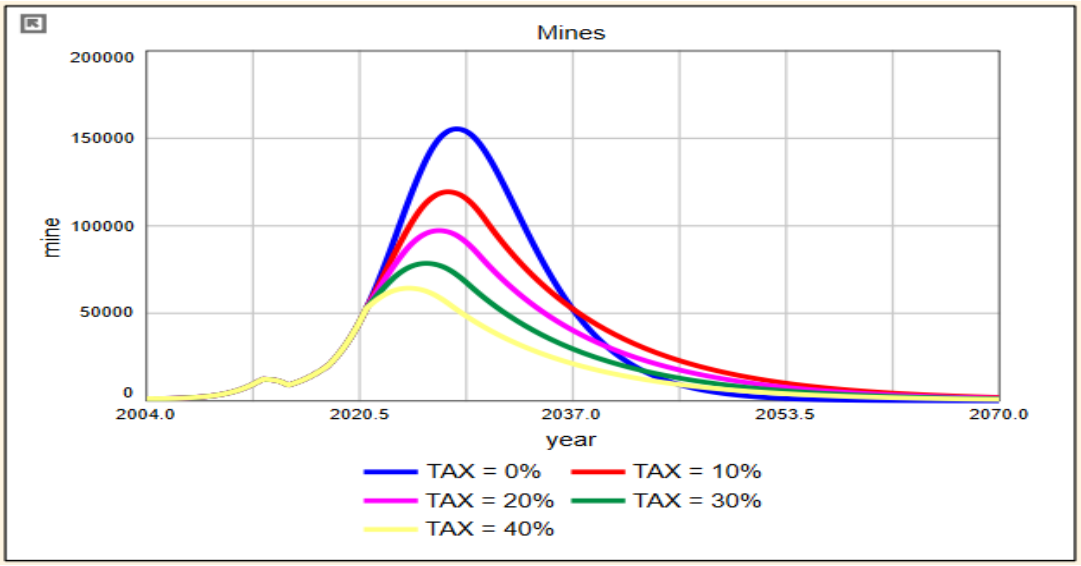


Figure 44 Nature of number of mines after policy in 2070

There is a strong relationship between tax rate charged and profit the miners and the government alike accrue. This is depicted by the graphs 42 and 43. Graph 42 indicators the income benefits the government achieves through taxation. When the tax policy is activated in 2021, the government will begin to obtain income from the sector. The higher the tax rate, the more the taxes the miners pay. This reduces the income margin of the miners making the cost of gold production very high, but substantially increases the government's initial income gotten from tax. With high cost of production, many mines' investors may not be able to stay in operations. When this happens, the number of mines will grow at a decreasing rate. With decreased number of mines available now, the tax income of the government will grow at a decreasing rate since the amount of tax income is directly proportional to the number of active mines.

On the other hand, the miners' income after tax seems to enjoy a steady increase (proportional to the increase in mines growth) until the policy is activated in 2021. The more taxes the miners' pay (after 2021), the lesser their income after tax and vice versa. For example, with 40% charged, the number of mines will grow decreasingly until 2023 when it begins to fall more rapidly. thereafter, the mines will decrease at a decreasing rate but will slow down its decline rate in a very gentle proportion until 2070. There will be about 778 mines available, accumulating a total of 38 billion

USD for the government through tax and also a total of 76.5billion USD for the miners through income after tax.

Also, with 10% tax rate charged, the number of mines (which is also true for the income level) will grow in will continue to increase initially until it slows down in its growth until about 2027. This will reduce the growth rate of the income after tax level. As number of mines decreases, the accumulated income level after tax will continue to grow more sluggishly until 2070. There will be around 1930 active mines by 2070, realizing a total of about 194 billion USD for miners as accumulated income after tax and 19.4 billion USD as accumulated tax income for the government.

30% tax rate will result in about 1090 active mines, 37.3 billion USD accumulated tax income for the government and 106 billion USD accumulative income after tax for the miners by 2070.

Also, 20% tax rate will result in 1480 active mines, 31.6 billion USD accumulative tax income for the government and 146 billion USD accumulative income after tax for the investors by 2070.

However, the real threat lies in having no policy in place. When there is no policy, or when the tax rate is zero, the number of mines will grow more steeply initially and a bit slowly afterwards until 2028 (more gold dug initially making it more expensive to mine another ton of gold afterwards). Thereafter, the number of mine will decline more swiftly (very limited gold reserves available hence much more expensive to mine). The boom-bust effect is so great with no policy in place. The intense decline in number of mines will slow down around 2040 after most of the mines are displaced. From 2041 onwards, the number of mines will continue its decline rate but in a more gradual manner.

It is important to note that, there is a striking resemblance between the number of mines and the accumulated income of miners. So the swift rise and fall in the number of mines reflects perfectly on the accumulated income level of the investors. From 2041 onwards, the accumulated income level will barely see a rise in its level due to fewer and fewer mines being remained with the passage of time. The sector would have accumulated about 247 billion USD in 2045 but would only be able to have 4 billion USD extra from that time until 2070 when there are around only 16 active mines remaining. The ridiculous aspect is that the government would have received 0 USD dollars with an environmental cost of 83.9 billion USD confronting the economy of the nation.

CHAPTER 6 DISCUSSION OF CONCLUSIONS FROM THE MODEL POLICY

6.1 INTRODUCTION

This study is conducted in the perspective of formalizing and maximizing the benefit of the small-scale mining sector in Ghana. The study evaluates the motivating force behind the exponential growth rate of the number of mines involved in this business. By means of qualitative and quantitative secondary data collected, and also observation (since this researcher lived in a mining community in Ghana), a system of cause and effect relationships was designed to serve as the basis of this study. On this basis, a stock and flow diagram was developed to reproduce the historical reference mode through reasonable calibrations and structured validation tests. Insights from the simulation model were used to answer the research questions and ultimately the research objective.

6.2 Answering the Research Question.

The objective for this research is to find out why illegal gold mining in Ghana continues to flourish and how the small-scale mining sector can be formalized. To achieve this objective, the following questions were answered.

a. Why does the illegal mining sector continue to flourish despite the government's attempt to crack it down?

b. Which robust policy can formalize the Artisanal Small-Scale Mining sector?

c. How does formalization of the sector help to reduce the environmental challenges associated with the illegal mining sector?

a. ***Why does the illegal mining sector continue to flourish despite the government's attempt to crack it down?***

Due to its crucial importance to the jewel, finance and investing, electronic, aerospace and electronics industries among others, gold is a highly sought-after and highly regarded precious material. (Sepanek, 2012). The search for profit from gold metals has attracted a host of investors,

both local and foreign, into the mining sector of Ghana to start mining. Increase in number of mines proportionally increases the amount of money resulting from total revenue. With increased amount in revenue, and with no robust policy impeding the revenue growth, a high level of return on investment is realized. With a perceived high return on investment, a host of investors are lured into the venture consequently. This wheel is reinvented each year since the sector seems to be doing well resulting in an exponential growth. Exponential growth, nonetheless, is not sustainable. The increasing number of mines may soon cause the depletion of this gold resource, collapsing the sector eventually. (Breierova, 2007). This truly calls for a policy intervention.

b. Which robust policy can formalize the Artisanal Small-Scale Mining sector?

A gold resource, due to its limited quantity in nature, is susceptible to overshoot and collapse when being mined. (Breierova, 2007). Its susceptibility to a collapse raises the concern of how well to formalize this sector, to get the most out of it before its eventual collapse. The government of Ghana in her attempt to regulate this sector introduced a crackdown policy, which made it extremely expensive to undergo mining operations due to the risk of having mining equipment. ceased (and even destroyed in some instances).

This study has discovered that, introduction of the right amount of tax can equally limit the growth in the number of mines in the industry as crackdown. The tax however has an added advantage of recouping income for the country. When a reasonably higher tax rate is introduced, the miners are forced to pay more in expenses. In other words, the cost of gold production will be higher. Since staying in operation becomes expensive the number of investors will decrease. This triggers a decrease in the volume of gold that is produced. This means that, there will be relatively enough gold reserves ready to be harvested the next time. This prolongs the overshoot and ultimately the collapse of the mining sector. Besides, tax incomes can help the government focus on building a substitute job opportunity to replace the mining business in the future.

c. How does formalization of the sector help to reduce the environmental challenges associated with the illegal mining sector?

The needless stress overwhelming the environment is also relieved when tax policy is introduced. The policy ensures that, investors have a detailed plan for reclaiming/restoring the environment

just after a mine is exhausted. In the model, the burden of environmental cost is shifted on the investors as part of their expenses as soon as the policy is activated. The environment will continually be restored and cared for throughout the lifespan of the mining sector. In case of eventual collapse, farmers have recovered lands for cultivation which will reduce the unemployment rate.

6.3 Limitations of The Model and Hints For Further Research

A cogent and a diligent approach was employed in conducting this study. Also, system dynamic principles are carefully adhered to in building the model for this study. Inspite of these, there are shortcoming that limit the robustness of the study. These could be served as a foundation for further research. The limitations include the following.

1. The model does not fully represent the ideal world condition of illegal mines in Ghana. Factors such as unemployment rate, corrupt nature of government official who supervise mining activities, availability and accessibility of land, the role of the media among others that influence illegal mining business in Ghana are missing in this study.
2. Also, how other government intervening policies affect the operation of the sector are not accounted for by this study. Example, government policies such as galamsey court, drone technology supervision, alternate livelihood for those living in mining communities among others, to some extend have impacted how the sector is growing.
3. Again, the amount of money (logistics and personnel) required to implement the proposed policy (tax) is not accounted for by this study. Implementation of this policy may not be ideal if the cost for implementation is equal to or larger than the amount gained from introducing the policy. That is the tax income.
4. Since the whole business is conducted illegally, there is a general lack of accurate and verified data in regard to this industry. The following variables lack accurate data and may be ideal for future investigation.

a. The two graphical variables (effect of relative profit and effect of depleting gold on cost of mining) seem to have massive impact on the model and hence require further validation.
b. There is no clear data about how much gold on average is produced by a small-scale mine each year. Accurate data on this may help us to have a more accurate insight about the profitability of the sector.
c. The actual relationship between gold already produced (or volume of gold reserves remaining) and the cost of opening a new mine (or managing an existing mine) is made on assumption. Further research could be conducted to actualize the true relationship.

6.4 CONCLUSION

Illegal gold mine has been a thorn in the flesh of the country of Ghana. This unbridled rush for gold has unleashed inestimable damages to the economy of Ghana including child labor, environmental stress, loss of revenue, and health crises in mining communities. As a limited resource commodity, gold in Ghana will eventually get exhausted, either sooner or later. The ideal condition will therefore be to formalize the sector in a practically sustainable way. The many already failed policies are an indication that outright ban for mining illegally is extremely challenging. The people will definitely want to have their share in this common pool resource as precedence has shown. With the high returns on investment due to the high profitability nature of the illegal mines business, people are motivated to engage in it. Instead of a total preventive policy, like crackdown, that eventually compels people to steal the resource, the sector could satisfactorily be formalized using tax regulations. As proven by this study, introduction of tax policy can sustainably control the growth rate of the sector. It however has an added advantage of mitigating the environmental challenges associated with this sector and more importantly also generates revenue for the country. The tax policy ensures that, accepted regulations for mining are adhered to. This will minimize child labor and also reduce the use of harmful extraction ingredients such as mercury and cyanide. By using the self-organized approach of resource management, foreigners are highly limited from taking part of this business, since the indigenous people will endeavor to

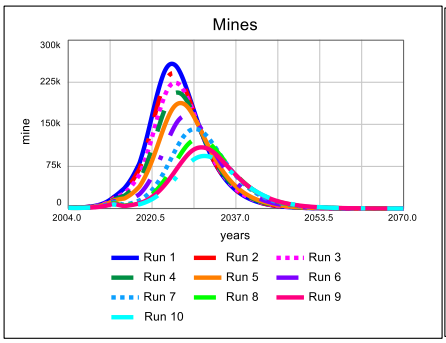
protect their territories. This will largely reduce the billions of dollar worth of gold that is smuggled out of the country every year.

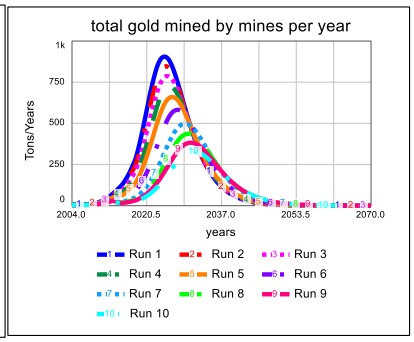
APPENDIX A: SENSITIVITY ANALYSIS

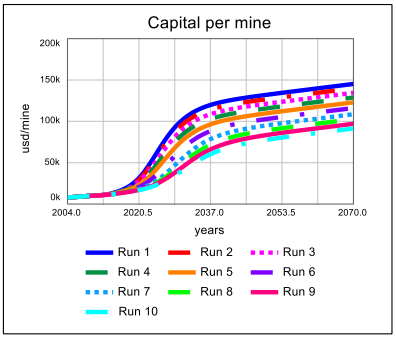
Variable Tested: Dealing fee fraction.

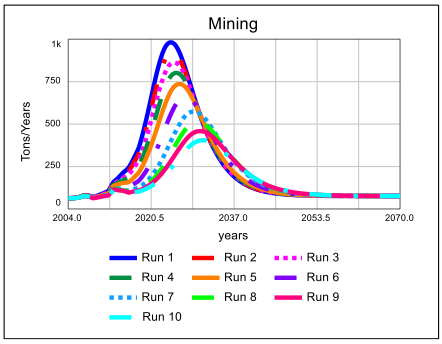
This part of the study examines how various variable used in building the model affects the behavior the model exhibits. These variables are a little bit unknown. So a wide range of figures were checked, and the results reveal that, the behavior of the model is sensitive to these variables. Looking at the gravity of influence exerted by these variables on the behavior of the model, it is highly recommended that, these variables must be researched into. This can allow for a more robust conclusions and insights to be made from the model.

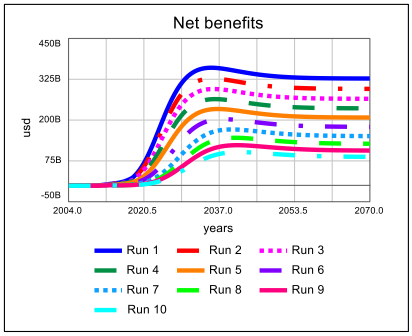
RUN	Dealing Fee Fraction
Run 1	0.1
Run 2	0.127777777778
Run 3	0.155555555556
Run 4	0.183333333333
Run 5	0.211111111111
Run 6	0.238888888889
Run 7	0.266666666667
Run 8	0.294444444444
Run 9	0.322222222222
Run 10	0.35

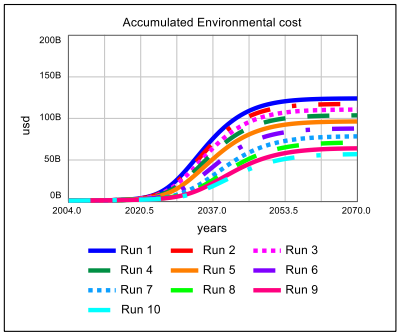




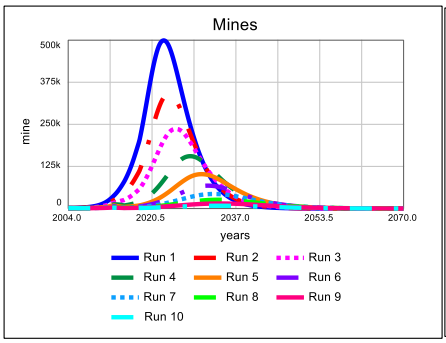


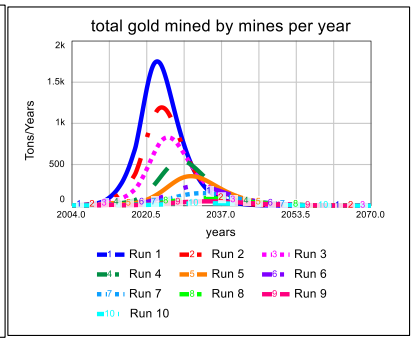


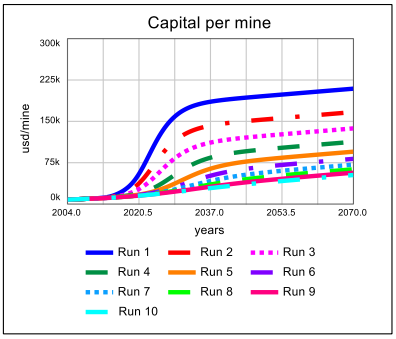


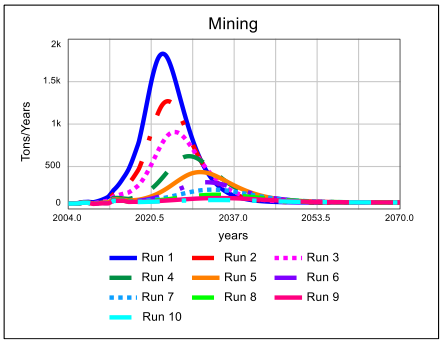


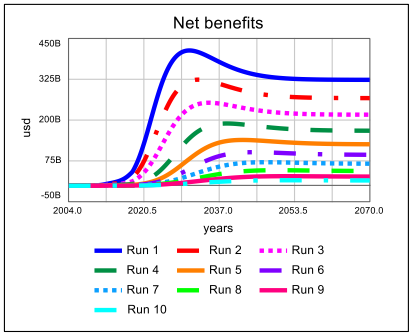
RUN	Required ROI
Run 1	0.05
Run 2	0.0666666666667
Run 3	0.0833333333333
Run 4	0.1
Run 5	0.116666666667
Run 6	0.133333333333
Run 7	0.15
Run 8	0.166666666667
Run 9	0.183333333333
Run 10	0.2

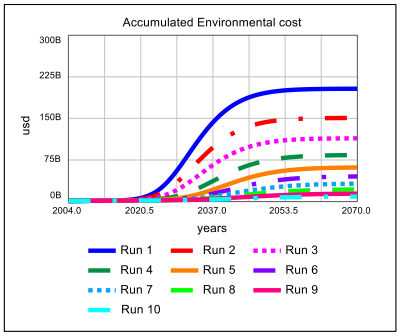






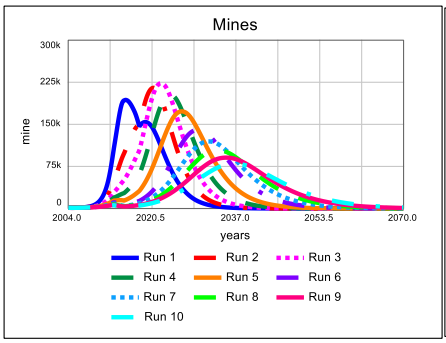


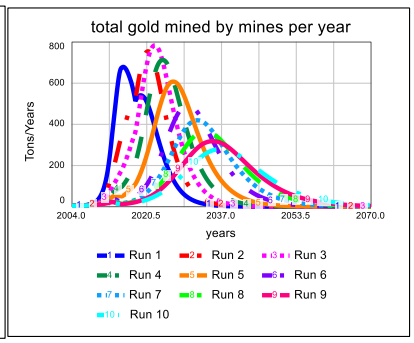


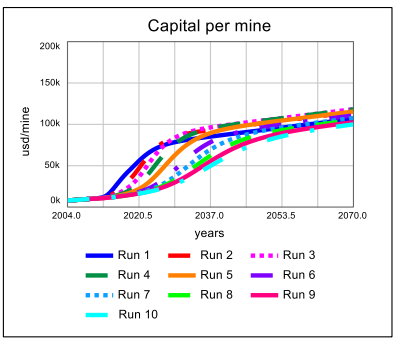


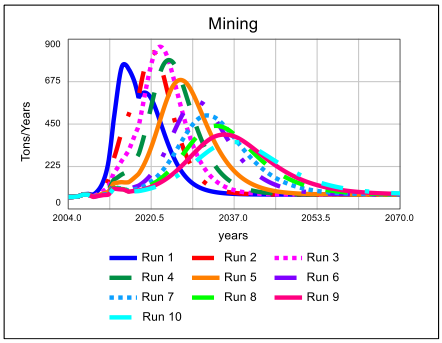
Time to expand Sensitivity.

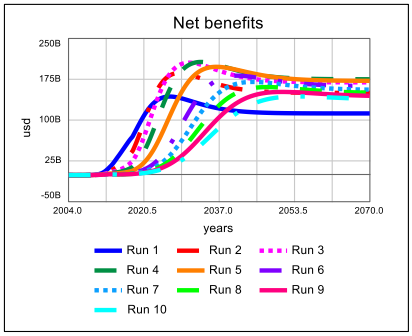
RUN	Time to Expand
Run 1	1
Run 2	1.22222222222
Run 3	1.44444444444
Run 4	1.66666666667
Run 5	1.88888888889
Run 6	2.11111111111
Run 7	2.33333333333
Run 8	2.55555555556
Run 9	2.77777777778
Run 10	3

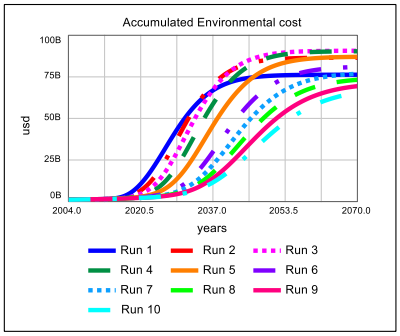




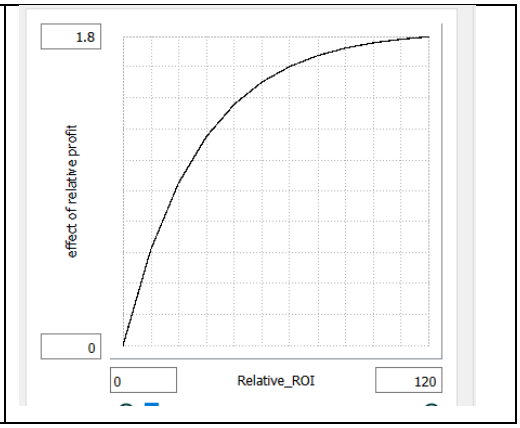


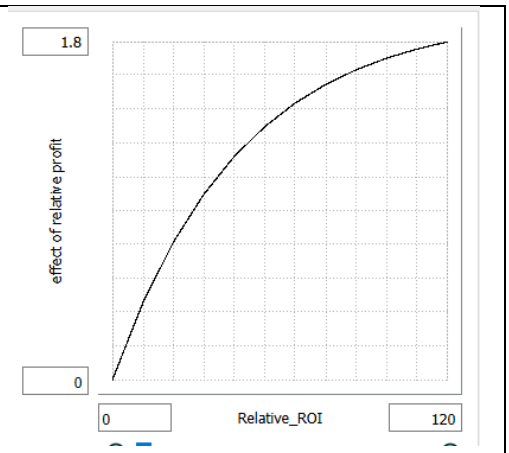
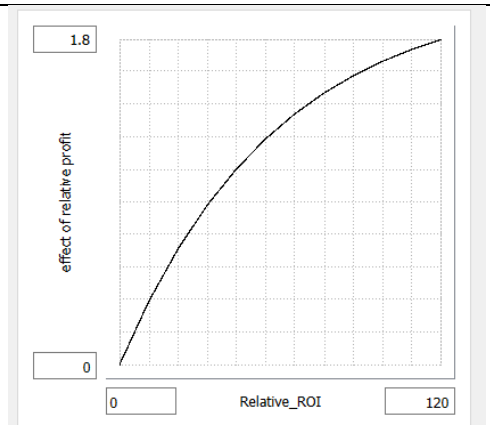
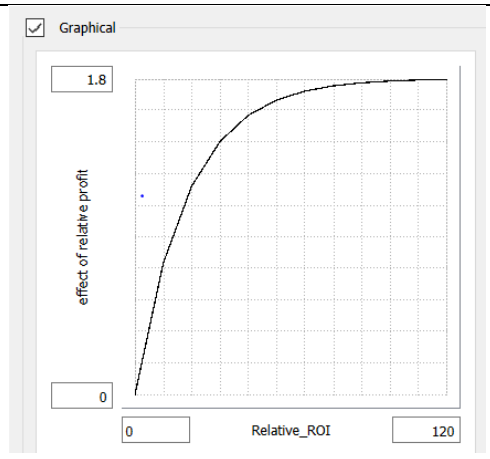


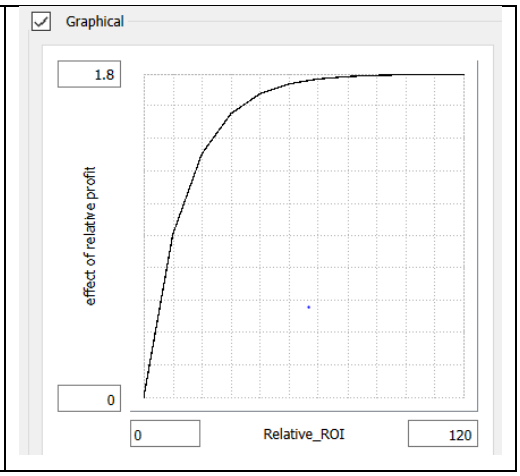


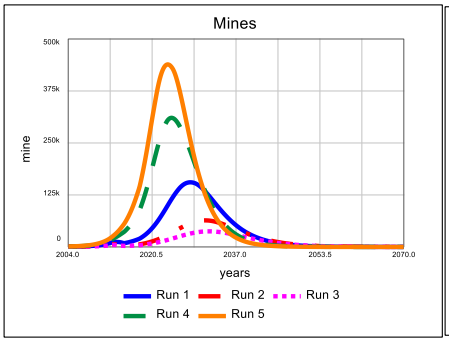


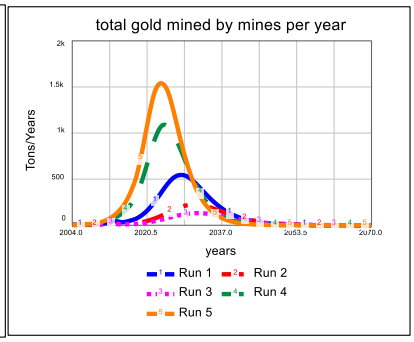
Effect of ROI on profit

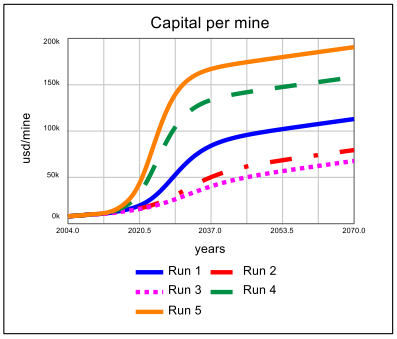
Run 1	

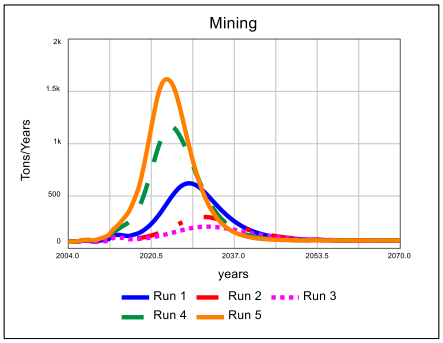
Run 2	
Run 3	
Run 4	

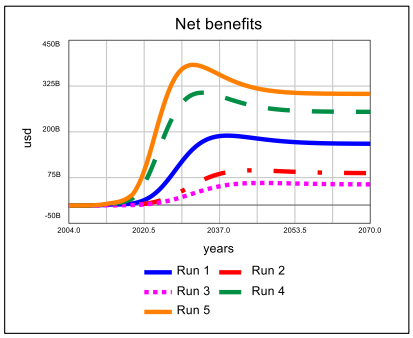
Run 5	

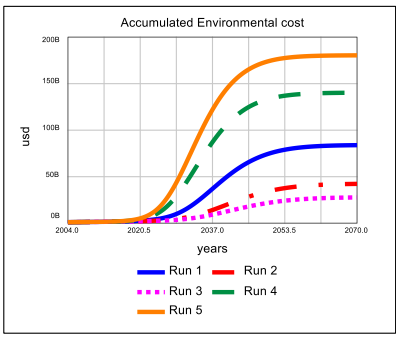




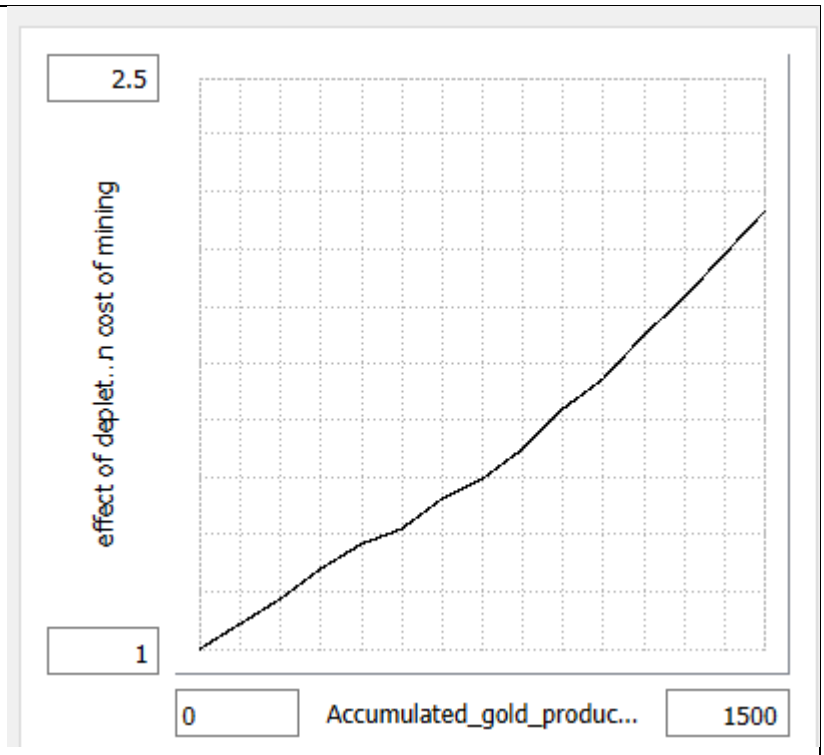
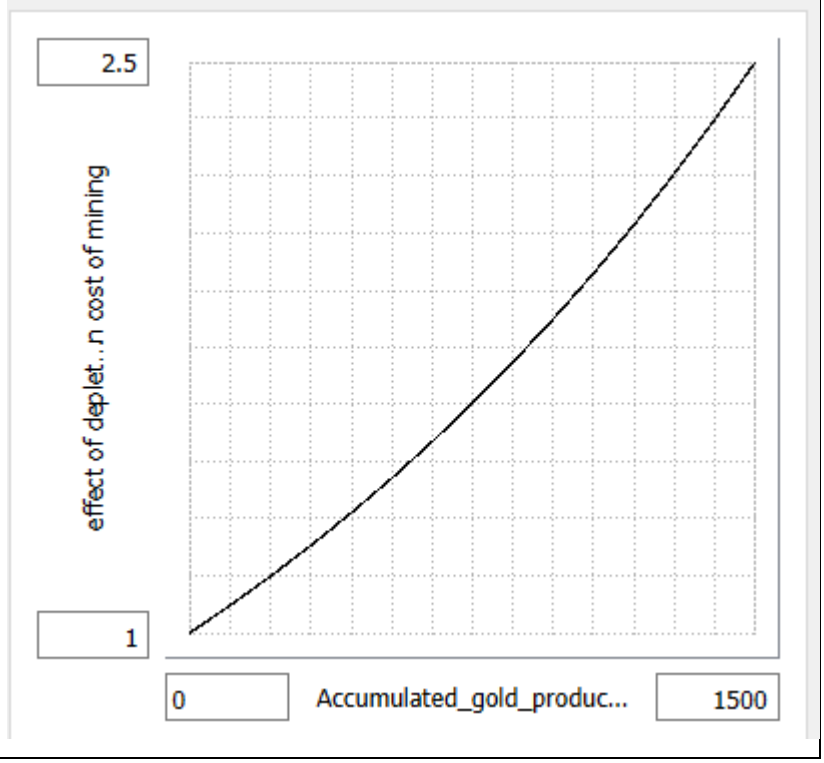


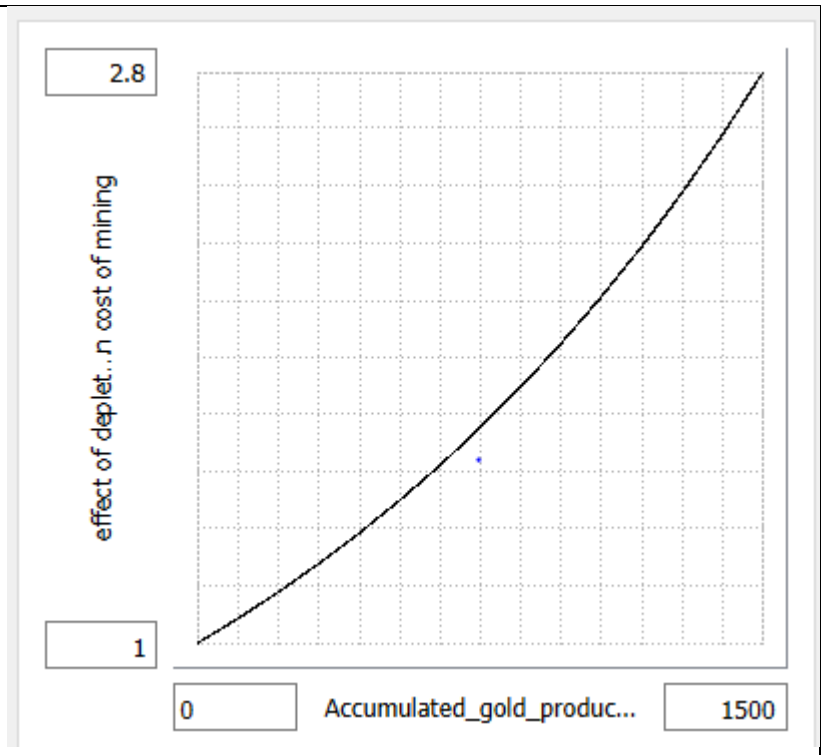
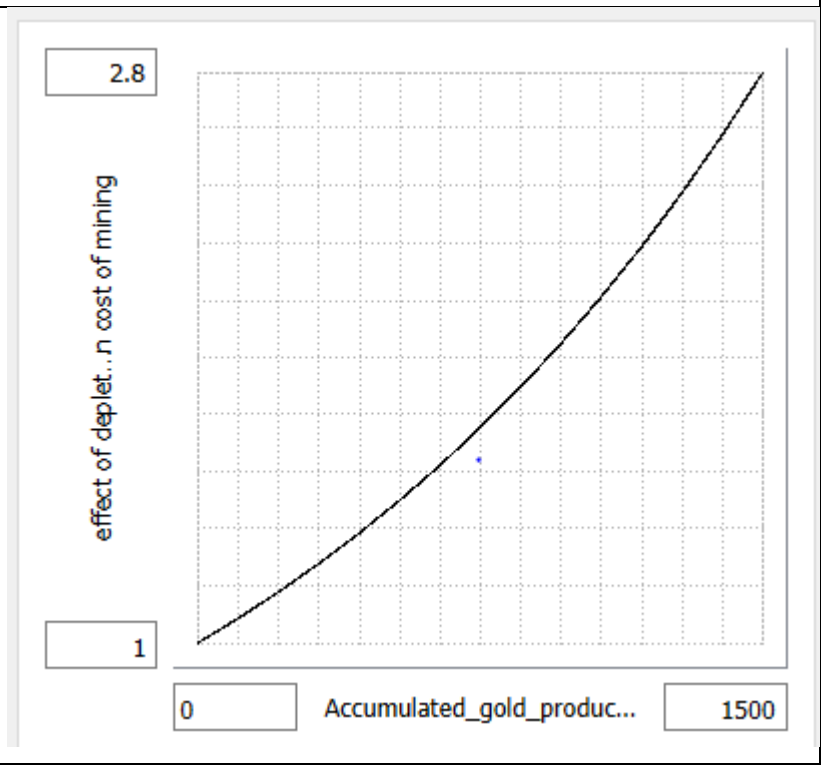




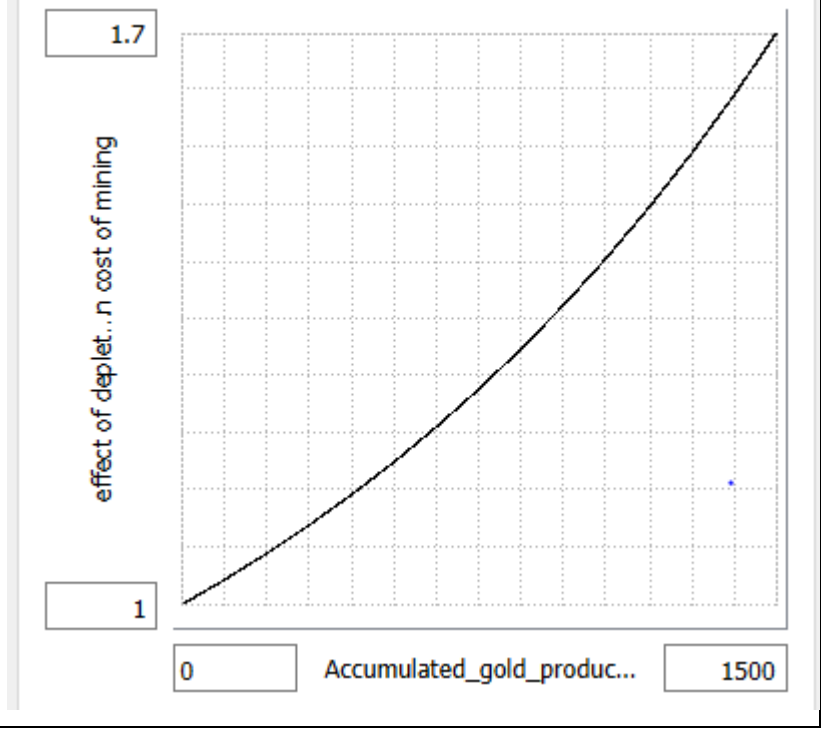


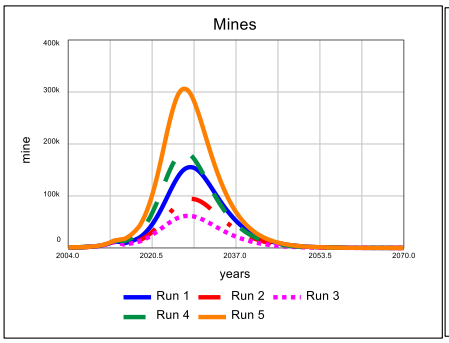
Effect of depleting gold on cost of mines variable

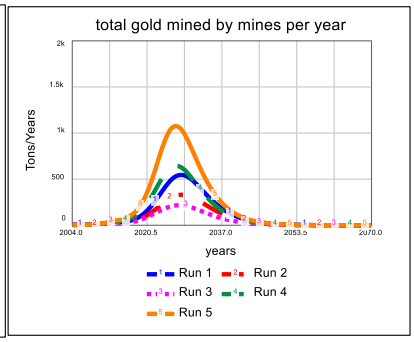
Run 1	 2.5 effect of deplet..n cost of mining 1 0 Accumulated_gold_produc... 1500
Run 2	 2.5 effect of deplet..n cost of mining 1 0 Accumulated_gold_produc... 1500

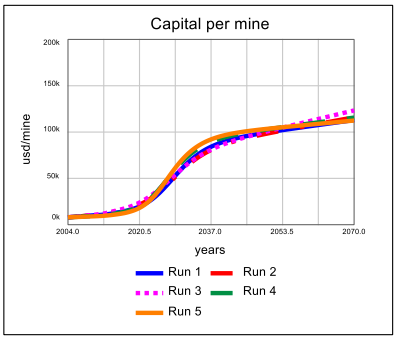
Run 3	 2.8 effect of deplet...n cost of mining 1 0 Accumulated_gold_produc... 1500
Run 4	 2.8 effect of deplet...n cost of mining 1 0 Accumulated_gold_produc... 1500

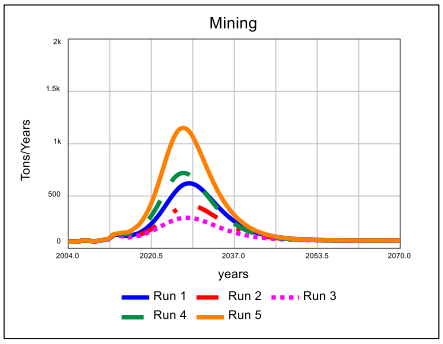
Run 5

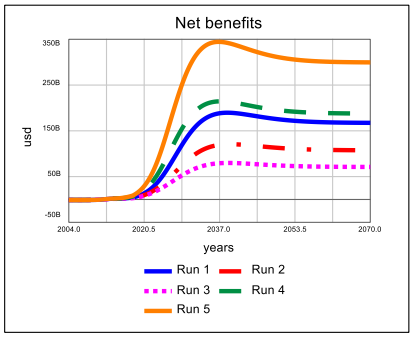

1.7
effect of deplet..n cost of mining
1
0
Accumulated_gold_produc...
1500

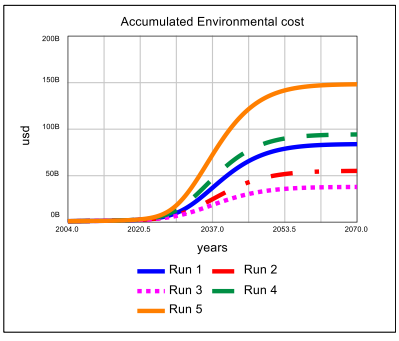

Mines
mine
400k
300k
200k
100k
0
2004.0
2020.5
2037.0
2053.5
2070.0
years
Run 1
Run 2
Run 3
Run 4
Run 5


total gold mined by mines per year
Tons/Years
2k
1.5k
1k
500
0
2004.0
2020.5
2037.0
2053.5
2070.0
years
Run 1
Run 2
Run 3
Run 4
Run 5


Capital per mine
usd/mine
200k
150k
100k
50k
0k
2004.0
2020.5
2037.0
2053.5
2070.0
years
Run 1
Run 2
Run 3
Run 4
Run 5


Mining
Tons/Years
2k
1.5k
1k
500
0
2004.0
2020.5
2037.0
2053.5
2070.0
years
Run 1
Run 2
Run 3
Run 4
Run 5

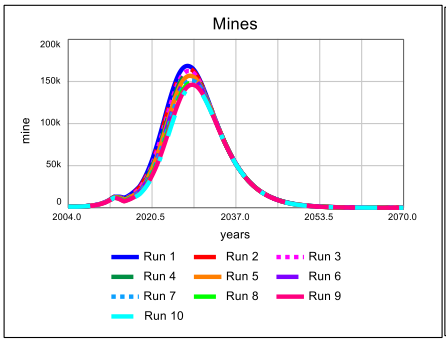

Net benefits
usd
350B
250B
150B
50B
-50B
2004.0
2020.5
2037.0
2053.5
2070.0
years
Run 1
Run 2
Run 3
Run 4
Run 5

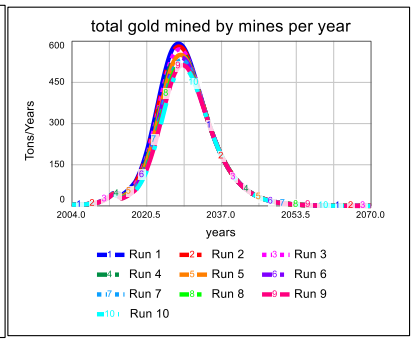

Accumulated Environmental cost
usd
200B
150B
100B
50B
0B
2004.0
2020.5
2037.0
2053.5
2070.0
years
Run 1
Run 2
Run 3
Run 4
Run 5

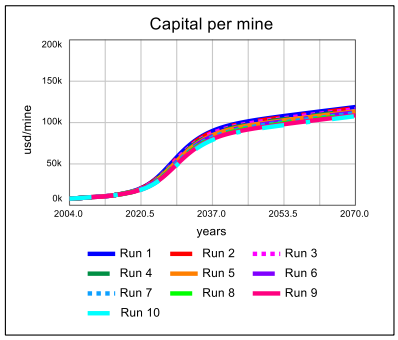
INTEREST RATE SENSITIVITY

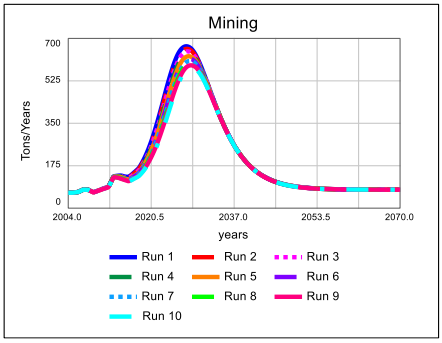
interest rate

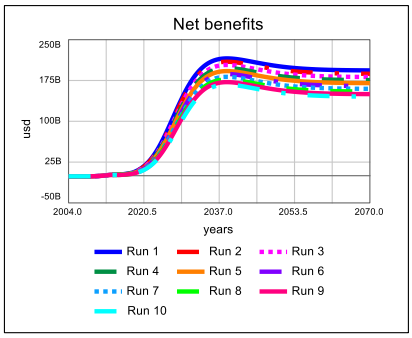
Run 1	0.15
Run 2	0.172222222222
Run 3	0.194444444444
Run 4	0.216666666667
Run 5	0.238888888889
Run 6	0.261111111111
Run 7	0.283333333333
Run 8	0.305555555556
Run 9	0.327777777778
Run 10	0.35

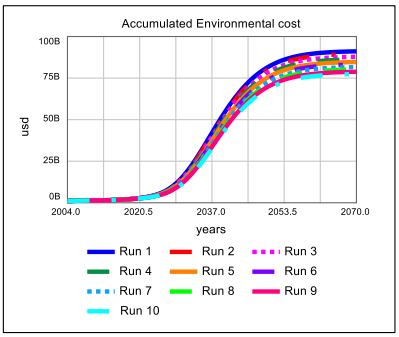








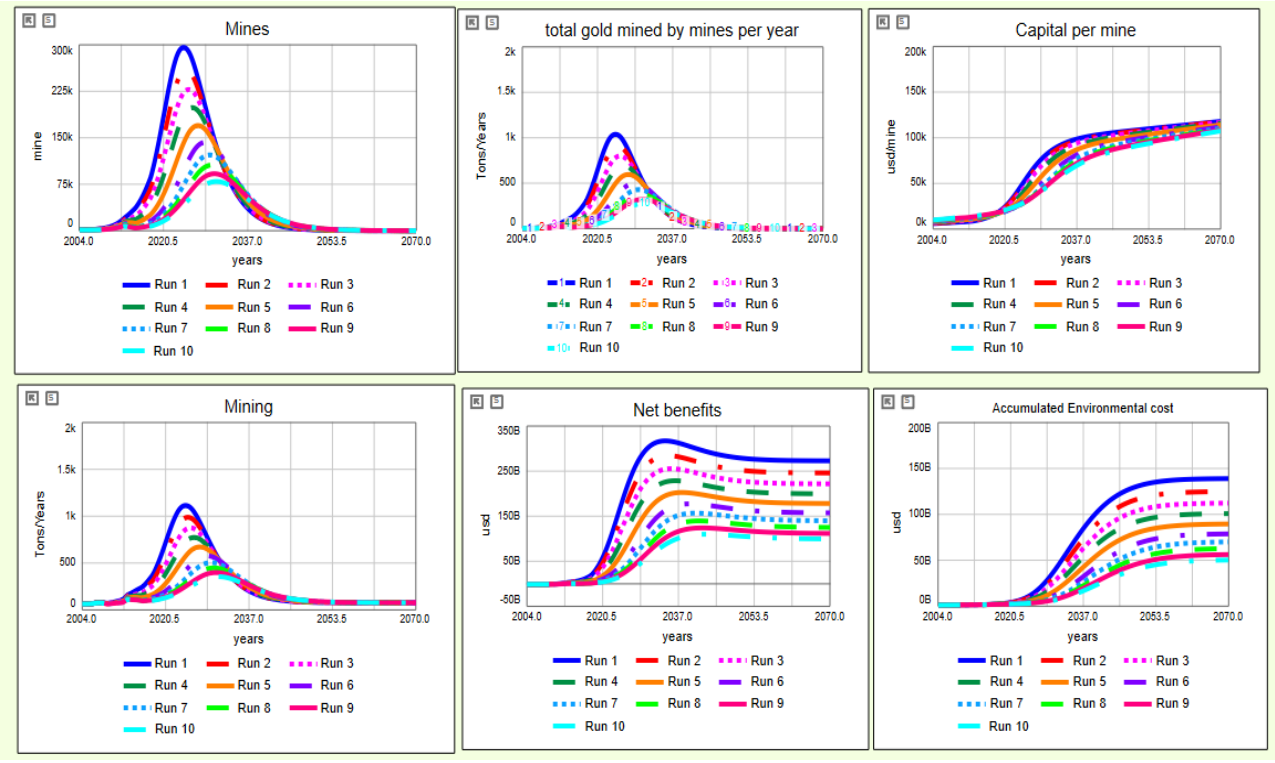




BASE CAPITAL SENSITVITY

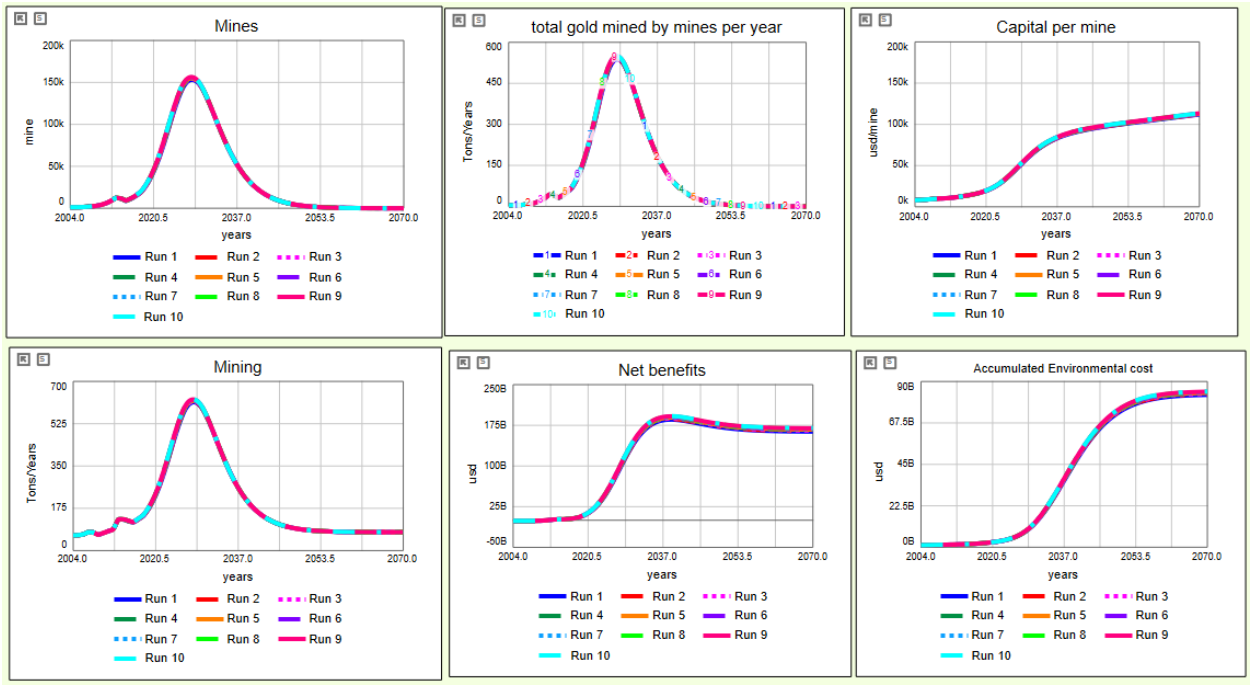
Base Capital per mine

Run 1	6000
Run 2	6444.44444444
Run 3	6888.88888889
Run 4	7333.33333333
Run 5	7777.77777778
Run 6	8222.22222222
Run 7	8666.66666667
Run 8	9111.11111111
Run 9	9555.55555556
Run 10	10000



AVERAGE LIFETIME OF CAPITAL

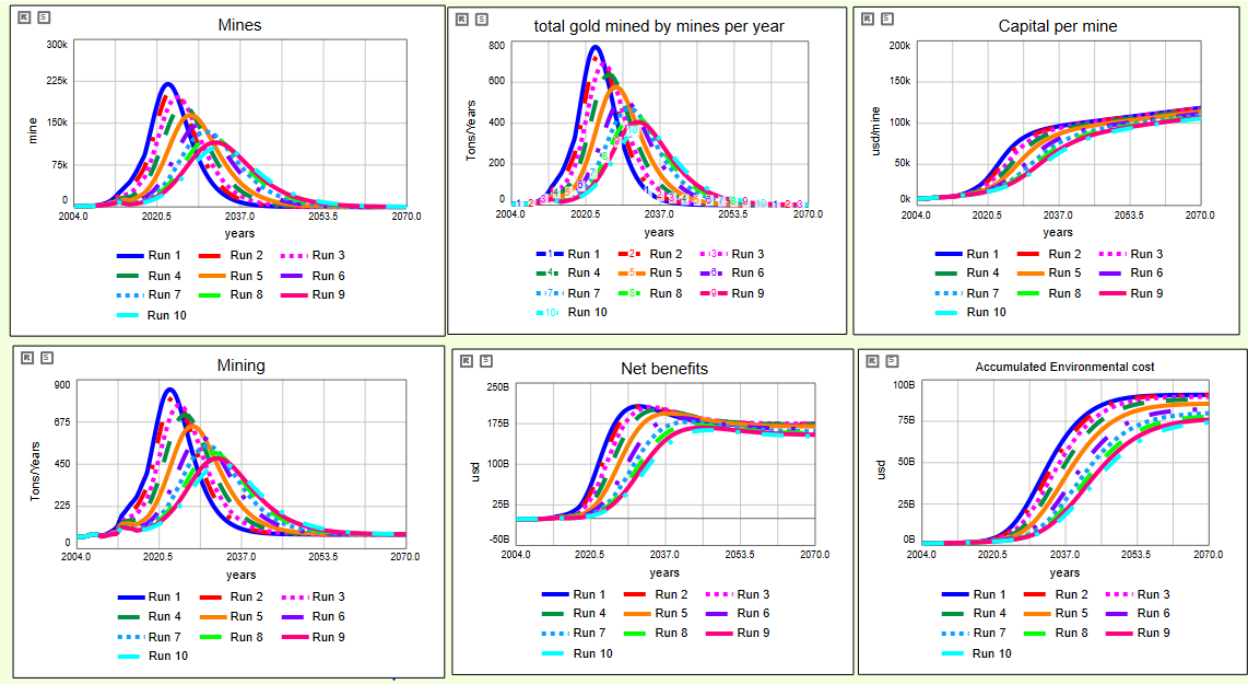
average lifetime of capital
Run 1 15
Run 2 16.1111111111
Run 3 17.2222222222
Run 4 18.3333333333
Run 5 19.4444444444
Run 6 20.5555555556
Run 7 21.6666666667
Run 8 22.7777777778
Run 9 23.8888888889
Run 1025



TIME TO EXPAND

Time to expand

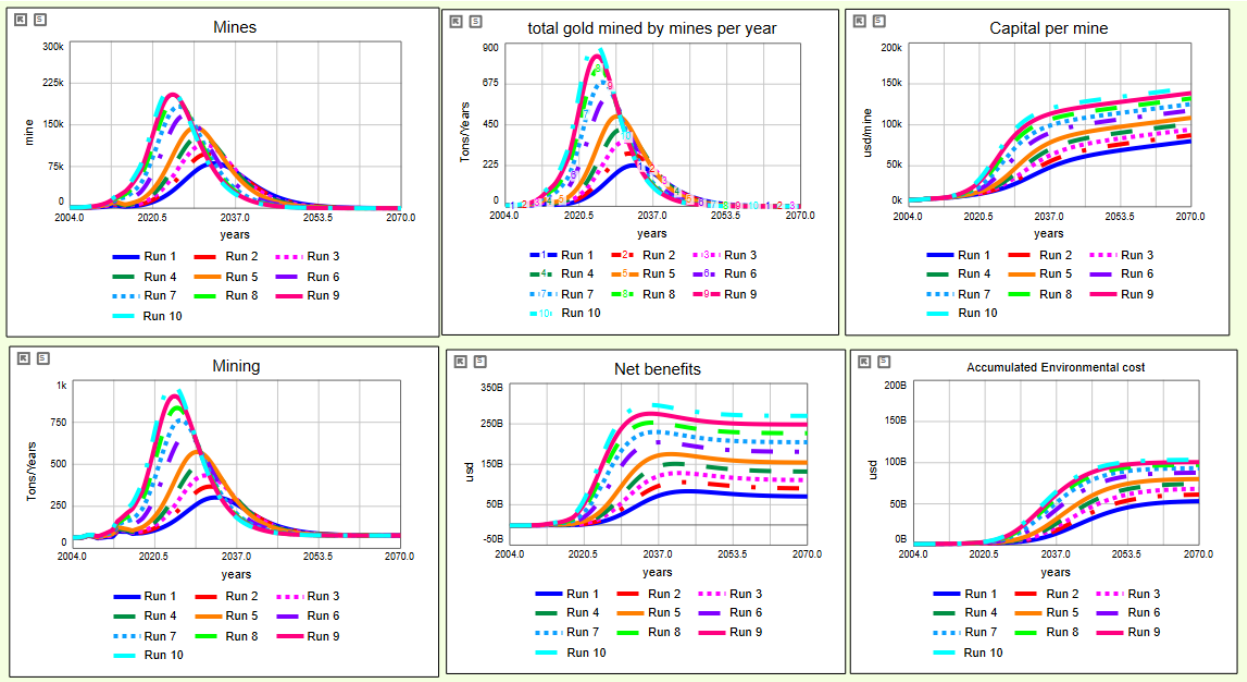
Run 1	1.5
Run 2	1.61111111111
Run 3	1.72222222222
Run 4	1.83333333333
Run 5	1.94444444444
Run 6	2.05555555556
Run 7	2.16666666667
Run 8	2.27777777778
Run 9	2.38888888889
Run 10	2.5



TON PER MINE PER REAR SENSITIVITY

	tons per mine per year
Run 1	0.00281

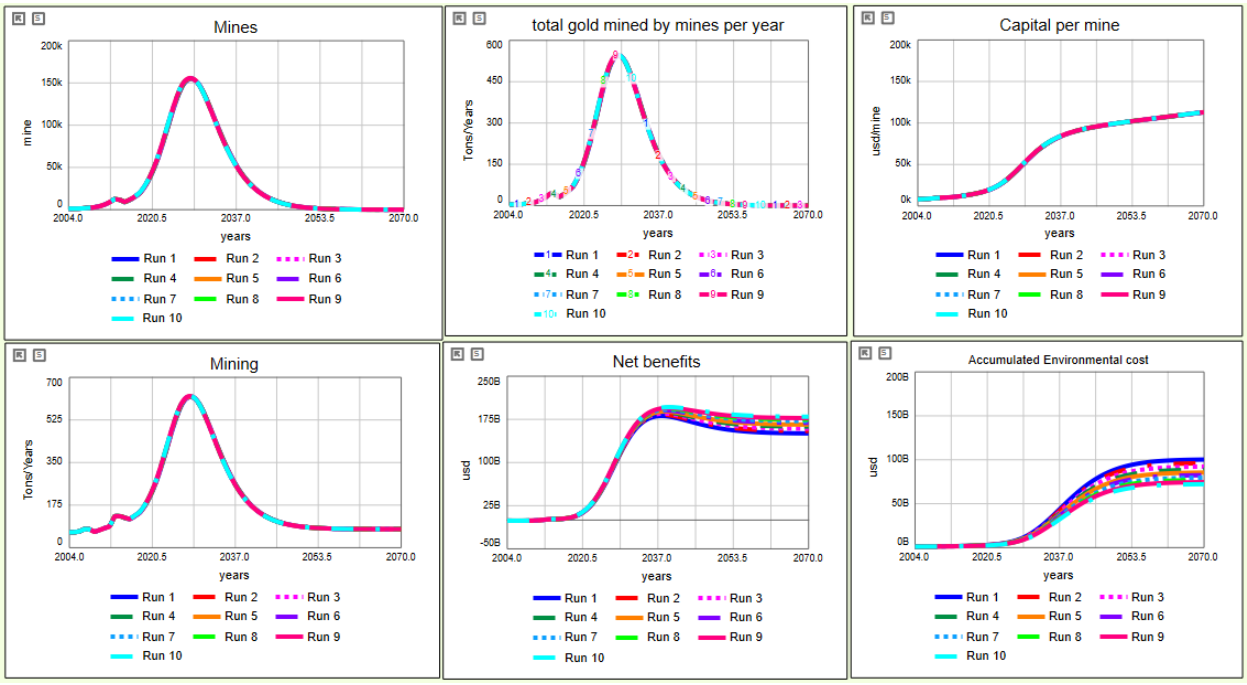
Run 2	0.00296555555556
Run 3	0.00312111111111
Run 4	0.00327666666667
Run 5	0.00343222222222
Run 6	0.00358777777778
Run 7	0.00374333333333
Run 8	0.00389888888889
Run 9	0.00405444444444
Run 10	0.00421



Mine Average Lifespan (Normal Time)

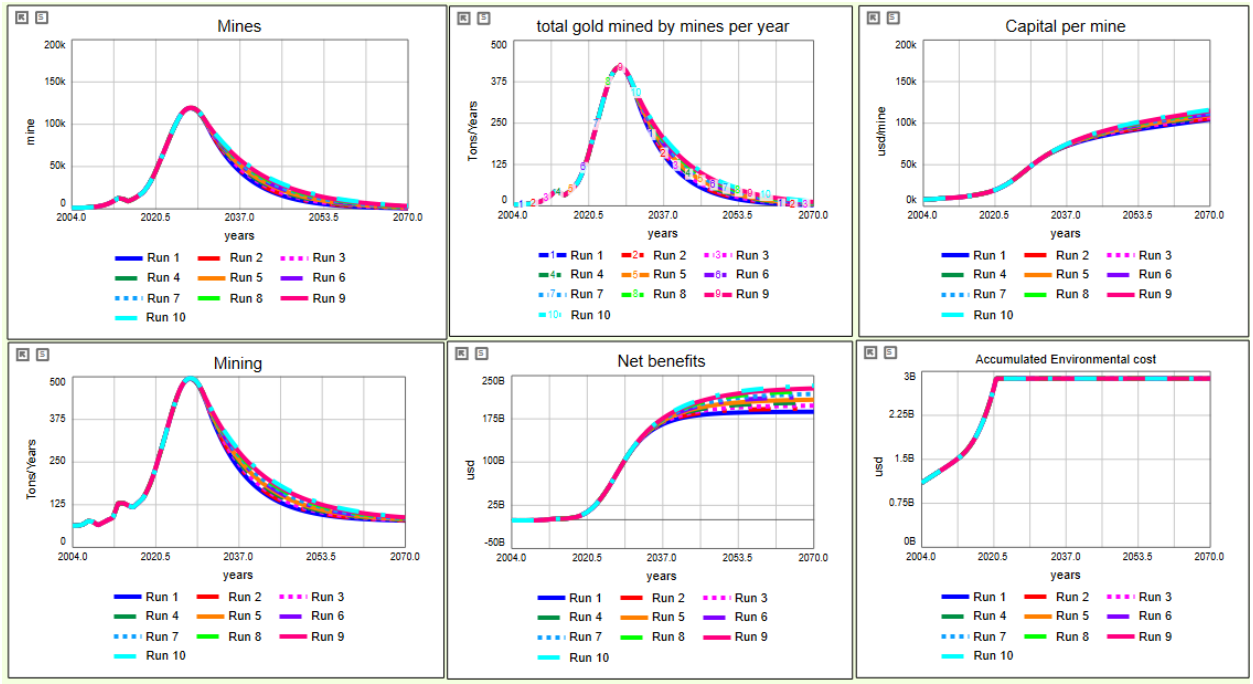
	normal time
Run 1	2.5

Run 2 2.61111111111
Run 3 2.72222222222
Run 4 2.83333333333
Run 5 2.94444444444
Run 6 3.05555555556
Run 7 3.16666666667
Run 8 3.27777777778
Run 9 3.38888888889
Run 103.5



MINE AVERAGE DESIRED LIFESPAN (POLICY ON)

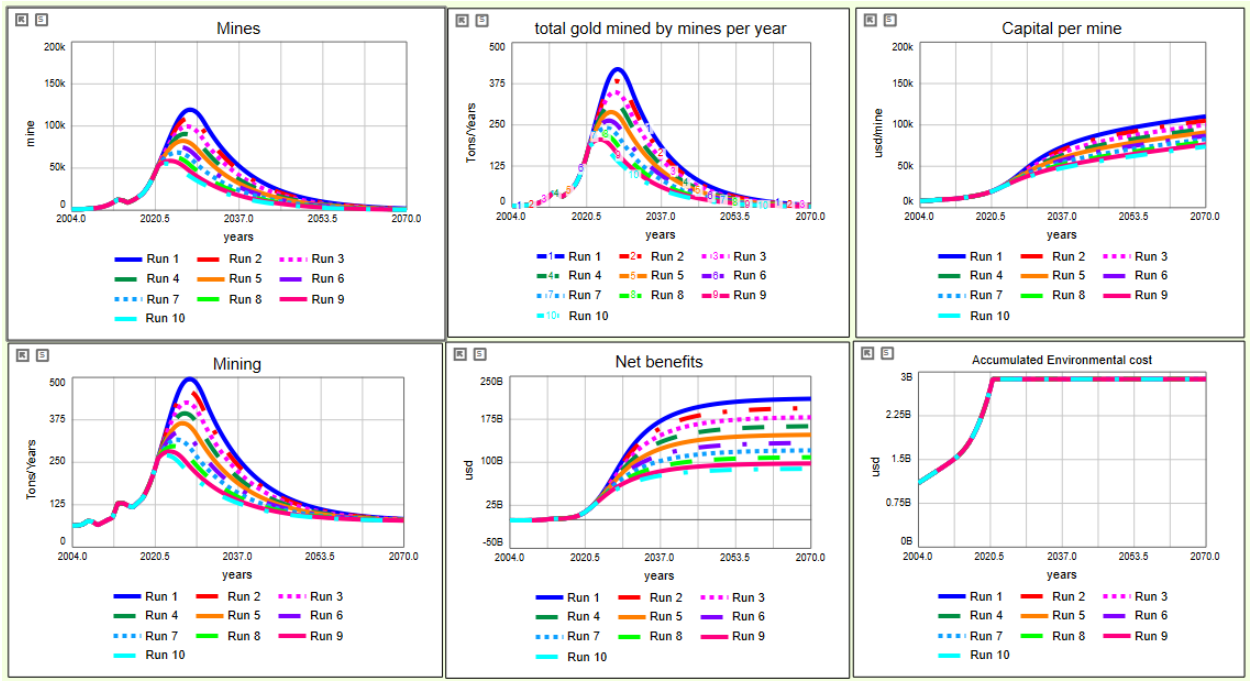
	policy desired time
Run 1	8
Run 2	8.44444444444
Run 3	8.88888888889
Run 4	9.33333333333
Run 5	9.77777777778
Run 6	10.2222222222
Run 7	10.6666666667
Run 8	11.1111111111
Run 9	11.5555555556
Run 10	12



TAX RATE SENSITIVITY

tax rate

Run 1	0.1
Run 2	0.144444444444
Run 3	0.188888888889
Run 4	0.233333333333
Run 5	0.277777777778
Run 6	0.322222222222
Run 7	0.366666666667
Run 8	0.411111111111
Run 9	0.455555555556
Run 10	0.5



APENDIX B: DOCUMENTATION

Description of Variable	Units
Name: Accumulated Environmental cost **Equation:** Accumulated_Environmental_cost (t - dt) + (accumulating_environmental_cost) * dt. **Description** This represents the total amount of money needed to reclaim lost or degraded land by the sector	USD
Name: Accumulated Gold Produced. **Equation:** Accumulated_gold_produced (t - dt) + (Mining) * dt. **Description** This represents the total amount of gold mined every year	Tons
Name: Accumulated Income After Tax. **Equation:** Accumulated_income_after_tax (t - dt) + (accumulating_income_after_tax) * dt. **Description** This represents the total profit generated by miners in the sector	USD
Name: Accumulated Tax Incomes **Equation:** Accumulated_tax_incomes (t - dt) + (accumulating_tax_income) * dt. **Description** This represents the total amount of profit generated from tax from the sector	USD
Name: Accumulated Wages **Equation:** accumulated_wages (t - dt) + (Accumulating_Wage) * dt.	USD

Description This amounts to the total amount of money paid to workers within the years under consideration	
Name: Forest and farmland. **Equation:** Forest_and_farm_land (t - dt) + (afforestation - forest_depletion) * dt. **Description** This accounts for the total land size of Ghana. It is initialized with 23853500. **Source:** Mapping and Monitoring Small-Scale Mining Activities in Ghana using Sentinel-1 Time Series (2015–2019) Gerald Forkuor, Tobias Ullmann 2 and Mario Griesbeck 2 Received: 30 January 2020; Accepted: 3 March 2020; Published: 12 March 2020	Hectares
Name: Mines **Equation:** Mines (t - dt) + (opening_mine - closing_mine) * dt. **Description** this refers to the total number of active mines in place at any time within the years under consideration. it is measured in mine.	Mine
Name: Unusable Land **Equation:** Unusable_land (t - dt) + (forest_depletion - afforestation) * dt. **Description** this refers to the mass of land that is not good for cultivation because of its degradation by galamsey activities. this mass of land is highly eroded and lying idle	Hectares
Name: Accumulating Environmental Cost **Equation:** (1-Policy) *Cost_of_afforestation **Description:** This refers to the rate of accumulating environmental cost	USD /Year
Name: Accumulating Income After Tax	USD /Year

Equation: net_income_after_tax **Description:** This refers to the rate by which income after tax is accumulated.	
Name: Accumulating Tax Income **Equation:** tax income **Description:** This represents the rate of accumulating the profit from tax	USD /Year
Name: Accumulating Wage **Equation:** total_operating_expenses*wage_percentage. **Description** Accumulating wages paid to workers every year.	USD /Yar
Name: Afforestation **Equation:** (Unusable_land/Time_to_Recover_naturally) *(1-afforestation_policy) +(Unusable_land/time_to_recover_actively) *afforestation_policy **Description** This accounts for the actual regrowth process of the depleted land into a farm or forested land. It alternates between the natural regrowth process and tree planting. When switch is on, then the tree planting as a policy is activated and vice versa.	Hectares/Year
this refers to the annual reduction in the number of active illegal mines in place. This reduction is accounted for by the annual drop out fraction times the average lifespan of the mines times the number of active illegal mines. it is measured in operation per year	Mine/Years
Name: Forest Depletion **Equation:** New_land_used_in_mining. **Description**	Hectares/Year

This refers to the rate of land degradation. This start or intensifies when a new mine is born	
Name: Mining **Equation:** (Average_gold_mined_by_large_mine_per_year+total_gold_mined_by_mines_per_year) **Description** This represents the rate at which gold is mined annually.	Tons/Years
Name: Opening Mine **Equation:** MAX (0, (indicated_mines-Mines)//time_to_expand+closing_mine) **Description** this refers to the number of mines that are created or opened each year. it is measured in operation per year.	Mine/Years
Name: Acres to Hectares **Equation:** 2.471 **Description** This represents a conversion from acres to hectares **Sources:** https://housing.com/calculators/hectare-to-acre.	Acres/Hectare
Name: Actual hectares of mines closed **Equation:** closing_mine*average_size_per_mine_in_hectares **Description** this represents the total number of hectares of abandoned land.	Hectares/Year
Name: Actual return on investment **Equation:** net_income_after_tax//capital	1/Year

Description: It is the actual Return on Investment income given any year divided by the total amount invested to produce that income in that year	
Name: Afforestation policy **Equation:** IF TIME > 2021 THEN afforestation_policy_switch ELSE 0 **Description** It produces the value of the afforestation from the years 2021 onwards.	Dimensionless.
Name: Afforestation policy switch **Equation:** tax_rate_switch **Description** This is a switch that regulates (activates or deactivates) the afforestation policy. It has two values, 0 and 1. It activates turns on the policy when it is 1 and turns it off when it is 0. It has no dimension	Dimensionless.
Name: Average gold mined by large mine per year. **Equation:** GRAPH(TIME) Points: (2004.00, 58.71927), (2005.00, 59.49828), (2006.00, 62.13713), (2007.00, 71.0243), (2008.00, 68.42755), (2009.00, 55.61076), (2010.00, 58.77564), (2011.00, 60.29654), (2012.00, 57.40152), (2013.00, 85.7984), (2014.00, 88.256), (2015.00, 91.48725), (2016.00, 77.00152), (2017.00, 77.81953), (2018.00, 76.20) **Description** This refers to the average amount of gold mines by the large mines sector of Ghana every year **Source**: Galamsey in Ghana and China's illegal gold rush (Leudi, 2019).	Tons/Year

https://www.asiabyafrica.com/point-a-to-a/galamsey-ghana-illegal-mining-china	
Name: Average gold mined per mine per year. **Equation:** tons_per_mine_per_year*ounce_to_ton **Description** this refers to the volume of ounces of gold produced by each mine on a yearly basis It is measured in ounce/mine/year **Source**: It is derived from a figure given by LEUDI (Leudi, 2019)	Ounce/Mine/Year
Name: Average lifetime of capital. **Equation:** 20 **Description** this refers to the average time it takes for machines, money and other equipment invested initially into the mines to become no more usable. **Source**: (Assore, n.d.)	Years
Name: Average size per mine in hectares. **Equation:** size_of_mine_in_acres/acres_to_hectares **Description** This shows the converted value of hectares from acres. 10.1 acres are equivalent to 1 hectare **Source**: https://housing.com/calculators/hectare-to-acre.	Hectares/Mine
Name: Base Capital per mine. **Equation:** 8000 **Description** the refers to the base capital per mine at the beginning of the simulation.	USD/Mine

Source:	
Name: Capital **Equation:** Capital_per_mine*Mines **Description** this refers to the total amount of money invested in the illegal mining operation in Ghana. it is the product of capital per mine and the total number of illegal mines available. It is measured in USD	USD
Name: Capital Per Mine **Equation:** effect_of_depleting_gold_on_cost_of_mining*Base_Capital_per_mine **Description** the actual capital per mine calculated by taking the base capital per mine multiply by the index.	USD/Mine
Name: Cost for reclaiming unusable land **Equation:** land_reclamation_cost_per_hectare*Unusable_land **Description** This accounts for how much money is required to reclaim all unusable land. It is a product of land reclamation cost and the total land declared unusable	USD
Name: Cost_of_afforestation **Equation:** Delayed_afforestation*land_reclamation_cost_per_hectare. **Description** this refers to the total amount of money required to reclaim available abandoned hectares of degraded land. It is a product of how much it cost to reclaim a hectare of land and the total hectares of land available to be reclaimed.	USD/Year
Name: Cost of capital **Equation:** capital*(interest_rate+1/average_lifetime_of_capital) **Description**	USD/Year

this refers to the amount of money spent on payment of interest.	
Name: Cost per ton **Equation:** total expenses/total_gold_mined_by_mines_per_year **Description** This represents how much money it required to mine a ton of gold each year	US D/Tons
Name: Crackdown **Equation:** MIN ((STEP(6.7, 2013) + STEP(-6.7, 2015)) *1e8, total_revenue) **Description** This was an intervention strategy implemented by the government to halt the operation of the illegal mining sector in 2014.It came as a huge cost to the sector as many excavators, water pumps and other mining equipment were seized and or destroyed by the government	USD/Year
Name: Dealing fee fraction **Equation:** .25 **Description** this represents gold transaction cost. This refers to the fraction of the revenue lost when miners sell gold to dealers or middlemen source: (Lawson, 2015)	Dimensionless.
Name: Degraded Land by galamsey activities **Equation:** 23800000*.02 **Description**	Hectares
Name: Delay time **Equation:** 10 **Description** Delayed time refers to the average time it takes to regrow the depleted forest	Year
Name: Delayed afforestation	Hectares/Year

Equation: SMTH3(actual_hectares_of_mines_closed, delay_time) **Description** a third order exponential delay process of the land as it is retired due to mines closing their operations	
Name: Desired expenses **Equation:** (Mines*operating_expenses_per_mine) +environmental_cost_to_the_mines **Description** This represents the average lifespan of a mine when it is mined illegally. The average mine of a galamsey mine is 3 years according to Leudi. **Source:** Galamsey in Ghana and China's illegal gold rush JANUARY 16, 2019 By: Jeremy Luedi	USD/Year
Name: Effect of depleting gold on cost of mining **Equation:** GRAPH(Accumulated_gold_produced) Points: (0, 1.000), (107.142857143, 1.066), (214.285714286, 1.132), (321.428571429, 1.211), (428.571428571, 1.276), (535.714285714, 1.316), (642.857142857, 1.395), (750, 1.447), (857.142857143, 1.526), (964.285714286, 1.632), (1071.42857143, 1.711), (1178.57142857, 1.825), (1285.71428571, 1.924), (1392.85714286, 2.038), (1500, 2.152) **Description** This refers to the effect of depleting gold on the cost of mining. The more readily available gold deposits are, the cheaper they are to mine and vice versa.	Dimensionless.
Name: Effect of relative profit **Equation:** GRAPH(Relative_ROI) Points: (0.0, 0.000), (10.9090909091, 0.558978986139), (21.8181818182, 0.947549834455), (32.7272727273, 1.21766250042), (43.6363636364, 1.40542968014), (54.5454545455, 1.53595489508), (65.4545454545, 1.62668870575), (76.3636363636, 1.68976176333), (87.2727272727, 1.73360661636), (98.1818181818, 1.76408509973), (109.090909091, 1.7852720324), (120.0, 1.800) **Description**	Dimensionless.

This accounts for the attractiveness, or the attractive power of the mining sector based on how profitable is seems. The more the profit, the more it attracts new investors and vice versa. For any value from negative to 1, the ROI is not adequate enough and hence the sector is not attractive enough to attract new investors. this means that the indicated mines will be 0	
Name: Environmental cost to the miners **Equation:** Policy*Cost_of_afforestation **Description** This represents the amount of money needed by the miners to maintain or reclaim the environment	USD/Year
Name: Expected net income per mine **Equation:** net_income_after_tax/Mines **Description:**	USD/Mine/Year
Name: Income before tax **Equation:** total_revenue-total_expenses **Description** This is the total annual profit accrued from the mining sector before paying of tax.	USD/Year
Name: Indicated mines **Equation:** effect_of_relative_profit*Mines **Description** this refers to the number of mines expected to be established based on the number of investors arrived and average number of investors per operation.	Mine
Name: Interest Rate **Equation:** .25 **Description**	Dmnl/Year

this refers to the assumed interest rate on the capital used in the industry	
Name: Land reclamation cost per hectare **Equation:** 11000 **Description** this refers to the amount of money required to reclaim one hectare of degraded land. It is estimated at $1100, a figure gotten from a researched source. https://www.ghanaweb.com/GhanaHomePage/NewsArchive/Galamsey-Government-to-spend-GHC60-000-to-reclaim-one-hectare-of-degraded-land-599883	USD/Hectare
Name: Mine land area **Equation:** Mines*average_size_per_mine_in_hectares **Description** This refers to the average total land area (in hectares) occupied by the active mines at any time.	Hectares
Name: Mines Average Lifespan **Equation:** normal_time*(1-Policy) + policy_desired_time*Policy **Description** this refers to the total time within which a mine stays active. When this time is over or exhausted, the mine cease to operate.	Year
Name: Net benefits **Equation:** (Accumulated_tax_incomes+Accumulated_income_after_tax)-Accumulated_Environmental_cost **Description** This refers to the output of the absolute benefit of the mining sector. Positive of results means the sector is good and negative results means otherwise.	USD
Name: Net income after tax	USD/Year

Equation: (Income_before_tax) *(1-policy_tax_rate) **Description** this refers to the total amount (total revenue) left after expenses. it is calculated by subtracting expense from the total revenue. it is measured in USD	
Name: New land used in mining **Equation:** opening_mine*average_size_per_mine_in_hectares **Description** This accounts for the average land size in hectare that the yearly new mines occupy	Hectares/Year
Name: Normal expenses **Equation:** Mines*operating_expenses_per_mine **Description** Desired time This represents the average lifespan of a mine when it is mined illegally. Averagely, it takes a total of 10 years for a legal small-scale mine to stay in operation.	USD/Year
Name: Normal time **Equation:** **3** **Description** This represents the average lifespan of a mine when it is mined illegally. The average mine of a galamsey mine is 3 years according to Leudi. Galamsey in Ghana and China's illegal gold rush JANUARY 16, 2019 By: Jeremy Luedi	Year
Name: Number of galamsey **Equation:** GRAPH(TIME) Points: (2004.00, 1299.920588), (2005.00, 2162.858824), (2006.00, 2258.785294), (2007.00, 3686.382353), (2008.00, 3551.602941), (2009.00, 3590.364706), (2010.00, 5163.635294), (2011.00, 6559.252941), (2012.00, 8697.2), (2013.00, 14194.58824), (2014.00, 14601.17647), (2015.00,	Mines

9952.279412), (2016.00, 13880.72941), (2017.00, 14633.37353), (2018.00, NaN), (2019.00, NaN), (2020.00, NaN), (2021.00, NaN) **Description** Reference mode	
Name: Number of workers per mine. **Equation:** 100 **Description** This refers to the number of laborers who work in the illegal mines sector. It is estimated that every mine has an average of 150 employees. It is measured in person per mine	Person/Mine
Name: Operating Expenses Per Mine **Equation:** 20000 **Description** Expenses incurred by each mine every year	USD/Mine/Year
Name: Ounce to ton **Equation:** 32000 **Description** This refers to the conversion of gold produced from ounce to tons. 1 ton of gold is equivalent to 32000 ounces. It is measured in ounce per ton	Ounce/Ton
Name: Policy **Equation:** IF TIME>2021 THEN policy_switch = 1 ELSE 0 **Description** It produces the value of the lifespan policy switch from the years 2014 onwards.	Dimensionless.
Name: Policy desired time **Equation:** 10	Year

Description Desired time This represents the average lifespan of a mine when it is mined illegally. Averagely, it takes a total of 10 years for a legal small-scale mine to stay in operation	
Name: Policy switch **Equation:** tax_rate_switch **Description** policy switch of the lifespan of a mine policy. The policy is activated when switched on and vice versa	Dimensionless.
Name: Policy tax rate **Equation:** IF TIME > 2021 THEN tax_rate_switch*tax_rate ELSE 0 **Description** it produces the value of the tax from the years 2021 onwards	Dimensionless.
Name: Price **Equation:** IF TIME < 2018 THEN price_of_gold ELSE 1800 **Description** this refers to the price of the historical price of gold from 2004 to 2018 where historical data is available. From 2018 onwards, it assumes a constant figure or number of 1800 USD/Ounce.	USD/Ounce
Name: Price of Gold **Equation:** GRAPH(TIME) Points: (2004.00, 442.974), (2005.00, 509.423), (2006.00, 629.513), (2007.00, 803.618), (2008.00, 819.94), (2009.00, 1135.012), (2010.00, 1393.512), (2011.00, 1652.725), (2012.00, 1687.342), (2013.00, 1221.588), (2014.00, 1200.44), (2015.00, 1068.317), (2016.00, 1152.165), (2017.00, 1265.674), (2018.00, 1249.887) **Description** this represents the gold price from 2004 to 2018 in the world market. **Source:** https://datahub.io/core/gold-prices#resource-annual DataHub.io	USD/Ounce

Name: Relative ROI **Equation:** MAX (0, actual_return_on_investment//required_ROI) **Description** the actual expressed as a percentage of the required	Dimensionless.
Name: Required ROI **Equation:** .1 **Description** this refers to the percentage of the total amount invested that an investor would need to earn each year in profit to make it a worthwhile investment	1/Year
Name: Size of mine in acres **Equation:** 25 **Description** This refers to the average mines size measured in acres. It is initialized with 25 being the average size of a mine in Ghana. **Source**: Ghana's battle with illegal artisanal and small-scale mining by: Marie-Noelle Nwokolo. July 15th, 2019. **Source:** https://blogs.lse.ac.uk/africaatlse/2019/07/15/ghana-illegal-asm-artisanal-mining/	Acre/Mine
Name: Tax income **Equation:** income_before_tax*policy_tax_rate **Description** This shows the results of income gotten from tax.	USD/Year
Name: Tax rate **Equation:** .1 **Description**	Dimensionless.

This refers to the percentage of income that the government charges on the total income of miners. It has no dimension.	
Name: Tax rate switch. **Equation:** **0** **Description** This is a switch that regulates (activates or deactivates) the tax policy. It has two values, 0 and 1. It activates turns on the tax policy when it is 1 and turns it off when it is 0. It has no dimension	Dimensionless.
Name: Time to expand **Equation:** 2 **Description** This accounts for the time taken for investor to fully get a mine site operational. It is measured in years	Year
Name: Time to recover actively **Equation:** 10 **Description** Delayed time refers to the average time it takes to regrow the depleted forest	Year
Name: Time to Recover naturally **Equation:** 50 **Description** This is the average time it takes for the degraded land to naturally grow back to become a forest	Year
Name: Tons per mine per year **Equation:** .00351 **Description** this refers to the volume of Tons of gold produced by each mine on a yearly basis It is measured in ounce/mine/year	Tons/Mine/Year

Source is derived from a figure given by LEUDI (Leudi, 2019).	
Name: Total agricultural land in Ghana **Equation:** 15700000 **Description**	Hectares
Name: Total Expenses **Equation:** cost_of_capital+total_operating_expenses+crack_down **Description** This refers to the total cost incurred every year for the operations of the mining sector in Ghana	USD/Year
Name: Total gold mined by mines per year **Equation:** Mines*tons_per_mine_per_year **Description** This represents the total amount of gold mined each year by the small-scale mines sector	Tons/Years
Name: Total hectares of land in Ghana **Equation:** 23853500 **Description**	Hectares
Name: Total number of workers **Equation:** number_of_workers_per_mine*Mines **Description** This refers to the total number of persons in the illegal gold mines sector. It is assumed that every mine is owned by one person/investor who in turn employs some number of people as laborers. It is equivalent to the number of illegal mines in place times the total number of workers employed. It is measured in person	Person
Name: Total operating expenses	USD/Year

Equation: normal_expenses*(1-Policy) + desired_expenses*Policy **Description** This represents the total expenses incurred annually by the sector	
Name: Total revenue **Equation:** (price*average_gold_mined_per_mine_per_year*Mines) *(1-dealing_fee_fraction) **Description** this refers to the total amount of gross income generated from the illegal mining operations in a year. it is generated by the number of illegal mines times the price of gold times the quantity of gold mined.	USD/Year
Name: Wage percentage **Equation:** .70 **Description** Fraction of the total expenses designated for payment of wages of workers	Dimensionless.

Total	Count	Including Array Elements
Variables	83	83
Sectors	4	
Stocks	8	8
Flows	9	9
Converters	66	66
Constants	25	25
Equations	50	50
Graphical	5	5
Macro Variables	10	

Run Specs	
Start Time	2004
Stop Time	2070
DT	1/32
Fractional DT	True
Save Interval	0.03125
Sim Duration	1.5
Time Units	years
Pause Interval	0
Integration Method	Euler
Keep all variable results	True
Run By	Run
Calculate loop dominance information	True
Exhaustive Search Threshold	1000

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