The Assessment of New Mining Projects in Thailand

From the Faculty of Georesources and Materials Engineering of the
RWTH Aachen University

Submitted by

Kridtaya Sakamornsnguan - Master of Sciences

from Bangkok, Thailand

in respect of the academic degree of

Doctor of Natural Sciences

approved thesis

Advisors: **apl. Prof. Dr. rer. pol. Jürgen Kretschmann**
Univ.-Prof. Dr.-Ing. Dipl.-Wirt.Ing. Per Nicolai Martens
Univ.-Prof. Dr.-Ing. Helmut Mischo

Date of the oral examination: 21.07.2017

Abstract

Mining is an anthropogenic activity that creates both positive and negative impacts on society and the environment. Governmental authorities play an important role in managing mining activities throughout a project's life cycle. The concession granting process is a common mechanism applied at the early stage of every mining project to regulate and balance the positive and negative results. Inefficient decision-making in this process can lead to short- and long-term problems with extensive negative impacts. Thus, governments need to evaluate and ensure that a new mining project is worth developing before approving it. This study develops an assessment framework that will provide information for the Thai government for a better decision-making performance in relation to the development of new mining projects.

The development of this assessment framework is based on Buddhist principles, which are the foundation of Thai values and national policies. It will help identify and overcome the weaknesses of the current assessment approaches which are driven by an emphasis on self-interest and the influence of reductionism within the concept of sustainable development. The assessment framework considers the necessity of mining projects and the negative impacts of these projects, each of which is determined by a set of key risks and anticipated impacts of the proposed projects on the main stakeholders arranged in a hierarchy. The project’s worthiness is presented as a development priority. The case of underground potash mining in Bamnet Narong, Thailand is used as an example for the application of the new assessment framework. The assessment results confirm the applicability of the framework and provide information that can support decision-making during the approval process. They can also be used by the Thai authorities as well as by investors in order to manage the risks and impacts of projects at later stages.

Abstract

Bergbau ist eine anthropogene Aktivität, die sowohl positive wie auch negative Auswirkungen auf die Gesellschaft und die Umwelt haben kann. Staatliche Stellen spielen eine wichtige Rolle bei der Verwaltung von Bergbauaktivitäten während der gesamten Laufzeit eines Projektes. Die Vergabe von Abbaurechten spielt in der frühen Phase jedes Bergbauprojekts eine entscheidende Rolle, um die positiven und negativen Auswirkungen zu bewerten. Ineffiziente Entscheidungsprozesse können kurz- und langfristigen Problemen verursachen, da negativen Auswirkungen unterschätzt werden. Infolgedessen sollten staatliche Stellen vor der Genehmigung abschließend bewerten und sicherstellen, dass neue Bergbauprojekt nachhaltig und risikoarm durchgeführt werden können. Die vorliegende Studie hat einen Bewertungsrahmen entwickelt der dazu beitragen wird, Informationen für die thailändische Regierung zur Verfügung zu stellen um ihre Entscheidung im Zusammenhang mit der Entwicklung und Vergabe neuer Bergbauprojekte zu verbessern.

Dieser Bewertungsrahmen basiert auf den buddhistischen Prinzipien, die die Grundwerte der thailändischen Gesellschaft und der nationalen Politik darstellen. Mit dieser Principien werden die Schwachstellen der bisherigen Bewertungsansätze identifiziert und überarbeitet, die durch eine Betonung des Eigeninteresses und den Einfluss des Reduktionismus im nachhaltigen Entwicklungskonzept zugrunde gelegt werden sind. Der Bewertungsrahmen legt die Notwendigkeit sowie die negativen Auswirkungen eines Bergbauprojekts zur Grunde und wägt diese gegen die wesentlichen Risiken und die erwarteten Auswirkungen der vorgeschlagenen Projekte auf die wichtigsten Stakeholder ab. Die Würdigkeit des Projekts wird als eine Entwicklungspriorität gezeigt. Diese Fallstudie nutzt ein Kali-Untertagebergwerk in Bamnet Narong, Thailand als Beispiel für die Anwendung des vordefinierten Bewertungsrahmens. Die Auswertungen bestätigen die Anwendbarkeit des Bewertungsrahmens und geben Auskunft, über die Verbesserung der Entscheidungsprozess bei der Vergabe von Abbaurechten. Die Ergebnisse können in Zukunft von den thailändischen Regierungsbehörden sowie von Investoren zur Bewältigung der Risiken und Auswirkungen von Bergbauprojekten in späteren Phasen verwendet werden.

Acknowledgement

Throughout the four and a half years of my doctoral study in Germany, I have received support and encouragement from many people, to whom I would like to express my sincere gratitude. First and foremost, I would like to thank my supervisor Professor Dr. rer. pol. Jürgen Kretschmann for his continuous support of my research, study, and my well-being in Germany. I appreciate all his efforts, patience, motivation, ideas, and plenty of opportunities I obtained for internships, networking, teaching, and even writing a book. He was a 'Doktorvater' in the actual sense of the work.

I would also like to express my gratitude to Professor Dr.-Ing. Dipl.-Wirt. Ing. Per Nicolai Martens for his support of my PhD work and life as well as the opportunities to participate in different academic events. My sincere thanks also go to the rest of my dissertation committee: Professor Dr.-Ing. Helmut Mischo, Professor Dr. rer. nat. Georg Roth, and Assistant Professor Dr. Thitisak Boonpramote, for their insightful comments which allowed me to improve the quality of my research and my knowledge. My thanks also go to Associate Professor Dr. Pinyo Meechumna, who recommended me to come to Germany and introduced me to Professor Kretschmann. I would have ended up in a different path if I had not followed his advice to come to Germany. Many thanks also go to my superiors at the Department of Primary Industries and Mines and staffs of ASEAN Potash Mining PLC, who helped me a lot with the data for the case study; the professors at THGA and Chulalongkorn University, who provided support and opportunities to attend lectures and events; BBK I and THGA colleagues, who were very friendly and helped me in every occasion from the beginning to the end; executives and colleagues at NRW Bergbehoerde, Ercosplan, and K+S, who gave me precious opportunities to do internships and share useful information; Dr. Thi Hoai Nga Nguyen, who gave me a helping hand in the first-time registration as well as advice and support; the Kretschmann-Von der Beck and the Plien families for their warm Christmas parties; national and international friends who made my life in Germany more fun and colorful; and my family who keeps supporting and encouraging me through both fun and hard time.

Last but not least, I would like to thank the Royal Thai Government and the Department of Primary Industries and Mines for providing me with the financial support and the opportunity to study abroad. Without this support, it would not have been possible for me to conduct this research.

Content

Page

Abstract (English) ... iii
Abstract (German) ... v
Acknowledgement ... vii
Content ... ix
List of Figures ... xiii
List of Tables ... xv

1 Introduction ... 1
1.1 Background ... 1
1.2 Problem description ... 2
1.3 Dissertation arrangement ... 5

2 Thailand and its mining administration system ... 7
2.1 Country profile ... 7
2.1.1 Geography ... 7
2.1.2 Economics and social structure ... 8
2.1.3 Political structure and public administration ... 8
2.1.4 Culture and national values ... 9
2.1.5 Economic and social development strategies in the past decades ... 9
2.2 Overview of Thailand's mining industry ... 10
2.2.1 Resources ... 10
2.2.2 Production and trade ... 11
2.3 Mining administration system in Thailand ... 11

3 Mining project assessment and Thai ethics ... 15
3.1 Buddhist principles and the modern society ... 15
3.1.1 The Four Noble Truths ... 15
3.1.2 Applications of Buddhist principles in modern society ... 17
3.1.2.1 Buddhist economics ... 17
3.1.2.2 Philosophy of Sufficiency Economy ... 17

Page

3.2 Implication of Buddhist principles on mining project assessments 18

3.3 Mining project assessment: a review of assessment tools 23

3.3.1 Feasibility study 24

3.3.2 Impact assessment 25

3.3.3 Risk assessment 27

3.3.4 Sustainability performance indicators 28

4 A framework for assessing new mining projects in Thailand 31

4.1 Objectives of the assessment framework 31

4.2 Model for mining project assessment 31

4.2.1 Assessment matrix 31

4.2.2 Scope, components, and structure of the assessment 33

4.2.2.1 Necessity of mining project development 33

4.2.2.2 Negative impacts of the mining project 37

4.3 Risk assessment: An approach for mining project assessment 45

4.3.1 Risk concept 45

4.3.2 Source of data 47

4.3.3 Data aggregation 47

4.4 Criteria for rating the components in the assessment hierarchy 49

4.4.1 Necessity of mining project development 49

4.4.1.1 Service provision 49

4.4.1.2 Positive contributions of a mining project to society 53

4.4.2 Negative impacts of mining projects 59

4.4.2.1 Negative impacts on workers 59

4.4.2.2 Negative impacts on communities 79

4.4.2.3 Negative impacts on the environment 105

4.4.2.4 Negative impacts on shareholders 115

5 Case study: the assessment of an underground potash mining project in Thailand 121

5.1 Project description 121

5.1.1 Background 121

5.1.2 Project's facilities 122

Page

5.1.3 Mining and processing methods 123

5.1.4 Data relevant to the mining project assessment 125

5.1.4.1 Project's mass flow 125

5.1.4.2 Substance flow of potassium in the Thai economy 126

5.2 Assessment: necessity of mining project development 126

5.2.1 Service provision 126

5.2.1.1 Contribution to domestic demands 126

5.2.1.2 Contribution to end use 128

5.2.1.3 Resource availability 128

5.2.2 Positive contributions of the mining project to society 128

5.2.2.1 Positive contributions to workers 129

5.2.2.2 Positive contributions to communities 129

5.2.2.3 Positive contributions to the environment 134

5.3 Assessment: negative impacts of the mining project 134

5.3.1 Negative impacts on workers 135

5.3.1.1 Occupational diseases 135

5.3.1.2 Harmful working conditions 138

5.3.1.3 Accidents 143

5.3.2 Negative impacts on communities 153

5.3.2.1 Health and safety 153

5.3.2.2 Community's access to livelihood assets 165

5.3.2.3 Vulnerability to external changes 173

5.3.3 Negative impacts on the environment 177

5.3.3.1 Habitat loss 177

5.3.3.2 Pollution 179

5.3.4 Negative impacts on shareholders 184

5.3.5 Result aggregation 186

5.4 Data aggregation into the necessity-impacts matrix 186

6 Result discussion 187

6.1 Assessment results of the case study 187

6.2 Implementation of the framework 193

Page

7 Conclusions and recommendations 199

8 Bibliography 207

Appendix A: Summary of components and rating criteria A-1

Appendix B: Mass flow calculation for the operation phase of the case study B-1

Appendix C: Flows of potassium in the Thai economy C-1

Appendix D: Calculation of potash price volatility D-1

List of Figures

Page

Figure 2.1: Geography of Thailand....7
Figure 2.2: Laws imposed on mining activities throughout the project life cycle....14
Figure 3.1: Components of the Four Noble Truths....16
Figure 3.2: Sustainable development approaches and Buddhist-based development approaches....24
Figure 4.1: Components and structure of necessity of mining project development....36
Figure 4.2: Components and structure of negative impacts....46
Figure 4.3: Earthquake risk zone in Thailand....78
Figure 4.4: Typical water residence times in inland water bodies....87
Figure 5.1: Project location and boundary....121
Figure 5.2 Mine panel layouts: (a) room and pillar with and without additional benching and (b) room and pillar with long pillar....124
Figure 5.3: Mass flow of the project's facilities....126
Figure 5.4: Substance flow of potassium in Thailand in year 2012....127
Figure 5.5: Substance flow of potassium in Thailand if the project is operated at full capacity using the data in 2012 as a basis....127
Figure 5.6: Location of flammable substances and facilities....145
Figure 5.7: Geological structure of Bamnet Narong deposit....147
Figure 5.8: Seepage prevention measures in the waste storage facility....161
Figure 5.9: Land use in the project area....169
Figure 5.10: Location of exploration drill-holes....184
Figure 6.1: Summary of the ratings of the necessity of project development....187
Figure 6.2: Summary of the ratings of the negative impacts....188
Figure 6.3: Objective of mineral policy and development strategies....196
Figure 6.4: Possible applications of the assessment framework and its results by the government....197

List of Tables

Page

Table 2.1: Key mineral resources in Thailand at the end of 2013 10
Table 4.1: Necessity-impacts matrix for identifying the development priority of a mining project 33
Table 4.2: Risk rating matrix 47
Table 4.3: Heat index and assessment rating 65
Table 5.1: Number of employment 129
Table 5.2: Number of people who will benefit from the incrased water storage capacity 130
Table 5.3: Number of people who will benefit from the incrased forest area 130
Table 5.4: Population within 5 kilometers of the project compound and the waste facility 132
Table 5.5: Number of medical staff in the healthcare facility located within 5 kilometer of the mining compound and the waste facility 132
Table 5.6: Number of students and teachers in the primary and secondary schools located within 5 kilometers of the mining compound and the waste facility areas . 133
Table 5.7: Presence of species in the mining lease and the waste facility areas 134
Table 5.8: Release of respiratory hazards from the project's facilities 135
Table 5.9: Number of workers adjusted by exposure period 136
Table 5.10: Assessment of the impact of noise-induced hearing loss on workers 138
Table 5.11: Assessment of the impact of whole-body vibration on workers 138
Table 5.12: Assessment of the impact of heat on workers 141
Table 5.13: Assessment of the impact of fire and explosion on workers 146
Table 5.14: Assessment of the impact of water or semi-solid inrush on workers 151
Table 5.15: Assessment of the impact of waste facility failure on communities 156
Table 5.16: Communities within the mining lease area 157
Table 5.17: Amount of air pollutants released by the project 158
Table 5.18: Number of population within 5 kilometers of the mining lease and from waste facility areas 159
Table 5.19: Assessment of the impact of seepage from the waste storage facility on communities 162

Page

Table 5.20: Assessment of the impact of waste storage facility failure on communities 164
Table 5.21: Amount of indirect soil contaminants released by the project 165
Table 5.22: Amount of affected population with the consideration of occupation type .. 167
Table 5.23: Amount of population within 5 kilometers from mining lease with the consideration of occupation type 168
Table 5.24: Current and estimated future traffic in the main highway next to the project compound 171
Table 5.25: Capacity and current rail traffic along the route to the port (....................... 172
Table 5.26: Amount and occupation of population who might be affected by floods due to ground subsidence 174
Table 5.27: Assessment of the current state of drought potential 175
Table 5.28: Amount and occupation of population potentially affected by drought 176
Table 5.29: Assessment of the extent of land cover loss 178
Table 5.30: Amount of air pollutants released by the project 180
Table 5.31: Presence of aquatic species in the waste facility and its 5-kilometer surrounding area 181
Table 5.32: Assessment of the impact of seepage from the waste facility on the environment 182
Table 5.33: Assessment of the impact of the waste storage facility failure on the environment 182
Table 5.34: Presence of species in the mining lease and its 5-kilometer surrounding area 183
Table 5.35: Necessity-impacts matrix of the potash mining project 186

1 Introduction

1.1 Background

Today, many natural materials our modern societies require are derived through mining. In 2011, more than 49,400 million tonnes of minerals were mined throughout the world, accounting for approximately 64% of total primary raw materials extracted from the natural environment (Sustainable Europe Research Institute, 2014). The development and operation of a mining project have both positive and negative consequences. Mining can create wealth and distribute it to society through, for example, increased national incomes, economic development, tax payments, and employment (International Council on Mining and Metals, 2012a). It can also provide economic advantages to local economies and can lead to investments that help improve the quality of life of the local population; promote investment, environment, and economic development; and enhance the capability of the local workforce such as those described in Crowson (2009). On the other hand, mining can cause undesirable changes and damages since it involves multiple hazards which can have a fatal impact on human health and the natural world. It can also negatively influence the quality of life of local communities and increase social stresses through environmental and social changes throughout the project life time through a competition in the use of natural resources, a degradation of environmental quality, infrastructure development, resettlement, and the influx of non-local workers, which create a drastic change in social structure and lifestyles. Traditional values and believes can be influenced by foreign values. Mining can produce different outcomes, so developing a mining project can result in conflicts among stakeholders. Government plays an important role in regulating and optimizing the use of available resources while maintaining public welfare and balancing the needs of stakeholders. In order to do so, it imposes a concessional process, which involves the decision on granting exploration and mining rights and which determines whether new mining projects can be developed, as a primary step to regulate mineral resources. In Thailand, the approval of mining lease applications is an important part of the concessional process. It is based mainly on engineering design and planning and environmental impact assessment (Sakamornsnguan et al., 2015). However, the decision is often subject to the question whether the project is worth developing or not. The government's mining authority is often unable to provide strong arguments and efficiently communicate with stakeholders and therefore face a variety of problems. This is especially reflected in a lack of trust and public acceptance resulting in widespread opposition to mining projects. The conflicts arise in all types of mines such as quarries, potash mines, coal mines, and gold mines (Chalermlarp and Kiatwongthong, 2004). On the governmental side, the priority of mineral resource development has become overridden by other development needs, particularly those on environmental conservation and competing land use, causing Thailand to lose its opportunities to exploit existing mineral resources.

To improve the situation, the governmental agency needs to ensure that it makes reasonable decisions during the concessional process based on a thorough understanding of the consequences of each mining project. A concrete, systematic framework the authority can use for evaluating new mining projects can help improve the quality of decisions made by the government and alleviate the current problems. Hence, the aim of this study is to develop a framework for assisting the government in assessing whether a new mining project is worth developing and in communicating with stakeholders so that the mineral resources can be exploited efficiently and to their full potential.

1.2 Problem description

The consideration whether a mining project is worth developing is multi-faceted. The ‘worthiness’ of a mining project can be interpreted differently, depending on individual points of view. The decision criteria for assessing a mining project vary according to the user of the evaluation results. Most private investors aim for profits, whereas governments should consider a broader range of advantages and disadvantages, i.e. not only private but also social welfare (Torries, 1998).

According to Torries (1998), the project evaluation process consists of valuation and decision phases. The consequences of different actions are compared and used as a basis for decision-making. It was further described that the evaluation can be carried out by either positive or normative evaluations. A positive evaluation measures the quantifiable factors for economic efficiency such as investment appraisals, which compare economical data and are determined differently by different agents. A normative evaluation measures qualitative factors such as environmental and social issues, which are difficult to quantify in terms of market-based prices and costs.

The concept of sustainable development – a worldwide-adopted concept defined as “*development that meets the needs of the present without compromising the ability of future* *generations to meet their own needs*" (United Nations, 1987) – also contributes to the development of principles, criteria, indicators, and methods for assessing the impacts of mining in different areas and at different levels. For example, the guiding principles for sustainable development practice in mining operations, such as the ICMM's Ten Sustainable Development Principles (International Council on Mining & Metals, 2003) and the Seven Questions to Sustainability (International Institute for Sustainable Development, 2002) were introduced and have been widely adopted by companies. The indicators such as the United Nations Commission on Sustainable Development Indicators of Sustainable Development (United Nations, 2007) were developed as general guidelines to evaluate sustainable development progresses. At project and local levels, the Global Reporting Initiative's Sustainability Reporting Guideline (Global Reporting Initiative, 2013a, 2013b) was launched as a basis for the assessment and reporting of corporate sustainability performance and has been used by mining companies worldwide (Ernst & Young Australia, 2016; Global Reporting Initiative, 2015). Different types of tools and methods are available for assessing mining consequences in addition to the typical feasibility study, for example, impact assessment, cost-benefit analysis, life cycle assessment, and risk assessment.

The availability of the evaluation methods and the assessment principles, criteria, indicators, and methods mentioned above are helpful for the assessment of mining projects. However, they cannot provide a clear answer to the value of a project development if there is no clear and concise definition of its worthiness. Even though the concept of sustainable development provides a common ground for assessing the value of a mining project, it is not fully compatible with the situation in Thailand and its mining sector since the sustainable development concept is criticized for its conceptual ambiguity. Despite a broad agreement on the concept's definition and key components, the idea lacks a common interpretation and practice and is made rational to the situation it is applied to (Cantor, 2011; Fernando, 2003; Graham, 2006). The interpretation dynamics call for a clear identification of what forms of sustainability Thailand's mineral industry and Thai society should achieve. They might be similar to or different from the commonly-defined development objectives due to the characteristics of Thailand and the dissimilarities between Thailand and other countries, especially the so-called developed countries. This is especially true with regards to domestic and international political and economic statuses, available resources, values, needs, and the global situation. The concept of sustainable development is not only criticized for its interpretation dynamics but also for being culturally unneutral (Cordes, 2000, pp. 1–25). The concept of sustainable development is influenced by the Western values and beliefs of individual liberty, political democracy, rule of law, human rights and cultural freedom (Huntington, 1997). These concepts are connected to the ideas of growth and modernization, which have become a driving force of many developing nations, and are now a challenge for nations pursuing these objectives while maintaining their cultural identity (Cordes, 2000, pp. 1–25).

The weakness of sustainable development with regards to the interpretation dynamics and cultural un-neutrality makes it necessary to implement the sustainable development-related concept, principles, approaches, and methods in line with local circumstances and local values. This requirement also applies to the definition and the assessment of the worthiness of the development of new mining projects. It is thus a challenge for the Thai government to define the issues concerning mining and its development needs and the local values. In this study, Buddhist values will represent the cultural identity of the Thai society since Buddhism has a long history within the country and strongly influences the values of Thai people. Moreover, Buddhist principles have become the foundation for recent policies in Thailand. Applying the Buddhist principles to define mining development objectives and to provide a basis for mining project assessment offers a constructive alternative to the adaption of the available evaluation and assessment frameworks, linking local values to development issues. Accordingly, the research questions of this study are formulated as follows:

Main research question: "*How can the worthiness of the development of a new mining project be assessed based on the Buddhist ethics?*"

To answer the main research questions, the following sub-questions need to be considered.

- What characteristics should be reflected in the assessment framework that determines the worthiness of a mining project?
- How should the assessment framework be structured so that it can reflect the worthiness characteristics?
- How can the assessment be integrated in the current administration system?

1.3 Dissertation arrangement

The contents of this dissertation are presented in six parts. In chapter two, basic information of Thailand and its mineral administration system is introduced to provide an overview of the current situation and mechanisms related to mining concessions and control in Thailand. Chapter three answers the first sub-question of this research. It provides a brief review of some assessment tools frequently applied to mining projects. A description of Buddhist principles and their implications on mining project assessments are discussed. Then, the characteristics of the framework for determining the worthiness of mining projects are identified. In chapter four, the characteristics of worthiness in chapter three is formulated into an assessment framework for new mining projects. The components and structure of the framework are identified, and their criteria are explained in detail. In chapter five, the framework is then applied to a real case of an underground potash mining project in Northeastern Thailand. Project information is provided, and the assessment according to the proposed framework is explained. The results are discussed in chapter six together with their implications on mineral policy and management and possible integration of the assessment to the existing administration system. Finally, chapter seven provides a short overview of the dissertation together with limitations and recommendations for future research.

2 Thailand and its mining administration system

This chapter will present background information on Thailand detailing different aspects. The chapter is divided into three parts. The first part provides basic information about the country. The second part explains briefly the situation of Thailand's mining industry. The third part describes the mining administration system currently implemented in Thailand.

2.1 Country profile

2.1.1 Geography

The geographical information of Thailand according to Nee (2014, chap. 2) is described as follows: Thailand, or the Kingdom of Thailand, is located in the Southeast Asian region between latitude 5° 37'N to 20° 27'N and longitude 97° 22'E to 105° 37'E. Its total area is 513,120 square kilometers, of which 510,890 is land area. The territory shares its 4,863-kilometer-long border with four other countries. Laos and Cambodia are located in the East, with a border of 1,754 and 803 kilometers, respectively. Myanmar and the Andaman Sea are located in the West while the Gulf of Thailand and Malaysia are in the South. The border with Myanmar and Malaysia stretches over 1,800 and 506 kilometers, respectively. Based on climatic and cultural characteristics, Thailand can be divided into six main regions, namely, North, Northeastern, Eastern, Central, Western, and South (Royal Institute, 1982). Figure 2.1 shows the geography of Thailand.

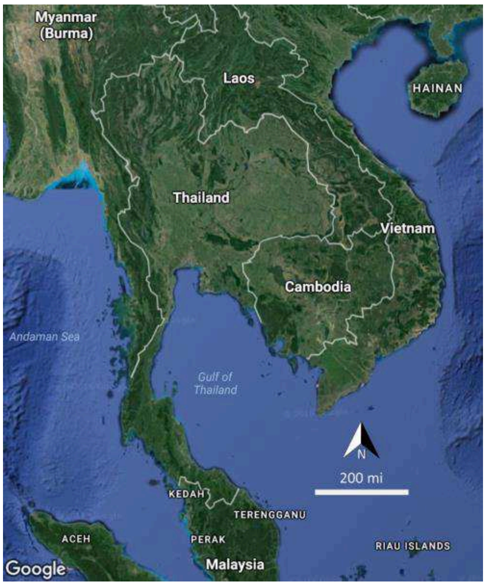


Figure 2.1: Geography of Thailand (Google Maps, 2016)

2.1.2 Economics and social structure

The gross domestic product of Thailand in 2014 was 13,132,241 million Baht (404,267 million USD), of which 59% came from the services sector, 32% from the industrial sector, and 10% from the agricultural sector (Office of the National Economic and Social Development Board, 2014, pp. 41–43). In terms of social structure, the statistics of Thailand's Department of Public Administration (2016) indicated that Thailand had a population of 65.1 million at the end of 2014, increasing by 0.5% from the previous year, of which around 10.6 million lived in the Bangkok Metropolitan Region. About 66% of the population were aged between 15 and 59 years. The proportion between male and female population was 0.96. The literacy rate of the population over 15 years old was approximately 95% (National Statistics Office, 2014). Around 93.6% of the population was Buddhist; the rest consisted of 4.9% Muslims, 1.2% Christians, and 0.3% others (National Statistics Office, 2010). The national language is Thai.

2.1.3 Political structure and public administration

Thailand is a country, in which the hereditary monarch is the head of state and the Prime Minister is the head of the government. The Constitution of Thailand, the supreme law of the land, divides the government into the Legislative, the Executive, and the Judiciary branches.

In terms of public administration, Thailand is organized on 3 main levels – central, regional, and local administrations (Royal Thai Government Gazette, 1991). The central administration is characterized by 20 ministries (Royal Thai Government Gazette, 2002), under which the responsibility and authority are passed down to departments. The regional administration is characterized by 76 provinces (excluding Bangkok, the capital of Thailand), which are governed by the assigned provincial governors, and Amphoe (district) – a sub-unit of the province that is further sub-divided into Tambon (sub-district) and then Moo-ban (village) (Department of Public Administration, n.d.). In 2011, Thailand contained 927 districts, 7,409 sub-districts, and 74,944 villages (Department of Agricultural Extension, 2011). Local administration is characterized by local administration organizations, including the Provincial Administration Organization, Sub-district Municipality, and Sub-district Administration Organization. Unlike the regional administration which handles public administration issues, the local administration organizations, whose members are directly elected, are responsible mainly for conducting local development projects as well as taking care of local natural resources.

2.1.4 Culture and national values

In terms of cultural and national values, the three main values governing social relationships in Thai society are self-cognition, grateful relationship orientation, and smooth interpersonal relationship orientation (Komin, 1991). Self-cognition entails respect for an individual's feelings and personage either by acting in such a way that no-one loses face, by avoiding criticism, or by avoiding discomfort or inconvenience. A grateful relationship orientation is characterized by the relationship between a person who provides help and the recipient of this help. This relationship infers that the receivers remember the provider’s kindness and express their gratitude through pleasant and reciprocal behavior. Smooth interpersonal relationship orientation is based on the modest personality of the Thai people and is defined by a harmonious surface. Moreover, Thai society, especially in rural communities, is characterized by cooperative behaviors (Komin, 1991). This reflects the values of interdependence and co-existence. These findings correspond to the recent study by Hofstede and Hofstede (2010) that Thai people tend to accept inequality, have a high-context culture (more collectivism), and avoid confrontations.

2.1.5 Economic and social development strategies in the past decades

Since 1961, Thailand’s socio-economic development has been directed by the National Economic and Social Development Plans, which are five-year strategic plans guiding public governance and administration. From past to present, these plans have been adjusted to the domestic situation and the international circumstances. In Plan 1 to 3 (1961-1976), the main development objective was to promote economic growth (Office of the National Economic and Social Development Board, 1971, 1966, 1963, 1960). In Plan 4 (1977-1981), the focus on economic growth was maintained, and efforts were underway to restructure the economy in order to achieve the shift to a semi-industrialized country by the end of the plan (Office of the National Economic and Social Development Board, 1976). However, the expectation was not met as the country was seriously affected by the global economy and the oil crisis, so Plan 5 (1982-1986) targeted at improving the national balance deficit and social services (Office of the National Economic and Social Development Board, 1981). During Plan 6 (1987-1991), the actions to maintain economic growth and improve social services continued, together with efforts to enhance development performance and national competitiveness (Office of the National Economic and Social Development Board, 1986). In conjunction with the recovering global economy, Thailand experienced high economic growth at the end of Plan 6; however, socio-cultural and environmental problems became more critical, so Plan 7 (1992-1996) aimed to sustain economic growth, distribute wealth, and ensure human and natural resource development (Office of the National Economic and Social Development Board, 1991). The ongoing problems from an imbalanced development led to a strategic change in the following period. Plan 8 (1997-2001) shifted its focus from boosting the economy to social issues (Office of the National Economic and Social Development Board, 1996). Human development was still emphasized in Plan 9 (2002-2006), and the Philosophy of Sufficiency Economy was applied as a guiding development principle (Office of the National Economic and Social Development Board, 2001). The concept was further applied to Plan 10 (2007-2011) and Plan 11 (2012-2016). Plan 10 targeted human and community development, economic restructuring, maintaining natural resources and biodiversity, and promoting good governance whereas Plan 11 focused on equality, human development, productivity and competitiveness, and environmental quality (Office of the National Economic and Social Development Board, 2011, 2006).

2.2 Overview of Thailand's mining industry

2.2.1 Resources

The mineral resources in Thailand are characterized by industrial minerals. The country has abundant resources of stones and evaporite minerals, especially gypsum, rock salt, and potash. Other important minerals are lignite, feldspar, and some metals. Table 2.1 shows important mineral resources in Thailand.

Table 2.1: Key mineral resources in Thailand at the end of 2013 (Department of Mineral Resources, 2015, p. 59)

Mineral group	Mineral	Resources (Million tonnes)
Energy	Lignite	12,121
Stone: Aggregate	Limestone	294,758
	Others	100,602
Stone: Cement	Limestone	612,408
	Shale	115,075
Non-metallic minerals	Gypsum	348
	Feldspar	5,633
	Kaolin and ball clay	841
	Barite	31
	Fluorite	14
	Quartz	117
	Rock salt	18,000,024
	Potash	407,000
Metallic minerals	Gold (metal, in tonnes)	144
	Zinc	4.2
	Iron	50
	Tungsten	1.0
	Tin	7.4
	Copper (metal, in tonnes)	1.0

2.2.2 Production and trade

The mining sector plays a relatively low role in the Thai economy in terms of gross domestic products and employment. In 2014, mining and quarrying (excluding petroleum activities) contributed to 0.5% of GDP (current market price) (Office of the National Economic and Social Development Board, 2014). Stone, industrial minerals, and lignite are the main pillars of the industry. According to the Department of Primary Industries and Mines (2015a), in 2014, Thailand produced 38 types of minerals from around 550 active mines, in which more than 13,000 workers were employed. The production value was approximately 1,976 million USD. Among this, lignite had the largest share with 27%, followed by aggregate (19%) and limestone for cement production (13%). In terms of quantity, stone materials were the major products of the industry, accounting for more than three-fourths of the total production amount. Other minerals with significant production volumes and/or value included gypsum, dolomite, rock salt and feldspar. Key metal production included iron ore, zinc, and gold.

The statistics from the Department of Primary Industries and Mines (2015a) showed that Thailand imported nearly 70 types of minerals in 2014. The import amounted to more than 20 million tonnes and valued around 1,953 million USD. Coal and coke products were the major imported products, accounting for nearly 75% in value and more than 90% in quantity. The data also revealed that twenty-eight minerals were exported in the same year. The total export valued approximately 762 million USD. Tin metal, gold and silver, and gypsum and anhydrite were the major exported products, accounting for 87% of the total mineral export value. On the other hand, gypsum and anhydrite accounted for nearly three-fourths of total mineral export quantity.

2.3 Mining administration system in Thailand

Mining activities are subject to various laws and regulations. The main law regulating mineral-related activities is the Mineral Act B.E. 2510 (1967) and its related Ministerial Regulations. The Mineral Act specifies rights and responsibilities of the governmental agencies and the concessionaires as well as terms and conditions for permit issuance, operations, and termination.

According to the Mineral Act (Royal Thai Government Gazette, 1967), no exploration can be carried out without a prospecting or exploration license (article 25) and no mining activities can be carried out without a mining lease (article 43). There are three types of prospecting and exploration license: prospecting license, exclusive prospecting license, and special exploration license, each of which has different terms and conditions, mainly on area, activity, and validity period. The validity of a mining lease depends on reserve and production capacity but should not exceed 25 years. Other mineral-related activities that require permits include mineral processing, metallurgical processing, import and export of certain minerals, transaction with artisanal miners, as well as the construction of mining facilities. However, the details related to these permits are beyond the scope of this section; only the information related to mining concessions is described in more detail.

The process for obtaining a mining lease is regulated by a number of laws and authorities. Basically, the process of approval follows the requirements in the Mineral Act and its regulations. The mining lease applicant must submit a mining plan for approval. At this stage, the environmental law becomes effective. The National Environmental Protection and Promotion Act B.E. 2535 (1992), which is the main environmental law in Thailand, requires that an environmental impact assessment (EIA) report be submitted and approved by the EIA Committee (Royal Thai Government Gazette, 1992a). This process is included under the mining lease application process, and the environmental measures stated in the EIA are legally-binding. For mining projects that are likely to severely impacts the environment, natural resources, and health, an Environmental and Health Impact Assessment (EHIA) is required instead of the normal EIA according to the Constitution of Thailand B.E. 2550 (2007) and the National Environmental Protection and Promotion Act B.E. 2535 (1992).

According to the regulation (Royal Thai Government Gazette, 2016), the participation of local communities in the form of opinion statements from the villagers and the sub-district municipalities or the sub-district administration offices, in which the project is situated, is compulsory during the assessment of a mining lease application. Permits under other laws might also be required at this stage, especially those related to land use. The mining lease applicants must obtain the rights for land use from the authorized rights holders prior to the approval of the mining lease. Forest areas are regulated by the Royal Forestry Department under the Reserved Forest Act B.E. 2507 (1964) while the Self-Help Settlement area is supervised by the Department of Social Development and Welfare under the Land Allocation for Living Act B.E. 2511 (1968). Agricultural Land Reform areas are administrated by the Agricultural Land Reform Office under the Agricultural Land Reform

Act B.E. 2518 (1975). The terms and conditions of the laws on land use permits and fees for mining purposes are enforced in addition to those specified in the Mineral Act.

When all the required permits, approvals, and documents have been obtained, the Committee of the Mineral Act makes a resolution and submits it to the Ministry of Industry to obtain the final decision on the mining lease issuance. If the mining lease is granted, the lease holder must commence operations and conform to the mining-related laws and regulations. There are several non-mining laws related to mining. For instance, the Labor Protection Act B.E. 2541 (1998), which specifies the basic rights of employees and responsibilities of employers regarding employment. It also prohibits female employees in mining and underground tunnels unless the working conditions are not harmful to their health (Royal Thai Government Gazette, 1998). The Occupational Safety, Health and Environment Act B.E. 2554 (2011), which specifies the responsibilities of employers with regards to basic working conditions, requires every mining operation to have a safety guideline and a safety officer who controls and reports safety conditions within the workplace (Royal Thai Government Gazette, 2011). The Guns, Munitions, Explosive Devices, Fireworks and Improvise Guns Act B.E. 2490 (1947) and the Hazardous Substances Act B.E. 2535 (1992) require a permission from specific government authorities for the possession of explosives and chemical substances and the handling and storage of explosives to be complied with the regulation announced by the authority (Royal Thai Government Gazette, 1992b, 1947).

Mining lease holders are subject to royalty payments as specified in the Mineral Act. The rates and market prices for calculating royalties are announced by the Department of Primary Industries and Mines according to the Mineral Royalty Rates Act B.E. 2509 (1966) and its regulations. The royalty rates for most minerals are flat rates between 2-10%. Progressive rates are applied to some metals, i.e. tin, lead, zinc, and gold (Department of Primary Industries and Mines, 2016a). The collected royalty payments must be allocated to the Local Administration Organizations at the share of 60% as specified by the Determining Plan and Process of Decentralization Act B.E. 2542 (1999) (Royal Thai Government Gazette, 1999).

At the end of its life cycle, a mine must be restored in line with the Mineral Act (article 72). However, issues related to mine closures and post-mining management are mainly regulated by the EIA measures on a case-by-case basis. There are no specific regulations on mine rehabilitation and post-closure management. Figure 2.2 shows the enforcement of the laws mentioned above throughout the project life time.

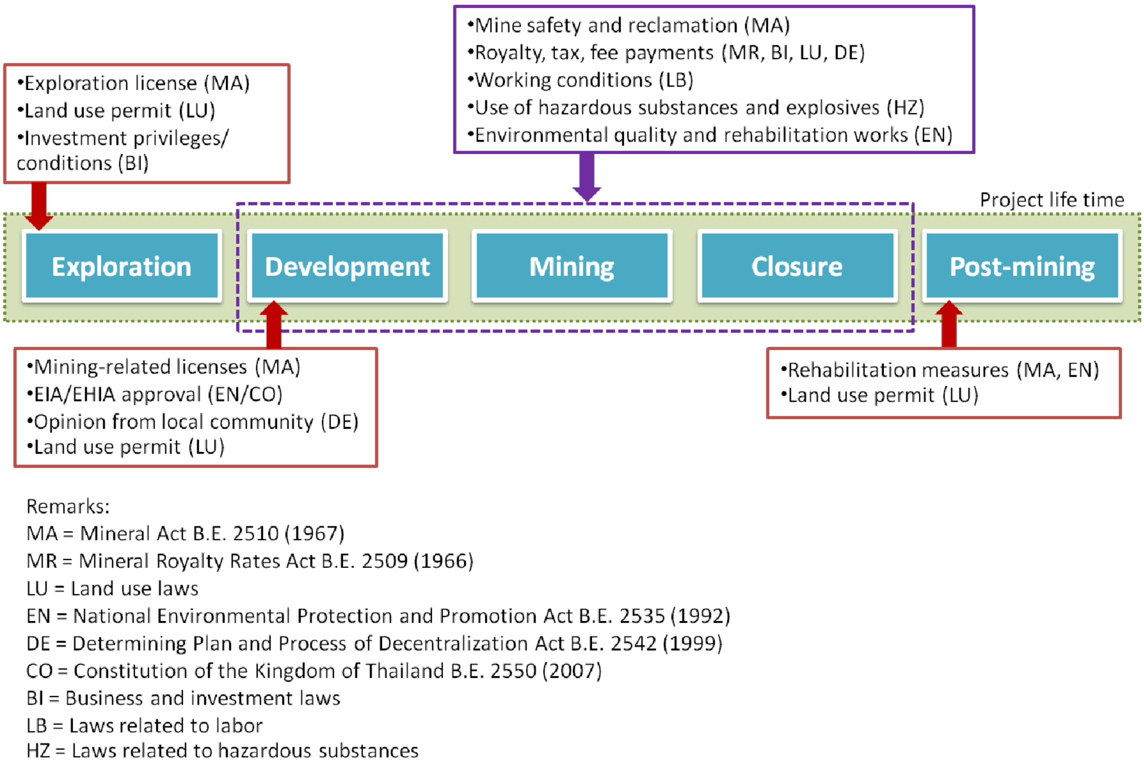


Figure 2.2: Laws imposed on mining activities throughout the project life cycle

3 Mining project assessment and Thai ethics

This chapter will identify the characteristics of the assessment framework for determining the worthiness of mining projects. The chapter is divided into three parts. The first part introduces the core Buddhist principles and their applications in modern society. The second part discusses the implications of Buddhist principles on the assessment of mining projects. The third part provides a short review of the project assessment tools frequently used with mining projects and their applicability to new mining project assessment under Buddhist ethics.

3.1 Buddhist principles and the modern society

3.1.1 The Four Noble Truths

Buddhism is "*a widespread Asian religion or philosophy, founded by Siddartha Gautama in NE India in the 5th century BC*" (Oxford University Press, 2016). The Buddhist teachings are based on the ultimate reality of nature and concentrate on suffering. Buddhism acknowledges that life contains suffering, and its teachings are dedicated to how to end suffering. The core Buddhist teaching – the Four Noble Truths – indicates the path of suffering and the path to overcome suffering. It consists of four components, namely, suffering, origin of suffering, cessation of suffering, and the Noble Eightfold Path.

Suffering. Suffering refers to the state which is "*difficult to bear*" or "*hard to endure*" (Payutto, 2012a). It occurs throughout human life and can involve either physical or mental states such as starvation and unhappiness due to unsatisfied desires. Suffering happens in different forms which can be summarized as the Five Aggregates of Clinging, consisting of the attachment to forms, feeling, perception, mental formation, and consciousness (Buddhatasa Bhikku, 1983, pp. 125–129). A person should attempt to comprehend the presence and the conditions of suffering (Payutto, 2016, p. 156).

Origin of suffering. Suffering originates from craving or the attachment to desire, which occurs in the forms of sense craving, craving to be, and craving not to be (Buddhatasa Bhikku, 1983, p. 129). Craving has its root in ignorance or the lack of knowledge or understanding of reality as it is. Ignorance and craving influence a person's mind and cause suffering through a causal relation called the Dependent Origination, and individuals should attempt to diagnose the origin of suffering and eradicate it (Payutto, 2016, p. 156).

Cessation of suffering. The cessation of suffering refers to the suffering-free state, in which craving and ignorance are eliminated (Payutto, 2016, p. 155). The cessation of suffering can be classified by the difficulty to practice (and the duration of cessation period) and grouped into five levels: cessation by suppression, by substitution of opposites, by cutting off, by tranquillization, and by getting freed (nirvana) (Payutto, 2012b, p. 862). A person should attempt to envision the solution and realize the cessation of suffering (Payutto, 2016, p. 156). The goal of practice in Theravarda Buddhism is the ultimate state of cessation, nirvana. However, a person can aim for the temporary states of cessation, which are less difficult to practice, and continue to improve step-by-step.

The Noble Eightfold Path. The Noble Eightfold Path is the guiding path for self-practicing towards the suffering cessation. The Buddha calls it the 'middle way'. The Path is characterized by eight components, namely, right understanding (understanding the Four Noble Truths), right intention (free from what cannot bring satisfaction), right speech (speaking truthfully and skillfully), right action (not killing, stealing, or involving in irresponsible sexual behavior), right livelihood (not engaging in an occupation that harms others), right effort (encouraging wholesome states of mind), right mindfulness (aware of physical and mental experiences), and right concentration (being focused) (Sivaraksa, 2009, p. 24). These components can be grouped into wisdom (right understanding and right intention), ethical conduct (right speech, right action, and right livelihood), and concentration (right effort, right mindfulness, and right concentration). A person should attempt to practice the Noble Eightfold Path (Payutto, 2016, p. 156). Figure 3.1 shows the components of the Four Noble Truths.

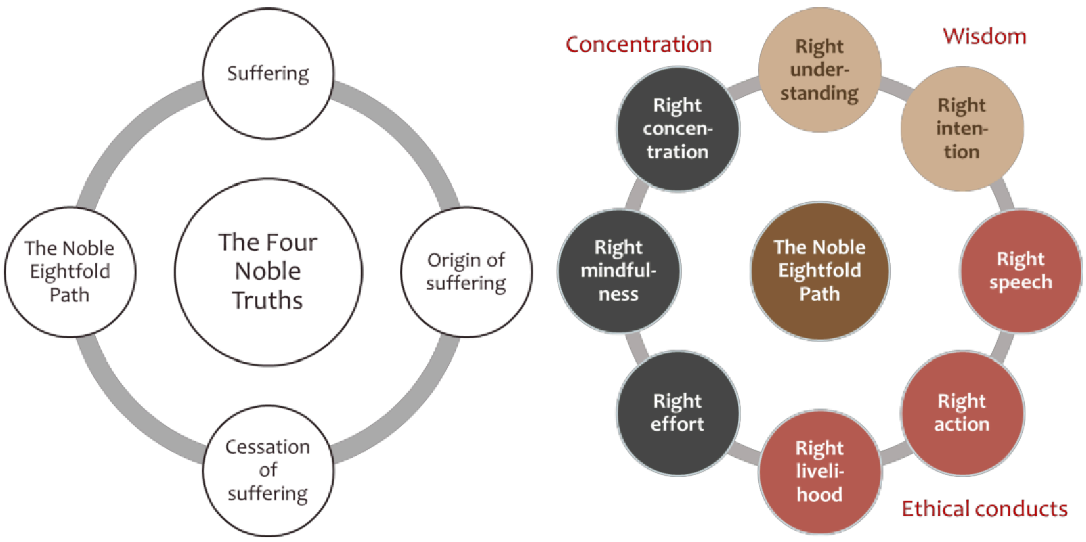


Figure 3.1: Components of the Four Noble Truths

3.1.2 Applications of Buddhist principles in modern society

Although the Buddhist principles were discovered and taught by Buddha more than two thousand years ago, these fundamentals are still valid today. Two well-known applications of the Buddhist principles to economics and development, namely, Buddhist economics and the Philosophy of Sufficiency Economy, are mentioned in this section.

3.1.2.1 Buddhist economics

Buddhist economics is an alternative economic idea characterized by moderation. Inoue (1997, pp. 67–72) identified key characteristics of Buddhist economics in three phases: "*1) an economics that benefits oneself and others; 2) an economics of tolerance and peace; and 3) an economics that can save the earth*". These phases imply the attributes of compassion and non-violence (or harmlessness). Together with moderation, these values provide different perspectives which can contribute to the conceptual improvement of mainstream economics. Schumacher (1973) points out some important differences in attitudes between those founded upon the mainstream economics and the Buddhist economics including the attitudes towards work, development targets, and the choices of natural resources. Zsolnai (2009) also pinpoints the different perspectives between mainstream and Buddhist economics. He explains that mainstream economics is characterized by the maximization of profit, desires, markets, instrumental use, and self-interest; bigger is seen as better, and more is quantitatively interpreted as more. On the other hand, Buddhist economics is characterized by the minimization of suffering, desires, violence, instrumental use, and self-interest as well as the idea of small is beautiful and less is more, which should promote happiness, peace, and sustainable production and consumption in a society. These differences can affect business conducts through the definition of objectives, preferences, and approaches. Seen as a strategy applicable to any economic situations (Zsolnai, 2009), Buddhist economics is believed to contribute to the decrease in extreme and harmful actions along the socio-economic development path.

3.1.2.2 Philosophy of Sufficiency Economy

The Philosophy of Sufficiency Economy is a guiding concept towards a society of moderation introduced by H.M. King Bhumibol Adulyadej of Thailand. The Office of the National Economics and Social Development Board (2007, pp. 6–9) explains that this Philosophy is established upon the 'middle path' principle and consists of five components, namely, moderation, reasonableness, self-immunity, all-round knowledge, and ethics. The former three components are recognized as the pillars of the concept. Moderation refers to a living that is un-extreme and not harmful to oneself and others. Reasonableness refers to thoughtful decision-making based on the consideration of related factors on the causal side and possible consequences. Self-immunity refers to preparedness for changes and an uncertain future. The latter two components are considered supporting conditions for all decisions and actions. Knowledge allows all considerations and planning to be effective and conscientious while ethics direct thought and action towards righteous and determined living. The Philosophy of Sufficiency Economy has been applied as a guiding principle in the National Economic and Social Development Plan (Office of the National Economic and Social Development Board, 2011, 2006, 1996). Moreover, its application in the agricultural sector, i.e. sufficiency agriculture practices (so-called the New Theory), has widely been promoted and applied throughout Thailand.

3.2 Implication of Buddhist principles on mining project assessments

The assessment of mining projects is closely related to the implementation of the sustainable development concept, which plays a role as a background objective. To identify the implications Buddhist principles have on mining project assessments, one must first understand the differences in concepts and approaches between the sustainable development concept and Buddhist principles.

The concept of sustainable development and Buddhist principles share similar characteristics in many respects. Both are human-centered (Matsuoka, 2005; United Nations, 1972, para. 1) and view the different aspects of humankind such as capability, happiness, and relation to the environment. In addition, both emphasize actions. In Buddhism, this characteristic is reflected in the Noble Eightfold Path, which is the 'practicing path' towards the cessation of suffering. In the sustainable development concept, this attribute is reflected as a variety of development goals, implementation plans, and practices. Despite these similarities, both concepts have different foundations. Buddhist principles are based on the ultimate reality of nature (or natural truth), which is universal, whereas the concept of sustainable development is established upon the combination of natural truths and worldly rules set up by humans for social purposes under specific conditions (Payutto, 2003, pp. 219–227). Unlike natural truths, the worldly rules can contain and be affected by human biases. Although worldly truths can be part of the ultimate one, this is not always the case. For example, a medical treatment carried out to cure sick people conforms with the natural truths, but the treatment to generate high income is based on worldly rules (Payutto, 2003, p. 223). The differences in foundations influence the perception and are reflected in the values and the approaches of development.

The two main components of concern of sustainable development are human needs and well-being which have an impact on the outcome of the development. The sustainable development concept requires that the needs of intra- and intergenerations are met (United Nations, 1987, para. 1). The term 'needs' refers to both basic needs, including food, energy, housing, water supply, sanitation, and health care, and the needs to "*satisfy their aspirations for a better life*" (United Nations, 1987, para. 4 and 42-47). Satisfying the basic needs signifies the achievement of well-being according to the objective-list theory, under which well-being is identified by what is good for people regardless of their judgment. However, the broadened scope of needs corresponds to the perception of well-being according to hedonism and subjective well-being theories, under which well-being is determined by pleasure and the ability to satisfy one's desires. This extended scope of needs to cover unlimited wants is where biases can play a role. Important preconceptions lie in the development concepts, particularly economics. The sustainable development concept is influenced by economic liberalism, an economic concept stating that individuals are free to make choices and pursue their own interests. The basic ideas of economic liberalism, comprising the natural order of the economy, the individualistic idea of freedom, self-interest as the driving force in the economy, and competition as the steering wheel of the economy (Stegmann, 2004), are thus encompassed in the concept. The fulfillment of hedonistic well-being with these attitudes can contribute to misguided production and consumption patterns. A production striving for maximum profit rather than serving essential consumption and a consumption stimulated by production and satisfying limitless human desires lead to an excessive exploitation of natural resources and to environmental damage. Furthermore, the ideas of the economic concept are reinforced by the values developed throughout Western history. The important values are frontier mentality, in which natural resources are considered abundant, humanity is not seen as part of the environment and is considered superior to other forms of life, and a belief in progress, in which technological advancement is believed to bring prosperity to society (Payutto, 2003, pp. 122–140). Based on these values, a belief in evolution and dominance of the environment takes hold. The pursuance of self-interest coupled with the conviction of human superiority can cause a depletion of resources and destruction to the environment.

Although technological progress might contribute to a decrease of negative effects, it entails the risk of unknown drawbacks (United Nations, 1987, para. 14). Albeit that the sustainable development concept admits the failures of previous developments influenced by the aforementioned human ideas, the same ideas are still prominent in the adjusted development regimes and practices. Technological progress and free markets are seen as tools for correcting the unsustainable production and consumption patterns (United Nations, 1993). Efforts have been devoted to increasing production and consumption efficiency as well as improving the management of human and environmental hazards (United Nations, 2016, pp. 16–17) rather than to altering the values misguiding the development.

The perception of human needs is different in Buddhism. Human needs are classified by their necessity into different types. Rather than equally satisfying all types of needs as much as possible, each type of need is handled differently. The term 'needs' refers to the four necessities of life – clothing, food, lodging, and medicine (Payutto, 2016, p. 123); these necessities are the basic factors that prepare the human conditions for practicing and achieving the Noble Eightfold Path. 'Wants' are desires, which are inner motivations that drive actions. Payutto (2012b, p. 975 and 1010, 2003, p. 176) explains that there are two types of desires: selfish desire (or craving) and desire for well-being (aspiration). The former refers to the desire to satisfy selfish notions and is based on ignorance. It is the cause of human suffering and should be controlled, minimized, and utilized to promote righteous actions. The latter, on the other hand, is the desire to achieve certain virtues and is based on wisdom which leads to intentional behavior. It is a positive desire and should be satisfied. Humans can learn to alter and meditate their conducts, which suggests they can learn to manage their desires (Payutto, 2005, p. 82). Individuals who are aware of the desires that cause suffering and especially craving are then able to eliminate them. However, people with a lower level of consciousness are oblivious to their selfish desires and continue to pursue them. The ability to control cravings differs from person to person and is different in the same person at different points in time. The power to handle different types of needs determines the level of well-being in Buddhism. This is because Buddhist well-being emphasizes the internal human state. It is possible to reach the state of well-being (i.e. having a steady and peaceful state of mind) when selfish desires are detached or at least restrained with wisdom and awareness so that a person does not need the fulfillment of all selfish desires in order to find satisfaction (Payutto, 2012b, pp. 1061–1066)).

The differences in the perception of needs and well-being lead to different development approaches under the mainstream sustainable development concept and Buddhist principles. The former is characterized by an outside-in perspective while the latter shows an inside-out view. In other words, needs and well-being perceived by the sustainable development concept are driven by personal motives and are to be fulfilled by external factors such as goods, services, and preferable conditions. The approaches towards sustainable development are characterized by an improvement in efficiency. That is, the pursuance and fulfillment of needs are carried out under controlling mechanisms and measures. Technologies, institutional framework, and economics, which are external factors, are applied as tools for enhancing positive consequences and the minimizing negative ones of an individual's actions.

Unlike the approaches in sustainable development, Buddhist principles focus on self-control. The contentment from the suffering cessation, understood as Buddhist well-being, can be achieved by individuals through their own efforts. The need for necessities is seen as the basic condition which sustains Buddhist well-being to be accomplished in a virtuous manner. In contrast, the desire for pleasure possessions (or selfish desires) should be harnessed and responded to in a reasonable way in line with personal ability and potential consequences for oneself and others. Individuals should learn to think and act in a manner that causes less suffering to themselves and others and, if possible, pursue societal and environmental wellness.

The differences between the two approaches become more obvious when considering the current international agenda on sustainable development. The globally-consented implementation plans focus on external controls but lack self-controls. The recommended actions are linked to the role of technology, institutional frameworks, and economics and globalized trade in order to promote economic efficiency and to enhance human growth and progress (United Nations, 2012, para. 19). The ideas of sustainable production and consumption patterns emphasize efficiency improvement and responsible consumption rather than limiting desires for consumption. Moreover, some of the globally-agreed positions are incompatible with the Buddhist view, for instance, the promotion of economic growth, globalized trade, and outside-job employment. The contrasting perspectives are also reflected through implementation measures such as extending capacity and using technology and through the applied indicators. Progress in sustainable development is identified by indicators such as growth, consumption, distribution, money, wealth distribution, education, job, and income. These indicators reflect the ability to pursue basic needs and non-basic wants but do not concern the ability to detach desires and uphold non-harmful actions. When the practices under the sustainable development concept are applied, the satisfaction of needs (i.e. desires) should not be at the forefront of measures since the inherent preconceptions can lead to excessive production and consumption and harmful actions. From this point of view, external control alone is not sufficient to create long-term well-being. Self-control should be applied in conjunction as it helps reduce consumption and thus harmful effects from production. In addition, when a person is self-motivated, external rules are less important.

The differences in how needs and well-being are perceived under the sustainable development concept and Buddhist principles reveal the weaknesses of mainstream sustainable development approaches, i.e. preconceptions and self-interested orientation. Buddhist principles provide a different perspective complementing current development approaches and thus contributing to improvements. The integration of Buddhist principles in mainstream sustainable development approaches can overcome the above mentioned weaknesses. The attributes for strengthening the current development approaches can be extracted from the Noble Eightfold Path, which is grouped into three interconnected categories, namely, wisdom, ethical conduct, and concentration (or the so-called Threefold Partition). Wisdom helps improve the perception of concepts and approaches, enhancing the awareness of suffering. Ethical conduct and concentration complement the social rules and norms through decent actions and self-awareness. Four components are proposed as the key qualities for complementing the outside-in perspective of the sustainable development concept with the inside-out view of the Buddhist principles, including neutral understanding, self-control, compassion, and heedfulness.

Neutral understanding. Understanding is the basis of thoughts and actions. Neutral understanding is the key component in a Buddhist-based development found both in Buddhist economics and the Philosophy of Sufficiency Economy. An understanding with fewer preconceptions can contribute to the sustainable development concept by reflecting on causes and effects, using related knowledge, and formulating development objectives and plans as well as enhancing the understanding of individuals and parties about their roles and responsibilities in development processes.

Self-control. Self-control is characterized by the key Buddhist characteristics, moderation and non-violence (or harmlessness). It can improve the sustainable development concept by restraining individuals from pursuing extreme desires and self-interests that might have harmful effects on themselves, other human-beings, or the environment. This component is similar to the concept of social responsibility in the sustainable development practices. However, the important difference lies in the notion that self-control is based on neutral understanding and the awareness of biases.

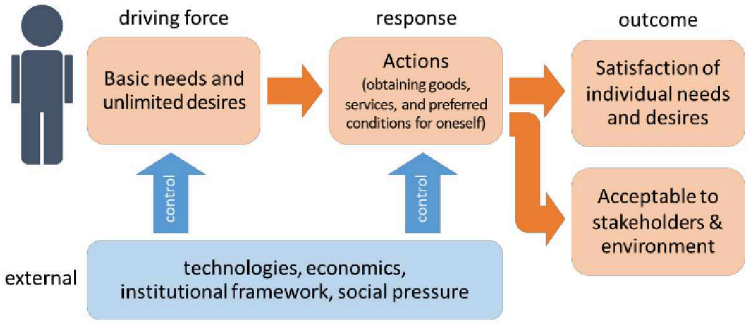
Compassion. Compassion refers to the motivation to relieve others from suffering. It can contribute to the improvement in sustainable development concepts and practices by drawing more attention to non-self-interest issues. Supporting and fulfilling public interests based on agreements and just motives can help promote well-being, build trust, and increase cooperation among parties within society.

Heedfulness. Heedfulness is a thoughtful and determined attitude to maintain righteous thoughts and actions. This attribute can improve the sustainable development concept by enhancing self-awareness. It helps ensure that actions stay on track and are not strongly influenced by human biases, so society continues to improve. This feature is similar to the continuous improvement concept in quality management, but the additional mandate is that neutral understanding, self-control, and compassion are the foundation of thoughts and related actions.

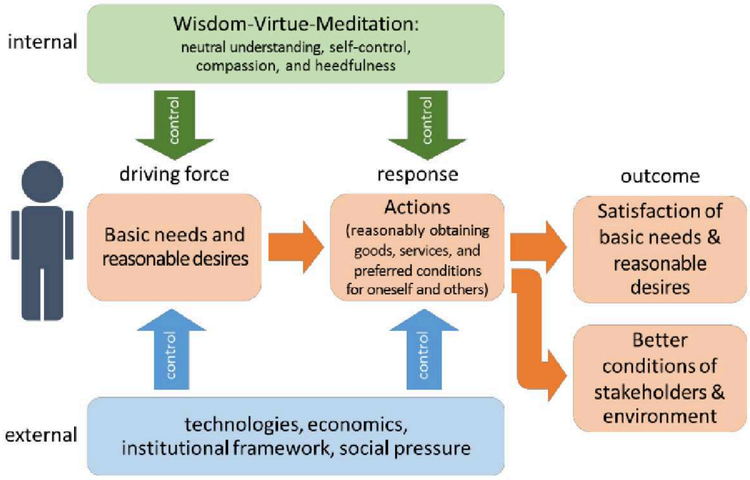
Figure 3.2 illustrates the contribution of Buddhist principles to the improvement of mainstream sustainable development approaches.

3.3 Mining project assessment: a review of assessment tools

Various tools are available and applicable for the assessment of new mining projects. The objective of the assessment determines the type of tool used. The four types of tools commonly applied to mining projects are feasibility studies, impact assessment, risk assessment, and sustainability performance indicators. They are reviewed in this section with respect to their practicality for assessing new mining projects based on Buddhist ethics.



(a) Mainstream sustainable development approaches



(b) Buddhist-based development approaches

Figure 3.2: Sustainable development approaches and Buddhist-based development approaches

3.3.1 Feasibility study

A feasibility study is a methodology for evaluating comparable financial opportunities of investment of a mining project. It is normally carried out before any investment decisions have been made and can be achieved by a single, continuous-step or by a multiple-step (three-phase) approach (Bullock, 2011). Borquez and Thompson (1990, p. 396 and 411) explain that a feasibility study mainly contains the technical designs and planning and economic analyses. Technical designs and planning demonstrate the technical practicability and determine the costs of investment and operation. Economic analyses determine the project viability. Moreover, the evaluation criteria depend on the investment objectives. In most cases, the comparison of investment alternatives is based on profitability. Profitability criteria are divided into non-discounted (such as payback period and accounting rate of return) and discounted cash flow (such as net present value (NPV), internal rate of return (IRR), profitability index (PI), and benefit-cost ratio). Among them, NPV is the most common indicator for evaluating and comparing investments (Nelson, 2011, p. 302; Torries, 1998).

A feasibility study is important for project assessment as it contains technical data as well as market- and management-related information. However, the objective of the study is to identify the economic viability of a project under specified conditions, so its result contains underlying assumptions and provides a limited perspective on information, mainly profitability. The information in feasibility studies can be useful in the Buddhist-based assessment, but the user must be aware of the assumptions which must be taken into account along with other aspects of information.

3.3.2 Impact assessment

Impact assessment is "*the process of identifying the future consequences of a current or proposed action*" (International Association for Impact Assessment, 2009). It can be applied to various types of projects and can cover one or more specific issues. For mining, the environmental impact assessment (EIA) is one of the most widely-applied processes and is a compulsory step in the project approval process in many countries (Li, 2008; Wood, 2003). It is used to identify and predict the impacts of proposed activities on the bio-geophysical environment and on human health and well-being. It is also helpful for data interpretation and communication (Munn, 1979). Other types of impacts such as social and health impacts can be assessed as an extended part of the EIA or in an independent study.

The key procedure of an environmental impact assessment includes defining a project (and alternatives), screening the project, scoping impacts, analyzing impacts of the proposed action as well as its alternatives, identifying mitigation measures, evaluating the significance of residual impacts, preparing reports, reviewing and decision-making, and following-up. The assessment should be carried out as early as possible because it allows effective management of anticipated impacts (Environmental Law Alliance Worldwide, 2010; Senécal et al., 1999).

Another type of impact assessment is the life cycle assessment (LCA), which is the "*compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle*" (International Standard Organization, 2006). The assessment consists of four parts: the goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA), and interpretation. The assessment results are expressed by impact category indicators, derived from the summation of specific classes of environmental impacts.

These different impact assessments are helpful for the governmental assessment of a mining project under the Buddhist-based criteria because they can be accomplished at an early stage in the development. Furthermore, the assessments are based on factual or scientific data, so they provide a neutral understanding of the actual condition of the environment, health, and/or society. However, the assessments do not delineate the development value of a mining project but aim to identify the foreseeable impacts and deal with them. Moreover, the identification and the perception of impacts contain weaknesses that can hinder their applications in many ways. Firstly, the ability to identify consequences affects the extent and reliability of the assessment. The scope of assessment is identified by a scoping process accomplished either by a technocratic or a participatory approach (Joyce and MacFarlane, 2001, p. 8). The completeness of the results depends on the ability and knowledge of the scoping participants. Several methods for identifying impacts have been applied to overcome this weakness such as checklists, matrices, questionnaires, and participation, consultation, and expert opinion (Canter and Sadler, 1997). In a social impact assessment (SIA), the identification of impacts and goals is more problematic because social impacts are dynamic and qualitative. In most SIAs, the pressure on social systems is measured rather than the actual impacts. What is more, SIA studies conducted by companies might incline towards economic prosperity because the studies are based on stereotypes of a modern, developed economy (Joyce and MacFarlane, 2001, pp. 16, 20). The incomplete identification of impacts and the biased perception can mislead the understanding of project objectives and consequences. Secondly, the impact measurement and data accumulation can direct the understanding of the result-users in the wrong direction. Impact refers to both positive and negative impacts. Impact measurements sometimes focus purely on financial aspects. Using monetary quantities to represent the level of impacts has two crucial shortcomings. The first weakness is the conversion of real values to monetary values, which is dependent on assumptions and affected by preconceptions of human judgments. For example, in the assessment of impacts on the environment, criticism is voiced as to how the values are defined, the extent to which market prices represent public interest, and the negligence of intrinsic values. (Pearce, 2006, pp. 3–5). The second flaw concerns the aggregation of positive and negative impacts, which leads to ill-conceived understanding and actions. Aggregating impacts in terms of cost and benefit according to the following equation:

net public benefit/cost = net benefit or cost from project – net public infrastructure costs – net social and environmental costs + net other economic impacts (New South Wales Government, 2012, p. 4)

can make people overlook the real value of impacts such as lost functions that cannot be compensated with the gain of other positive consequences. Gibson (2000) points out that minimizing or justifying damage and maximizing desirable net gains had different implications.

In the case of LCA, the assessment method provides an alternative for measuring and presenting impacts because it covers the impacts of the whole product life cycle and groups the impacts into specific problematic areas. However, using LCA for assessing the values of a mining project according to the Buddhist-based criteria contains limitations. LCIA focuses on environmental issues. The impact categories that are applicable to mining are, for example, global warming, ozone depletion, human toxicity, fresh water aquatic ecotoxicity, acidification potential, eutrophication potential, land use impacts, and energy use impacts (Awuah-Offei and Adekpedjou, 2011). They do not represent a comprehensive impact of a mining project. However, the improvements in the methodology such as those suggested by Weidema (2006) and the assessment concept and procedure can be useful for the assessment of a mining project.

3.3.3 Risk assessment

The definition and the description of risk assessment according to the International Standard Organization (2009) can be summarized as follows. Risk assessment is a process of assessing the effects of uncertainty on identified objectives. It consists of three steps, namely, risk identification, risk analysis, and risk evaluation. Risk is identified from risk sources, incidents, and their potential consequences on stakeholders' needs by using historical data, theoretical analysis, and obtaining informed and expert opinions. The analysis of identified risks determines the degree of risk from the combination of consequences and their probability. Risk evaluations determine whether the level of risk from the analysis is acceptable.

Risk assessment is applicable to a wide range of issues. It provides a basis for specific types of assessments such as health impact assessments (HIA) (International Council on Mining and Metals, 2010) and is also used to improve the impact assessment process. For example, the integration of ecological risk assessments (ERA) to the EIA process helps identify potential hazards, extend the assessment, prioritize actions, and handle uncertainty (Hyett, 2010). Furthermore, risk assessment is an important process to evaluate uncertainty. It can be carried out at every stage of the project and is part of the continuous improvement process (International Standard Organization, 2009). The strength of risk assessment is that it is backed by scientific facts and accountability, and that it is flexible and returns quantifiable and comparable results. However, using risk assessments for evaluating the benefits of a mining project in line with Buddhist ethics needs a close study of the available data as uncertainties might arise due to missing or variable data and limited knowledge. Providing users are aware of the limitations, risk assessment has its own merits which contribute to the assessment of mining projects based on the Buddhist philosophy of good mining.

3.3.4 Sustainability performance indicators

There are several indicators for assessing mining projects. An important set of indicators is the one launched by the Global Reporting Initiative (GRI) as a part of the sustainable reporting guideline, which has become a reference for organizational sustainability reporting worldwide (Global Reporting Initiative, 2015). The GRI's Sustainability Reporting Guidance provides a framework for information disclosure by organizations over time. The framework is linked to international practices such as the United Nations Global Compact Ten Principles, the OECD Guidelines for Multinational Enterprises, and the United Nations Guiding Principles on Business and Human Rights (Global Reporting Initiative, n.d.) and contains a supplement for the mining and metals sector (Global Reporting Initiative, 2013b). It consists of performance indicators in economic, environmental, and social categories. The social category is divided into four sub-categories, namely, labor practices and decent work, human rights, society, and product responsibility (Global Reporting Initiative, 2013a).

The GRI's Sustainability Reporting Guidance is criticized for not integrating indicators. This makes companies focus on specific issues, thus failing to comprehend the holistic view of sustainability and camouflaging unsustainable practices (Fonseca et al., 2014; Moneva et al., 2006). Moreover, its economic and social indicators are inclined towards the weak sustainability approach (Moneva et al., 2006). Benefits, as identified by the performance indicators, refer to revenue and distributed economic value, infrastructure and services development, job opportunities, and development programs. Indicators for negative impacts include resource consumption and its efficiency, affected biodiversity, risks and damages from emissions and waste materials, injuries and diseases from work and product use, discrimination and inequality, violation of human rights (employee, indigenous people, and in the supply chain), child labor and forced labor, corruption, and anti-competitive behavior. These indicators characterize how an organization affects stakeholders interacting economically with the organization and not the actual impacts. This quality does not create a neutral understanding because weak sustainability nurtures materialistic patterns (i.e. economics).

To sum up this chapter, Buddhist ethics identify two important weaknesses in the conception and the tools for assessing mining projects. The first weakness lies in the inherent values of the sustainable development concept that are influenced by self-interest and focused on the roles of social mechanisms in governing human activities. Another weakness lies in the quality of the available assessment tools. That is, the tools are influenced by preconceived and ignorant theories, which prevent an objective understanding and which facilitate self-interest. Therefore, they cannot provide the government and stakeholders with comprehensive and objective information about a project's worthiness in keeping with Buddhist ethics. To overcome these weaknesses, the new assessment framework should entail the following characteristics:

- taking into account the self-interest of a mining company's shareholders and the interests of stakeholders
- providing a comprehensive view of the consequences of mining projects while minimizing the partiality, which promotes an excessive pursuance of self-interests
- useful for the improvement of internal controls and for communication among stakeholders

Combining useful features of the available assessment tools and organizing them in a framework containing the characteristics mentioned above will yield a helpful tool to improve the decision and the communication performances of the Thai governmental agency as well as increase the efficiency of impact management in companies.

4 A framework for assessing new mining projects in Thailand

This chapter will develop a framework for assessing new mining projects in Thailand. The chapter is presented in four parts. The first part identifies the objectives of the framework as well as intended applications and users. The second part introduces the description of the assessment model, including its components and their structural arrangement. In the third part, the assessment method is explained. Finally, the fourth part provides a description of the criteria and the indicators of each component.

4.1 Objectives of the assessment framework

The framework for assessing new mining projects assists the Thai governmental agency in its decision-making process as well as in its communication with stakeholders. It denotes the worthiness (value) of newly-proposed mining projects at an early stage of the project, i.e., before the construction for the application. The assessment framework should meet the characteristics mentioned in the previous chapter and the following application requirements:

- applicable under limited data availability, which is a common condition of a pre-developed project;
- able to provide comprehensive and detailed information about the major gains and losses possibly caused by a mining project throughout the project life cycle; and
- able to integrate into the current administration system and connect with mineral resource management and social development schemes.

4.2 Model for mining project assessment

4.2.1 Assessment matrix

The assessment framework determines the worthiness of new mining projects from the characteristics defined in the previous chapter, including (1) self-interest and the interests of stakeholders, (2) ability to provide a comprehensive view of the consequences of mining projects while minimizing the biases that promote the excessive pursuance of self-interest, and (3) useful for the improvement of internal controls and for communication among stakeholders. The framework is established upon the idea of the evaluation of product worthiness proposed by Mitsuru Tanaka and mentioned in Inoue (1997, pp. 98–100), in which the worthiness of a product is ranked in a matrix of the necessity to consume and the negative environmental impacts caused by the product. Following this idea, the worthiness of a mining project is determined by the necessity of the project development and the negative impacts on humans and the environment.

The necessity of project development and the negative impacts on humans and the environment are ranked as low, medium, and high. A high ranking shows that a project could be vital to society. A medium ranking indicates that a project is not essential but that it could contribute positively to society. A low ranking means a project is less likely to contribute positively to society. Low negative impacts infer that the negative impacts caused by a project are likely to be limited to an acceptable degree or cause insignificant or slight harm to the population and/or the environment. Medium negative impacts indicate that the negative impacts could be more widespread or more critical but that the damage would not be critical and would still be manageable. High negative impacts mean that the negative impacts might be critical either temporally or spatially or cause serious damage to the population and/or the environment.

The necessity ratings of project development and the negative impacts are put together in a 3x3 matrix to classify the development priority of the project. Three classes rate the development priority. A high-priority project is worth developing, i.e. it is essential or could contribute positively to society and will have low to medium negative impacts. A medium-priority project is worth developing if the negative impacts and the positive contributions can be properly handled. It belongs to the group of projects that could benefit society or are not essential but will not have a critical negative impact on society and the environment. A low-priority project is the least appealing project in terms of project development because it does not contribute substantially to public well-being and causes many negative impacts. If a project of this class were pursued, it would require careful attention and stringent measures for controlling the negative impacts. Table 4.1 shows the necessity-impacts matrix for identifying the development priority of a mining project from the viewpoints of the stakeholders and the governmental agency.

Table 4.1: Necessity-impacts matrix for identifying the development priority of a mining project

Necessity of project development	Negative impacts of the project		
	Low	Medium	High
High (vital for society)	High priority	High priority	Medium priority
Medium (not absolutely necessary but can positively contribute to society)	High priority	Medium priority	Low priority
Low (not really necessary)	Medium priority	Low priority	Low priority

4.2.2 Scope, components, and structure of the assessment

This assessment framework considers the effects of a mining project on both national and local levels in order to provide an overview of the development worthiness of new mining projects. The national-level effects are the functional values that a mining project has on society, and the local (project)-level effects are the consequences of the project's operation. The consequences at different phases of the mining project life cycle are taken into account with an emphasis on the operation and the post-closure phases. The spatial boundary of the assessment varies, but, in most cases, it should cover the area within the mining lease and/or related permits. The ratings of the necessity of project development and the negative impacts of the mining project are derived from various data. Each consists of a set of sub-components arranged in and assessed through a hierarchy. The idea to use a hierarchical structure to determine the necessity and the negative impacts ratings are inspired by the Analytic Hierarchy Process (AHP), a decision-supporting tool that prioritizes alternatives by pairwise comparisons of criteria. Part of its process is to set up a hierarchy with the decision goal at the top and broad objectives and criteria on the intermediate levels (Saaty, 2008). This step is adapted to establish the assessment framework in this study since it allows a systematic arrangement of criteria and distinguishes the criteria's relation to the goal. The components included in the assessment are identified based on the information about mining impacts found in literature as explained below.

4.2.2.1 Necessity of mining project development

The necessity of developing a mining project is based on its contributions to socio-economic and environmental well-being. It is characterized by service provision and positive contributions to society.

(1) Service provision

Service provision represents the objectives of mining activities. It emphasizes the major role minerals play in modern markets. The demand for minerals grows in line with the expansion of socio-economic activities. The necessity for a mining project lies in its ability to serve the needs and secure the continuation of socio-economic activities. However, from a Buddhist perspective, the exploitation of mineral resources is better when the consumption is moderate, products are produced from locally available resources for local needs, and renewable resources are used rather than non-renewables (Schumacher, 1973, chap. 4). Based on these attributes, service provision is determined by three components: contribution to domestic demand, contribution to end use, and resource availability.

(2) Positive contribution of mining projects on society

Positive contribution means the improvement of social and environmental well-being created by the development of a new mining project. It implies the compassionate actions of a mining company. The positive contribution of a mining project is considered in relation to workers, communities, the environment, and shareholders.

(2.1) Positive contribution to workers

The following aspects are identified by the GRI's Sustainability Reporting Guidance (2013a) as labor practices that an organization affects to uphold sustainability: employment, labor/management relations, occupational health and safety, training and education, diversity and equal opportunity, equal remuneration for women and men, supplier assessment for labor practices, and labor practices grievance mechanisms. It also points to the aspects of human rights that are related to workers, including non-discrimination, freedom of association and collective bargaining, child labor, forced or compulsory labor, and security practices. Among these aspects, employment is the aspect that plays a positive role. It directly provides income as well as other forms of benefits to employees in exchange for their labor. Therefore, the positive contribution of a mining project to workers is determined by the rate of employment and hence the number of people who benefit from income, fringe benefits, and skills training offered by the mining company.

(2.2) Positive contribution to communities

The physical well-being or suffering of communities is determined by their livelihoods, which mean "*adequate stocks and flows of food and cash to meet basic needs*" (World Commission on Environment and Development, 1987). Therefore, a mining project contributes positively to a community by improving its ability to secure or gain a better livelihood. According to Chambers and Conway (1991), household livelihood is acquired by a combination of capabilities, assets, and activities for living. Of these, access to assets is an important factor determining capabilities and livelihood strategies of households. Livelihood assets are tangible and intangible resources, including human, social, natural, physical, and financial resources (Carney, 1998; Scoones, 1998). A mining project affects access to livelihood assets for communities both during and after the operation phase, especially access to natural resources and basic facilities and services. Many closed mines have been restored or developed to serve different land use functions. These include agriculture, forestry, lakes or pools, intensive recreational land-use, non-intensive recreational land-use, conservation, and pit backfilling (Mborah et al., 2015). Several mining companies also invested in community infrastructure such as those mentioned by the International Council on Mining and Metals (2012a), Kemp et al. (2010), and Minerals Council of Australia (2015). Based on the information above, six types of community rights to resources and services delineate the key assets necessary to ensure a community's basic welfare and livelihood and thus the contribution of a mining project to communities, namely, water, forestry, financial resources, infrastructure, healthcare, and education.

(2.3) Positive contribution to the environment

Mining is a decisive cause of environmental damage and degradation, but a mining project can also improve the environment, especially through mine rehabilitation. Because mining is a temporary activity, the use of land by a mining project comes to an end after a certain period of time. Restoring degraded land has become a priority of anthropological land use, including mining, in correspondence with conservation strategies (MacMahon and Holl, 2001). The rehabilitation of mining areas used to aim at returning the landscape and ecosystem to its pre-existing state. However, this view has gradually changed towards an emphasis on biodiversity and ecosystem functions (Doley et al., 2012). Many empirical studies have shown that restoring flora positively affected the return of fauna and that the rehabilitated area could attain equal or higher density and richness of species (Cristescu et al., 2012). The environmental gain created by rehabilitation is important because the post-mining period is boundless compared to the period of development and operation which lasts between less than a decade and more than a century. Based on the aforementioned information, the contribution of a mining project to the environment is assessed from the habitat gain through rehabilitation and offset schemes (if any).

(2.4) Positive contribution to shareholders

The positive contribution of a mining project to shareholders is connected to shareholder values. Shareholder values are "*a measurement of the change in value of the firm's investment over a period of time*" (Johnson, 2001, p. 18). They are financial and non-financial values. Non-financial values are intellectual assets including human, relational, and structural resources (Śledzik, 2013). The financial value is generally determined by the return on investment, whereas the non-financial value is connected to different issues. From a Buddhist perspective, the contribution of a mining project to shareholders should be judged from both components. However, the return on investment can be interpreted either as positive or as negative, depending on the actual values. A project is interesting if it expects adequate return, but the consequence is more significant if the project cannot reach the anticipated profits. As a result, the financial value in this assessment framework is considered as part of the negative impacts which allows a better reflection of the effect of a mining project on shareholder's suffering. The non-financial value, on the other hand, is relatively difficult to assess before a mining project commences because it is related to the management at the operation phase. Therefore, it is not directly included as part of the positive contribution to stakeholders but is assessed indirectly.

Figure 4.1 summarizes the components of the necessity of mining project development as well as their arrangement into a hierarchy.

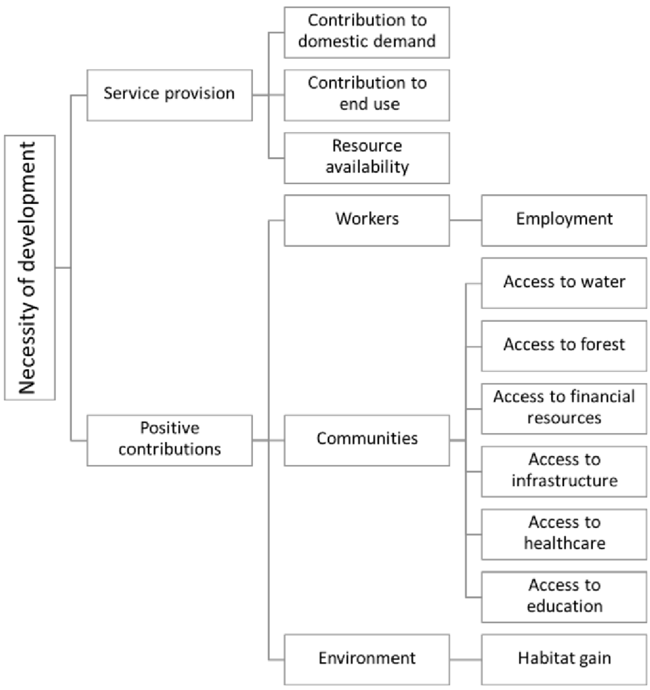


Figure 4.1: Components and structure of necessity of mining project development

4.2.2.2 Negative impacts of the mining project

The negative impacts of a mining project are far-reaching and influence the well-being of stakeholders and the environment. The negative impacts are assessed from those on workers, communities, the environment, and shareholders.

(1) Negative impacts on workers

The welfare of workers is related to different issues and can be categorized as subjective or objective well-being. In public decisions, the workers' well-being should be objective well-being allowing mutual agreements independent of preferences and feelings. The key areas of workers' well-being are health and basic survival, economics, environment, culture, society, and politics (Xing and Chu, 2011). Of these, health and safety are the most critical as they affect workers' ability to survive and tolerate physical sufferings. They are a basic responsibility of mining companies as stated in the International Labour Organization (ILO)'s document, which demands employers eliminate or minimize the risks to safety and health in their mines (International Labour Organization, 1995a, sec. 7). Therefore, health and safety issues stand for the impacts of mining on workers in this assessment framework. Three issues of workers' health and safety are included, namely, occupational diseases, harmful working conditions, and accidents. Although they are referred to as the impacts on the health and safety of workers, they are actually risks and their actual impacts are uncertain.

(1.1) Occupational diseases

Occupational diseases result primarily from an exposure to risk factors present at work, especially occupational health hazards, including pollution, noise, and vibrations. Among the occupational diseases most frequently found in mining are respiratory diseases, noise-induced hearing loss, and musculoskeletal disorders (Vingård and Elgstrand, 2013). Thus, these major diseases will represent the impacts of occupational diseases in this assessment framework.

(1.2) Harmful working conditions

Harmful working conditions are a part of occupational health hazards. This framework separates these issues from occupational diseases because their effects are mostly shown in the short term. Two conditions important to mining, namely, exposure to heat and the lack of oxygen, are selected to represent the impacts of harmful working conditions.

(1.3) Accidents

Accidents in mining can be fatal. The ILO's Safety and Health in Mines Recommendation specifies the critical forms of safety hazards in mining, including mine fires and explosions, gas outbursts, rockbursts, an inrush of water or semi-solids, rockfalls, susceptibility of areas to seismic movements, hazards related to work carried out near dangerous openings or under particularly difficult geological circumstances, and loss of ventilation (International Labour Organization, 1995b). Most of these issues form the basis for considering the impacts of accidents in this framework. The assessment determines five forms of accidents, namely, fire and explosion, gas outburst, rockburst, an inrush of water or semi-solids, and ground failure. The loss of ventilation is not included in this section but in the harmful working conditions.

(2) Negative impacts on communities

The well-being of communities is related to many issues. Among them, those hindering a good livelihood should be prioritized since they are related to physical suffering. A mining project can negatively impact the livelihood of local communities directly and indirectly. Three types of changes in living conditions are selected to represent the negative impacts of mining on communities, including health and safety, access to livelihood assets, and vulnerability to external changes.

(2.1) Health and safety of communities

Health and safety is the basis for humans to live and to go about their daily business. Mining can affect a community's health and safety through different forms of hazards. The important ones are accidents, pollution, and changes in lifestyles and social conditions.

Accidents in a mining project can be catastrophic and cause immediate fatalities and injuries. One such form of fatal accident is the collapse of waste storage facilities. Because waste storage facilities are generally large-scale, their destruction can cause a substantial mass of waste spill into the neighboring area, resulting in death, injury, and damage to public and private assets as was seen in the recent bursts of the Bento Rodrigues dam (Brazil), red mud dam in Dahegou Village (China), waste dump in Hpakant town (Myanmar), and other incidents such as those reported by Blight and Fourie (2004). In the longer term, noxious substances in the facilities can contaminate and accumulate in the environment, affecting the health of people in the vicinity. A further type of accident that endangers people's lives and assets is sinkhole, which often occurs without prior notice.

Some important sinkhole incidents recorded in literature are those reported by Whyatt and Varley (2008). Therefore, in this assessment framework these two forms of accidents are used to represent the impacts of accidents on communities.

Pollution can directly and indirectly affect the health of people in a community. Depending on the type of pollutants and the extent of exposure, communities suffer from irregular conditions and illnesses. Evidence from the past shows several incidents of acute and chronic diseases of the respiratory system, blood system, organ functions, and reproductive system. Several studies have proven shorter lifespans in communities (CCSG Associates, 2004; Cronjé et al., 2013; Stephens and Ahern, 2002).

Changes in lifestyle and social conditions can be the source of illness and accidents. The report of the CCSG Associates (2004) describes different examples of these problems. It indicates that mining attracts sex workers due to the number of usually male migrant workers, so it might spread sexually transmitted diseases such as HIV. The report states that the expansion of communities and the change in lifestyle are the causes of accidents, stress, mental difficulties from displacement, alcoholism, addiction, and violence. Moreover, migrants sometimes contract diseases owing to a lack of immunity. The study also points out that, in a changing and sometimes polluted environment, locals are suffering malnutrition because they rely heavily on nature for their food.

This framework determines the impacts of a mining project on a community's health and safety based on the hazard information above. However, the socially-induced health impacts cannot be estimated at an early stage of the project because they occur during the process of social change. Therefore, accidents and pollution are used to ascertain the impacts. The failure of a waste storage facility and sinkhole occurrences represent the accident forms in this assessment framework. Pollution to the three environmental elements, air, water (and sediment), and soil, is examined. Air pollution is determined by direct releases of air pollutants. Water pollution occurs through a planned discharge and an undesired release of pollutants into water. The planned discharge refers to direct disposal of water into natural water bodies. Undesired release is the discharge of polluted water by an accident or an unplanned event. They are determined by three types of incident, including mine drainage, seepage from the storage facility, and failure of the waste facility. Soil pollution is assessed from direct disposal and indirect releases of pollutants through dust deposition.

(2.2) Community's access to livelihood assets

Access to livelihood assets means access to a suitable living, which is not hindered or diminished. Losing access to natural resources is detrimental for peoples' livelihood, especially for indigenous people and people with primary occupations, whose livelihood relies significantly on natural resources. As mentioned earlier, there are five groups of livelihood assets: human, social, natural, physical, and financial. Among them, the negative impacts of mining on access to natural and physical assets are relatively explicit; therefore, they are used to represent the access to livelihood assets in this assessment framework.

(2.2.1) Access to natural assets

Land, water, and forest are important natural assets, to which the development of a mining project can hinder a community's access. People can lose their access to land through the expropriation or land acquisition by mining companies. Despite compensations, local people might lose their land through unfair deals and rising land prices from speculation, which makes it difficult for the locals to buy new land in the neighboring area (International Institute of Environment and Development, 2002, p. 160). Polluted soil also causes land loss. The disposal of waste and unintentional release of pollutants lead to soil contamination, which reduces the usability of land for other purposes.

Different groups such as fishers, farmers, communities, and tourists might be denied access to water affected by mining (Northey et al., 2016). Mining uses water for extraction and processing activities, which results in competing water use. Landscape transformation by mining activities can change surface water and groundwater flows, affecting the availability of water. In addition, mining can pollute the water quality through direct water discharge or unintended spills such as acid mine drainage and tailing dam failure, hindering a community's use of local water resources (Kemp et al., 2010). Deforestation is the main cause for loss of access to wood. Mineral deposits are often located in forest areas, so mining operations must take place there. Generally, the development of mining compounds and facilities requires land clearing. Mining, especially surface mining, deals with a large-scale removal of vegetation and overburden (Kaushik and Kaushik, 2006, p. 10). These deforestation activities change a community's access to food, medicines, and natural products.

Based on the information above, this assessment framework illustrates three components that are accountable for the negative impacts of a mining project on a community's access to natural resources including competing use of water, competing land use, and competing use of forests. The effects of degradation are not included in this subject but in other parts of the framework.

(2.2.2) Access to physical assets

The physical assets to which a community's access can be affected by a mining project are mainly public infrastructure and basic services. Because a mining project involves a growing population and expanding local economies, there is increased demand for public infrastructure and basic services. A rapid rise in population due to mining-induced migration causes problems not only for the traffic system but also to sanitary and waste handling (especially in underdeveloped areas). Moreover, it often results in increasing housing prices and an over-stretching of public services (International Institute of Environment and Development, 2002, pp. 201–203). In many cases, mining projects increase the traffic volume not only for the transport of supplies, products, and wastes but also for the growing population (Petkova et al., 2009). Based on the information above, this assessment framework determines the negative impacts of a mining project on a community's access to physical assets from the competing use of infrastructure and services. Four types of infrastructure and services are included in the assessment, namely, road, rail, healthcare, and education.

(2.3) Vulnerability to external changes

Mining influences the livelihoods of communities by making them more vulnerable to external changes. Natural hazards are a crucial factor in terms of vulnerability because they can critically impact poor people who have limited access to assets (Wisner et al., 2003, pp. 12–13). There are different kinds of natural hazards. The Centre for Research on the Epidemiology of Disasters classifies natural disasters into six hazard categories: geophysical (earthquake, mass movement, and volcanic activity), meteorological (extreme temperature, fog, and storm), hydrological (flood, landslide, and wave action), climatological (drought, glacial lake outburst, and wildfire), biological (epidemic, insect infestation, and animal accident), and extra-terrestrial (impact and space weather) (Guha-Sapir et al., 2015). Of these, the effects of geophysical, hydrological, and climatological hazards are likely to be linked to mining. For example, mining-induced ground subsidence can increase the flood risk in an area, lower groundwater levels or the changes of water levels caused by mining might magnify the effect of drought.

Next to the natural hazards, local communities are vulnerable to economic changes especially if they become highly dependent on mining companies. Such communities are then vulnerable to fluctuations in the mineral market as well as to the state of the mining company. Moreover, if the mine closes, the dependency leads to problems in terms of higher unemployment, lower property prices, and no longer access to mine-provided infrastructures and services (Jenkins and Obara, 2008; Lapalme, 2003, p. 19; Laurence, 2006). Natural hazards and dependency on mining will represent the vulnerability-related changes in this framework. In Thailand, natural hazards occur in eight categories, which are tropical cyclones, earthquakes, floods, thunderstorms, landslides, storm surges, forest fires, and droughts. From these, the damages from floods and droughts were the worst (Health Information System Development Office, 2013, p. 72). Together with the fact that their impacts are enhanced by the effect of mining, floods and droughts are selected to represent the major forms of natural hazard. Mass movement and landslides are also important hazards in mining. However, they are considered in another part of the model, so the issues are not assessed in this section. The impacts of mining on the vulnerability to external changes are assessed from three angles: vulnerability to floods, vulnerability to droughts, and dependency on mining. Only the negative impacts that undermines a community's ability to have a good livelihood are examined.

(3) Negative impacts on the environment

We can divide the natural environment into two main types: physical and biological. The physical environment consists of the lithosphere, hydrosphere, and atmosphere, whereas the biological environment is composed of flora, fauna, and microorganism (Sivakumar, 2010, p. 4). Both types of environment benefit humankind through different forms of ecosystem services, comprising provisioning, regulating, supporting, and cultural services (Alcamo et al., 2003, p. 5). Human activities put significant pressure on the environment rendering changes to environmental states and leading to different types of environmental impacts. The impacts are measured at different points in the causal chain, including the pressure on the environment, changes in the environmental state, midpoint impacts, and finally endpoint damages such as human health, ecosystem, and abiotic resource. The well-being of the environment is linked to the condition of humans and other living-beings through the ecosystem services. Accordingly, the negative impacts of a mining project on the natural environment in this framework emphasize the services of biotic and abiotic resources and their interdependency and are considered in relation to biodiversity loss.

Biodiversity refers to "*the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems*" (United Nations, 1992). It is divided into three groups: species, genetic, and ecosystem (Secretariat of the Convention on Biological Diversity Netherlands and Commission for Environmental Assessment, 2006, pp. 13–14). The value of biodiversity is characterized by different domains, including richness, complementarity, rarity, threat, irreplaceability, representativeness, area size, and naturalness (Bröring and Wiegleb, 2005). Human activities can threaten biodiversity in different ways. The key direct drivers of change include habitat loss, degradation, and fragmentation, over-exploitation of biological resources, pollution, especially nutrient loading, introduction and establishment of invasive alien species, and multiple pressures on ecosystems (Secretariat of the Convention on Biological Diversity, 2014, p. 25). These direct drivers are also influenced by indirect drivers such as demographic, economic, socio-political, cultural and technological processes or interventions (Secretariat of the Convention on Biological Diversity Netherlands and Commission for Environmental Assessment, 2006).

Mining can intensify biodiversity loss, for example, through habitat loss due to extensive land clearance, habitat fragmentation, alteration of ecological processes from changes such as the interruption of hydrological regimes or disruption of soil structures, pollution (to air, water, and soil), and disturbances (International Council on Mining and Metals, 2006, p. 12). These can occur throughout the project life cycle. Lloyd (2002, pp. 20–42) explains the common problems at different phases of a mining project as follows. Exploration and prospecting activities involve ground clearing and grid-line creation, which result in a direct disturbance of habitats, vegetation, and drainage patterns. Remaining drill-holes also lead to wildlife entrapment and erosion. Development and construction often deal with vegetation and top soil removal and excavation work. They lead to changes to the soil quality, landscape, and hydrology. The subsequent erosion, siltation, sedimentation and turbidity also disrupt aquatic life. Moreover, an improved infrastructure results in an increase in population and consequently in over-exploitation, pollution, and disrupted habitats. Mining and mineral processing generates waste materials of huge quantities, some of which contain toxic substances. The storage of these wastes in open air facilities endangers birds. The release of toxic wastes, regardless whether intentionally or not, contaminates and damages the ecological system. In addition, mining operations affect the biodiversity by polluting the air, water, and soil. Sulphur dioxide emissions from the combustion of fuels, especially those containing sulfur, are detrimental to flora and fauna through their acidic attributes. Likewise, the releases of nitrogen oxides, mainly from fuel combustion and the use of explosives, induce nutrient deposition and acidification, changing the presence and diversity of species. Toxic substances from acid mine drainage, leachate from mine wastes, and eroded ground contaminate the neighboring grounds and streams, jeopardizing the health and survival of flora and fauna. In the post-closure stage, abandoned mines, especially those not properly restored, are often the source of pollutants such as leaked acid waste, which damages natural water bodies and lives. Geophysical changes such as ground subsidence also change the hydrology and contamination (Tripathi and Singh, 2010), affecting landscapes, vegetation, and the characteristics of the ecosystem.

Based on the aforementioned possible causes and effects, this assessment framework looks at the impacts of a mining project on biodiversity from the viewpoint of habitat loss and habitat degradation due to pollution.

(3.1) Habitat loss

Habitat loss is classified as terrestrial and aquatic habitat losses, each of which is reflected from the position of direct losses and indirect losses.

(3.2) Pollution

Pollution means air, water, and soil pollution. Air pollution is determined by direct releases of air pollutants. Water pollution is assessed from planned discharge and undesired release of water pollutants. A planned discharge is the direct disposal of pollutants into natural water bodies. An undesired release is specified by three types of polluted water discharge by an accident or unexpected event, including mine drainage, seepage from a waste storage facility, and failure of the waste storage facility. Soil pollution is the outcome of an indirect release of pollutants through dust deposition.

(4) Negative impacts on shareholders

The negative impacts of a mining project on shareholders can be represented by a business failure, which refers to business that "*ceased operations following assignment or bankruptcy; ceased doing business with a loss to creditors after such actions as foreclosure or attachments; voluntarily withdrew leaving unpaid debt; were involved in court action such as reorganization [...]; or voluntarily compromised with creditors*" (Newton, 2009, p. 21). According to Gaughan (2011, pp. 437–438), the most common factors contributing to a business failure include economic factors (e.g. industry weakness and insufficient profits), financial factors (e.g. high operating expenses and lacking capital), and weaknesses in managerial experience (e.g. lack of business knowledge, line experience and managerial experience). Other less common causes include neglect, fraud, disaster, and strategy factors. Based on this information, this assessment framework determines the negative impacts of a mining project on shareholders from the project's return on investment.

Figure 4.2 summarizes the components of the negative impacts of a mining project as well as their arrangement into a hierarchy.

4.3 Risk assessment: An approach for mining project assessment

4.3.1 Risk concept

As previously mentioned, the assessment of a mining project needs to be carried out at an early stage of the project. It means that there will be no actual development other than planning and preparation when the project is being assessed. Missing data can make it difficult to assess the impacts of the project. Thus, the concept of risk is applied to estimate the extent of impacts instead of actual measurements, unless it is stated otherwise. This implies that the impacts included in this assessment cover not only the anticipated outcome of company actions but also the risks that might occur intentionally and unintentionally from a company's activities.

The term 'impact' used in this study refers to the level of anticipated impacts or the level of intentional or unintentional risks derived from a risk assessment process. The level of risk or risk rating is obtained from the combination of likelihood and consequence in a risk matrix. A 3x3 matrix is used in this assessment because it is a preliminary assessment containing a lot of inaccurate and uncertain data.

Likelihood refers to the chance of something happening. It is determined from the causal factors of the event that leads to the respective impacts. Consequence means the outcome of the event that affects objectives. It is determined from the factors influencing the extent of the outcome. Both likelihood and consequence have three different levels. Likelihood is classified into low, medium, and high. Low likelihood indicates that the specified event is least likely to occur according to the conditions of its causal factors. Medium likelihood and high likelihood show that the specified event is likely and most likely to occur, respectively.

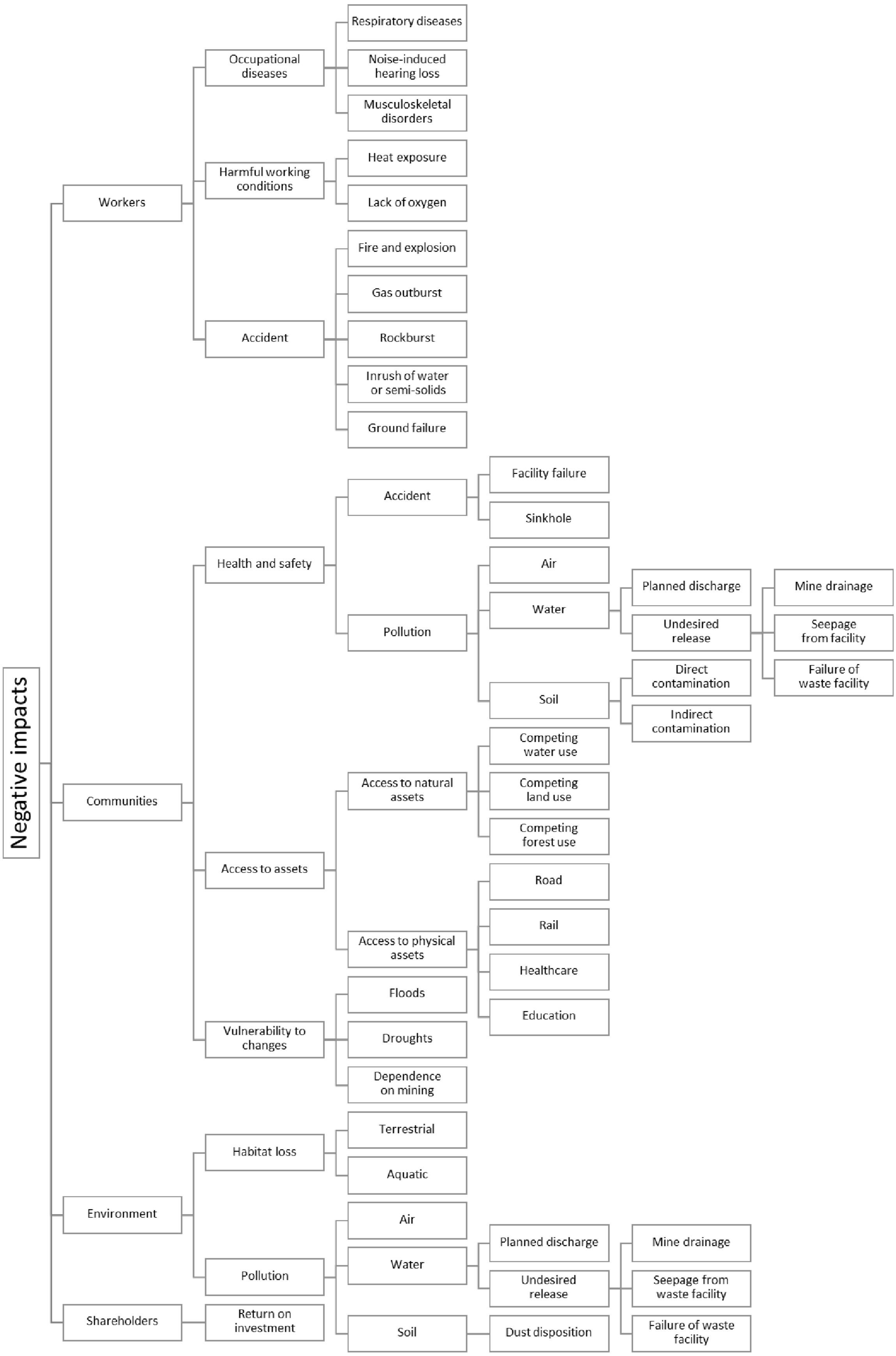


Figure 4.2: Components and structure of negative impacts

Similarly, consequence is classified as low, medium, and high. Low consequence means the effect of the concerned event could be slightly harmful to the target objects (human or environment). Medium and high consequences indicate that the effect of the concerned event could be harmful and very harmful to the target objects, respectively. The risk rating is classified into three levels as shown in the matrix in Table 4.2. Insignificant or low risk refers to the risk that does not require any actions or requires only minor actions to improve the likelihood or consequence conditions. Medium risk is the risk that might be tolerable in a short term but efforts to mitigate the risk are required. High risk represents the level of risk that requires mitigation measures before activities start. If the mitigation of risk is not achievable, the activities should not be carried out.

Table 4.2: Risk rating matrix

Likelihood	Consequence		
	Slightly harmful (score=1)	Harmful (score=2)	Very harmful (score=3)
Least likely (score=1)	Low risk (1)	Low risk (2)	Medium risk (3)
Likely (score=2)	Low risk (2)	Medium risk (4)	High risk (6)
Most likely (score=3)	Medium risk (3)	High risk (6)	High risk (9)

4.3.2 Source of data

The data required for this assessment framework covers different aspects. Technical data are obtained from geological reports and design and planning documents submitted to the governmental agency with the mining lease application. These documents are primarily checked by the governmental agency and should cover information about the project's geological characteristics, mining and processing methods, as well as the design of facilities and the selection of machinery. More than technical information, demographic and environmental data required for the assessment are generally available in the environmental impact assessment report submitted to the governmental agency during the mining lease application process. Additional data from statistical databases or literature might also be required for the assessment.

4.3.3 Data aggregation

The impact level of a mining project is determined by the necessity-impacts matrix. The level of the necessity of a mining project development and that of the negative impacts of the project are obtained from the aggregation of the ratings of the components in the hierarchy. Although the use of a hierarchical structure to determine the ratings of the necessity of project development and the negative impacts is inspired by the Analytic Hierarchy Process (AHP), the criteria for aggregating data within the hierarchy are different from those of the AHP. The ratings of components in the hierarchy are aggregated based on the following rules:

1. The ratings of the components are aggregated from the bottom to the top of the hierarchy.
2. Components, sub-components, and their determinants always have three levels: low, medium, and high, unless stated otherwise. Each of these levels is assigned a score for calculation. A low level scores one, a medium level scores two, and a high level scores three. Unrelated issues are rated as irrelevant which has a zero score.
3. Components of the same rank in the hierarchy are aggregated by the weighted sum method, which is one of the most simple and widely known methods in multi-criteria decision analysis (Pomerol and Barba-Romero, 2000, p. 75). They are considered as equally important, and an equal weight (with the total weight of one) is applied to the aggregation unless stated otherwise. The components with irrelevant rating must also be included in the calculation unless stated otherwise.
4. If there is more than one assessment for the same component in the hierarchy, the ratings are aggregated by a weighted sum method using an equal weight. The total weight is equal to one.
5. Ratings are aggregated by a geometric mean if their effects are dependent on one another or can be synchronized. This is because geometric aggregation can reflect the non-compensability characteristic of different components (OECD, 2008, p. 103). The rating of the aggregated value derived from the geometric mean method is classified as low if it is 1-<1.67, as medium if it is 1.67-<2.33, and as high if it is 2.33-3. These values are obtained by equally dividing the range of the aggregated value, which varies between 1 and 3, into three groups. When irrelevant values are involved, the rating of 0 or irrelevant is applied.
6. Ratings are aggregated by the weighted sum method if their effects are not dependent on one another. An equal weight is applied to the aggregation unless stated otherwise. This is based on the basic condition of a linear additive aggregation technique that components must be preferentially independent and on the full compensability characteristic (i.e., different components can compensate one another equally) (OECD,

2008, pp. 102–103). The components with an irrelevant rating must also be included in the calculation unless stated otherwise. The rating of the aggregated value derived from the weighted sum method, which varies between 1 and 3. The range is divided into three groups using the middle values between the full score, i.e., 1.5 and 2.5, as cut-offs. The range of >0-1 is added to the low range to cover the influence of irrelevant rating. The rating of irrelevant is assigned if the sum is zero. The rating is classified as low if the sum is >0-<1.5, as medium if the sum is 1.5-<2.5, and as high if the sum is 2.5-3.

4.4 Criteria for rating the components in the assessment hierarchy

This section describes the criteria for rating the components in the assessment hierarchy.

4.4.1 Necessity of mining project development

Service provision and positive contributions are the guiding components for assessing the necessity of a mining project development from the viewpoint of a governmental agency. The ratings of both components are aggregated by a weighted sum. However, both components are weighed unequally because of their different levels of importance. Service provision is considered more important because it has a nationwide impact as the main function of mining is to supply a country with natural resources. Positive contributions, on the other hand, are not major functions of mining and can also be created by other socio-economic activities. Moreover, their impacts on the country is relatively low in the case of Thailand owing to the characteristics of domestic mineral resources and socio-economic structure. The contributions at local level are likely to be more prominent. As a result, the weights of 67% and 33% are assigned to service provision and positive contributions, respectively. The share indicates that service provision is twice as important as the positive contributions.

4.4.1.1 Service provision

Service provision is determined by three components: the contribution to domestic demand, the contribution to end use, and resource availability. The ratings of these three components are aggregated by a weighted sum using an equal weight of 0.33.

(1) Contribution to domestic demand

The contribution to domestic demand shows the potential that a new project has with regard to domestic demand of the resource to be exploited. The contribution is measured by the relative amount of additional supply from the new project to the demand not satisfied by domestic products. This would provide a substitution to the products produced by the new project. Accordingly, the contribution is calculated from the ratio of the annual production rate of the project at full capacity to the current total non-domestic input of the same material, which is the initial demand before the development of the new project. The ratio of >0-≤1 indicates that there is room for additional supplies from the new project which could help satisfy the domestic demand not yet met by domestic production. The classification divides this range equally, so the values of 33% and 67% are used as the cut-offs. For the upper value of the high contribution, a 20%-tolerance is added to the value of 1 to provide room for growth and changes, so a value of 1.20 is used as the upper cut-off. Producing more than what domestic markets require could result in exports or, in a worse case, inundated markets, which makes it a low contribution. According to the aforementioned explanation, the rating criteria are summarized as follows: the ratio of <0.33 or >1.20 is rated as a low contribution, 0.33-0.67 as a medium contribution, and >0.67-1.20 as a high contribution.

(2) Contribution to end use

The contribution to end use indicates the potential that the additional supply from the new project has for the country. From a Buddhist perspective, it is more efficient if a society exploits local resources for local consumption. This implies that an increase of mineral products from the project to serve domestic use is preferable to an increase which would serve export purposes. If a new project is intended to contribute to the export sector, its development priority should be lower than that of a project supplying materials to the domestic market. This perspective appears similar to resource nationalism, which is perceived as an "*anti-competitive behaviour designed to restrict the international supply of a natural resource*" (UK Government, 2014, p. 2). Besides, one might argue that mining is a globalized business. Mineral imports could be a more economically and environmentally efficient way to acquire raw materials, and mineral exports also generate incomes and other benefits to the producing country. Moreover, larger projects could allow higher economic and environmental efficiencies through an economy of scale and better technology (Gajigo and Dhaou, 2015). It is true that a larger-scale production might be safer and more efficient and people often gain from the extraction of minerals. However, the distributional impacts cannot be neglected, especially the negative social and environmental impacts on local communities. Additionally, the locals might be indifferent to the profits of capital transformation (Langston et al., 2015). Giving a preference to the exploitation of local resources for local consumption does not mean to emphasize resource nationalism or to prohibit mineral exports. The national border is used to practically identify the spatial boundary of ‘being local’. Besides, exporting is given a lower priority because it involves a trade-off between public well-being and the benefits of specific stakeholders. This is an issue government agencies should consider in order to reduce an unequal distributional effect.

The contribution to end use is determined by two indicators – status of current end use and increase in mineral export. The ratings of both indicators are aggregated by a weighted sum using and equal weight of 0.5.

(2.1) Status of current end use

The status of the current end use is the share of the specific material in the current economic system. It is determined by the current percentage of mineral exports in the total output of the same resource. A high proportion of exports implies that supplies for domestic demands will reach a limit and that additional production is likely to serve exporting purposes. This means that additional production creates low contribution to domestic uses. A share of >0.50 is considered as export-oriented since the majority (more than half) of the minerals produced in the country is exported, so it is rated as the least preferable state in terms of contribution (low contribution). The share of 0.25-0.50 indicates a significant share of mineral exports (more than a quarter) and is rated as a moderately preferable state (medium contribution). The share of <0.25 (or less than a quarter) is used to represent a small share of exports and is rated as the most preferable state (high contribution).

(2.2) Increase in mineral exports

An increase in mineral exports shows the potential change in the rate of exports triggered by the new project. It is calculated from the expected increase in mineral exports caused by the new project (at full production) divided by the total amount of current exports of the mineral (before the new project has begun). The higher the increase in exports is, the less preferable the change is.

The increase in mineral exports should also take the value of natural resources into account. Wagner and Wellmer (2009) explain that the utilization value of resources can be ranked in a four-level hierarchy. At the top of the hierarchy are energy minerals, which are the most important group in terms of needs and limitation of supply (as exploitation causes an immediate depletion). At second place are natural ores and pure scrap that can be recycled to the same quality. At third place are bulk raw materials which are abundant in the earth crust or nature such as construction materials and minerals from seawater. At bottom place are wastes and residues available as secondary resources. Wagner and Wellmer point out that using lower-order materials is preferable to using higher-order materials and substituting higher-order materials with lower-order resources is desirable. The idea of ranking the utilization values is part of the assessment. The minerals are classified into two groups: non-bulk and bulk minerals. The increase in mineral exports is rated differently for both mineral groups. Their cut-offs are identified with reference to the mineral export data between 2011 and 2015 provided by the Department of Primary Industries and Mines (2016b) that the yearly changes of the total mineral export (by weight) during the period vary in a range of ±15% and their average is estimated at 2.7%. They are also tested with the recent statistical data of different minerals to ensure the values are valid.

- Non-bulk minerals are minerals directly depleted with exploitation such as fossil fuels or whose resources are limited such as metallic and non-metallic minerals. The values of 5% and 15% are used as cut-offs. An increase in mineral exports of >15% is interpreted as a high increase of the export share and is rated as a low contribution to end use, 5-15% as a medium contribution, and <5% as a high contribution.
- Bulk minerals are minerals abundant in the earth crust or nature such as construction materials. This group of minerals is more desirable for utilization. This quality is expressed by a higher tolerance limit compared to that of the non-bulk minerals. The criteria are adjusted by increasing the values of the non-bulk criteria by 5%. The increase of >20% is interpreted as a low increase in export shares (a low contribution to end use), 10-20% as a medium contribution, and <10% as a high contribution.

(3) Resource availability

Resource availability rates the degree to which the exploitation by a new mining project affects the unexploited mineral resources. It is calculated from the ratio of undeveloped resources in the new mining project to available domestic resources of the same mineral. A greater ratio means the project development will cause a significant decrease in the unexploited resource, which is negative with regards to the necessity of the project development. The idea of ranking mineral utilization values correlates with the different criteria for depletion rates. The ratios of the total resources in the mines to the total resources in mineral deposits in 2007, which are the latest data provided by the Department of Primary Industries and Mines (2007), are used as guiding values for setting the criteria. As well as the contribution to end use, minerals are classified into non-bulk and bulk mineral groups, to which different rating criteria are applied.

- For non-bulk minerals, the ratios of the total resources in the mine to the total resources in mineral deposits ranged between 2.1×10^{-7} and 0.63 and their average was 0.22. Based on this information, the ratios of 0.01 and 0.1 are chosen as the cut-off values. The ratio of >0.1 is defined as a low availability, 0.01-0.1 as a medium availability, and <0.01 as a high availability.
- For bulk minerals, the ratios of total resources in the mine to the total resources in mineral deposits ranged between 8.5×10^{-4} and 0.02 and their average was 8.6×10^{-3}. Based on this information, the ratios of 0.0005 and 0.005 are chosen as the cut-off values. The ratio of >0.005 is defined as a low availability, 0.0005-0.005 as a medium availability, and <0.0005 as a high availability.

4.4.1.2 Positive contributions of a mining project to society

The positive contributions to society are the contributions to workers, communities, and the environment. The ratings of these three components are aggregated by a weighted sum using an equal weight of 0.33.

(1) Positive contributions to workers

The rate of employment determines the positive contributions of a mining project to workers. However, employment can take on different forms, affecting not only the responsibilities but also the extent of benefits. Full-time employees generally obtain more benefits than temporary or part-time employees. According to the Sustainable Reporting Guidelines issued by the Global Reporting Initiative (2013c, p. 147 and 158), the basic benefits for full-time workers include mostly life insurance, health care, disability and invalidity coverage, parental leave, retirement provision, and, in some cases, stock ownership. The same document also includes training and education issues in its performance indicator list. It emphasizes life-long learning and skill improvement opportunities for workers and suggests a measurement in terms of average training hours per employee per time unit, e.g. year. This is another form of positive contribution of a mining project to workers. As a consequence, the calculation of the rate of employment includes the employment type and employment period. A different weighting is applied to different employment types since the benefits obtained by full-time and part-time employees differ, especially in terms of payment rates, fringe benefits, and skills training opportunities. Temporary and part-time employees as well as contractors are designated half of the weight of full-time employees, i.e. the weight of 0.5 is applied to the former group and 1 to the latter. Together, the period of employment is added to the calculation to include the difference in employment at different stages in a project lifetime. The rate of employment is calculated from the following equation:

$$\text{number of employment} = \sum ((\text{number of full-time employee}_i \times 1 \times \text{time period in year}_i) + (\text{number of non-full-time employee}_i \times 0.5 \times \text{time period in year}_i))$$

where, i = activity in each stage

The calculated result is rated as low employment (thus a low positive contribution to workers) for the value of <1,250 employee-year, medium for 1,250-5,000 employee-year, and high for >5,000 employee-year. These values represent the average amount of 50 and 200 employees per year, which is the maximum number of employees in small and medium sized enterprises according to the Ministerial Regulations under the Small and Medium Enterprises Promotion Act B.E.2543 (Ministry of Industry, 2002), in 25 years, which is the maximum term of a mining lease. It is noted that this assessment only takes the number of direct employees into account. The number of indirectly employed is not included because it is difficult to identify the scope and make predictions at an early stage of a project development.

(2) Positive contributions to communities

The positive contributions of a mining project to communities are defined by six components, namely access to water, forests, financial resources, infrastructure, healthcare, and education. The ratings of these six components are aggregated by a weighted sum using an equal weight of 0.17.

Access to water. Access to water ascertains how likely it is that people have access to water and the consequences of this access. The ratings of likelihood and consequence are aggregated by a geometric mean.

- *Likelihood.* Improved water storage capacities enhance the likelihood of people's access to water. The volume of one million cubic meters, which is the threshold for defining a small reservoir according to the Standard for Small Reservoirs and Dams implemented by the Department of Local Administration (n.d., p. 3), is used for setting the criteria. An additional storage capacity of <0.5 million cubic meters is rated as a slight increase (thus a low likelihood), 0.5-1 million cubic meters as a moderate increase, and >1 million cubic meters as a large increase. A zero increase in water storage capacity or/and affected people is assessed as irrelevant.
- *Consequence.* Consequence is determined by the number of people able to benefit from the additional storage capacity. This number is set in reference to the size of the Local Administration Organization in Thailand that the minimum population of a Sub-district Administration Organization is 2,000 (Royal Thai Government Gazette, 2009a, sec. 41) and that of a District Municipality is 10,000 (Royal Thai Government Gazette, 2009b, sec. 10). Thus, the population of >0-<2,000 is rated as a low consequence, 2,000-10,000 as a medium consequence, and >10,000 as a high consequence.

Access to forests. Access to forests ascertains how likely it is that people have access to forests and the consequences of this access. The ratings of likelihood and consequence are aggregated by a geometric mean.

- *Likelihood.* An increase in forest areas determines the likelihood that people have access to forests. It is calculated by measuring the difference between remaining or reforested areas after a mine is closed and the areas deforested during the development and operation stage. The area is rated in reference to the criteria for defining a forest and for granting a mining lease. 0.5 hectares, which is the threshold area for forests (FAO Forestry Department, 2010), and 48 hectares, which is the maximum area per mining lease according to Thailand's Mineral Act (Royal Thai Government Gazette, 1967, sec. 44), are used as the cut-offs. Based on these values, the difference of ≤0 is considered as irrelevant, >0-<0.5 hectares as a low likelihood of better access to forests, 0.5-48.0 hectares as a medium likelihood, and >48.0 hectares as a high likelihood.
- *Consequence.* Consequence is determined by the number of people who will benefit from a larger forest. The cut-offs are based on the population size of the Local Administration Organization as mentioned previously. A population size of >0-<2,000 is rated as a low consequence, 2,000-10,000 as a medium consequence, and >10,000 as a high consequence.

Access to financial resources. Access to financial resources is determined by the likelihood and the consequence of access. The ratings of likelihood and consequence are aggregated by a geometric mean.

- *Likelihood.* Likelihood is ascertained by comparing the share of expected annual payments (mineral royalty) allocated to local administration offices (at full production) with the revenue of the local administration before a mine opens. A value of 10% is used to mark that the share is significant, and a value of 50%, which indicates the majority of the share, is used to indicate that the share becomes substantial. The ratio of <10% is rated as low allocation (thus a low likelihood), 10-50% as medium allocation, and >50% as high allocation.
- *Consequence.* Consequence shows the number of people who will benefit from the allocation. Although the money is allocated to different administration units of different sizes, the main impact lies in the local administration office(s) where the mining project is located. Accordingly, this area is used for the calculation. The cut-offs are again based on the population size of the Local Administration Organization. A population of >0-<2,000 is rated as a low consequence, 2,000-10,000 as a medium consequence, and >10,000 as a high consequence. It is noted that the smallest administration unit to which the royalty is allocated is at the sub-district level, so the affected area will always be populated.

Access to infrastructure. A mining project is often involved in developing public infrastructure. In this assessment, the contribution to a community's access to infrastructure is evaluated by the number of people expected to benefit from transport networks (i.e. road, rail, and port), water and energy distribution systems, and waste disposal facilities. The number of people expected to benefit from each type of facility is rated and aggregated by a weighted sum using an equal weight of 0.33. The cut-offs are based on the previously mentioned population size of the Local Administration Organization. A population of >0-<2,000 is rated as a low impact, 2,000-10,000 as a medium impact, and >10,000 as a high impact. If no construction is involved, this component is rated as irrelevant.

Access to healthcare. The contribution of a mining project to healthcare access is determined by a change in the ratio of population to medical staff. The change is rated as irrelevant when it is negative. The criteria are based on information on the density of medical staff calculated from statistical data obtained from the Ministry of Public Health

(2016a, pp. 98–111). The density of medical staff (including doctors, dentists, and professional nurses) per 10,000 population in 2013 was 28.9. An increase of 1 staff within a sub-district, of which the population in 2011 was 8,848 (Department of Agricultural Extension, 2011; Department of Public Administration, 2016), is equivalent to an increase of 1.1 per 10,000 inhabitants and means a change of 3.9%. A value of 5% marks the lower changes in the criteria, and its triple marks the higher changes as a small increase in staff number can result in a significant change in the ratio. A positive change of <5% is rated as a low contribution, 5-15% as a medium contribution, and >15% as a high contribution.

Access to education. The change in the ratio of student to teacher ascertains how a mine contributes to access to education. The change is rated as irrelevant when it is negative. The criteria are based on the ratio of teacher to student on a basic educational level, which was 1:18 in the years 2012-2013 (or 5.6 teachers per 100 students) (Ministry of Education, 2014, p. 19), and the average number of students in basic education level per district, which was 1,547, calculated from the number of students and the number of sub-districts in Thailand (Department of Agricultural Extension, 2011; Ministry of Education, 2014). An increase of 1 teacher within a sub-district would result in a change in ratio by 1.2%. The value of 5% marks the lower change in the criteria, and its double marks the higher changes because a significant change in the ratio requires a large increase in staff number. A positive change of <5% is rated as a low contribution, 5-10% as a medium contribution, and >10% as a high contribution. Primary education is used for calculating the ratio because schools are located in the communities whereas vocational training institutions and colleges or universities are excluded because they are usually in bigger cities and have students from further afield.

(3) Positive contributions to the environment

An increase in habitats ascertain the positive contributions of a mining project to the environment. Its extent is determined by the likelihood and the consequence of habitat gain, of which the ratings are aggregated using a geometric mean.

Likelihood. An increase in forested areas defines the likelihood. The increase is calculated by comparing the difference between the reforested area that remains after a mine has been closed and the area deforested during the development and operation. The cut-offs are based on the criteria for defining a forest and for granting a mining lease as already outlined. Thus, a difference of ≤0 is considered as irrelevant, >0-<0.5 hectares as a low likelihood of habitat gain, 0.5-48.0 hectares as a medium likelihood, and >48.0 hectares as a high likelihood.

Consequence. Consequence measures the number of species in the project's neighborhood. This is a site-specific characteristic indicating how sensitive to change the area is. It is determined in correspondence with the level of species vulnerability and the number of species found in the area according to the following equation:

$$\text{presence of species} = \sum (\text{score of vulnerability level}_i \times \text{rating of adjusted number of species found in the area}_i) / \sum (\text{score of vulnerability level}_i)$$

where, i is the level of vulnerability. The calculated value of the presence of species is classified into three levels. A value of >0-1 is rated as a low consequence, >1-2 as a medium consequence, and >2-3 as a high consequence.

Species vulnerability. The vulnerability of a species is classified by its rarity in 3 groups, based on the IUCN Red List classification (International Union for Conservation of Nature and Natural Resources, 2012). The group of un-threatened species has a low vulnerability level (i.e. the IUCN's 'least concern' and 'not evaluated' categories) and is assigned a score of 1. The medium vulnerability level refers to the group of potentially endangered species (i.e. the IUCN's 'near threatened' or 'data deficient' categories) and is assigned a score of 2. The high vulnerability level defines the group of endangered species (i.e. the IUCN's 'critically endangered', 'endangered', and 'vulnerable' categories) and is assigned a score of 3.

Number of species found in the area. The abundance and the number of species found in the study area determines the population density. The number of species found in the area is rated as a low, medium, or high quantity. The number of times a species is present in a certain proportion every time a survey is carried out defines species abundance. A proportion of 1-33% is rated as a low abundance, 34-66% as a medium abundance, and 67-100% as a high abundance. The actual number of species found in the area is adjusted by multiplying the value with species abundance weight according to the following equation:

$$\text{number of species found in the area} = \sum (\text{actual number of species found in the area}_i \times \text{weight of species abundance}_i)$$

where, i is the level of species abundance. Low abundance has a weight of 0.33, medium abundance 0.67, and high abundance 1.

The number of species is rated based on the results of the biodiversity survey in some natural and reserved areas in Thailand such as those studied by the Forestry Research Center (2013), Netbood (2009), Sanchaisuriya et al. (2012), Seangtharathip et al. (2015), and Suyana (2009). They showed that the number of animals, insects, plants, and microbial species found in the observation areas ranged from around 150 to more than 1,000 species, and the number of threatened species found ranged from 0 species in natural areas to more than 30 in high biodiversity areas. For threatened and potentially threatened species, the number of species of 1-5 species is classified as a low amount, 5-10 as a medium amount, and >10 as a high amount. For non-threatened species, the range of 1-100 species is classified as a low amount, 101-500 as a medium amount, and >500 as a high amount.

Appendix A contains a summary of the components and rating criteria for assessing the necessity of a mining project development.

4.4.2 Negative impacts of mining projects

Four impact groups show the negative impacts of a mining project: impacts on workers, communities, environment, and shareholders. The impact ratings of these four components are aggregated by a weighted sum using an equal weight of 0.25.

4.4.2.1 Negative impacts on workers

The negative impacts of a mining project on workers comprise those from occupational diseases, harmful working conditions, and accidents. The impact ratings of these three components are aggregated by a weighted sum using an equal weight of 0.33.

(1) Occupational diseases

The impacts of occupational diseases are viewed from respiratory diseases, noise-induced hearing loss, and musculoskeletal disorders. The impact ratings of these three components are aggregated by a weighted sum using an equal weight of 0.33.

(1.1) Respiratory diseases

The impact of respiratory diseases on workers is determined by the likelihood and the consequence of exposure to respiratory hazards. The ratings of both components are aggregated by a geometric mean. If there is more than one group of risks, all ratings must be aggregated by a weighted sum using the adjusted number of workers (in the consequence) as weights.

Likelihood. The common respiratory diseases miners suffer from are pneumoconiosis, silicosis, asbestosis, emphysema and chronic bronchitis, tuberculosis, and lung cancer. These diseases are related to the following key hazards: respirable dust, silica dust, coal dust, diesel exhaust, asbestos, radon progeny, and some heavy metals (Australian Safety and Compensation Council, 2006; Donoghue, 2004a; Nelson, 2013; Ross, 2004). The likelihood of a worker's exposure to these hazards is determined by the release of respiratory hazards calculated from the data in the technical plans. The emission is determined relative to the exposure limit of the respective substances, represented by an 8-hour time weighted average (TWA) exposure limit, at an air volume of 0.5 million cubic meters per day, which is the approximate amount of air required for 20 diesel construction trucks assuming the truck requires 1,100 cubic meters of air per hour (Poulin, 2006). The proportion in percentage of <50% is rated as a low likelihood, 50-100% as a medium likelihood, and >100% as a high likelihood.

Consequence. The number of workers exposed to the respiratory hazards and the exposure period determine the consequence. The number of exposed workers is counted in men per day and is adjusted to the degree of exposure. The workers operating regularly in the proximity of hazards are given a weight of 1. Those who are often and occasionally present in the proximity of hazards are assigned a weight of 0.67 and 0.33, respectively. Workers who rarely or never get close to hazards are given a weight of 0. According to Thailand's mineral statistics provided by the Department of Primary Industries and Mines (2016c), the employment per mine (by mineral type) from 2011 to 2015 was between 4 and 278. The overall employment per mine during the same period ranged from 21 to 25, with an average of 23. Based on this information, the values 20 and 150 are selected as cut-off values. The sum of the adjusted number of workers valuing <20 (full-time) men per day is rated as a low consequence, 20-150 men per day as a medium consequence, and >150 men per day as a high consequence.

(1.2) Noise-induced hearing loss

Noise is generated from various processes and activities in mining and mineral processing and can be classified into different types, including continuous noise (narrow- and wide-band), impact or impulsive noise, repetitive impact noise, and intermittent noise (Tripathy, 2007). Of these, continuous and impulse noises are commonly considered as the main causes of hearing losses. Continuous noise is defined as "*noise with negligibly small fluctuations of level within the period of observation*" (U.S. Department of Health and Human Services, 1998, p. xii) such as that from extraction equipment, power packs and transmission systems, and conveyors. Impulsive noise refers to noise "*characterized by a sharp rise and rapid decay in sound levels and is less than 1 second in duration*" (U.S. Department of Health and Human Services, 1998, p. xiv) such as that from drilling and blasting. Noise-induced hearing loss refers to a decrease in hearing ability caused by exposure to noise. Suter (1998) mentions that the loss generally occurrs gradually over years, depending on the level of noise, exposure duration, and individual conditions. Immediate and permanent damage could also happen, but this is comparatively rare and is sometimes considered an injury rather than an occupational illness. He also points out that the effects of continuous noise on a worker's hearing ability are evident, and the degree of impairment varies by the degree of exposure. Likewise, the effects of impulse noise on hearing ability depend mainly on the level and the duration of an impulse as well as background noise. The impairment could be severe, particularly when the noise is generated with a high frequency.

With this information, the negative impacts of noise-induced hearing loss on workers are ascertained based on the level of noise at source and the extent of exposure (likelihood) and the number of workers that are exposed to noise (consequence). The ratings of both components are aggregated by a geometric mean. If there is more than one group of exposure, all ratings must be aggregated by a weighted sum using the adjusted number of workers as weights.

The level of noise is identified by noise intensity zones, which is the area in which the noise sources (machinery and activity) are located, and classified into low, medium, and high noise intensity zones. The values 80 and 90 are selected as cut-off values. They are based on the tolerable noise exposure duration (Johnson et al., 2001, p. 95) and the permissible exposure limit, which is 90 dBA (Occupational Safety and Health Administration, 2013). An intensity of <80 dBA is defined as low intensity, 80-90 dBA as medium intensity, and >90 dBA as high intensity.

The extent of exposure is determined by how frequently the workers are in the exposure area. It is classified into four levels, to which different ratings are assigned. No exposure (rating = 0) means rare presence in the proximity of noise hazards. Low exposure (rating = 1) refers to short or non-frequent presence in high noise intensity zones or occasional presence in medium noise intensity zones. Medium exposure (rating = 2) is defined as a frequent presence of workers in medium noise intensity zones or occasional presence in high noise intensity zones. High exposure (rating = 3) refers to a regular presence of workers in medium noise intensity zones or a frequent to regular presence in high noise intensity zones.

The number of workers exposed to noise for each exposure level must be identified. The impact level of noise-induced hearing loss is determined by a weighted sum of the ratings of different levels of exposure groups using the number of exposed workers in each group as weights. It is worth noting that the effects of using personal protective equipment (PPE) are not taken into account because its effectiveness in actual practice might be unreliable or highly variable from the expected level of protection (Jensen, 2014, p. 214; U.S. Congress, 1985, p. 179).

(1.3) Musculoskeletal disorders

Musculoskeletal disorders refer to a variety of minor physical disabilities due to injuries or pains in muscles, bones, joints, ligaments, nerves, tendons, and limb-, neck-, and back-supporting structures. It can be caused by different factors (Industry & Investment NSW and Queensland Department of Mines and Energy, 2009). In mining, vibration from the use of tools and machinery is among the crucial causes of these disabilities. The main types of vibration which cause occupational diseases in mining are hand-arm vibrations and whole body vibrations (Chaudhary et al., 2015; Foster and Burgess, n.d.; Kunimatsu and Pathak, 2012).

Hand-arm vibrations occur through the vibration of tools transmitted via hands into the arm and body. It is associated with the use of hand-held vibrating tools and can cause workers to experience different symptoms such as tingling in their fingers, numbness, loss of muscle control, and finger blanching (Nyantumbu et al., 2006; Weir, 2005). If exposure continues, more serious symptoms might arise and wider areas might become affected.

Whole-body vibrations are vibrations transmitted via feet and buttock to the body. This type of vibrations is associated with the driving or riding on non-smooth surfaces or the standing on large, fixed machines that vibrate (Health and Safety Executive, 2005). Mine workers experience whole-body vibrations when operating mobile equipment such as loaders, trucks, and scrapers (Donoghue, 2004a). Exposure to whole-body vibrations can cause health effects such as lower-back pain and damage to the spine (Chaudhary et al., 2015; Hulshof and Veldhuijzen van Zanten, 1987).

The impact level of vibrations is determined by the likelihood and the consequence of the exposure to hand-arm and whole-body vibrations. The ratings of likelihood and consequence are aggregated by a geometric mean. Since different groups of workers are subject to different levels of impacts, the overall impact level is calculated by a weighted sum of their impact ratings using the number of workers in each group as weights.

Likelihood. The likelihood of exposure is determined by the level of vibration. The rating criteria are specified in two sets. For hand-held vibration tools, a vibration of <2.5 m/s^2 is classified as a low likelihood, 2.5-5.0 m/s^2 as a medium likelihood, and >5.0 m/s^2 as a high likelihood. For mobile equipment, a vibration of <0.50 m/s^2 is classified as a low likelihood, 0.50-1.15 m/s^2 as a medium likelihood, and >1.15 m/s^2 as a high likelihood. These values are based on the daily exposure action values and the daily exposure limit values imposed by the European Union (2002).

Consequence. Consequence is determined by the number of workers that might be exposed to vibration. The criteria are based on the employment statistics as explained earlier. The number of exposed workers of <20 (full-time) men per day is rated as a low consequence, 20-150 men per day as a medium consequence, and >150 men per day as a high consequence.

(2) Harmful working conditions

Harmful working conditions are a part of occupational health hazards but are examined separately because their effects are mostly shown in the short term. In this assessment, the impacts of harmful working conditions on workers are determined by an exposure to heat and a lack of oxygen. The impact ratings of both conditions are aggregated by a weighted sum using an equal weight of 0.5.

(2.1) Exposure to heat

Prolonged exposure to high temperatures can induce the human body to overheat and show symptoms of heat illnesses. The impact level of heat on a worker's health is determined by the likelihood and the consequence of exposure. The ratings of both components are aggregated by a geometric mean. Since different groups of worker are subject to different levels of impacts, the overall impact level is calculated by averaging the impact levels of all worker groups using the number of workers in each group as weights.

Likelihood. The effect of heat depends on internal and external heat stress as well as exposure duration. It varies from temporary symptoms such as heat cramps and heat exhaustion due to insufficient blood circulation and subsequent dehydration to serious heat disorders such as heat strokes, which can be fatal or cause permanent disability if not treated appropriately (Donoghue, 2004b, 2000; Hunt, 2011, pp. 80–88). The severity, however, depends on the factors determining the heat balance of a human body, comprising air temperature, radiant temperature, humidity, air movement (wind speed), clothing, and the metabolic heat from human physical activity (Parsons, 2003). In mining, heat illnesses result from exposure to sunlight in surface mining, and rising rock temperatures from the geothermal gradient along with the depth and auto-compression of the air column in underground mining (Donoghue, 2004a; Hunt et al., 2013). Three factors determine the likelihood of exposure, namely, apparent temperature, metabolic rate, and ventilation. The ratings of these indicators are aggregated by a geometric mean.

- *Apparent temperature.* Apparent temperature is represented by a heat index, the perceived temperature under the effect of humidity. Heat index can be identified by the average working (air) temperature and relative humidity according to Table 4.3. The U.S. Occupational Safety and Health Administration (n.d.) classifies a heat index into four levels: lower (<32.78°C), moderate (32.8-39.4°C), high (39.4-46.1°C), and very high to extreme (>46.1°C). Following the same criteria, the likelihood is rated as low for the heat index of <32.8°C, medium for 32.8-39.4°C, and high for >39.4°C
- *Metabolic rate.* Metabolic rate indicates the extent to which heat is generated by a human body when it carries out activities. The metabolic rate is determined by the type of activity and is classified into three groups. The activities that cause a body to produce heat of ≤130 watts per unit surface area of human body in square meter (W/m^2) are identified as light work (low likelihood), >130-200 W/m^2 as moderate work (medium likelihood), and >200 W/m^2 as heavy work (high likelihood) (International Standard Organization, 2004).

Table 4.3: Heat index and assessment rating

Relative humidity	Environmental temperature (°C)										
	26.7	27.8	28.9	30.0	31.1	32.2	33.3	34.4	35.6	36.7	37.8
	Apparent temperature or heat index (°C)										
40%	26.7	27.2	28.3	29.4	31.1	32.8	34.4	36.1	38.3	40.6	42.8
45%	26.7	27.8	28.9	30.6	31.7	33.9	35.6	37.8	40.0	42.8	45.6
50%	27.2	28.3	29.4	31.1	32.8	35.0	37.2	39.4	42.2	45.0	47.8
55%	27.2	28.9	30.0	31.7	33.9	36.1	38.3	41.1	44.2	47.2	51.1
60%	27.8	28.9	31.1	32.8	35.0	37.8	40.6	43.3	46.7	50.6	53.9
65%	27.8	29.4	31.7	33.9	36.7	39.4	42.2	45.6	49.4	53.3	57.8
70%	28.3	30.0	32.2	35.0	37.8	40.6	44.2	48.3	52.2	56.7	
75%	28.9	30.0	33.3	36.1	39.4	42.8	46.7	51.1	55.6		
80%	28.9	31.7	34.4	37.8	41.1	45.0	49.4	53.9			
85%	29.4	32.2	35.6	38.9	43.3	47.2	52.2	57.2			
90%	30.0	32.8	36.7	40.6	45.0	50.0	55.0				
95%	30.0	33.9	37.8	42.2	47.2	52.8					
100%	30.6	35.0	39.4	44.4	49.4	55.6					

Remarks: white=low consequence, yellow=medium consequence, orange=high consequence
Source: adapted from National Oceanic and Atmospheric Administration (n.d.) and Occupational Safety and Health Administration (n.d.)

- *Ventilation.* Ventilation helps the body surface to cool down. It is represented by air velocity at the working area. The criteria are based on the subjective response to air motion, which considers the velocity of <0.05 meters per second (m/s) as stagnation and >0.51 as constant awareness of air motion (Bradshaw, 2006, p. 21). An air velocity of >0.5 m/s is defined as a preferable condition for cooling the body down and is rated as a low likelihood; a wind speed of 0.1-0.5 m/s is rated as a medium likelihood, and <0.1 m/s as a high likelihood.

Consequence. Consequence is determined by the number of workers exposed to heat. The criteria are based on the aforementioned employment statistics. The number of exposed workers of <20 men per day is rated as a low consequence, 20-150 men per day as a medium consequence, and >150 men per day as a high consequence.

(2.2) Lack of oxygen

Lack of oxygen can cause asphyxiation and is a severe problem in mining, especially in underground mines where operations take place in a confined space. The impact level of a lack of oxygen is only of interest in an underground mining and is determined by the likelihood and the consequence of exposure. The ratings of both components are aggregated by a geometric mean.

Likelihood. A lack of oxygen can result from the presence of asphyxiant gases, mainly nitrogen, carbon dioxide, methane, and carbon monoxide. These gases are released from either material strata or human activities such as blasting, use of diesel engines, and fires and explosions (Vutukuri and Lama, 1986, pp. 87–91). Mine ventilation is an important factor regarding gas exposure because it helps dilute the gases. Based on this information, the likelihood of a low-oxygen condition is assessed from the presence of asphyxiant gases and ventilation condition. The ratings of both components are aggregated by a geometric mean.

- *Presence of asphyxiant gases.* The presence of asphyxiant gases is assessed from the capacity of key gas-releasing sources, including strata gases, explosives, and diesel engines. The ratings of these three factors are aggregated by a weighted sum using an equal weight of 0.33.
    - *Strata gases.* The geological conditions determine the presence of gases in the deposit. The criteria are defined with reference to the gas contents for identifying gas outburst potentials, which are mostly related to coal mining. Lama and Saghafi (2002) stipulate a gas content of >8 cubic meters methane per tonne (m^3/t) as one of the criteria for outburst prone characteristics of coal seams and suggest that the gas content should be lower if carbon dioxide is the main seam gas. The United Nations (2010, pp. 14–15) mentions that the content of methane in coal seams typically ranges from trace levels to about 30 m^3/t and that coal seams are considered gassy if the gas content is equal to or higher than 10 m^3/t. A study of Shubina and Lukyanov (2016) follows the Instruction on Mine Air Content Monitoring, Gas Content Determination and Mine Classification based on Methane and Carbon Dioxide Concentrations and classifies four levels of gas contents in coal deposits, ranging from normal to very gassy types, using the gas content of ≤5, >5-10, >10-15, and >15 m^3/t. Referring to the above information, the values of 4 and 8 m^3/t are selected as the cut-offs. The average gas content in the deposit of >0-<4 m^3/t is rated as a low presence of gases and a low likelihood, 4-8 m^3/t as a medium likelihood, and >8 m^3/t as a high likelihood. Zero presence of gas is considered as irrelevant.
    - *Explosives.* The uses of explosives of <1,500 kilograms per day is classified as a low presence of gases and a low likelihood, 1,500-15,000 kilograms per day as a medium likelihood, and >15,000 kilograms per day as a high likelihood. Zero use of explosive is considered irrelevant. These values are defined in relation to the approximate amounts of explosives required for producing 1,000 and 10,000 tonnes of stone per day. The amounts of explosives are calculated

from the powder factor of 3.9, which is the average of the powder factor range applied in underground mining (0.9-7.0 kilograms per cubic meters (Jimeno et al., 1995, p. 188)).

- *Diesel engines.* The release of gases from diesel engines is represented by the total power required by the engines, which corresponds to fuel consumption and emissions. The power requirement of <2,500 kilowatts is rated as a low presence of gas and a low likelihood, 2,500-13,500 kilowatts as a medium likelihood, and >13,500 kilowatts as a high likelihood. Zero use of diesel engines is considered as irrelevant. These values are defined in relation to the approximate power of the diesel fleet in the underground mines producing ores at 1,000 and 5,000 tonnes per day. The power of the diesel fleet is estimated from the average power per tonne of daily production (2.7 kilowatts per tonne per day) calculated from the information of twenty underground mines in Righettini and Mousset-Jones (2004, p. 434) and Mafuta et al. (2014, p. 574).

- *Ventilation conditions.* The air velocity in the working area represents the ventilation conditions. The criteria are set with reference to the mandatory limits on air velocity in the U.S. as mentioned by McPherson (2008, pp. 9–13). An air velocity of 1-4 meters per second (m/s) is determined as a preferable condition for gas ventilation and is rated as a low likelihood. A wind speed of 0.3-1 or >4 m/s is rated as a medium likelihood, and <0.3 m/s as a high likelihood.

Consequence. The number of workers exposed to the gases represents the consequence of the exposure to asphyxiant gases. The criteria are based on the aforementioned employment statistics. The number of exposed workers of <20 men per day is rated as a low consequence, 20-150 men per day as a medium consequence, and >150 men per day as a high consequence.

(3) Accidents

Accidents in mining can be fatal. The International Labour Organization's Safety and Health in Mines Recommendation (1995b) specifies the critical forms of safety hazards in mining, including mine fires and explosions, gas outbursts, rockbursts, an inrush of water or semi-solids, rockfall, susceptibility of areas to seismic movements, hazards related to work carried out near dangerous openings or under particularly difficult geological circumstances, and loss of ventilation. Based on this information, the negative impacts of five forms of accidents, namely, fires and explosions, gas outbursts, rockbursts, an inrush of water or semi-solids, and ground failure are assessed. The impact ratings of these five components are aggregated by a weighted sum using an equal weight of 0.2. A loss of ventilation is not included as it has already been dealt with in the section on harmful working conditions.

(3.1) Fire and explosions

Fire and explosions occur when fuel, oxygen, and ignition sources are on site (Health and Safety Executive, n.d.). The impact level of fire and explosions is determined by the likelihood and the consequence of the occurrence. The ratings of both components are aggregated by a geometric mean. Since there can be more than one fuel source, each one must be assessed, and their rating must be aggregated by a weighted sum using an equal weight.

Likelihood. The likelihood of a fire and an explosion occurring is determined by the presence of fuel, oxygen, and ignition source. Their ratings are aggregated by a weighted sum using an equal weight of 0.33.

- *Presence of fuel.* Fuels are solid, fluid, or gaseous flammable materials such as wood, plastic, paper, diesel, oil and grease, coal (and coal dust), explosives, solvents, and strata gases. The quantity and sensitivity of the fuel are taken into account. The ratings of both indicators are aggregated by a geometric mean.
    - *Quantity.* The criteria on quantity are defined by the fact that storage cells are generally used for storing up to 2,500 kilograms or liters of dangerous substances (European Commission, 2006, p. 178) and that the maximum quantity of flammable liquids stored in cabinets should not exceed 250 liters (Health and Safety Executive, n.d.). Because diesel is the main kind of flammable liquid in mining, its density (840 kilograms per cubic meters) is used for converting volume to weight. The approximate values of 200 and 2,000 are selected as the cut-off values. The fuel quantity of <200 kilograms is identified as a low quantity (thus a low likelihood), 200-2,000 kilograms as a medium quantity, and more than 2,000 kilograms as a high quantity.
    - *Sensitivity.* Fuel sensitivity is rated into three groups based on the classification of flammable liquids imposed by the U.S. Occupational Safety and Health Administration (2016). Low sensitivity indicates a lesser likelihood of fire and explosion occurrences. Materials that must be preheated to create ignition (flash

point ≥93°C) are classified as a low sensitivity. Materials that require moderate heating before it is ignited (flash point ≥23-<60°C) are classified as a medium sensitivity. Materials that can be ignited under almost all normal temperature conditions, very flammable gases, or very volatile flammable liquids (flash point <23°C) are classified as a high sensitivity.

- *Presence of oxidizing agent.* Oxidizing agents enhance combustion. The presence of oxidizing agents implies an increased likelihood of fires and explosions. In mining operations, air is the most common form of oxidizing agent available throughout the site. Ventilation can draw air to the operating area, increasing the available oxygen for combustion. Other sources of oxidizing agents are ammonium nitrate, bottled oxygen, compressed air, and chemicals labeled as oxidizing agents. These agents can cause fire and explosions if fuel and ignition sources are present. Therefore, the presence of oxidizing agents is assessed from two indicators: air velocity and the distance of oxidizing agents to flammable substances. Their ratings are aggregated by a weighted sum using an equal weight of 0.5.
    - *Air velocity.* The criteria are based on experimental data from a case study in which the spread of flames was unaffected by an air velocity of less than 0.4 meters per second (m/s) (Drysdale, 2011, chap. 7) and data from a case study in which an air velocity of 1.5 m/s was used to distinguish the fuel-controlled and ventilation-controlled fires in confined channels (Wang and Chateil, 2007). An air velocity of <0.4 m/s is rated as a low presence of oxidizing agents (thus a low likelihood), 0.4-1.5 m/s as a medium presence, and >1.5 m/s as a high presence.
    - *Distance to flammable substance.* The criteria are based on the UK good practice that the outdoor storage of flammable liquids should have a minimum separation distance of 2.0-7.5 meters, depending on the storage quantity, and the Netherlands' practice that the outdoor storage of hazardous materials should be located more than 10 meters from the storage of flammable materials (European Commission, 2006, pp. 179–180). Also, a minimum separating distance of 100 meters for explosive storage specified by Thailand's law is taken into account (Royal Thai Government Gazette, 2008). The cut-off values of 10 and 100 meters are selected for the criteria. The presence of oxidizing agents within a distance of >100 meters from flammable substances is considered as a long distance and is rated as a low presence of an oxidizing agent (thus a low

likelihood), 10-100 meters as a medium presence, and <10 meters as a high presence.

- *Presence of ignition source.* An ignition source is heat from friction, electrical sparking, air compression, detonation, open flame and hot work, and spontaneous combustion. The distance from the flammable agents ascertains the presence of ignition sources. Since the state of flammable substances influences the potential for reaching the ignition source, the distance criteria are specified in two sets. For gaseous flammable substances, a distance of >200 meters is considered a long distance and is rated as a low presence of ignition source, 100-200 meters as a medium presence, and <100 meters as a high presence. For solid and liquid flammable substances, a distance of >100 meters is rated as a low presence of ignition source, 10-100 meters as a medium presence, and <10 meters as a high presence. These values are based on the aforementioned information about the separating distances. However, the values for flammable gaseous substances are adjusted by using the upper cut-off for solid and liquid flammable substances as the lower cut-off and use the double value for the upper cut-off.

Consequence. The consequence of a fire and explosion occurrence depends on the number of workers that might be affected by such an incident. The criteria are based on the employment statistics. The presence of <20 workers per shift is rated as a low consequence, 20-150 workers per shift as a medium consequence, and >150 workers per shift as a high consequence.

(3.2) Gas outburst

A gas outburst is a violent, sudden release of a large amount of gases and associated rocks. The impact level of gas outburst depends on the likelihood and the consequence of an outburst incident. The ratings of both components are aggregated by a geometric mean. This topic is only considered in case of an underground mining. For other types of mining, it is identified as irrelevant.

Likelihood. An outburst occurrence is influenced by different factors. The important ones include gas content in the deposit, geological structure, rock mass properties, and stress conditions (Lama and Saghafi, 2002; Xue et al., 2010, pp. 33–34). Based on this information, the likelihood of an outburst occurrence is determined by three conditions: the presence of gases, the geological structures, and the mining depth. The ratings of these three components are aggregated by a geometric mean.

- *Presence of gases.* The presence of gases in a mineral deposit depends on geological conditions. Gases associated with gas outbursts in mines are methane formed during coalification and/or by microbial processes and carbon dioxide from, for example, magmatic activity (Lama and Saghafi, 2002). Thus, the gas content in the deposit is the reason for the presence of gases. The information used for specifying the criteria is described in the topic 'lack of oxygen' and the same cut-offs are applied. The average gas content in a deposit of >0-<4 m^3/t is rated as a low presence of gases and a low likelihood, 4-8 m^3/t as a medium likelihood, and >8 m^3/t as a high likelihood. Zero presence of gases is considered as irrelevant.
- *Geological structures.* Geological structures indicate the presence of discontinuities, which affect the quality of rock mass, especially overall strength and permeability. Three groups classify the structures based on the classification in Rock Structure Rating (Wickham, G. E. Tiedemann and Skinner, 1972). Massive to slightly folded or faulted structures indicate low discontinuities and less potential for gas migration, so they are rated as a low likelihood. Moderately folded or faulted structures are rated as a medium likelihood, and intensely folded or faulted as a high likelihood.
- *Mining depth.* Mining depth influences the in-situ stress condition. Stress which increases with depth and production tends to enhance the intensity and frequency of outbursts. Since the relationship of depth and in-situ stress is linear (Brown and Hoek, 1978), the cut-off values are selected in reference to the minimum depth of gas outbursts in different countries. The average minimum depth of approximately 250 meters, calculated from the data of 16 countries given by Lama and Saghafi (2002), is used as the lower cut-off. The upper cut-off refers to the depth of deep mining in China and the Ivory Coast according to Kouame et al. (2017), which is 700 meters in average. A depth of <250 meters is considered to bear low stress and is rated as a low likelihood, 250-700 meters as a medium likelihood, and >700 meters as a high likelihood.

Consequence. The consequence of occurrence is determined by the number of workers that might be affected by a gas outburst incident. The criteria are based on the employment statistics as explained earlier. The presence of <20 workers per shift is rated as a low consequence, 20-150 workers per shift as a medium consequence, and >150 workers per shift as a high consequence.

(3.3) Rockburst

Rockburst is an instantaneous failure of rock due to over-stressing. The deformation occurs when the rock elastic limit is exceeded, resulting in an immediate release of accumulated energy. According to the Ontario's Occupational Health and Safety Act, rockburst is defined as an event that causes equipment damage or a material displacement of more than five tonnes (Government of Ontario, 2016, sec. 21). The impact level of rockburst is determined by the likelihood and the consequence of a rockburst occurrence. The ratings of both components are aggregated by a geometric mean.

Likelihood. The main factors determining the potential for a rockburst are rock properties and stress concentrated in the surrounding rock. Stress states caused by excavation can also influence the possibility of rockburst (Faling and Xiaoming, 1993). The likelihood of rockburst is determined by rock properties and stress in the surrounding rock. The ratings of both conditions are aggregated by a geometric mean.

- *Rock properties.* The rock properties are assessed from the type of rock and from discontinuities. The ratings of both conditions are aggregated by a geometric mean.
    - *Type of rock.* The type of rock indicates the ability of rock to accumulate energy before being deformed. Hard, strayed, and brittle rock is more likely to burst than rock with plastic or visco-elastic qualities. Some mechanical properties can be used in a composite form to identify the rockburst potential such as brittleness coefficient, linear elastic energy, burst energy coefficient, strain energy storage coefficient, and rock quality designation (RQD) of rock mass. In this assessment, the brittleness coefficient is used to determine the likelihood of rockburst. It is calculated from the ratio of the uniaxial compressive strength to tensile strength. The criteria used by Cai (2016) and Li et al. (2006) are applied. A ratio of >26.7 is classified as a low likelihood, 14.5-26.7 as a medium likelihood, and <14.5 as a high likelihood.
    - *Discontinuities.* Discontinuities in a rock mass often contribute to the burst prone conditions. They are classified in relation to the geological structures in three groups based on the classification in Rock Structure Rating (Wickham, G. E. Tiedemann and Skinner, 1972). Massive to slightly folded or faulted structures indicate low discontinuities and are rated as a low likelihood. Moderately folded or faulted structures are rated as a medium likelihood, and intensely folded or faulted as a high likelihood.

- *Stress in surrounding rock.* Stress in the surrounding rock influences the tendency and severity of rockburst through accumulated energy. Four indicators ascertain stress: mining depth, opening design, extraction ratio, and advance rate. The ratings of these four indicators are aggregated by a geometric mean.
  - *Mining depth.* Depth influences the magnitude of stress. Increasing depth results in higher in-situ stress. The same cut-off values as those in the gas outburst subject are applied here. A depth of <250 meters is rated as low stress (thus a low likelihood), 250-700 meters as medium stress, and >700 meters as high stress.
  - *Opening design.* The opening design determines the distribution of stress in the surrounding rock. The ratio between width and height of the opening determines the effect of the opening design on the stress level. The criteria are based on the information that a (opening's) height-to-width ratio less than one is likely to contribute to high stress concentrations around single openings in a unidirectional stress field (Caudle and Clark, 1955, p. 23). An opening's width-to-height ratio of <0.5 is rated as low stress (thus a low likelihood), 0.5-1.0 as medium stress, and >1.0 as high stress.
  - *Extraction ratio.* The extraction ratio affects the magnitude of stress in the surrounding rock. High extraction ratio tends to increase stress concentrations on the rock. The criteria are based on the relation of the area extraction ratio and the pillar stress concentration factor and the information that the change in the pillar stress concentration factor is small if the area extraction ratio is less than 75% (Brady and Brown, 1985, p. 323). A ratio of <38% is less likely to increase stress concentrations to a critical level and is rated as a low likelihood, 38-75% as a medium likelihood, and >75% as a high likelihood.
  - *Advance rate.* A fast advance rate can increase the tendency of rockburst because it does not allow fracture zones to occur gradually and to reach a stress equilibrium (Blake and Hedley, 2003, p. 8). The rating criteria are defined by the advance rates of 12 drilling-and-blasting cases (4-9 meters per day) and those of mechanical excavation cases during 1980-2004 (8-45 meters per day) (Stewart et al., 2006). The criteria are divided into two sets. For mining with drilling and blasting, an advance rate of <7 meters per day is rated as low stress (thus a low likelihood), 7-15 meters per day as medium stress, and >15 meters per day as high stress. For mining with other production techniques, an advance

rate of <10 meters per day is rated as low stress, 10-30 meters per day as medium stress, and >30 meters per day as high stress.

Consequence. The consequence of an occurrence is determined by the number of workers that might be affected by a rockburst incident. The criteria are based on the employment statistics. The presence of <20 workers per shift is rated as a low consequence, 20-150 workers per shift as a medium consequence, and >150 workers per shift as a high consequence.

(3.4) Inrush of water or semi-solids

Mine inundation is defined by three categories, which are event controlled inundation, accidental inundation, and spontaneous inundation (Vutukuri and Singh, 1995). Event controlled and accidental inundations are mining induced, whereas spontaneous inundations are natural. The impact level of water or semi-solid inrush is determined by the likelihood and the consequence of the incident. The ratings of both components are aggregated by a geometric mean. This assessment only applies to underground mining.

Likelihood. A review of past mine inundation cases by Singh (1986) showed that an event-controlled inundation resulted from subsidence patterns, hydrogeology of the rock mass, geological structures and discontinuities, and major and periodic roof falls in the goaf. Accidental inundations were caused by contact with water-logged mine excavation, unstable fluidized strata, and natural water bodies as well as unexpected inflows of surface water. Spontaneous inrushes were determined by the presence of a large quantity of water, hydraulic pressures, thickness of the protective barrier, and fracture zones and a state of high stress within the barrier. Therefore, the likelihood of an inrush is studied under two conditions in this assessment, the presence of water or of semi-solids and mass movement potentials. The ratings of both conditions are aggregated by a geometric mean.

- *Presence of water or semi-solids.* Two factors indicate the presence of water or semi-solids: the distance of the mine opening (working area) to adjacent water or semi-solid sources and the capacity of water or semi-solids. The ratings of both conditions are aggregated by a geometric mean.
    - *Distance to the adjacent water or semi-solid sources.* According to Singh (1986), the areas where water can be or is accumulated includes:
        - Adjacent (surface or underground) mines or abandoned mines, in which water bodies might be present

    - Adjacent working areas, in which water can accumulate or in which hydraulic or paste backfilling operations take place
    - Adjacent impoundments
    - Connecting channels to natural water bodies (i.e. aquifers, groundwater, and flooding water)
    - Boreholes connecting to water strata
    - Shafts, raises, or wells connecting to water strata.

  The reference is a distance of 50 meters, which is recommended a safe distance by the Australian Work Health and Safety Act (NSW Department of Trade and Investment, 2015). A distance of >100 meters, which is the minimum distance multiplied by a factor of two, is rated as a low likelihood of inundation, 50-100 meters as a medium likelihood, and <50 meters as a high likelihood. If no adjacent water or semi-solid source is present, the rating irrelevant is applied.

  - *Water or semi-solid capacity.* The water pumping capacity in one- and three-day periods, assuming a pumping rate of 100 liters per second (based on the pump information in McCarthy and Dorricott, 2011, p. 777) are taken as reference. The capacity of water or semi-solids of <9,000 cubic meters is rated as a low likelihood, 9,000-27,000 cubic meters as a medium likelihood, and >27,000 cubic meters as a high likelihood.

- *Mass movement potentials.* Mass movement potentials are determined by two indicators: geological structures (discontinuities) and effect of ground subsidence. The impact ratings of both indicators are aggregated by a geometric mean.
  - *Discontinuities.* Discontinuities indicate the possibilities that water or semi-solids move through open channels. They are grouped into three categories in relation to geological structures based on the classification in the Rock Structure Rating (Wickham, G. E. Tiedemann and Skinner, 1972). Massive to slightly folded or faulted structures indicate low discontinuities and are rated as a low likelihood of mass movement. Moderately folded or faulted structures are rated as a medium likelihood, and intensely folded or faulted structures as a high likelihood.
  - *Effect of ground subsidence.* Mining-induced subsidence can result in fissure. Singh (1992) suggested that the horizontal strain should be kept below 5×10^{-3} (or within the range of $5\text{-}10 \times 10^{-3}$) to avoid severe damage to aquifer and surface water. The cut-offs are based on these values. The horizontal strain of $>0\text{-}<5 \times 10^{-3}$

is rated as a low likelihood, $5x10^{-3}$-$10x10^{-3}$ as a medium likelihood, and >$10x10^{-3}$ as a high likelihood.

Consequence. The consequence of occurrence is determined by the number of workers that might be affected by an inrush incident. The employment statistics are used as a basis for identifying criteria. The presence of <20 workers per shift is rated as a low consequence, 20-150 workers per shift as a medium consequence, and >150 workers per shift as a high consequence.

(3.5) Ground failure

Ground failure is one of the major hazards in mining causing injuries and deaths (National Research Council and Institute of Medicine, 2007, p. 156). It can occur both in surface and underground mining, but the forms of failure are different. The impact level of ground failure is determined by the likelihood and the consequence of failure. The ratings of both components are aggregated by a geometric mean.

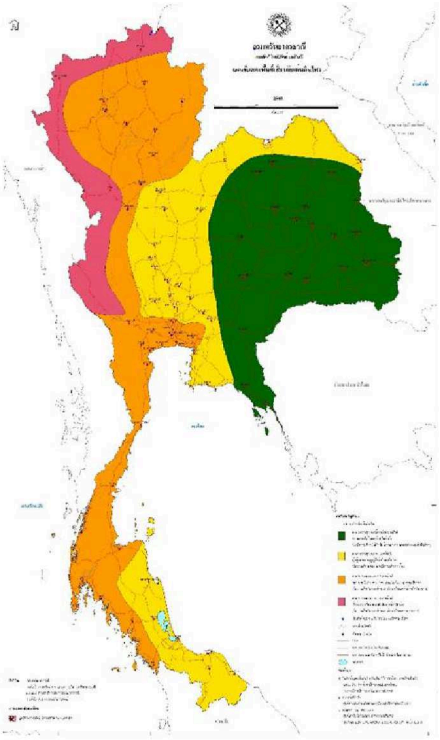
Likelihood. In surface mining, ground failure is closely related to slope stability. Different types of slope failure can occur such as plane shear failure, step path failure, simple wedge failure, step wedge, topping failure, and rotational shear failure (Call and Savely, 1990, p. 872). The failure in surface mining is influenced by factors such as rock properties, structure, stress, and moisture conditions. In underground mining, an uncontrolled fall of ground means a material displacement of more than 50 tonnes (Government of Ontario, 2016, sec. 21). Many factors influence the fall of ground. The important factors are geological structures, rock stress (both in-situ and the effect from excavation), engineering properties of the ground, and water factors (Iannacchione et al., 2006; Safe Work Australia, 2011). Based on this information, two groups of conditions, including geological characteristics and design parameters, determine the likelihood of occurrences. The impact ratings of both conditions are aggregated by a geometric mean.

- *Geological characteristics.* Three factors rate geological characteristics: rock strength, geological structures, and water factors. The ratings of these conditions are aggregated by a geometric mean.
    - *Rock strength.* Uniaxial compressive strength is the ability of rock to withstand loads. Higher strength contributes to lesser potential for failure. The criteria are defined according to the strength classification in Bieniawski (1992). A strength of >100 MPa is considered a high strength

and is rated as a low likelihood, 25-100 MPa as a medium likelihood, and <25 MPa as a high likelihood.

  - *Geological structures.* The geological structures indicate the presence of discontinuities, which affect the quality of the rock mass, especially its overall strength. The structures are divided into three categories based on the classification in Rock Structure Rating (Wickham, G. E. Tiedemann and Skinner, 1972). Massive to slightly folded or faulted structures indicate high strength and less potential for failure, so they are rated as a low likelihood. Moderately folded or faulted structures are rated as a medium likelihood, and intensely folded or faulted as a high likelihood.
  - *Water factors.* Water influences the stability of rock slopes because it determines water pressure in rock and rock discontinuities. The criteria for water factors are based on the general conditions of groundwater of the Rock Mass Rating System (Bieniawski, 1989). Dry to damp conditions indicate a low water content and is less likely to contribute to slope failure, so it is rated as a low likelihood. A wet condition is identified as a medium likelihood, and a dripping to flowing condition is classified as a high likelihood.

- *Design parameters.* Two sets of criteria define the design parameters.
  - *Surface mining.* Safety and seismic conditions determine the design parameters. The ratings of both indicators are aggregated by a geometric mean.
    - *Factor of safety.* The factor of safety reflects the structural capacity to bear loads beyond the expected value. A higher safety factor affirms the reliability of a design. The acceptable value of the safety factor for a pit slope design is 1.3 or more (Read and Stacey, 2009; Steffen et al., 2006). Accordingly, a safety factor of >1.3 is considered a more reliable design and is rated as a low likelihood, 1-1.3 as a medium likelihood, and <1 as a high likelihood.
    - *Seismic condition.* The seismic condition influences mine stability. It is rated by the earthquake risk zone in Thailand classified by the Department of Mineral Resources (DMR) shown in Figure 4.3. Zone 0-1 is classified as a low intensity zone (thus a low likelihood), zone 2A as a medium intensity zone, and zone 2B as a high intensity zone.



Legends:
■ Zone 0: Modified Mercalli Intensity Scale less than III
(very low risk to engineering structure)
■ Zone 1: Modified Mercalli Intensity Scale III-V
(low risk to engineering structure)
■ Zone 2A: Modified Mercalli Intensity Scale V-VII
(low to moderate risk to engineering structure)
■ Zone 2B: Modified Mercalli Intensity Scale VII-VIII
(moderate risk to engineering structure)

Figure 4.3: Earthquake risk zone in Thailand (Department of Mineral Resources, 2001)

- *Underground mining.* Design parameters are based on the safety factor, the opening design, and the extraction ratio. Their ratings are aggregated by a geometric mean.
  - *Factor of safety.* According to Zipf Jr. (2001), the safety factor typically applied for pillars in main development headings or panels during the production is 2 while a value of 1.1-1.3 is used after retreat and less than 1 is applicable to mining using the caving method. Singh and MacDonald (2001) point out that the acceptable factor of safety applied in the South African mining industry is 1.5-1.6, whereas Maury (1993) indicates that a factor of safety of 3-5 is generally used for a conservative pillar design. The values 1.8 and 3 are selected for the criteria. A safety factor of >3 is considered a more reliable design and is rated as a low likelihood, 1.8-3 as a medium likelihood, and <1.8 as a high likelihood.
  - *Opening design.* The opening design determines the distribution of stress in the surrounding rock. The width to height ratio of the opening design determines its effect on the stress level. The criteria are based on the information that a (opening's) height-to-width ratio less than one is likely to contribute to high stress concentrations

around single openings in a unidirectional stress field (Caudle and Clark, 1955, p. 23). An opening's width-to-height ratio of <0.5 is rated as low stress (thus a low likelihood), 0.5-1.0 as medium stress, and >1.0 as high stress.

- *Extraction ratio.* As mentioned earlier, the extraction ratio is related to the stress in the surrounding rock, and a change in the concentration factor of the pillar stress is small if the area extraction ratio is less than 75% (Brady and Brown, 1985, p. 323). Therefore, a ratio of <38% is less likely to increase stress concentrations to a critical level and is rated as a low likelihood, 38-75% as a medium likelihood, and >75% as a high likelihood.

Consequence. The consequence of ground failure is determined by the number of workers that might be affected by the incident. The employment statistics are used as a basis for the identifying criteria as explained earlier. The presence of <20 workers per shift is rated as a low consequence, 20-150 workers per shift as a medium consequence, and >150 workers per shift as a high consequence.

4.4.2.2 Negative impacts on communities

The negative impacts of a mining project on communities are viewed from the changes in health and safety, access to assets, and vulnerability to external changes. The impact ratings of these three components are aggregated by a weighted sum using an equal weight of 0.33

(1) Health and safety of communities

The negative impacts of a mining project on the health and safety of communities are viewed from the risks of accidents and pollution. The impact ratings of both components are aggregated by a weighted sum using an equal weight of 0.5.

(1.1) Risk of accidents

The accident risk is measured with regards to two issues: the failure of waste storage facilities and sinkholes. The impact ratings of both components are aggregated by a weighted sum using an equal weight of 0.5.

(1.1.1) Failure of waste storage facility

There are two types of waste storage facilities: waste dumps (including leaching heaps) and tailing dams. The impacts of their failure are determined by the likelihood and the consequence of a failure incident. The ratings of both indicators are aggregated by a geometric mean.

Likelihood. The likelihood of failure is determined by the design factors of the storage facility. Seven indicators are considered, which include the type of material, facility height, slope angle, seismic condition, amount of rainfall, foundation condition, and water content in waste. The ratings of these indicators are aggregated by a geometric mean.

- *Type of material.* The type of material is rated according to the following criteria:
    - *Waste dump.* The properties of waste materials especially their particle size and shape affect the strength of the pile through the repose angle and friction angle (Williams, 2000, p. 276). The type of waste materials is classified in terms of material quality. The rating criteria suggested in the waste pile stability rating scheme of Piteau Engineering Ltd. (1991, pp. 67–68) are applied. Strong, durable material with <10% fine particles is identified as high quality waste material less likely to cause failure and is rated as a low likelihood. Material with moderate strength, variable durability, and 10-25% fine particles is classified as moderate quality and is rated as a medium likelihood. Weak material which is subject to slaking or degradation and >25% fine particles is defined as poor material and is rated as a high likelihood.
    - *Tailing dam.* The tailing dam type is determined by its material properties and the method of construction. Dams can be constructed from tailing materials, which can make the construction more economic. However, whether this is achievable depends on the tailing properties and its subsequent weakness to the embankment structure and must be monitored (Vick, 1990). A water retention dam is considered a more stable structure because it is generally constructed in one go, so it is rated as a low likelihood. Downstream- or centerline-type dams are rated as a medium likelihood, and upstream-type dams, which tend to have consolidation problems, are rated as a high likelihood.
- *Facility height.* The height of the waste storage facility is rated by the following criteria:
    - *Waste dump.* The height of a waste dump influences the facility's stability through material weight. The rating criteria suggested in the waste pile stability rating scheme of Piteau Engineering Ltd. (1991, pp. 67–68) are

  applied. A height of <50 meters is considered low and less likely to cause failure, so it is rated as a low likelihood, a height of 50-100 meters is rated as a medium likelihood and >100 meters as a high likelihood.

  - *Tailing dam.* The height of a tailing dam influences the dam stability through material weight. The height of dams classified as large by the International Commission on Large Dam (ICOLD) is 15 meters and 10-15 meters in the presence of extreme design parameters (Tanchev, 2014, p. 123). Tanchev (2014, p. 123) suggests the classification of dams into low, medium, high, and particularly high using the height ranges of ≤30, 30-80, 80-150, and >150 meters, respectively. This assessment follows the lower values of the ICOLD definition. A dam height of <10 meters is classified as low and is rated as a low likelihood. A height of 10-30 meters is rated as a medium likelihood and >30 meters as a high likelihood.

- *Slope angle.* The rating criteria for a slope angle are specified in two sets as follows:
  - *Waste dump.* The slope angle affects the shear strength of waste piles through the friction angle and erosion. Flat dump slopes show a low contribution to failure. The rating criteria suggested in the waste pile stability rating scheme of Piteau Engineering Ltd. (1991, pp. 67–68) are applied. A dump slope of <26° is rated as a low likelihood, 26-35° as a medium likelihood, and >35° as a high likelihood.
  - *Tailing dam.* The slope angle of the tailing embankment influences stability through its relation to the repose angle. A tailing dam slope varies from 1:1.5 to 1:5 (vertical: horizontal) (Alsharedah, 2015, p. 34), and the embankment slope of an upstream tailing dam is generally set at 1:3 (Michael P. Davies et al., 2002). On the other hand, the embankment of a small earth (water) dam should not be steeper than 1:2 on the upstream and 1:1.75 on the downstream side (Stephens, 2010, p. 52). Based on this information, an embankment inclination of <20° is considered gentle and is rated as a low likelihood, 20-35° as a medium likelihood, and >35° as a high likelihood.

- *Seismic condition.* The seismic condition is rated by the earthquake risk zone in Thailand classified by the Department of Mineral Resources (DMR) as shown in Figure 4.3. Zone 0-1 is classified as a low intensity zone (thus a low likelihood), zone 2A as a medium intensity zone, and zone 2B as a high intensity zone.

- *Amount of rainfall.* Precipitation rates influence the water amount percolating through the pile and accumulating in the tailing dam. The amount of rainfall is determined by the maximum annual rainfall in a 30-year period. The rating criteria are specified in reference to the 30-year precipitation records of Thailand (1981-2010), of which the average annual rainfall of different regions within the country ranges between 1,230 and 2,720 millimeters per year with a mean of 1,588 millimeters per year (Thailand's Meteorological Department, 2016). A precipitation of ≤1,500 millimeters per year is rated as low rainfall (thus a low likelihood), >1,500-2,000 millimeters per year as medium rainfall, and >2,000 millimeters per year as high rainfall.
- *Foundation conditions.* The foundation is important for the stability of waste facilities because it bears all the loads. Classification, strength, permeability, and consolidation properties of the foundation materials are important foundation qualities which affect the stability of the waste dump (Orman et al., 2011, p. 672). The rating criteria suggested in the waste pile stability rating scheme of Piteau Engineering Ltd. (1991, pp. 67–68) are applied. A competent foundation specified by foundation materials as strong as or stronger than waste rock, which are not subject to adverse pore pressures or adverse geologic structure, is less likely to cause failure and is rated as a low likelihood. An intermediate foundation has foundation materials that are between competent and weak, foundation soils gain strength with consolidation, and adverse pore pressure dissipates controlled loading rate. It is rated as a medium likelihood. A weak foundation is defined as having a limited bearing capacity, soft soils, subject to adverse pore pressures or groundwater, and shear strength sensitive to strain or liquefaction potential. It is rated as a high likelihood.
- *Water content in waste*. The liquid content in tailing and waste materials affects the pressure on the foundation, pore water pressure and phreatic surface, and the amount of liquid that can seep through the embankment and the bottom of the facility. The rating criteria for water contents are specified as follows:
    - *Waste dump.* The criteria for water content are based on data that the moisture content in some coal waste dumps ranges from a few to more than 10% by weight or from 25 to 50% by volume (Szczepanska and Twardowska, 2004, p. 345). A low water content implies less contribution to failure potential, so a content of <10% is rated as a low likelihood, 10-30% as a medium likelihood, and >30% as a high likelihood.

- *Tailing dam.* The liquid content in the tailing dam is measured by the degree the tailing is dewatered. Following the liquid contents in tailing materials mentioned by Davies et al. (2010), the subsequent criteria are applied. Cake or dry tailing (>70% solid) is rated as a low liquid content (thus a low likelihood), thickened or paste (45-70% solid) as a medium liquid content, and slurry or liquid (<40% solid) as a high liquid content.

Consequence. Consequence is determined by the population that might be affected by the incident, especially those in the run-out area. The affected population lives within 0.5 kilometers of the waste dump and one kilometer of the tailing dam. The cut-offs are defined in relation to the population of the smallest administration unit in Thailand - a village. According to the Ministry of Interior (1996), establishing a new village requires a minimum population of 200 for rural areas and 600 for non-rural areas. Thus, a number of affected people of <200 is rated as a low consequence, 200-600 as a medium consequence, and >600 as a high consequence.

(1.1.2) Sinkhole

The impact level of a sinkhole is determined by the likelihood and the consequence of a sinkhole incident.

Likelihood. The likelihood of a sinkhole incident is determined by the presence of sinkhole-related geology or structures and the presence of water. The ratings of these indicators are aggregated by a geometric mean.

- *Presence of sinkhole-related geology or structures.* The occurrence of a sinkhole is related to karst geology, soluble minerals such as salt beds and domes, gypsum, and limestone and other carbonate rock, and also old mines with potential subsidence or collapse. The presence of any of these conditions increases the potential for a sinkhole occurrence, and the rating of high likelihood is assigned. Otherwise, it is considered as irrelevant.
- *Presence of water.* High water presence infers the potential of a sinkhole occurrence. The presence of water is considered from two indicators: amount of rainfall and groundwater velocity. The ratings of both indicators are aggregated by a weighted sum using an equal weight of 0.5.
    - *Amount of rainfall.* The amount of rainfall is determined by the average annual rainfall in a 30-year period. The criteria are based on meteorological

statistics. A precipitation of ≤1,500 millimeters per year is rated as low rainfall (thus a low likelihood), >1,500-2,000 millimeters per year as medium rainfall, and >2,000 millimeters per year as high rainfall

  - *Groundwater velocity.* Groundwater velocity generally ranges between 1 meter per day and 1 meter per year (Waltham, 1994, p. 36). A groundwater velocity of ≤0.1 meters per day is rated as a low velocity (thus a low likelihood), >0.1-1 meters per day as a medium velocity, and >1 meter per day as a high velocity.

- *Consequence.* Consequence is determined by the population that might be affected by the incident. The cut-offs are based on the population size in a village. An affected population of <200 is rated as a low consequence, 200-600 as a medium consequence, and >600 as a high consequence.

(1.2) Pollution

The level of the impacts of pollution on communities is considered from air, water (and sediment), and soil pollution. The impact ratings of these three components are aggregated by a weighted sum using an equal weight of 0.33.

(1.2.1) Air pollution

The impact level of air pollution is determined by the likelihood and the consequence of the exposure to air pollutants. The ratings of both components are aggregated by a geometric mean.

Likelihood. The likelihood of exposure is assessed from two factors: the release of pollutants and pollutant dilution. The ratings of both components are aggregated by a geometric mean.

- *Release of pollutants.* Mines release air pollutants throughout the project lifetime. The major pollutant is fugitive dust. Other important air contaminants include point-source dust, hydrocarbon from combustion, and emissions from mills (Gilbert, 1997, pp. 52–53). The pollutants which are measured are those present in the air quality standards, including particulate matter (PM10), sulfur dioxide, nitrogen dioxide, carbon monoxide, ozone, benzene, and key heavy metals including arsenic, cadmium, lead, and mercury, which are the main chemicals of concern regarding health impacts (European Commission, 2013, p. 9). The emission is determined regarding the air quality standards of the respective substances in an air volume of 1,000 million cubic meters per day, which is a round-up number of the air volume flowing through the cross-section of 100 by 100 square meters at the speed of 1 meter per second. A percentage of <50% is rated as a low likelihood, 50-100% as a medium likelihood, and >100% as a high likelihood.

- *Pollutant dilution.* The dispersion of air pollutants is affected by wind speed and direction, atmospheric turbulence, and atmospheric stability. Wind speed and direction determine the distribution and, as a result, the concentration of pollutants. Canter (1999) explains that increasing wind speed helps transport and dilute the pollutants while a shift in wind direction results in a change in disposition area and thus concentration. It is also described that atmospheric turbulences caused by atmospheric heating and the obstruction of wind by objects can enhance the dispersion of pollutants and reduce their concentrations. Moreover, atmospheric stability, which refers to air movement due to the change of temperature with height, can cause unstable conditions and positively affect pollutant dispersion. Besides dispersion, the concentration of air pollution can also be influenced by wet and dry removal processes such as gravity and washout as well as by atmospheric reactions. Based on this information, three indicators are selected to represent the degree of pollutant transport and dilution, namely, wind speed, topography, and average rain days per year. Their ratings are aggregated by a geometric mean.
    - *Wind speed.* Higher wind speed indicates better dilution and less pollutant concentration, implying lower exposure. The ranges of wind speed are identified according to the Beaufort wind force scale (Hasse, 2003). A wind speed of >5 meters per second (m/s), which is a moderate breeze or faster wind speed, is rated as a low exposure likelihood (good dilution), 1-5 m/s as a medium exposure likelihood, and <1 m/s, which refers to a calm condition, as a high exposure likelihood.
    - *Topography.* Topography affects pollutant dispersion in many ways such as temperature inversion and atmospheric stability as well as wind obstruction. Flat terrain and the topography that facilitates air flow horizontally and vertically imply a better pollutant dispersion and are rated as a low exposure likelihood. The topography that interrupts air flow such as that around buildings is rated as a medium exposure likelihood. Valley topography which is more likely to have temperature inversion and other topography

that tends to have problems with atmospheric stability is rated as a high exposure likelihood.

- *Average rain days per year.* The average number of rain days per year indicates the tendency of natural washout, i.e. pollutants are cleaned out from the atmosphere by precipitation. The rating criteria of the average rain days are defined in relation to the 30-year weather records of Thailand (1981-2010), which show the number of average rain days in different regions between 116 and 178 days per year (Thailand's Meteorological Department, 2013). The average number of rain days of >150 days per year is considered a high washout potential and consequently a low concentration of pollutants. It is therefore rated as a low exposure likelihood. The value of 100-150 days per year is rated as a medium likelihood and <100 days per year as a high likelihood.

Consequence. Consequence is determined by the population size living within 5 kilometers from the source. The cut-offs are based on the population size at sub-district level. A population of <2,000 is rated as a low consequence, 2,000-10,000 as a medium consequence, and >10,000 as a high consequence.

(1.2.2) Water pollution

The impact level of water (and sediment) pollution is considered from two components: planned discharge and undesired release of pollutants. The impact ratings of both components are aggregated by a weighted sum. Both components are assigned different weights to distinguish between anticipated and possible impacts. A weight of 67% is applied to a planned discharge and 33% to an undesired release.

(1.2.2.1) Planned discharge of water pollutants

The impact level of a planned discharge of water pollutants is determined by the likelihood and the consequence of the exposure to pollutants. The ratings of both components are aggregated by a geometric mean.

Likelihood. The likelihood of an exposure to pollutants is assessed from the pollutant discharge and pollution dilution. The impact ratings of both components are aggregated by a geometric mean.

- *Pollutant discharge.* Pollutants to be assessed include arsenic, cadmium, lead, mercury, uranium, and cyanide. The discharge of pollutants is considered in an annual period and regarding the amount calculated from water quality standards at an effluent discharge rate of 1,500 cubic meters per day (or approximately 1 cubic meter per minute), which is comparable to the discharge rate of a stream (Meybeck et al., 1996a). A released amount of <50% of standard concentration is rated as a low exposure likelihood. An amount of 50%-100% of the standard concentration is rated as a medium exposure likelihood. Otherwise, it is rated as a high exposure likelihood.
- *Pollutant dilution.* An important parameter influencing water pollution is the residence time of water in the water body. It determines the extent to which water pollutants are dispersed and reflects the time needed by the aquatic system to recover from the exposure. A short residence time reflects the tendency of pollution dispersion and transport, which assists the recovery of the aquatic system. For surface water, the residence time in streams (lotic system) and shallow lakes (lentic system) tends to be shorter than that in rivers (lotic system) and deep lakes (lentic system). For groundwater, the residence time tends to increase from days to centuries in the following orders: bank filtration, karst, alluvial aquifers, sedimentary aquifers, and deep aquifer. Figure 4.4 shows the residence times in freshwater bodies.

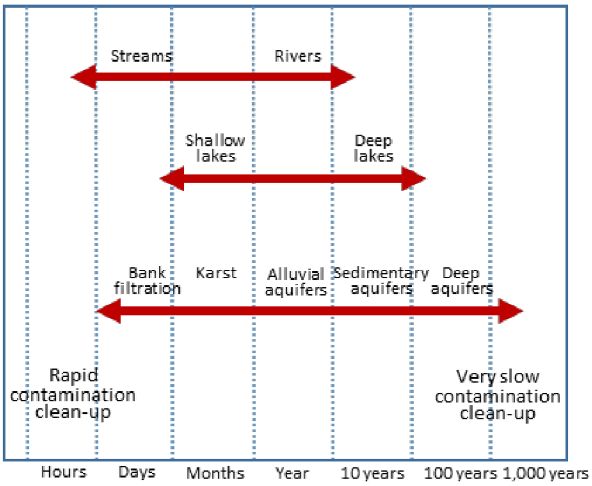


Figure 4.4: Typical water residence times in inland water bodies (Recreated after Meybeck et al., 1996b)

Based on the aforementioned information, the characteristics of water bodies, which influence the residence time of water, are used to represent pollutant dilution. Both surface- and groundwater are included. Streams or shallow lakes (≤30 meters) in case of surface water and bank filtration and karst in case of groundwater are considered to have a low residence time (days and months) and a good dilution potential. They are thus rated as a low likelihood. Rivers and alluvial aquifers, which have longer residence times (i.e. years), are rated as a medium likelihood. Deep lakes (>30 meters), sedimentary aquifers, and deep aquifers, which might require a decade or more to clean-up the pollutants, are rated as a high likelihood.

Consequence. Consequence is determined by the affected population living downstream or around the reservoir. The cut-offs are based on the population size at sub-district level. An affected population size of <2,000 is rated as a low consequence, 2,000-10,000 as a medium consequence, and >10,000 as a high consequence.

(1.2.2.2) Undesired release of water pollutants

The impacts of an undesired release of pollutants on communities are assessed from leaching and contamination from mine drainage, seepage from the waste facility, and failure of the waste facility. The impact ratings of these three components are aggregated by a weighted sum using an equal weight of 0.33.

a) Leaching and contamination from mine drainage

Mining creates a fresh surface area, which can stimulate reaction of ground materials with air and water. This can lead to increasing oxidation rates, acidification (and alkalization), and the dissolution of soluble substances into water. An important problem related to leaching and contamination is acid mine drainage, which refers to acidic water generated from the oxidation of sulfide minerals. Therefore, the impact level of leaching and contamination from mine drainage is considered in relation to acid mine drainage and heavy metal contamination. It is determined by the likelihood and the consequence of human exposure to pollutants. The ratings of both components are aggregated by a geometric mean.

Likelihood. Acid mine drainage can result from various processes such as the entering of groundwater into surface or underground mines, the contact of precipitation with pit faces, the infiltration of precipitation into stockpiles, leach piles, or waste piles, the inflow of precipitation and flood water into the tailing facility, rainfall runoff, migration of surface water and pore fluids of mineral-bearing materials to surface or groundwater aquifers, and the discharge of process water from waste facilities or leaching piles (Lottermoser, 2007, pp. 98–100). The generation of acid mine drainage depends on acid generation potential, determined by the amount of sulfide minerals, acid neutralizing minerals (especially carbonate minerals), and contaminants, surface area of minerals, as well as the presence of water, oxygen, and stimulating bacteria. Other factors influencing the generation of acid mine drainage include the control of the products obtained from oxidation, the physical management of waste facility that will affect the reaction and the migration of acid, and other downstream factors such as the improvement of drainage quality (U.S. Environmental Protection Agency, 1994, p. 6). Another important issue related to leaching and contamination is metal contamination. Metals present in mining area can be dissolved in water, resulting in a high metal content in water, metal deposition in sediment, and bioaccumulation. Acidity or alkalinity (pH) and oxygen content can affect the degree of contamination as acidic condition and low oxygen contents promote the dissolution of metals. Based on the information above, the likelihood of exposure is assessed from two factors: the presence of pollutants and water. The ratings of both factors are aggregated by a geometric mean.

- *Presence of pollutants.* In this subject, pollutants refer to acid-generating substances and heavy metals. The presence of both acid-generating substances (i.e. sulfide minerals) and neutralizing substances (such as carbonate and silicate minerals) are identified as a low contamination likelihood because the acidic condition can be reduced by neutralizing substances. The presence of acid-generating substances without (or with insignificant amounts of) neutralizing substances is determined as a medium contamination likelihood. The presence of both acid-generating substances and heavy metals, regardless of the neutralizing substances, is considered as a high contamination likelihood.
- *Presence of water.* The presence of water reflects the potential of drainage and existing oxygen for oxidation. It is determined by two indicators: amount of rainfall and groundwater velocity. The ratings of both indicators are aggregated by a weighted sum using an equal weight of 0.5.
    - *Amount of rainfall.* The amount of rainfall is determined by the average annual rainfall in a 30-year period. The cut-offs are based on meteorological statistics as described earlier. A precipitation of ≤1,500 millimeters per year is rated as low rainfall (thus a low likelihood), >1,500-2,000 millimeters per year as medium rainfall, and >2,000 millimeters per year as high rainfall.
    - *Groundwater velocity.* The criteria are based on the aforementioned range of groundwater velocity. A groundwater velocity of ≤0.1 meters per day is

rated as a low velocity (thus a low likelihood), >0.1-1 meters per day as a medium velocity, and >1 meter per day as a high velocity.

Consequence. Consequence is determined by the population size within 5 kilometers of the source. The cut-offs are based on the population size at sub-district level. The affected population of <2,000 is rated as a low consequence, 2,000-10,000 as a medium consequence, and >10,000 as a high consequence.

b) Seepage from waste facility

Seepage refers to the movement of water through and around the waste storage facilities (U.S. Environmental Protection Agency, 1994, p. 47). It is an inevitable issue in waste storage facilities, particularly tailing impoundments (Vick, 1990). Without appropriate management, seepage (and leakage) can lead to surface water and groundwater contamination in the short, medium, and long terms. This is because mining wastes, i.e. materials from extraction and processing consisting of overburden, waste rock, low grade ore stockpile, tailing, and heap leach spent ore (Van Zyl et al., 2002), can be generated in very large amounts and might contain substantial amounts of harmful substances such as heavy metals, acidic solution, and cyanide. The impact level of a seepage from a waste storage facility is determined by the likelihood and the consequence of human exposure to pollutants. The ratings of both components are aggregated by a geometric mean.

Likelihood. Likelihood is determined by the seepage potential and the exposure potential. The ratings of both components are aggregated by a geometric mean.

- *Seepage potential.* Seepage can occur in either horizontal or vertical direction. The fluid movement can cause pollutants to migrate and to contaminate natural water bodies. The extent of seepage depends on geological and hydrological factors. In a tailing dam, important factors include the presence of discontinuity and permeability in the foundation, rainfall intensity, soil type, and surface conditions (U.S. Environmental Protection Agency, 1994, p. 47). In a waste dump, important factors affecting the migration of leachate are hydraulic head, the infiltration of rainwater, waste deposition method, characteristics of the unsaturated (vadose) zone especially the thickness, permeability, moisture contents, hydraulic conductivity, and the local hydraulic gradient of the geological unit (Hakami, 2016). The seepage potential in this assessment is determined by five components: capacity of waste storage facility, water content in waste, control measures, presence of water, and waste management after closure. The ratings of these five factors are aggregated by a geometric mean.

- *Capacity of waste storage facility.* The capacity of a waste storage facility determines the extent to which seepage takes place. The surface area of the facility indicates the scale of the seepage. A larger storage area allows more contact between tailing or leachate and the ground. The height of materials stored in the facility influences the pressure on the ground surface of the facility. In the tailing impoundment, increased height means increased weight and hydraulic head. In a waste dump, more height can result in more seepage through the dump due to increasing pore water pressure. A capacity of <0.02 million cubic meters is rated as a low capacity (and a low seepage likelihood), 0.02-0.05 million cubic meters as a medium capacity, and >0.05 million cubic meters as a high capacity. These values are based on the definition that a large tailing storage facility (TSF) has an embankment of 5 meters or higher and a storage capacity of 50 million liters (ML) or more, an embankment of 10 meters or higher and a storage capacity of 20 ML or more, or an embankment of 15 meters or higher, regardless of storage capacity, or the combined storage capacity of all TSFs on the site is greater than 50 ML (Department of Economic Development, Job, Transport and Resources, Victoria, 2016).
- *Water content in waste*s. The criteria for liquid contents in tailing and waste materials are specified as follows:
    - *Waste dump.* The criteria for water contents are based on the information of coal waste dumps. A water content of <10% is rated as a low likelihood, 10-30% as a medium likelihood, and >30% as a high likelihood.
    - *Tailing dam.* Water content in a tailing dam is represented by the degree tailing is dewatered. Following the liquid contents in tailing materials mentioned by Davies et al. (2010), the subsequent criteria are applied. Cake or dry tailing (>70% solid) is rated as a low water content (thus a low likelihood), thickened or paste (45-70% solid) as a medium water content, and slurry or liquid (<40% solid) as a high water content.

- *Control measures.* Control measures regulate seepage loss in a tailing dam and a waste dump. They can be classified into measures to prevent and to capture seepage. Seepage prevention aims at minimizing the permeability at the bottom of the dump by applying low permeability materials as liners such as tailing, clay, and geomembrane, whereas seepage capture aims at intercepting and collecting seepage by, for example, using filter drains and toe drains (Bell, 1999, p. 505). The rating criteria are defined based on this information. The presence of both seepage prevention and capture measures is considered effective to prevent seepage, so it is rated as a low seepage potential (thus a low likelihood). The presence of either prevention or capture measures is rated as a medium potential. If neither measure is implemented, a rating of high potential is applied.
- *Presence of water.* Presence of water reflects the potential that seepage water contacts with groundwater. It is determined by two indicators: amount of rainfall and the depth of groundwater. The impact ratings of both indicators are aggregated by a weighted sum. The weights of 0.67 and 0.33 are applied to the amount of rainfall and the depth of groundwater, respectively. The amount of rainfall is assigned twice as much weight as the depth of groundwater because it can affect not only the amount of water in the storage area but also the level of groundwater.
    - *Amount of rainfall.* The amount of rainfall is determined by the maximum annual rainfall in a 30-year period. The criteria are based on the meteorological statistics. A precipitation of ≤1,500 millimeters per year is rated as low rainfall (thus a low likelihood), >1,500-2,000 millimeters per year as medium rainfall, and >2,000 millimeters per year as high rainfall.
    - *Depth of groundwater.* A shallow groundwater level indicates easier contact between the released pollutants and the water body. The criteria are specified based on those for assessing groundwater pollution risks suggested by Foster and Hirata (1988, p. 59). A groundwater depth of >100 meters is rated as a low likelihood, 10-100 meters as a medium likelihood, and <10 meters as a high likelihood.

- *Waste management after closure.* As well as during the operating stage, seepage from the waste facility can occur and become problematic after a mine closure. To prevent contamination, it is important to prevent mine wastes from having any contact with water. Hydrologic control measures such as waste removal and consolidation, water diversion, and erosion prevention are commonly applied for this purpose (Bell, 1999, p. 505; Colorado Division of Minerals and Geology, 2002, p. 13; Williams, 2014). The rating criteria are therefore identified in relation to the presence and the effectiveness of management measures. Moving waste to a dry area is the most preferable option to prevent seepage and is rated as a low likelihood. The storage of waste in a wet area with an adequate implementation of capping, water diversion and erosion prevention is rated as a medium likelihood. The storage of waste in a wet area without or with inadequate application of capping, water diversion, and erosion prevention measures is rated as a high likelihood.

- *Exposure potential.* Exposure potential is determined by pollutant concentration and pollutant dilution. The ratings of both components are aggregated by a geometric mean.
    - *Pollutant concentration.* Pollutants to be assessed comprise arsenic, cadmium, lead, mercury, uranium, cyanide, acidity-alkalinity, and salinity. The concentration is determined relative to the water quality standards of the implicated substances. A proportion (in percentage) of <50% is rated as a low concentration (thus low consequence), 50-100% as a medium concentration, and >100% as a high concentration.
    - *Pollutant dilution.* The dilution of pollutants is mainly influenced by diffusion and dispersion mechanisms. A common method to assess the vulnerability to contamination of groundwater is the DRASTIC index, which determines the water depth, net recharge, aquifer media, soil media, topography, impact of vadose zone media, and hydraulic conductivity of the aquifer (Focazio et al., 2002). In this assessment, groundwater velocity is selected to represent the degree of pollutant transport and dilution. The cut-offs are based on the range of groundwater velocity as mentioned earlier. A velocity of >1 meters per day is considered a high velocity thus dilution and is rated as a low exposure likelihood, 0.1-1 meters per day as a medium likelihood, and <0.1 meter per day as a high likelihood.

Consequence. Consequence is determined by the population potentially affected by pollutants living within 5 kilometers of the facility. The cut-offs are based on the population size on sub-district level. A population of <2,000 is rated as a low consequence, 2,000-10,000 as a medium consequence, and >10,000 as a high consequence.

c) Failure of waste storage facility

The level of the negative impacts of a waste storage facility failure is determined by the likelihood and the consequence of human exposure to pollutants. Their ratings are aggregated by a geometric mean.

Likelihood. The likelihood of exposure is determined by the failure potential of a waste facility and the exposure potential. The ratings of both components are aggregated by a geometric mean.

- *Failure potential.* Seven indicators determine the failure potential: type of material, facility height, slope angle, seismic condition, amount of rainfall, foundation condition, and water content in waste. The rating criteria explained in section 4.4.2.2(1.1.1) are also applied in this part. The impact ratings of these indicators are aggregated by a geometric mean.
- *Exposure potential.* The exposure potential is determined by pollutant concentration and dilution potential. The ratings of both components are aggregated by a geometric mean.
    - *Pollutant concentration.* The pollutants, which will be examined, are arsenic, cadmium, lead, mercury, uranium, cyanide, acidity-alkalinity, and salinity. Their concentrations are determined relative to the water quality standards of the respective substances. The proportion (in percentage) of <50% is rated as a low concentration (thus a low likelihood), 50-100% as a medium concentration, and >100% as a high concentration.
    - *Dilution potential.* The dilution potential of pollutants is determined by the type of water body present within three kilometers of the facility. As explained earlier, streams and shallow lakes (≤30 meters) are considered as having a good dilution potential and are rated as a low likelihood, rivers as a medium likelihood, and deep lakes (>30 meters) as a high likelihood.

Consequence. Consequence is determined by the population potentially affected by pollutants living within 5 kilometers of the waste storage facility. The cut-offs are based on the population size at sub-district level. An affected population of <2,000 is rated as a low consequence, 2,000-10,000 as a medium consequence, and >10,000 as a high consequence.

(1.2.3) Soil pollution

Soil pollution is different from water and air pollution since the contamination lasts longer. Possible sources of pollutants include, for example, inorganic toxic compounds, organic wastes, pesticides, and radionuclides (Misra and Mani, 2009, p. 31). Mining can pollute soil by different activities during its lifetime. The information provided by the Environmental Law Alliance Worldwide (2010) can be summarized as follows. During operations, an excavation of earth materials increases the exposure of toxic substances in soil to the environment. Uncontrolled disposal of wastes and by-products increases the concentration of toxic substances in soil directly. Dust from combustion and production processes, which contains harmful substances, is dispersed and deposited in the neighboring area. Spills and residues at mine sites can cause soil contamination, which increases the risk of contact as well as water contamination if the material is misused. In addition to the information above, the erosion of encapsulated soil in a waste storage and improper handling of wastes also lead to soil contamination problems after the mine has closed. The impact level of soil pollution on the neighboring community is thus assessed from direct contamination and indirect contamination through dust deposition in this assessment. Their impact ratings are aggregated by a weighted sum using an equal weight of 0.5.

(1.2.3.1) Direct contamination

Direct contamination refers to contamination from direct contact between pollutants and topsoil. The likelihood and the consequence of human exposure to pollutants determine the level of the negative impacts of direct contamination. The ratings of both indicators are aggregated by a geometric mean.

Likelihood. The likelihood of exposure is determined by two indicators: polluted area and the type of land use. Their ratings are aggregated by a geometric mean.

- *Polluted area.* Polluted area refers to the area in which the topsoil is exposed to pollutants such as the mining area and the waste disposal area. The criteria are based on the classification of landfill size, under which the landfill areas of <5, 5-20, and >20 hectares are identified as small, medium, and large areas, respectively (Rao et al., 2017,

p. 46). A total area of <5 hectares is rated as a low likelihood, 5-20 hectares as a medium likelihood, and >20 hectares as a high likelihood.

- *Type of land use.* Type of land use implies the degree of human exposure to polluted soil. The use of polluted land for industrial and commercial purposes causes a low exposure to land users, so it is rated as a low likelihood. The use of land for residential or other purposes that might allow pollutants to reach certain groups such as children is rated as a medium likelihood. The use of land for farming or other purposes causes direct or indirect exposure to a large group of people and is rated as a high likelihood.

Consequence. Consequence is considered from pollutant concentration. Pollutants to be assessed are the key heavy metals: arsenic, cadmium, lead, and mercury. The concentration is determined relative to the soil quality standards of the respective substances. A proportion (in percentage) of <50% is rated as a low concentration (thus a low consequence), 50-100% as a medium concentration, and >100% as a high concentration.

(1.2.3.2) Dust disposition

The impact level of soil contamination from dust disposition is determined by the likelihood and the consequence of human exposure to pollutants. The ratings of both components are aggregated by a geometric mean.

Likelihood. The likelihood of exposure is determined by the release of pollutants and pollutant dilution. Their ratings are aggregated by a geometric mean.

- *Release of pollutants.* The pollutants which will be examined are arsenic, cadmium, lead, and mercury. Their release volumes are determined relative to the soil threshold limits of the respective substances at a quantity of deposited dust of 1,000 kilograms per day, which is an approximate deposition over the area within a 500-meter radius at the (South African) deposition limit of 1.2 grams per square meters per day (Kwata, 2014, pp. 43–44). A proportion (in percentage) of <50% is rated as a low likelihood, 50-100% as a medium likelihood, and >100% as a high likelihood.
- *Pollutant dilution.* The dilution of pollutants is determined by wind speed, topography, and average rain days per year. Their ratings are aggregated by a geometric mean.
    - *Wind speed.* The cut-offs are based on the Beaufort wind force. A wind speed of >5 meters per second (m/s) is rated as a low likelihood, 1-5 m/s as a medium likelihood, and <1 m/s as a high likelihood.

- *Topography.* Flat terrain and the topography that facilitates air flow horizontally and vertically imply a better pollutant dispersion and are rated as a low likelihood. A topography that interrupts air flow such as a built-up area is rated as a medium likelihood. A valley topography which is more likely to have temperature inversion and other topography that tends to have problems with atmospheric stability is rated as a high likelihood.
- *Average rain days per year.* The criteria are based on meteorological statistics. The average number of >150 rain days per year is considered to have high washout potential, thus a low concentration of pollutants. It is therefore rated as a low likelihood. The average number of 100-150 rain days per year is rated as a medium likelihood, and that of <100 days per year as a high likelihood.

Consequence. Consequence is determined by the population affected by pollution living within 5 kilometers of the source. The cut-offs are based on the population size at sub-district level. An affected population of <2,000 is rated as a low consequence, 2,000-10,000 as a medium consequence, and >10,000 as a high consequence.

(2) Community's access to livelihood assets

Access to natural and physical assets determines the negative impacts of a mining project on a community's access to livelihood assets. The impact ratings of both components are aggregated by a weighted sum using an equal weight of 0.5.

(2.1) Access to natural assets

Three components ascertain the impacts of a mining project on a community's access to natural resources: competing use of water, land, and forest. The impact ratings of these components are aggregated by a weighted sum using an equal weight of 0.33.

(2.1.1) Competing water use

The impact level of competing water use is determined by the effects of water abstraction and a lowered water level. The impact ratings of both components are aggregated by a weighted sum using an equal weight of 0.5.

Water abstraction. The effect of water abstraction is determined by the likelihood and the consequence of competing use. The impact ratings of both components are aggregated by a geometric mean.

- *Likelihood.* Likelihood is determined by the ratio of the abstraction quantity to available water supply. A value of 1 indicates that the water supply is sufficient. A ratio of >0-0.5 is rated as a low likelihood, >0.5-1 as a medium likelihood, and >1 as a high likelihood.
- *Consequence.* Consequence is determined by the population size living in the affected area and their types of occupations according to the following equation:

  $$\text{consequence} = \sum (\text{affected population}_i \times \text{weight of occupation type}_i)$$

  where, i = type of occupation. The type of occupation is defined in correspondence with the degree of dependency on natural resources. Different occupation types are assigned different weights for calculation. A primary occupation is an occupation directly relying on natural resources such as agriculture, horticulture, aquaculture, fishing, hunting, and mining. A weight of 1 (showing a high consequence from competing use) is assigned. A secondary occupation is an occupation that processes natural products such as handicraft and industrial manufacturing. It is assigned a weight of 0.67. A tertiary occupation is an occupation in the services sector and, in this case, unemployed and retired people. A weight of 0.33 is applied.

  The adjusted number of affected people is rated based on the population size at sub-district level. An adjusted number of <2,000 is rated as a low consequence, 2,000-10,000 as a medium consequence, and >10,000 as a high consequence.

Lowered water level. The impact level of a lowered water level is determined by the likelihood and the consequence of the water level sinking. The ratings of both components are aggregated by a geometric mean.

- *Likelihood.* Likelihood is determined by how deep the mine is and the distance of ground subsidence. The ratings of both components are aggregated by a weighted sum using an equal weight of 0.5.
  - *Depth of mine.* The depth of a mine impacts the effect of dewatering which can cause a depression in the groundwater table and consequently impact surface water and wetland. The criteria take into account that the groundwater level in Thailand varies from less than 1 to more than 150 meters below ground level (Department of Groundwater Resources, 2016) and that surface mining can be more than 500 meters deep. A depth of >50-100 meters is considered shallow and is rated as a low likelihood, >100-150 meters as a medium likelihood, and >150 meters as a high likelihood. A

depth of 0-50 meters as well as activities that do not affect groundwater level are rated as irrelevant.

- *Distance of ground subsidence.* The distance of ground subsidence represents the extent to which the ground surface changes and implies the potential alteration of surface water flow. The values 0.3 and 2.4 meters comparable to the current and historical maximum rates of ground subsidence due to groundwater extraction in Bangkok (1.3 and 9.7 centimeters per year (Department of Water Resources, 2013, pp. 19–21) in 25 years) are selected as cut-offs. A maximum subsidence of >0-<0.3 meters is rated as a low effect on water level (and a low likelihood), 0.3-2.4 meters as a medium effect, and >2.4 meters as a high effect.

- *Consequence.* Consequence is determined by the population size in the affected area and their occupations. The same calculation and rating criteria to those described in the sub-topic of water abstraction are applied.

(2.1.2) Competing land use

The impact level of competing land use is determined by the likelihood and the consequence of the competing use. The ratings of both components are aggregated by a geometric mean.

Likelihood. Likelihood is determined by the residential and agricultural area acquired by the mining project. The values 100 and 1,000 hectares are used as the cut-offs since they represent the approximate land uses of a village and a sub-district, respectively. These values are estimated from the average land use per capita in 2013 (0.54 hectares per person (calculated from the data by Department of Public Administration, 2016; Office of Agricultural Economics, 2016)) and the minimum population size of a village (200 people (Ministry of Interior, 1996)) and a sub-district (2,000 people (Royal Thai Government Gazette, 2009a, sec. 41)). An area of <100 hectares is rated as a low likelihood, 100-1,000 hectares as a medium likelihood, and >1,000 hectares as a high likelihood.

Consequence. Consequence is determined by the population size in the affected area and the occupations. The same calculation and rating criteria to those described in 4.4.2.2(2.1.1) are applied.

(2.1.3) Competing forest use

The impact level of competing forest use is determined by the likelihood and the consequence of the competing use. The ratings of both components are aggregated by a geometric mean.

Likelihood. Likelihood is determined by the forest and abandoned area acquired by the mining project. The cut-offs are based on the land uses of a village and a sub-district. An area of <100 hectares is rated as a low likelihood, 100-1,000 hectares as a medium likelihood, and >1,000 hectares as a high likelihood.

Consequence. Consequence is determined by the population size in the affected area and the people's occupations. The same calculation and rating criteria to those described in 4.4.2.2(2.1.1) are applied.

(2.2) Access to physical assets

Four indicators ascertain the negative impact of a mining project on a community's access to physical assets: the competing uses of road, rail, healthcare, and education. The impact ratings of these components are aggregated by a weighted sum using an equal weight of 0.25.

Road. The impact on a community's access to roads is determined by the ratio of expected vehicle number to road capacity. A ratio of <0.6 is rated as a low impact, 0.6-1.0 as a medium impact, and >1.0 as a high impact. These values are based on the criteria for the level of services in Dowling et al. (1997, p. 36).

Rail. The impact on a community's access to railroads is determined by the ratio of rail transport per day to the remaining transport capacity at the bottlenecks. Similar criteria to those of roads are applied. A ratio of <0.6 is rated as a low impact, 0.6-1.0 as a medium impact, and >1.0 as a high impact. If no railway use is involved, the impact is rated as irrelevant.

Healthcare. The impact on a community's access to healthcare is determined by the change in ratio of population and medical staff in the area as explained earlier in the assessment of positive contributions. The change is rated as irrelevant when it is positive or indifferent. A negative change of <5% is rated as a low impact, 5-15% as a medium impact, and >15% as a high impact.

Education. The impact on a community's access to education is determined by the change in ratio of student to teacher in the area as explained earlier in the assessment of positive contributions. The change is rated as irrelevant when it is positive or indifferent. A negative change of <5% is rated as a low impact, 5-10% as a medium impact, and >10% as a high impact.

(3) Vulnerability to external changes

The negative impacts of a mining project on a community's vulnerability to external changes are determined by three components: vulnerability to floods, vulnerability to droughts, and dependency on mining. The impact ratings of these components are aggregated by a weighted sum using an equal weight of 0.33.

(3.1) Vulnerability to floods

The impact level of a community's vulnerability to floods is determined by the effect of subsidence and the effect of sediment release to waterways. The impact ratings of both components are aggregated by a weighted sum using an equal weight of 0.5.

Effect of subsidence. Effect of subsidence is determined by the likelihood and the consequence of floods. The ratings of both components are aggregated by a geometric mean.

- *Likelihood.* The likelihood of floods is determined by the current state of flooding potential and the distance of ground subsidence. The impact ratings of both components are aggregated by a geometric mean.
    - *Current state of flooding potential.* The state of flooding potential is determined by the area and flooding risk according to the following equation:

      $$\text{flooding potential} = \sum (\text{area rating}_i \times \text{flooding risk rating}_i)$$

      where, i = flooding risk rating. The flood potential value of >0-<3 is rated as a low potential, 3-<6 as a medium potential, and 6-18 as a high potential.
        - *Area.* The size of a flood-prone area is graded into three levels. The cut-offs based on land uses of a village and a sub-district as mentioned earlier are applied. An area of >0-<100 hectares is rated as a small area (rating = 1), 100-1,000 hectares as a medium area (rating = 2), and >1,000 hectares as a large area (rating = 3).

        - *Flooding risk.* Thailand's Department of Disaster Prevention and Mitigation identified three risk ratings for flood-prone areas and the type of floods: low, medium, and high. This classification is used to rate the flooding risk in a calculation. A low risk rating scores 1, medium scores 2, and high scores 3.
    - *Distance of ground subsidence.* The distance of ground subsidence implies an increasing possibility of flooding due to lowered ground levels. The criteria are defined in reference to the subsidence from groundwater extraction. A maximum subsidence distance of >0-<0.3 meters is rated as a low effect on water levels (thus a low likelihood), >0.3-2.4 meters as a medium effect, and >2.4 meters as a high effect.
- *Consequence.* Consequence is determined by the population in the affected area and the people's occupations. The same calculation and rating criteria as described in 4.4.2.2(2.1.1) are applied.

Effect of the sediment release to waterway. The effect of sediment release to waterways is determined by the likelihood and the consequence of floods. The ratings of both components are aggregated by a geometric mean.

- *Likelihood.* The likelihood of floods is determined by the current state of flooding potential and the release of sediment to waterways. The ratings of both components are aggregated by a geometric mean.
    - *Current state of flooding potential.* The flooding potential is determined by the area and flooding risk as explained in the effect of subsidence part, but only the flooding risk in the water bank area is taken into account.
    - *Release of sediment to waterway.* The release of sediment to waterways can enhance the possibility of flooding along the waterway due to the disposition of mine sediment. The extent of its effect on the flooding potential is determined by two indicators: the annual release of suspended solid material and the type of water channel in the area. The ratings of both indicators are aggregated by a geometric mean. If there is no release of solid substance into the waterway, this part is rated as irrelevant.
        - *Annual release of suspended solid.* A release of >0-<13.7 tonnes per year is rated as a low release (thus a low likelihood), 13.7-27.3 tonnes per year as a medium release, and >27.3 tonnes per year as a

high release. These values are calculated from the concentration of suspended solid material (50 mg/L), which is the threshold according to Thailand's Industrial Wastewater Quality Standard (Royal Thai Government Gazette, 1996), and a wastewater discharge of 1,500 cubic meters per day, which is comparable to a stream flow rate.

  - *Type of water channel.* The type of water channel determines the ability of sediment transport. Water channels with a turbulent flow or high fluid force or bedform enhancing flow strength tend to have better sediment transport, so they are rated as a low contribution to the flooding likelihood. Water channels with a laminar flow or low fluid force or bedform that promotes a smooth flow are rated as a high contribution to the flooding likelihood. A medium rating is assigned to a water channel with characteristics between low and high ratings.

- *Consequence.* Consequence is determined by the population in the affected area and the people's occupations. The same calculation and rating as described in 4.4.2.2(2.1.1) are applied.

(3.2) Vulnerability to droughts

The impact level of a community's vulnerability to droughts is determined by the likelihood and the consequence of droughts. The ratings of both components are aggregated by a geometric mean.

Likelihood. The likelihood of droughts is determined by the current state of drought potential and the effect of a lowered water table. The ratings of both components are aggregated by a weighted sum using an equal weight of 0.5.

- *Current state of drought potential.* The drought potential is determined by the area and drought risk according to the following equation:

$$\text{drought potential} = \sum (\text{area rating}_i \times \text{drought risk rating}_i)$$

  where, i = drought risk rating. The drought potential value of >0-<3 is rated as a low potential, 3-<6 as a medium potential, and 6-18 as a high potential.

  - *Area.* There are three categories of drought-prone areas. The cut-offs based on the land use of a village and a sub-district as mentioned earlier are applied. An area of >0-<100 hectares is rated as a small area (rating = 1), 100-1,000 hectares as a medium-sized area (rating = 2), and >1,000 hectares as a large area (rating = 3).

    - *Drought risk.* Thailand's Department of Disaster Prevention and Mitigation classified drought-prone areas and their risks as very low, low, medium, and high risk. The risk rating according to this classification is used in the calculation. The very low to low risk is rated as low (rating = 1), the medium risk is rated as medium (rating = 2), and the high risk is rated as high (rating = 3).

- *Effect of lowered water table.* The effect of a lowered water table is determined by the mine's depth and the distance of ground subsidence. The ratings of both components are aggregated by a weighted sum using an equal weight of 0.5.
    - *Depth of mine.* The cut-offs based on the depth of groundwater in Thailand as mentioned earlier are applied. A mine depth of >50-100 meters is considered shallow and is rated as a low effect (thus a low likelihood), >100-150 meters as a medium effect, and >150 meters as a high effect. A depth of 0-50 meters as well as activities that do not affect groundwater level are rated as irrelevant.
    - *Distance of ground subsidence.* The distance of ground subsidence represents the extent to which the ground surface changes and implies the potential alteration of surface water flows. The cut-offs are based on subsidence from groundwater extraction. A maximum subsidence distance of >0-<0.3 meters is rated as a low effect on the water level (and a low likelihood), 0.3-2.4 meters as a medium effect, and >2.4 meters as a high effect.

Consequence. Consequence is determined by the population size in the affected area and the people's occupations. The same calculation and rating criteria as described in 4.4.2.2(2.1.1) are applied.

(3.3) Dependency on mining

The impact level of a community's dependency on mining is determined by the employment dependency and local spending by mining projects. The impact ratings of both components are aggregated by a weighted sum using an equal weight of 0.5.

Employment dependency. Employment dependency is determined by the rate of expected new employment for the local workforce. The criteria are based on the information that the employment in mining and quarrying sector in 2015 was less than 0.5% whereas the employment in the manufacturing (excluding mining) and construction sectors accounted for around 16.7% and 5.9%, respectively (Bank of Thailand, 2015). The cut-offs of 5% and 15% are selected to indicate the level of change. A change of >0-<5% is rated as a low dependency, 5-15% as a medium dependency, and >15% as a high dependency.

Local spending of mining project. A mining project can become a dominant but impermanent source of income, on which many local businesses and communities become reliant. The dependency is represented by the local spending of a mining project, determined by the ratio of expected spending of a local mine to the current size of the economy. The criteria are defined based on the contribution of different economic sectors to the gross domestic product during 2011 to 2015. The contribution of mining and quarrying (excluding petroleum) accounted for 0.5%, whereas that of manufacturing and construction valued 13.8% and 2.7%, respectively (Office of the National Economics and Social Development Board, 2015). The cut-offs of 5% and 15% are selected for this assessment. The change of >0-<5% is rated as a low dependency, 5-15% as a medium dependency, and >15% as a high dependency.

4.4.2.3 Negative impacts on the environment

The negative impacts of a mining project on the environment are assessed from two aspects: habitat loss and pollution. The impact ratings of both components are aggregated by a weighted sum using an equal weight of 0.5.

(1) Habitat loss

The negative impacts of mining-induced loss of habitat are viewed from the terrestrial habitat loss and aquatic habitat loss. The impact ratings of both components are aggregated by a weighted sum using an equal weight of 0.5.

(1.1) Terrestrial habitat loss

The impact level of terrestrial habitat loss is assessed from direct and indirect changes of land cover. Two forms of change are used to investigate the impacts, namely, the loss of land cover and the effect of ground subsidence. The impact ratings of both components are aggregated by a weighted sum. Both components are assigned different weights to distinguish between direct and indirect impacts. A weight of 67% is applied to the loss of land cover and 33% to the effect of ground subsidence.

(1.1.1) Loss of land cover

The impact level of land cover loss is determined by the likelihood and the consequence of loss. The ratings of both components are aggregated by a geometric mean.

Likelihood. Likelihood represents the extent of land cover loss, spatially and temporally. It is determined by the area and the period of loss using the following equation:

$$\text{likelihood} = \sum (\text{area rating}_i \times \text{loss period rating}_i)$$

where, i = loss period rating. The likelihood value of >0-<3 is rated as a low likelihood, 3-<6 as a medium likelihood, 6-18 as a high likelihood.

- *Area.* The cut-offs are defined based on the fact that the minimum habitat requirement for terrestrial animals can range from one (for birds and small animals) to more than 980 hectares (for predators) and that the recommended patch size to be protected according to the Canadian data is 55 hectares (Environmental Law Institute, 2003, p. 8). A loss of >0-<50 hectares is rated as a small area (rating =1), 50-1,000 hectares as a medium area, and >1,000 hectares as a large area (rating = 3).
- *Loss period.* The loss period denotes the level of damage and the ability of nature to recover. It is classified into four groups. Area without land cover removal or with land cover removal of ≤1 year is rated as a temporary loss (rating = 0), >1-≤3 years as a short-term loss (rating = 1), >3-≤10 years as a medium-term loss (rating = 2), and >10 years as a long-term loss (rating = 3). These values are based on the data of grasslands repeatedly disturbed over a long period (>10 years) recovering only slowly or not at all, and on the evidence that the recovery of Canadian forests after a wildfire required not more than 5 and 10 years respectively to reach a benchmark canopy cover of 10%, albeit that the regeneration after the wildfire was faster in the first few years and then continued at a slower rate (Bartels et al., 2016; Chazdon, 2003).

Consequence. The consequence of loss is represented by the presence of species, determined by species vulnerability and the number of species found in the area. The criteria for calculating and rating the presence of species were described in 4.4.1.2(3). They are also applied to this calculation.

(1.1.2) Effect of ground subsidence

Mine subsidence can cause not only direct changes at the ground surface but also indirect changes to land cover through the alteration of topography and hydrology (Bell et al., 2000; Singh, 1992). The impact level of ground subsidence on the ecosystem is determined by the likelihood and the consequence of subsidence. Their ratings are aggregated by a geometric mean.

Likelihood. Mining-induced subsidence is mainly influenced by geological and mining parameters as well as the nature of the structure. Singh (1992) indicates that the subsidence is characterized by five components, namely, vertical displacement, horizontal displacement, slope, horizontal strain, and vertical curvature. He further explains that horizontal strain is an important cause of environmental damage, and its value should be kept below 5 (to 10) $x10^{-3}$. The likelihood of subsidence is assessed from horizontal strain and the size of the area affected by subsidence according to the following equation:

$$\text{likelihood} = \sum (\text{area rating}_i \times \text{horizontal strain rating}_i)$$

where, i = horizontal strain rating. The likelihood value of >0-<3 is rated as a low potential, 3-<6 as a medium potential, and 6-18 as a high potential.

- *Area.* The cut-offs are defined based on the minimum habitat requirement explained above. A loss of >0-<50 hectares is rated as a small area (rating =1), 50-1,000 hectares as a medium-sized area, and >1,000 hectares as a large area (rating = 3).
- *Horizontal strain.* Horizontal strain of $<5x10^{-3}$ is rated as low (rating = 1), $5\text{-}10x10^{-3}$ as medium (rating = 2), and $>10x10^{-3}$ as high (rating = 3).

Consequence. The consequence of loss is represented by the presence of species, determined by species vulnerability and the number of species found in the area. The criteria for calculating and rating the presence of species were described in 4.4.1.2(3). They are also applied to this calculation.

(1.2) Aquatic habitat loss

Water is the main habitat of aquatic ecosystems, which can be classified as freshwater (lentic and lotic), saline, and brackish water ecosystems (Ahluwalia, 2015, p. 83). Among these three categories, the freshwater ecosystem is the system most impacted by inland mining. Involving earth-moving and construction, especially in wetlands, watercourses, and water bodies, mining can cause changes in geological, hydrological, and geographical conditions, resulting in flow modification (e.g. water diversion and damming) and destruction or degradation of the aquatic habitat (e.g. removal of water channels and water bodies, loss of water due to drainage, and upstream blockage). The impact level of aquatic habitat loss is viewed from two aspects: direct removal of water bodies and indirect water disruption. The impact ratings of both components are aggregated by a weighted sum. Both components are assigned different weights to distinguish between direct and indirect impacts. A weight of 67% is applied to the direct removal of water bodies and 33% to indirect water disruption.

(1.2.1) Direct removal of water body

Water body refers to "*any source of water or hydrologic feature such as stream, river, lake, pond, canal, wetland, reservoir or spring*" (Meixler, 1999). The impact level of water body removal is determined by the likelihood and the consequence of removal. Their ratings are aggregated by a geometric mean.

Likelihood. Likelihood represents the extent of water body loss. It is determined by area and period of loss according to the following equation:

$$\text{likelihood} = \sum (\text{area rating}_i \text{ x loss period rating}_i)$$

where, i = loss period rating. The likelihood value of 0-<3 is rated as a low likelihood, 3-<6 as a medium likelihood, 6-18 as a high likelihood.

- *Area.* The identification of the criteria is based on the classification of inland wetland, which distinguishes ponds and lakes by the area of eight hectares (Ramsar Convention Secretariat, 2012). A loss of >0-<1 hectare is rated as a small area (rating = 1), 1-8 hectares as a medium-sized area (rating = 2), and >8 hectares as a large area (rating = 3).
- *Loss period.* The loss period denotes the level of damage and the ability of nature to recover from it. The loss period is classified into four groups. An area without or with land cover removal of ≤1 year is rated as a temporary loss (rating = 0), >1-≤3 years as a short-term loss (rating = 1), >3-≤10 years as a medium-term loss (rating = 2), and >10 years as a long-term loss (rating = 3). These values are based on the information about forest recovery rates mentioned earlier.

Consequence. The consequence of loss is represented by the presence of species, determined by species vulnerability and the number of species found in the area. The criteria for calculating and rating the presence of species were described in 4.4.1.2(3). They are also applied to this calculation. However, the species to be assessed include fish, amphibian, and aquatic plant species.

(1.2.2) Indirect water disruption

The impact level of indirect water disruption is determined by the likelihood and the consequence of disruption. Their ratings are aggregated by a geometric mean.

Likelihood. Mining can cause disruption to an aquatic habitat by water blockage, diversion, and mining-induced drainage by, for example, upstream damming and sediment discharge. The likelihood of disruption is determined by the activity type, which reflects the degree and the period of disruption. Activities that can cause a minor temporary disruption (not longer than 1 year) to a downstream water body are rated as a low likelihood. Activities that can cause a temporary significant loss or long-term minor disruption to a downstream water body or a combination of up to three minor disruptions are rated as a medium likelihood. Activities that can cause a significant long-term loss of a downstream water body or a combination of more than three different activity types are rated as a high likelihood.

Consequence. The consequence of disruption is represented by the presence of species, determined by species vulnerability and the number of species found in the area. The criteria for calculating and rating the presence of species were described in 4.4.1.2(3). They are also applied to this calculation. However, in this case the species to be assessed include fish, amphibian, and aquatic plant species.

(2) Pollution

The impact level of pollution is assessed from air pollution, and water (and sediment) pollution, and soil pollution. The impact ratings of these components are aggregated by a weighted sum using an equal weight of 0.33.

(2.1) Air pollution

According to Barker and Tingery (1992), air pollution is the presence of contaminants, which can be dust, smoke, odors, fumes, mists, and gases, in the atmosphere. They also explain that air pollution affects biodiversity by changes in genetic diversity, less reproductive potential of biota, less productivity in vegetation, and hindered structures and functions of ecosystems. The impacts can occur at a local, a regional, and a global scale.

The impacts of air pollution emphasized in relation to ecosystems are acidification, eutrophication, and exposure to ozone (European Environment Agency, 2012, p. 60). Climate change is another important threat to biodiversity as it can cause a decline in genetic diversity (Bellard et al., 2012). The impact level of air pollution on the ecosystem is determined by the likelihood and the consequence of environmental exposure to air pollution. The ratings of both components are aggregated by a geometric mean.

Likelihood. The likelihood of exposure is assessed from the release of pollutants and pollutant dilution. The impact ratings of both components are aggregated by a geometric mean.

- *Release of pollutants.* Pollutants to be assessed are those contributing to acidification and climate change, namely, sulfur dioxide, nitrogen dioxide, and ground-level ozone. The rating criteria are specified in relation to emission standards in an air volume of 1,000 million cubic meters per year, which is a round-up number of the air volume flowing through the cross-section of 100 by 100 square meters at the speed of 1 meter per second. An emission rate less than that calculated from 50% of the standard concentration is rated as a low exposure likelihood. An amount not smaller than that calculated from 50% but not more than 100% of the standard concentration is rated as a medium exposure likelihood. Otherwise, it is rated as a high exposure likelihood.
- *Pollutant dilution.* The effect of pollutant dilution is determined by three indicators: wind speed, topography, and average rain days per year. The criteria for calculating and rating pollutant dilution were described in 4.4.2.2(1.2.1). The same criteria are applied to this calculation.

Consequence. Consequence is determined by the presence of species, determined by species vulnerability and the number of species found in the area. The criteria for calculating and rating the presence of species were described in 4.4.1.2(3). They are also applied to this calculation.

(2.2) Water pollution

The impact level of water (and sediment) pollution on the environment is viewed from two perspectives: planned discharge and undesired release of pollutants. The impact ratings of both components are aggregated by a weighted sum. Both components are assigned different weights to distinguish between anticipated and possible impacts. The weight of 67% is applied to a planned discharge and 33% to an undesired release.

(2.2.1) Planned discharge of water pollutants

The impact level of a planned discharge is investigated from the likelihood and the consequence of environmental exposure to pollutants. The ratings of both components are aggregated by a geometric mean.

Likelihood. The pollutant discharge and pollutant dilution determine the likelihood of exposure. The impact ratings of both components are aggregated by a geometric mean.

- *Pollutant discharge.* Water pollutants from mining can affect aquatic ecosystems through sedimentation, eutrophication, thermal alternation, dissolved oxygen, acidification, trace metals contamination, and non-metallic toxins (UNEP-GEMS/Water Programme, 2008). The main pollutants related to these problems include heavy metals, cyanide, suspended solid, acidity-alkalinity, salinity, and heat. Based on this information, the pollutants to be assessed consist of arsenic, cadmium, lead, mercury, uranium, cyanide, suspended solid, acidity-alkalinity, salinity, and heat. The release of pollutants is measured from the amount of pollutants discharged annually relative to the amount calculated from water quality standards at the effluent discharge of 1,500 cubic meters per day, which is comparable to a stream flow rate. The released amount less than that calculated from 50% of the standard concentration is rated as a low exposure likelihood. An amount not smaller than that calculated from 50% but not more than 100% of the standard concentration is rated as a medium exposure likelihood. Otherwise, it is rated as a high exposure likelihood.
- *Pollutant dilution.* The dilution potential is determined by the type of water body, which reflects the residence time of water in the water body. The criteria for calculating and rating the pollutant dilution were described in 4.4.2.2(1.2.2.1). The same criteria are applied to this calculation.

Consequence. The consequence of exposure is represented by the presence of species, determined by species vulnerability and the number of species found in the area. The criteria for calculating and rating the presence of species were described in 4.4.1.2(3). They are also applied to this calculation. However, the species to be assessed include fish, amphibian, and aquatic plant species.

(2.2.2) Undesired release of water pollutants

An undesired release is an unintentional release of polluted water or pollutants to the environment. It can occur in different forms such as leakage or seepage from storage facilities, spillage of chemicals, and release due to failure of containment (International Council on Mining and Metals, 2012b). These types of releases can affect surface or groundwater conditions and increase the threats to biodiversity, particularly from toxicity. The impact level of an undesired release of polluted water on the ecosystem is viewed from three perspectives: leaching and contamination from mine drainage, seepage from the waste facility, and failure of the waste facility. The impact ratings of these three components are aggregated by a weighted sum using an equal weight of 0.33.

(2.2.2.1) Leaching and contamination from mine drainage

The likelihood and the consequence of environmental exposure to pollutants determine the impact level of leaching and contamination from mine drainage. The impact ratings of both components are aggregated by a geometric mean.

Likelihood. Two factors measure the likelihood of exposure: the presence of pollutants and water. The criteria for calculating and rating the likelihood of leaching and contamination from mine drainage were described in 4.4.2.2(1.2.2.2)a). The same criteria are applied to this calculation.

Consequence. The consequence of exposure is represented by the presence of species within 5 kilometers from the source. The criteria for calculating and rating the presence of species were described in 4.4.1.2(3). They are also applied to this calculation. However, in this case the species to be assessed include fish, amphibian, and aquatic plant species.

(2.2.2.2) Seepage from waste storage facility

The likelihood and the consequence of environmental exposure to pollutants determine the impact of seepage from a waste storage facility. The ratings of both components are aggregated by a geometric mean.

Likelihood. Likelihood is determined by the seepage potential and the exposure potential. The ratings of both components are aggregated by a geometric mean.

- *Seepage potential.* The seepage potential is measured through five components: capacity of waste facility, water content in waste, control measures, presence of water, and waste management after closure. The criteria for calculating and rating the likelihood of seepage from a waste storage facility were described in 4.4.2.2(1.2.2.2)b). The same criteria are applied to this calculation.

- *Exposure potential.* The exposure potential is determined by the pollutant concentration and the pollutant dilution. The ratings of both components are aggregated by a geometric mean.
    - *Pollutant concentration.* Pollutants to be assessed comprise arsenic, cadmium, lead, mercury, uranium, cyanide, acidity-alkalinity, and salinity. Their concentrations are determined relative to the water quality standards of the respective substances. A proportion (in percentage) of <50% is rated as a low concentration (thus a low likelihood), 50-100% as a medium concentration, and >100% as a high concentration.
    - *Pollutant dilution.* The dilution of pollutants is determined by groundwater velocity. The criteria are based on the range of groundwater flow mentioned earlier. A velocity of >1 meter per day is a high velocity and a high dilution potential (thus a low exposure likelihood), >0.1-1 meters per day as a medium exposure likelihood, and ≤0.1 meters per day as a high exposure likelihood.

Consequence. Consequence is determined by the presence of species within 5 kilometers of the waste storage facility. The criteria for calculating and rating the presence of species were described in 4.4.1.2(3). They are also applied to this calculation. However, in this case the species to be assessed include fish, amphibian, and aquatic plant species.

(2.2.2.3) Failure of waste storage facility

The likelihood and the consequence of an incident determine the impact level of a waste storage facility failure. Their ratings are aggregated by a geometric mean.

Likelihood. The likelihood of a waste storage facility failure is determined by the failure potential and the dilution potential. Their ratings are aggregated by a geometric mean.

- *Failure potential.* Failure potential is determined by seven indicators: type of material, facility height, slope angle, seismic condition, amount of rainfall, foundation condition, and water content in waste. The rating criteria of these indicators were explained in 4.4.2.24.4.2.2(1.1.1). They are also applied in this assessment. The ratings of these indicators are aggregated by a geometric mean.
- *Exposure potential.* Exposure potential is determined by the pollutant concentration and the dilution potential. The ratings of both components are aggregated by a geometric mean.

- *Pollutant concentration.* Pollutants to be assessed comprise arsenic, cadmium, lead, mercury, uranium, cyanide, acidity-alkalinity, and salinity. The concentrations are determined relative to the water quality standards of the respective substances. A proportion (in percentage) of $<50\%$ is rated as a low concentration (thus a low likelihood), 50-100% as a medium concentration, and $>100\%$ as a high concentration.
- *Dilution potential.* The dilution potential of pollutants is determined by the type of water body present within three kilometers of the facility. The criteria are based on the water residence time in a reservoir explained earlier. Streams and shallow lakes (≤ 30 meters) are assumed to have a good dilution potential and are rated as a low likelihood, rivers as a medium likelihood, and deep lakes (>30 meters) as a high likelihood.

Consequence. Consequence is determined by the presence of species within 5 kilometers from the waste storage facility. The criteria for calculating and rating the presence of species were described in 4.4.1.2(3). They are also applied to this calculation. However, in this case the species to be assessed include fish, amphibian, and aquatic plant species.

(2.3) Soil pollution

The likelihood and the consequence of environmental exposure to pollutants determine the impact level of soil pollution from dust disposition. The ratings of both components are aggregated by a geometric mean.

Likelihood. The likelihood of exposure is assessed from the release of pollutants and the pollutant dilution. Their ratings are aggregated by a geometric mean.

- *Release of pollutants.* Pollutants to be assessed are four main heavy metals, including arsenic, cadmium, lead, and mercury. The emissions are determined relative to the soil threshold limits of the respective substances in the deposited dust of 1,000 kilogram per day. A proportion (in percentage) of $<50\%$ is rated as a low likelihood, 50-100% as a medium likelihood, and $>100\%$ as a high likelihood.
- *Pollutant dilution.* The dilution of pollutants is determined by wind speed, topography, and average rain days per year. Their ratings are aggregated by a geometric mean.
    - *Wind speed.* The criteria are based on the Beaufort wind force scale. A wind speed of >5 meters per second (m/s) is rated as a low likelihood, 1-5 m/s as a medium likelihood, and <1 m/s as a high likelihood.

- *Topography.* Flat terrain and a topography that facilitates horizontal and vertical air flow render a better pollutant dispersion and are rated as a low likelihood. A topography that disrupts the air flow such as built-up areas is rated as a medium likelihood. A valley topography which is more likely to have temperature inversion and other topography that tends to have problems with atmospheric stability is rated as a high likelihood.
- *Average rain days per year.* The criteria are based on the meteorological statistics. The average number of >150 rain days per year means a high washout potential and consequently a low concentration of pollutants. It is therefore rated as a low likelihood. The average number of 100-150 rain days per year is rated as a medium likelihood, and <100 rain days per year as a high likelihood

Consequence. The consequence of exposure is represented by the presence of species, determined by species vulnerability and the number of species found in the area. The criteria for calculating and rating the presence of species were described in 4.4.1.2(3). They are also applied to this calculation.

4.4.2.4 Negative impacts on shareholders

The negative impacts of a mining project on shareholders are ascertained from the profit or return on investment of the project. Profit refers to the surplus which remains after the total costs are deducted from all operational income. Profit is a decisive factor in any business. In mining, it should be in the forefront of consideration already at the design and planning stage. Torries (1998) explains that, theoretically, the main objective of mine design and planning is to maximize the project value, generally measured by monetary-related values using a discounted cash flow method and presented in forms of Net Present Value (NPV), Internal Rate of Return (IRR), discounted average cost, or payback period. He also points out that NPV is the most frequently used indicator for feasibility evaluation. The selection of discount rate for the calculation of a project value and project evaluation depends on a company's strategic goals, past costs, inflation expectations, and management judgment (Brazda and Thornburg, 1990, p. 426). A low discount rate indicates higher confidence in the future and yields higher project value. Key factors influencing the choice of a discount rate or an acceptable profit rate are the risks associated with the project, other investment opportunities, and money-raising abilities. The mining industry investments require a higher return due to seemingly higher risks (Runge, 1998, pp. 199–207).

In principle, the expected return on investment should at least be equal to the cost of capital plus risk premiums. There are many forms of risks associated with mining. The most significant risks include switch to growth, productivity improvement, capital access, resource nationalism, social license to operate, price and currency volatility, capital projects, access to energy, cybersecurity, and innovation (EY, 2015). Key risk premiums generally included in the consideration of return on investment are the cost of exploring and evaluating new reserves, the cost of upholding knowledge and intangible assets necessary for operation, and additional risks before the commencement of operations (Runge, 1998, pp. 199–207). O'Neil (1979) recommended a minimum acceptable rate of return of new mining operations at 20% owing to high risks (Brazda and Thornburg, 1990, p. 426). A discount rate of 15% (after tax), however, was suggested by a common guideline used by large companies in the mineral industry since the (after tax) cost of capital of most large mining companies was less than half of this rate (Runge, 1998, pp. 199–207). A study of an iron ore project value by Capoferri (2014) showed that discount rates between 7% and 10% were mostly applied to consider the investment of iron ore mining projects. This range resulted from the real interest rate of around 7.7% and a political risk premium of between -0.5 and 4.0%, depending on the location. However, it was proposed that a risk-adjusted discount rate of between 15.5 and 26% should be used for the cost of capital and between 18 and 31% for the nominal discount rate (capital cost plus premiums).

Based on the information above, the return on investment of a mining project is assessed in relation to the project risk. The level of project risks is classified into three groups by five indicators: exploration risk, technology and methods, price volatility, social conflicts, and company's reputation. The ratings of these five indicators are aggregated by a weighted sum using an equal weight of 0.2.

- *Exploration risk.* Several parameters influence the exploration risk. Exploration risks originate from a variation of deposit sizes and grades due to the differences in geological settings and a variation in economic returns (Singer and Kouda, 1999). This assessment investigates the risk in terms of the level of confidence of resource estimation. A lower level of confidence indicates a higher risk. The exploration risks of low, medium, and high are applied for measured, indicated, inferred resources, respectively.
- *Technology and methods.* Technology and methods denote the uncertainty in operation. Uncertainty regarding the implemented technology and methods is likely to negatively

affect the operation and profit. This framework classifies technology and method risks into three classes: low, medium, and high risks. A low risk is defined by well-known technologies and methods that are widely applied on a commercial scale and are familiar to local operators. Technologies and methods that are globally known but have never or rarely been applied within the country or in similar projects bear a medium risk. Newly developed technologies and methods or those applied in other fields and whose applications in the mining sector and/or on a commercial scale are still limited have a high risk.

- *Price volatility.* Price volatility represents market and economic risks. The price of mineral fluctuates over time. It can critically affect the return on investment of a project, particularly when it drops lower than expected. Higher volatility implies, in the worst case, a higher risk to attaining the expected profit. Price volatility is determined by variations in mineral prices over a 10-year period. It is classified into three categories. A variation of 0-<10% is rated as low volatility, 10-30% as medium volatility, and >30% as high volatility. These values are based on the information of a 10-year price volatility of key metals and the ranges of 37-year price variability of key minerals (Humphreys, 2011, p. 63; Mooiman et al., 2016, p. 367).
- *Social conflicts.* Social conflicts influence the investment climate. Such conflicts carry the risk of expropriation due to opposition. A low conflict risk is defined by no opposition or minor concerns, a medium conflict risk by the presence of minor opposition groups but with the majority giving consent to the project, and a high conflict risk by the presence of strong opposition groups or a large number of active protesters.
- *Company's reputation.* A company's reputation reflects its previous performance and can produce risks due to a lack of trust and a negative public attitude towards the company. According to the Harris Poll (2017), which measures the reputations of companies in the U.S., corporate reputation is determined by six dimensions, namely, social responsibility, vision and leadership, financial performance, products and services, emotional appeal, and workplace environment. These aspects are simplified into four indicators as follows. Their ratings are aggregated by a weighted sum using an equal weight of 0.25.
    - *Community's trust.* Community trust is gained by past performances in social relations. If a company was involved in any related scandals or legal violations during the last 3 years, it is less trustworthy and is rated as a high risk. If the company was not involved in any scandals or legal violations

during the last 3 years but had problems within the last 10 years, it is moderately trustworthy and is rated as a medium risk. If the company was not involved in any scandals or legal violations during the last 10 years or is newly founded, a low risk rating is applied.

- *Environmental performance.* Environmental performance reflects the past performance in environmental management. If a company was involved in any related scandals or legal violations during the last 3 years, it is less trustworthy and gets a high risk rating. If the company was not involved in any scandals or legal violations during the last 3 years but had problems within the last 10 years, it is moderately trustworthy and gets a medium risk rating. If the company was not involved in any scandals or legal violations during the last 10 years or is newly founded, a low risk rating is applied.
- *Financial performance.* Financial performance is evaluated by the past performance on shareholder returns. A net profit margin is used to determine the company's financial performance. In principle, a higher net profit margin means better performance, but the preferable value also depends on business types. The criteria for this assessment are selected based on the information from the investor's perspective. Mobius suggests that an investment is interesting if its net profit margin is higher than 10% (Serkin, 2015, p. 25). Dunn (2004, p. 20) suggests that a 5% net profit margin is acceptable, 15% is great, and 20% is outstanding. The values of 5% and 15% are selected as cut-offs. A net profit margin of >15% is rated as high performance, thus a low risk. A value of 5-15% is rated as a medium risk. A value of <5% is rated as a high risk. If the respective company is a start-up, a high risk rating is assigned by default.
- *Employees' trust.* Employees' trust is ascertained by the past performance in workforce relations. If a company was involved in any related scandals or legal violations during the last 3 years, it is less trustworthy and gets a high risk rating. If the company was not involved in any scandals or legal violations during the last 3 years but had problems within the last 10 years, it is moderately trustworthy and is rated as a medium risk. If the company was not involved in any scandals or legal violations during the last 10 years or is a start-up, a low risk rating is applied.

The return on investment is rated in correspondence with the level of the project risk by the following criteria:

- The rate of return of a low risk project that values >15% is rated as a low business failure potential, 5-15% as medium, and <5% as high.
- The rate of return of a medium risk project that values >20% is rated as a low business failure potential, 10-20% as medium, and <10% as high.
- The rate of return of a high risk project that values >25% is rated as a low business failure potential, 15-25% as medium, and <15% as high.

The components and rating criteria for assessing negative impacts of a new mining project are summarized in Appendix A.

5 Case study: the assessment of an underground potash mining project in Thailand

This chapter aims at applying the Buddhist-based assessment framework developed in the previous chapters to an actual mining project. A new underground potash mining project in Thailand, ASEAN Potash Mining, is used as a case study. The chapter consists of four sections. The first section introduces the background information of the project as well as the data for the assessment. The assessment is carried out in sections two to four. In section two and three, the necessity of a mining project development and the negative impacts of the mining project are assessed respectively. In section four, the assessment results are aggregated and summarized.

5.1 Project description

5.1.1 Background

The ASEAN Potash Mining project is a project resulting from a collaboration of the Association of Southeast Asian Nations (ASEAN). The project is located in the Bamnet Narong district, Chaiyapoom province, approximately 300 kilometers from Bangkok, Thailand. The mining lease was granted in February 2015 for 25 years (Department of Primary Industries and Mines, 2015b), covering an area of around 3,800 acres in three sub-districts. The project location is shown in Figure 5.1.

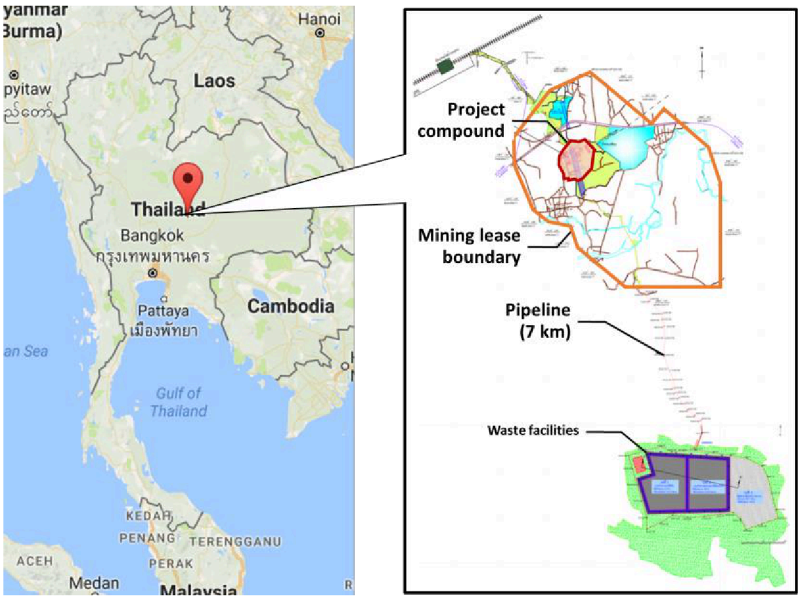


Figure 5.1: Project location and boundary (Adapted from ASEAN Potash Mining PLC, 2014a)

According to the mining plan submitted to the Department of Primary Industries and Mines (ASEAN Potash Mining PLC, 2014a), the mining-related activities in Bamnet Narong began in 1973, when the Department of Mineral Resources conducted an exploration and identified key deposits of rock salt and potash in Northeastern Thailand. Owing to its development potential, the project was approved by the Cabinet to be an ASEAN industrial project in 1989, and the ASEAN Potash Mining Co. Ltd. (APMC) was established in 1991 as a joint-venture of Thailand, Malaysia, Indonesia, the Philippines, Singapore, and Brunei Darussalam and later converted to a public company.

The information in the mining plan indicates that the potash ores in the Bamnet Narong deposit are mostly in carnallite ($KMgCl_3{\cdot}6H_2O$) form. They are found in the Mahasarakham formation of the late Cretaceous age. Given a cut-off grade of 10% KCl and 0.5 meters ore thickness, the resources within the mining lease area were estimated at 67.7 million tonnes KCl (potassium chloride) at an average grade of 15.78% and 211.95 million tonnes NaCl (sodium chloride) at an average grade of 43.78%.

It is further described that the deposit was first developed into a demonstration underground mine in 1990. A 935-meter-long decline access was constructed, and experimental mining was carried out by room and pillar using the long pillar method. However, the project was suspended in 2000 for economic reasons and law amendments. The project was resurrected after the company found strategic investors and applied for a mining lease.

5.1.2 Project's facilities

The mining plan submitted to the governmental agency by ASEAN Potash Mining PLC (2014a, chap. 8) contains the information about the project's facilities, which is summarized as follows. The project area is divided into two zones: the mining zone and the waste storage facility zone (See Figure 5.1). The mining zone is the mining lease area, which covers 1,553 hectares (9,707.2 Rai). The mining lease area covers the entire underground mining area, but not all the land in the mining lease boundary will be developed as a mining compound. An area of 115 hectares (720 Rai) is owned by the company, 53 hectares (334 Rai) of which will be developed for mine access and facilities (including processing plant) and 3 hectares (17 Rai) of which are arranged for the decline access. Wastes will be stored in the waste storage facility zone, located around 7 kilometers northwestern of the mining lease. It covers an area of 444 hectares (2,777 Rai). The storage area is divided into three main sections. The first section is a NaCl waste pile, which covers an area of 98 hectares (610 Rai) and is planned to have a volume of 14.4 million cubic meters. The second section is a brine retaining pond, which covers an area of 93 hectares (580 Rai) and will have a volume of 13.8 million cubic meters. The third section is an extension area of 118 hectares (735 Rai)

5.1.3 Mining and processing methods

The information about the production methods used in the project is mainly obtained from the mining plan submitted to the governmental agency by ASEAN Potash Mining PLC (2014a, chap. 4 and 6). It is estimated that the annual capacity of the underground mining will be 7.8 million tonnes of carnallite ore. The operation will require 2.5 years for development and will reach its full production of around 7.2 million tonnes per year in the sixth production year.

The project will apply a room and pillar mining method and will operate at a depth between 100 and 300 meters below surface. In addition to the existing decline, two vertical shafts with a diameter of 8 meters will be constructed using rock freezing techniques to provide key access to the mine. Then, the main conveyor drifts, consisting of four to six 6x4.5-square-meter drifts in carnallite and lower halite layers, will be developed using continuous miners in order to create access to the production areas and prepare operations. After that the panel conveyor drifts, which will have a similar size to the main conveyor drifts and half of which will be located on either side of the panels, will be developed to connect the production area to the main conveyor drift.

The production will take place in mine panels, each of which covers an area of 450x450 square meters. A panel will contain wall barrier pillars and an extraction area. Wall barrier pillars will be 25 meters wide and 450 meters long and surround the panel for safety purposes. An extraction area will be the operating area of 400x400 square meters surrounded by the safety pillars. Three mining methods will be applied depending on the ore thickness within the panel. The first is the room and pillar method with 15-meter-wide openings separated by 20x20-square-meter pillars as shown in Figure 5.2(a). It will be applied when the ore thickness ranges between 3 and 8 meters. The ore will be extracted either by continuous miners or by drilling and blasting. The second is the room and pillar method with additional benching. The size of openings and pillars will be similar to the first method. However, with benching the extraction will be executed through drilling and blasting. This method will be applied when the ore thickness is between 8 and 15 meters.

The third is the room and pillar with long pillar method. The openings will be 15 meters wide and 400 meters long and intersected by long pillars of 20 meters width and 400 meters length as shown in Figure 5.2(b). The opening development will begin by creating a bottom cut and a top cut with continuous miners, then ore will be extracted from the stope by drilling and blasting. This method will be applied when the ore thickness is more than 15 meters. The opening height will be limited to 25 meters to maintain the pillar's stability. A buffer distance of 150 meters will be applied around the shafts and 50 meters around the old demonstration mine and exploration drill-holes.

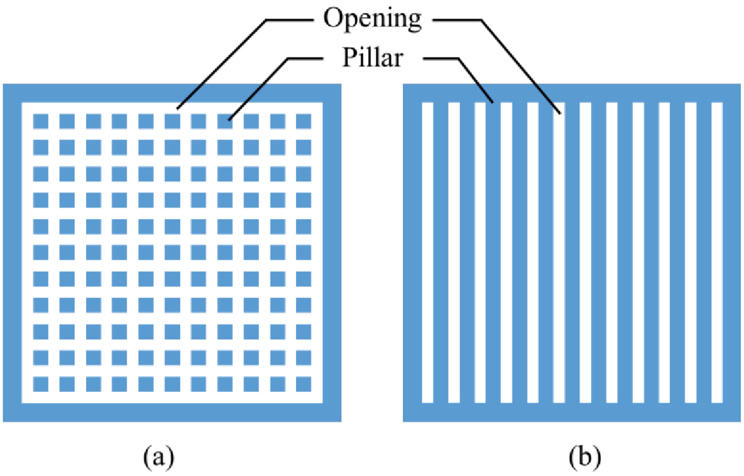


Figure 5.2 Mine panel layouts: (a) room and pillar with and without additional benching and (b) room and pillar with long pillar

Carnallite ore from the panels will be transported by conveyor belts through the drifts to the storage area and later transported to the surface by a pocketlift in the shaft. The run-off mine will be stockpiled before being fed to the processing plant. According to the mining plan, the plant capacity will be 1.1 million tonnes of 95% potassium chloride (KCl). The run-off mine will be processed by a hot crystallization process. The ore will be crushed by hammer mills to reduce the size to less than 5 millimeters and continue to a hot leaching process, in which ores will be dissolved at 105°C and separated from halite and other undissolveable substances. Solution from this stage will be clarified and sent to crystallizers while the gangues will be sent to a tailing storage facility. KCl will be crystallized from the clarified solution by lowering the temperature and is then separated from the remaining solution. The KCl concentrate will be cleaned by a cold leaching to remove sodium chloride (NaCl) and dewatered by hydrocyclones and centrifuges. The clean concentrate will then be dried in a dryer and classified. Concentrate smaller than 10 mesh will be sent to the storage area for blending while concentrate larger than 10 mesh will be crushed, compacted, and re-crushed to generate the granular product in the required size. Then, both products will be transported to the loading points. It is expected that the process has a recovery rate of not less than 90%. The amount of NaCl and that of magnesium chloride ($MgCl_2$) generated as by-products will be approximately 3.3 million tonnes and 2.0 million cubic meters annually during the full production years. Part of the NaCl will be sold but the remaining will be stored in the waste dump and tailing facilities before being used as backfilling materials.

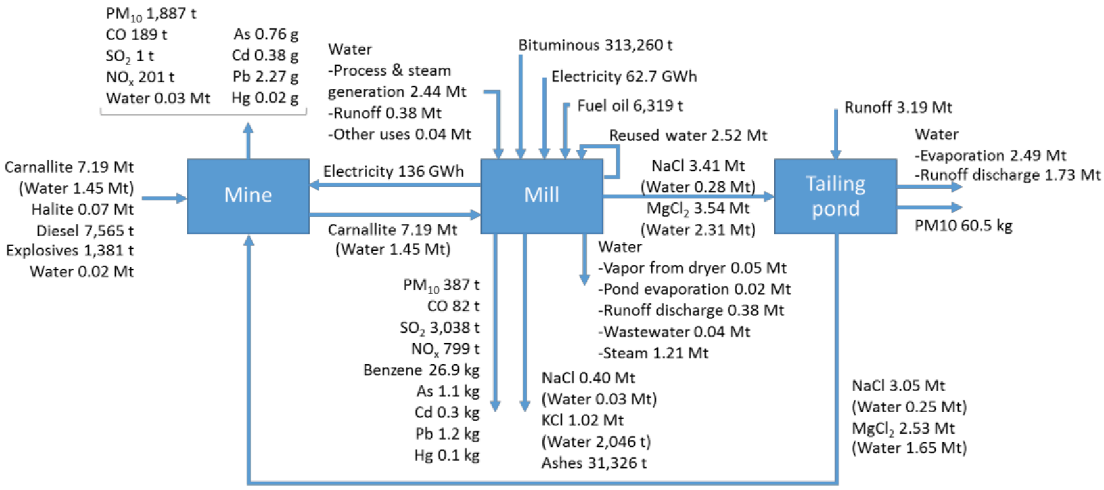
The old mines will be backfilled with tailings from the processing plant, using the hydraulic backfilling method. The operation will take place during the production years 5 to 21. NaCl and $MgCl_2$ will be mixed to create a brine solution, which will be pumped underground and discharged at the old mine panels. The salt will crystallize, and the remaining solution will be drained to the underground brine-retaining pond. Part of the brine will also be reused to create the backfill solution. According to the company's estimation, the ground subsidence induced by mining activities will be limited within the mining lease area, and the maximum vertical displacement will be 16 centimeters.

5.1.4 Data relevant to the mining project assessment

Two sets of data are compiled as a preparation for the assessment, including the project's mass flow and substance flow of potassium in the Thai economy.

5.1.4.1 Project's mass flow

The information in the mining plan about the underground mine, processing plant, and waste storage facility is used to create a mass flow, which will facilitate the assessment related to emissions. The mass flow is characterized by the flows of materials, energy, and water into and out of three main facilities: the underground mine, processing plant, and waste storage facility. The result is shown in Figure 5.3, and the calculation details are given in Appendix B.



Remark: g = gram; kg = kilogram; t = tonne; Mt = million tonnes; GWh = Gigawatt-hour

Figure 5.3: Mass flow of the project's facilities

5.1.4.2 Substance flow of potassium in the Thai economy

The substance flow of potassium in the Thai economy is based on the production, consumption, and trade statistics of potash-related substances. It is partly used in the assessment of mineral service provisions and is important information for the analysis of the assessment result. The flow of potassium in 2012 is shown in Figure 5.4 and Figure 5.5 displays the change that might occur when the mining project is fully operating and its products are introduced to the economy. The calculation details are given in Appendix C.

5.2 Assessment: necessity of mining project development

5.2.1 Service provision

Service provision is determined by three following components.

5.2.1.1 Contribution to domestic demands

Contribution to domestic demands is calculated from the ratio of the annual production rate of the project to current total non-domestic input of the same substance. According to the substance flow data, the non-domestic input of potassium in 2012 was 0.68 million tonnes. The new project will produce products containing 1.03 million tonnes of potassium. However, only 240,000 tonnes can directly replace single fertilizer imports. The ratio, calculated from the expected substitute and the total non-domestic input, values 0.35, so the contribution to domestic demands is assigned a medium rating.

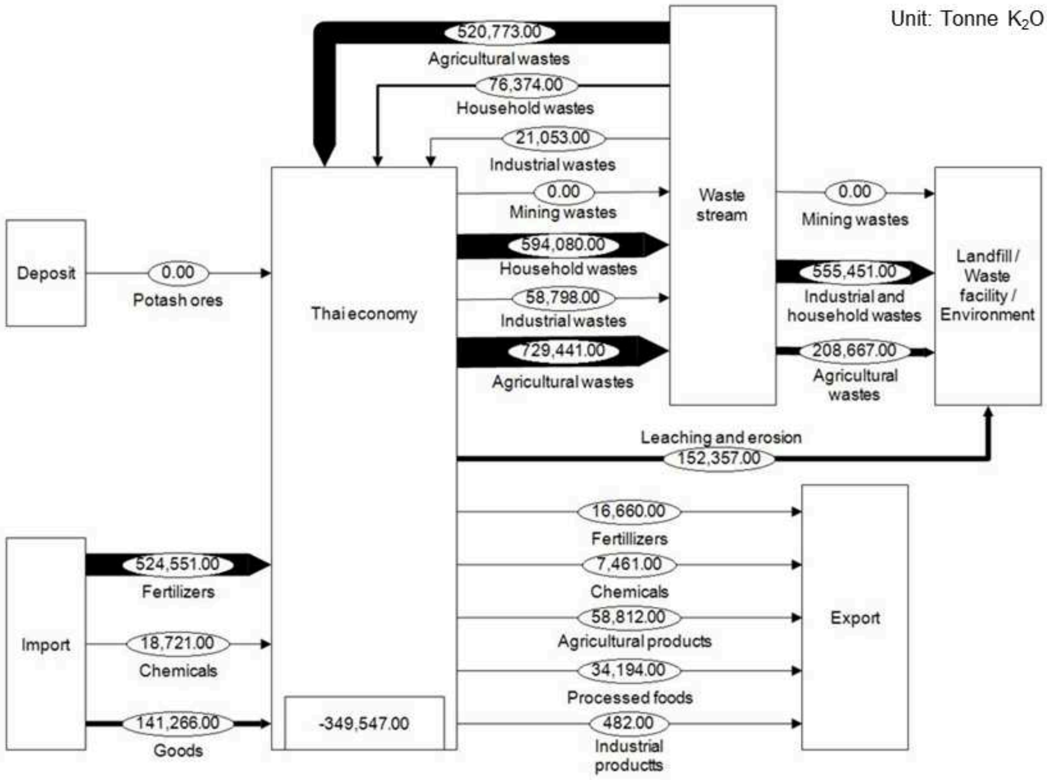


Figure 5.4: Substance flow of potassium in Thailand in year 2012

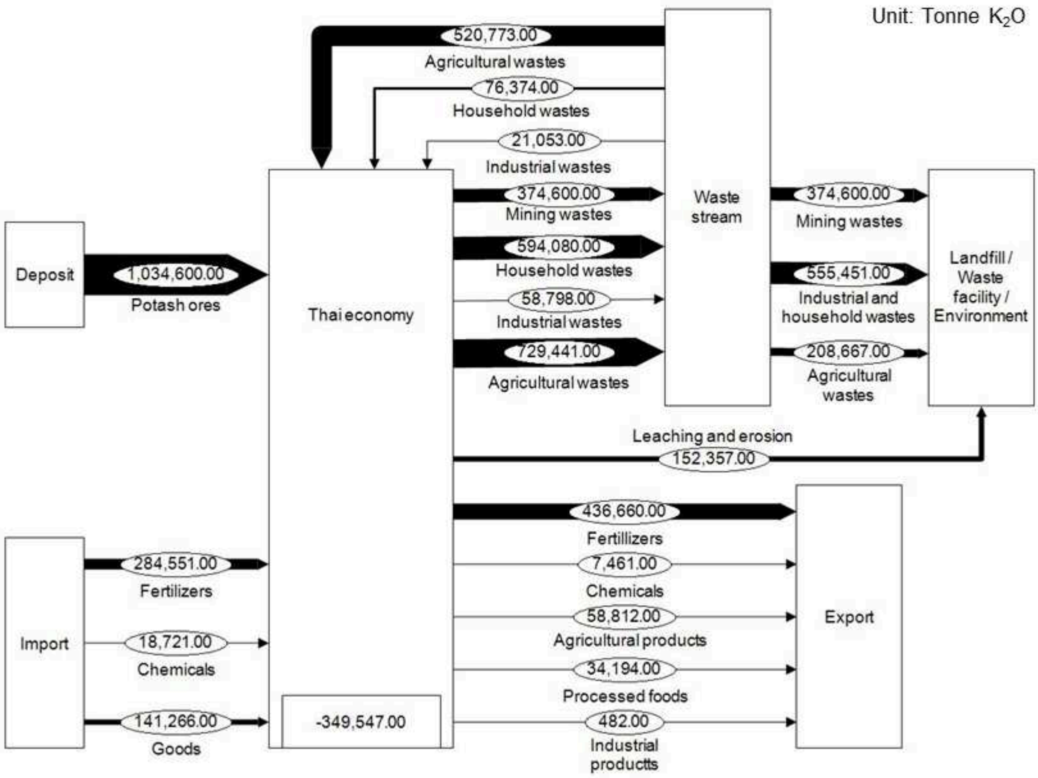


Figure 5.5: Substance flow of potassium in Thailand if the project is operated at full capacity using the data in 2012 as a basis

5.2.1.2 Contribution to end use

Status of current end use. The status of the current end use is calculated from the current share of mineral exports in the total output of the same substance. According to the substance flow data, the potassium exported in minerals in 2012 was 0 tonnes, and the total output was 1.65 million tonnes. Thus, the ratio value 0, indicate the low-export status (high necessity).

Increase in mineral export. The increase in mineral exports is calculated from the ratio of its expected export increase due to the new project in relation to the current mineral export. The mining project plans to export 700,000 tonnes of KCl a year (ASEAN Potash Mining PLC, 2014a, chap. 14), which will result in an additional export of 420,000 tonnes of potassium (K_2O). The potassium in the 2012 export flow amounted to 117,609 tonnes, of which 16,660 tonnes were fertilizer. This resulted in a ratio of 25.2. Applying the criteria for non-bulk minerals, a high increase rating (low necessity) is applied.

Aggregating the ratings of the status of current end use (high necessity) and the increase in mineral export (low necessity) by a weighted sum using an equal weight of 0.5, the contribution to end use is rated as medium.

5.2.1.3 Resource availability

Resource availability is calculated from the ratio of undeveloped resources in the new mining project to available domestic resources of the same mineral. It is reported that the total resource of this project amounted to 67.70 million tonnes KCl (or 429.02 million tonnes ore @ 15.78%KCl) (ASEAN Potash Mining PLC, 2014a, pp. 3–90). The Department of Primary Industries and Mines (2009) indicates that Thailand had a total potash resource of 407,000 million tonnes. Accordingly, the calculated ratio valued 0.001. Applying the criteria for non-bulk minerals, the resource availability (and necessity) is rated as high.

The rating of the contribution to domestic demand is medium, the contribution to end use is medium, and resource availability is high. The aggregated value of these three indicators is 2.33, so the service provision is rated as medium necessity.

5.2.2 Positive contributions of the mining project to society

The positive contributions are assessed from three components as follows:

5.2.2.1 Positive contributions to workers

The project's contributions to workers are determined by the rate of employment. The calculation of the rate of employment is shown in Table 5.1. The result shows a total employment of 26,110 full-time employees-year, so the level of contributions is rated as high.

Table 5.1: Number of employment

Stage	Number of employees[1]		Period[1] (years) [3]	Adjusted number of employees (persons-year) (([1]x1)+([2]x0.5))x[3]
	Full-time [1]	Non-full time [2]		
Development				
-Shaft sinking		120	2.5	150
-Construction		4,000	2.5	5,000
Operation				
-Mining	526		20	10,520
-Mineral processing	482		20	9,640
Closure				
-Shaft closure	50		5	250
-Deconstruction	100		3	300
Post-closure	50		5	250
Total				**26,110 (high)**

Remarks: [1]ASEAN Potash Mining PLC (2014a, pp. 4-204-4–208)

5.2.2.2 Positive contributions to communities

The positive contributions of the project to communities are assessed by the following components.

(1) Access to water

Likelihood. According to the mining plan (ASEAN Potash Mining PLC, 2014a, chap. 10), this project plans to tap water from the Lam Kan Choo reservoir, which is 26 kilometers away, and store it in the nearby Bueng Talae See Dor lake. Because the current condition of the Bueng Talae See Dor lake is not suitable for use, the company plans to deepen it over an area of 300 Rai (48 hectares) to increase its capacity by 0.70 million cubic meters, which will remain available for public use after the mine closes. This additional water storage capacity is rated as medium likelihood.

Consequence. Because the lake is small, the number of people that might benefit from the increased water storage capacity is estimated from the population in the neighborhood of the pond (1-kilometer radius). The villages located within a range of 1 kilometer of the lake and their population are summarized in Table 5.2. The number of the people who will benefit is 2,536, so the consequence is rated as medium.

Having medium likelihood and medium consequence, the contribution to the community's water access is rated as a medium contribution.

Table 5.2: Number of people who will benefit from the incrased water storage capacity

Village		Sub-district	Household	Average population per household	Population
Village number	Village name				
8	Ban Kok Pet	Ban Tan	81	3.51	284
11	Ban Hua Bueng	Ban Tan	78	3.51	274
1	Ban Hua Talae	Hua Talae	167	3.61	603
4	Ban Nong Pradoo	Hua Talae	260	3.61	939
11	Ban Hua Talae	Hua Talae	121	3.61	437
Total			707		2,536

Source: ASEAN Potash Mining PLC (2014b, pp. 3-223-3–245)

(2) Access to forest

Likelihood. The likelihood of better access to forests is determined by an increase in forest area. Originally, there was no forest within the mining lease area and 1.4 hectares of forest within the waste facility area. The forest in the waste facility area will be replaced by the facility. However, the company plans to reforest the entire waste area (308 hectares) when the mine closes (ASEAN Potash Mining PLC, 2014b, pp. 3–194). The area expected to gain from reforestation equals 306.6 hectares, so the likelihood is rated as high.

Consequence. The number of people that might benefit from an increased forest area is estimated from the population in the vicinity of the waste storage facility (1-kilometer radius). The villages located within a range of 1 kilometer of the waste facility area and their population are summarized in Table 5.3. The number of people who might benefit is 2,076, so the consequence is rated as medium.

Table 5.3: Number of people who will benefit from the incrased forest area

Village		Sub-district	Household	Average population per household	Population
Village number	Village name				
6	Ban Kok Saew	Hua Talae	147	3.61	531
7	Ban Nong Dong	Hua Talae	124	3.61	448
1	Ban Nong Nae	Nong Krad	118	4.05	478
3	Ban Nong Krad	Nong Krad	153	4.05	620
Total			542		2,076

Source: ASEAN Potash Mining PLC (2014b, pp. 3-223-3–245)

Having a high likelihood and a medium consequence, the contribution to the community's forest access is rated as a high contribution.

(3) Access to financial resources

Likelihood. Likelihood is calculated from the ratio of the expected annual revenue from mineral royalty allocated to the local administration organizations in comparison to the revenues of the same organizations before the mining project was started. The project feasibility study estimated that the average amount of money remunerated to the government between the 6th and 17th year (full production period) would be 33.5 million

USD (ASEAN Potash Mining PLC, 2014a, pt. Appendix I-2), of which 20% or 6.7 million USD would be allocated to three Sub-district Administration Organizations in which the mining lease is located, namely, the Hua Talae, Ban Tan, and Ban Pet sub-districts. These three local administration areas had a total revenue of 6.5 million USD in 2015 (34.25 USD/Baht) (Bank of Thailand, 2016; Department of Local Administration, 2016). This results in a ratio of due revenue to a current revenue of 1.03, which is rated as high allocation.

Consequence. The population size in the respective area of the three main Sub-district Administration Organizations in 2015 was 21,282 (Department of Public Administration, 2016). As a result, the consequence is rated as high.

Both the amount of due revenue and the number of affected people are rated as high, so the mining contribution to the community's access to financial resources is rated as high.

(4) Access to infrastructure

In the mining plan (ASEAN Potash Mining PLC, 2014a) and the environmental impact assessment (EIA) report (ASEAN Potash Mining PLC, 2014b, pp. 3-223-3–245), the company does not state any plan for investment in public infrastructure. The main construction will be only for internal use. Thus, this topic is rated as irrelevant (score = 0).

(5) Access to healthcare

The population within a range of 5 kilometers from the project compound and the waste facility is 22,084 (high). This number is estimated from the number of households and the average number of members per household in related sub-districts using the data in the environmental impact assessment (EIA) report (ASEAN Potash Mining PLC, 2014b, pp. 3-223-3–245). The details are shown in Table 5.4. The number of medical staff is 76. It is estimated from the number of doctors, dentists, and nurses in public health facilities within an approximate range of 5 kilometers from the project compound and the waste facility from the database of the Ministry of Public Health (2016b). The details are shown in Table 5.5. According to the EIA report, the company plans to arrange a mobile healthcare unit for the community and first-aid staff for the workers. The project will hire 1,008 full-time workers during its operation. Assuming a number of additional medical staff of three and 80% of non-local employees, the ratios of population and medical staff before and after the presence of the mining project will be 290.6:1 and 289.8:1. This marks a change of -0.3%, so the contribution to healthcare access is rated as irrelevant (i.e. no contribution because the change is negative).

Table 5.4: Population within 5 kilometers of the project compound and the waste facility

Village number	Village name	Sub-district	District	Household	Population/ household	Population
Moo 1	Ban Hua Bueng	Ban Tan	Bamnet Narong	218	3.51	764.2
Moo 2	Ban Tha Sala	Ban Tan	Bamnet Narong	115	3.51	403.1
Moo 3	Ban Kratoom Pra	Ban Tan	Bamnet Narong	77	3.51	269.9
Moo 4	Ban Tan	Ban Tan	Bamnet Narong	170	3.51	595.9
Moo 5	Ban Wang Ka Arm	Ban Tan	Bamnet Narong	189	3.51	662.5
Moo 8	Ban Kok Pet	Ban Tan	Bamnet Narong	81	3.51	283.9
Moo 9	Ban Nong Yai Bood	Ban Tan	Bamnet Narong	75	3.51	262.9
Moo 11	Ban Hua Bueng	Ban Tan	Bamnet Narong	78	3.51	273.4
Moo 12	Ban Tan Pattana	Ban Tan	Bamnet Narong	113	3.51	396.1
Moo 1	Ban Hua Talae	Hua Talae	Bamnet Narong	167	3.61	603.0
Moo 2	Ban Hua Sa	Hua Talae	Bamnet Narong	188	3.61	678.9
Moo 3	Ban Koom	Hua Talae	Bamnet Narong	219	3.61	790.8
Moo 4	Ban Nong Pradoo	Hua Talae	Bamnet Narong	260	3.61	938.9
Moo 5	Ban Kao Din	Hua Talae	Bamnet Narong	223	3.61	805.3
Moo 6	Ban Kok Saew	Hua Talae	Bamnet Narong	147	3.61	530.8
Moo 7	Ban Nong Dong	Hua Talae	Bamnet Narong	124	3.61	447.8
Moo 8	Ban Kao	Hua Talae	Bamnet Narong	168	3.61	606.7
Moo 9	Ban Non Sang	Hua Talae	Bamnet Narong	127	3.61	458.6
Moo 10	Ban Hua Sapan	Hua Talae	Bamnet Narong	79	3.61	285.3
Moo 11	Ban Hua Talae	Hua Talae	Bamnet Narong	121	3.61	436.9
Moo 12	Ban Hua Sa Mai	Hua Talae	Bamnet Narong	120	3.61	433.3
Moo 4	Ban Kok Sawang	Ban Pet	Bamnet Narong	226	3.27	738.0
Moo 5	Ban Kloy	Ban Pet	Bamnet Narong	117	3.27	382.1
Moo 6	Ban Tong Kam Ping	Ban Pet	Bamnet Narong	170	3.27	555.1
Moo 8	Ban Nong Kok	Ban Pet	Bamnet Narong	161	3.27	525.8
Moo 9	Ban Don Ta Ying	Ban Pet	Bamnet Narong	75	3.27	244.9
Moo 12	Ban Kok Faek	Ban Pet	Bamnet Narong	107	3.27	349.4
Moo 13	Ban Non Tong Lang	Ban Pet	Bamnet Narong	70	3.27	228.6
Moo 15	Ban Kam Ping Pattana	Ban Pet	Bamnet Narong	156	3.27	509.4
Moo 18	Ban Kok Sawang Wattana	Ban Pet	Bamnet Narong	137	3.27	447.4
Moo 22	Ban Sawang Sri Pattana	Ban Pet	Bamnet Narong	187	3.27	610.7
Moo 4	Ban Hin Tang	Ban Chuan	Bamnet Narong	138	4.12	568.0
Moo 1	Ban Na	Ban Kham	Jaturad	267	4.12	1,098.9
Moo 2	Ban Kham	Ban Kham	Jaturad	194	4.12	798.4
Moo 3	Ban Nong Look Chang	Ban Kham	Jaturad	103	4.12	423.9
Moo 1	Ban Nong Nae	Nong Krad	Dan Khun Tod	118	4.05	478.1
Moo 3	Ban Nong Krad	Nong Krad	Dan Khun Tod	153	4.05	619.9
Moo 1	Ban Nong Bua Kok	Ban Praeng	Dan Khun Tod	122	3.58	436.3
Moo 2	Ban Fai Boad	Ban Praeng	Dan Khun Tod	134	3.58	479.2
Moo 3	Ban Non Sa-Ard	Ban Praeng	Dan Khun Tod	155	3.58	554.3
Moo 9	Ban Nong Prue	Ban Praeng	Dan Khun Tod	185	3.58	661.6
Moo 12	Ban Samnak Piman	Kood Piman	Dan Khun Tod	113	3.94	445.6
Total				6,147		22,084

Source: ASEAN Potash Mining PLC (2014b, pp. 3-223-3–245)

Table 5.5: Number of medical staff in the healthcare facility located within 5 kilometer of the mining compound and the waste facility

Name	Location	Doctor	Dentist	Nurse
Sub-district hospital Hua Talae	Bamnet Narong, Chaiyapoom	-	-	1
Sub-district hospital Ban Kao Din	Bamnet Narong, Chaiyapoom	-	-	1
Bamnet Narong Hospital	Bamnet Narong, Chaiyapoom	7	3	55
Sub-district hospital Ban Tan	Bamnet Narong, Chaiyapoom	-	-	1
Sub-district hospital Nong Ee Lor	Bamnet Narong, Chaiyapoom	-	-	1
Sub-district hospital Ban Kham	Jaturad, Chaiyapoom	-	-	2
Sub-district hospital Ban Chuan	Bamnet Narong, Chaiyapoom	-	-	1
Sub-district hospital Chiwa Sutto	Jaturad, Chaiyapoom	-	-	1
Sub-district hospital Nong Krad	Dan Khun Tod, Nakon Ratchasima	-	-	1
Sub-district hospital Kood Piman	Dan Khun Tod, Nakon Ratchasima	-	-	2
Total		7	3	66

Source: Ministry of Public Health (2016b)

(6) Access to education

The current number of students and teachers in primary and secondary schools within a range of 5 kilometers from the project compound and the waste storage facility are 4,449 and 300, respectively. (See Table 5.6) According to the company's report, the company implemented a campaign to teach mental arithmetics to students in three primary schools (ASEAN Potash Chaiyaphum PLC, 2016). Additionally, the project will hire 1,008 full-time workers during its operation. Assuming three full-time teachers and an 80% share of non-local employees and one additional student for every four employees, the ratios of student and teacher before and after the presence of the mining project will be 14.8:1 and 15.4:1. This marks a change of -3.5%, so the contribution to the community's education access is rated as irrelevant (i.e. no contribution because the change is negative)

Table 5.6: Number of students and teachers in the primary and secondary schools located within 5 kilometers of the mining compound and the waste facility areas

School	Location			No. of teachers	No. of students
	Sub-district	District	Province		
Banna	Ban Kham	Jadturad	Chaiyapoom	5	62
Nonglukchang	Ban Kham	Jadturad	Chaiyapoom	5	80
Banpakotakor	Ban Chuan	Bamnet Narong	Chaiyapoom	11	189
Hintungpittayakon	Ban Chuan	Bamnet Narong	Chaiyapoom	4	48
Huatale	Ban Tan	Bamnet Narong	Chaiyapoom	11	158
Bantan	Ban Tan	Bamnet Narong	Chaiyapoom	8	91
Wangkaam	Ban Tan	Bamnet Narong	Chaiyapoom	5	56
Bankoksawang	Ban Pet	Bamnet Narong	Chaiyapoom	8	126
Nongkoksamakkee	Ban Pet	Bamnet Narong	Chaiyapoom	5	52
Chumchonbanphet	Ban Pet	Bamnet Narong	Chaiyapoom	19	487
Chumchonbanhnongwang	Ban Pet	Bamnet Narong	Chaiyapoom	13	212
Bannongphakwan	Ban Pet	Bamnet Narong	Chaiyapoom	27	584
Tongkumpingvitaya	Ban Pet	Bamnet Narong	Chaiyapoom	5	57
Huasrawittaya	Hua Talae	Bamnet Narong	Chaiyapoom	14	205
Khaodinpittayaruk	Hua Talae	Bamnet Narong	Chaiyapoom	6	71
Bankum	Hua Talae	Bamnet Narong	Chaiyapoom	10	102
Bannongdong School	Hua Talae	Bamnet Narong	Chaiyapoom	6	42
Nongpradoo Witthaya	Hua Talae	Bamnet Narong	Chaiyapoom	6	65
Bankhoksawae	Hua Talae	Bamnet Narong	Chaiyapoom	5	58
Banmaisrisook	Nong Krad	Dan Khun Tod	Nakon Ratchasima	5	63
Watnongkrad	Nong Krad	Dan Khun Tod	Nakon Ratchasima	16	233
Bannongnae	Nong Krad	Dan Khun Tod	Nakon Ratchasima	2	30
Bannongprue	Ban Praeng	Dan Khun Tod	Nakon Ratchasima	15	169
Banfaiboad	Ban Praeng	Dan Khun Tod	Nakon Ratchasima	6	83
Bang Amphan Witthayakhom	Ban Tan	Bamnet Narong	Chaiyapoom	17	226
Petpittayasan	Ban Pet	Bamnet Narong	Chaiyapoom	36	453
Nongkradwattana	Nong Krad	Dan Khun Tod	Nakon Ratchasima	30	447
Sum				300	4,449
Ratio of student to teacher				14.83:1	

Source: Office of the Basic Education Commission (2016)

To summarize, the contributions of mining to access to water, forest, financial resources, infrastructure, healthcare, and education are rated as medium, high, high, irrelevant,

irrelevant, and irrelevant. Aggregating these values by a weighted sum at an equal weight of 0.17 yields the value of 1.33, so the level of mining contributions to communities is low.

5.2.2.3 Positive contributions to the environment

Likelihood. The likelihood of ha5bitat gains is determined by an increase in forest area. The area expected to gain from reforestation was estimated in 5.2.2.2(2). The increased area equals 306.6 hectares, so the likelihood is rated as high.

Consequence. The density and the vulnerability of animal species found in the project area and the calculation of the consequence (presence of species) are shown in Table 5.7. The presence of species in the mining lease and the waste storage facility areas is rated as low.

Table 5.7: Presence of species in the mining lease and the waste facility areas

Vulnerability	Vulnerability rating	No. of species[1]			Adjusted no. of species	Rating
		LA	MA	HA		
Mining lease						
Unthreatened species	1	65	19	35	69.2	Low
Potentially threatened species	2	4	1	0	2.0	Low
Threatened species	3	3	0	0	1.0	Low
Average using vulnerability rating as weights						Low
Waste storage facility						
Unthreatened species	1	49	15	22	48.2	Low
Potentially threatened species	2	2	0	0	0.7	Low
Threatened species	3	0	0	0	0.0	Irrelevant
Average using vulnerability rating as weights						Low

Remarks: [1]ASEAN Potash Mining PLC (2014b, pp. 3-128-3–192)
LA = low abundance (weight = 0.33)
MA = medium abundance (weight = 0.67)
HA = high abundance (weight = 1)

The likelihood of habitat gain is rated as high while the consequence is rated as low, so the level of mining contributions to the environment is rated as medium.

The level of the positive contributions to workers is rated as high, to the community as low, and to the environment as medium. The aggregated value of these ratings is 2, so the positive contributions of the mining project is rated as medium.

The rating of the service provision is medium, and that of the positive contribution is medium. The aggregated value of both components using the weight of 0.67 and 0.33 respectively is 2, so it is rated as a medium necessity.

5.3 Assessment: negative impacts of the mining project

The negative impacts of the mining project on four stakeholder groups are assessed as follows.

5.3.1 Negative impacts on workers

The negative impacts on workers are those of occupational diseases, harmful working conditions, and accidents.

5.3.1.1 Occupational diseases

The impacts of occupational diseases are evaluated from those of respiratory diseases, noise-induced hearing loss, and musculoskeletal disorders.

(1) Respiratory diseases

Likelihood. The release of respiratory hazards is considered from three releasing units: mine, processing plant, and waste storage facility, as shown in the information in the mass flow. The aggregated rating of the released hazards in the mine is medium, in the processing plant is medium, and in the waste facility is low. Their details are summarized in Table 5.8.

Table 5.8: Release of respiratory hazards from the project's facilities

Hazard	Unit	Rating			Mine		Processing plant		Waste facility	
		Low	Medium	High	Value	Rating	Value	Rating	Value	Rating
Respirable dust	kg/ year	<456	456-913	>913	1.9×10^6	High	0.4×10^6	High	60.5	Low
Silica dust (crystalline silica)	kg/ year	<2.3	2.3-4.6	>4.6	-	-	-	-	-	-
Coal dust (>5% respirable quartz)	kg/ year	<9.1	9.1-18.3	>18.3	-	-	-	-	-	-
Nitrogen dioxide	kg/ year	<547	547-1,095	>1,095	0.2×10^6	High	0.8×10^6	High	-	-
Sulfur dioxide	kg/ year	<1,186	1,186-2,373	>2,373	1.0×10^3	High	3.0×10^6	High	-	-
Carbon dioxide	t/year	<821	821-1,643	>1,643	-	-	-	-	-	-
Carbon monoxide	t/year	<5	5-10	>10	189	High	82	High	-	-
Asbestos	Tfiber/ year	<9.1	9.1-18.3	>18.3	-	-	-	-	-	-
Radon progeny	MJ-h/ year	<1.3	1.3-2.6	>2.6	-	-	-	-	-	-
Heavy metals										
Arsenic	kg/ year	<0.9	0.9-1.8	>1.8	7.6×10^4	Low	1.1	Med	-	-
Cadmium	g/ year	<183	183-365	>365	0.38	Low	325	Med	-	-
Lead	kg/ year	<4.6	4.6-9.1	>9.1	2.3×10^3	Low	1.2	Low	-	-
Mercury	kg/ year	<2.3	2.3-4.6	>4.6	2.0×10^5	Low	0.09	Low	-	-
Average of all hazards (Weighted sum using equal weight)					2.0	Med	2.25	Med	1.0	Low

Consequence. The adjusted number of workers exposed to hazards in the mine is 386, in the processing plant 259, and in the waste facility 28. Thus, their consequence ratings are high, high, and medium, respectively. The calculation and rating details are shown in Table 5.9.

Table 5.9: Number of workers adjusted by exposure period

No.	Group (by exposure)	Description	No. of workers per day[1] [1]	Exposure score [2]	Consequence [1] x [2] [3]
Mine					
1	Operator	Miner	196	1	196
2	Maintenance and supporting staff	Backfill operator, technician, surveyor, mine controller, safety staff, assistant manager, foreman	258	0.67	172
3	Engineer and manager	Engineer, senior surveyor, manager	54	0.33	18
4	Services staff	Services-related staff, procurement staff, computer staff	18	0	0
Sum			526		386 (high)
Processing plant					
1	Operator	Operator	128	1	128
2	Maintenance and supporting staff	Maintenance, general services, transport, and supporting works	190	0.67	126.7
3	Engineer and manager	Quality control and laboratory	13	0.33	4.3
4	Services staff	Executive, services	123	0	0
Sum			454		259 (high)
Waste storage facility					
1	Operator	Tailing management	28	1	28
Sum			28		28 (medium)

Remarks: [1]ASEAN Potash Mining PLC (2014a, pp. 4-204-4–208)

In the mine, the likelihood is rated as medium and the consequence as high. This results in a high impact level. In the processing plant, the likelihood is rated as medium and the consequence as high. Thus, the impact level is high. In the waste storage facilities, the likelihood is rated as low and the consequence as medium. The impact level is thus medium. Summing up the impact ratings of these three facilities (high, high, and medium) using the number of workers as weights yields the value 2.96, so the impact of respiratory diseases on workers is rated as high.

(2) Noise-induced hearing loss

Noise levels are assessed in three operation areas: mine, processing plant, and waste storage facility. The noise in the areas of these units are classified according to the noise intensity into three zones based on the information in literature and machine specifications such as Atlas Copco (2010), Bauer and Kohler (n.d.), JEMA Agro (2006), McBride (2004), and U.S. Department of Transportation (2006).

Mine. Key areas and activities in the underground mine include the shaft transport, exploration, tunneling development and maintenance, extraction, the store and control room, inside transport vehicles, non-active openings, pumping stations, maintenance, and backfilling. The store and control room, inside transport vehicles, pumping stations, non-active openings, backfilling, and the shaft transport are low noise intensity areas. The maintenance area and exploration drilling area are medium noise intensity areas. The extraction area and tunneling development and maintenance area, in which heavy equipment is operated, are high noise intensity areas.

Processing plant. The mineral processing consists of 15 stages, including raw ore storage, ore crushing, hot leaching, hot clarification, KCl crystallization, mother liquor separation, brine storage, synthetic carnallite crystallization, surplus mother liquor evaporation, $MgCl_2$ brine separation, synthetic carnallite decomposition, cold leaching and product dewatering, product drying, product compaction, and product storage (ASEAN Potash Mining PLC, 2014a, chap. 6). Like the underground mine, the plant area is classified into three noise-level zones. The brine processing area, which mainly works with pumping systems, as well as the control room are considered low noise intensity areas. The potash and rock salt handling and stockpiling areas, where noise is generated from belt conveyors, spreaders, and scrapers are considered medium noise intensity areas. The areas with milling, crushing, and screening as well as conveyor transfer points are high noise intensity areas.

Waste facility. The waste storage facility is composed of two connecting parts - the waste pile and brine retaining pond. Tailing brine is transported to and from the tailing dam through pipelines, and solid tailing (mainly NaCl) is handled to and from the waste pile by belt conveyors. The brine retaining pond area, which mainly works with a pumping system, is a low noise intensity area. The waste pile area, where noise is generated from belt conveyors, spreaders, and scrapers, is a medium noise intensity area.

The assessment of the impact of noise-induced hearing loss is shown in Table 5.10. The average impact rating of noise-induced hearing loss on workers is rated as medium.

(3) Musculoskeletal disorders

According to the machinery list, the project does not employ any hand-held vibration tools and involves only the vibration of mobile equipment.

The impact of whole-body vibration is determined by the vibration of mobile equipment used in the project and the number of workers exposed to mobile equipment. The details of the assessment are shown in Table 5.11. The average impact of musculoskeletal disorders on workers is rated as medium.

Table 5.10: Assessment of the impact of noise-induced hearing loss on workers

	No. of workers[1]			
	Low exposure	Medium exposure	High exposure	Total
Mine				
Mining, backfilling, and exploration staff[2]	61	21	195	277
Maintenance and supporting staff			177	177
Engineers and managers		54		54
Services staff	18			18
Processing plant				
Operator[3]		102	26	128
Maintenance and supporting staff			190	190
Engineers and managers		13		13
Services staff	123			123
Waste facility				
Operator[4]	14	14		28
Sum	216 (Medium)	204 (Medium)	588 (Medium)	1,008
Impact rating	1.41 (Low)	2 (Medium)	2.45 (High)	
Weighed average of all groups using no. of worker as weights	2.37 (Medium)			

Remarks:
[1] ASEAN Potash Mining PLC (2014a, pp. 4-204-4–208)
[2] Estimated from machinery list
[3] Assuming 80% and 20% of the worker are moderately and highly exposed to noise, respectively because the processing plant deals mainly with pumping and liquid processing
[4] Assuming 50% of the worker are lowly and moderately exposed to noise because the brine management deals mainly with pumping while the salt is handled by conveyors and excavating equipment

Table 5.11: Assessment of the impact of whole-body vibration on workers

Equipment[1]	Equipment[2] (unit)	Likelihood	Consequence		Impact [2]
		Vibration level	Number of workers/day [1][2]	Rating	
Mine					
Low vibration equipment	Continuous miner (6), crane (2), and other site vehicles[3] (29)	Low	111	Medium	Low
Medium vibration equipment	Fork Lift (14) and roof bolter (4)	Medium	54	Medium	Medium
High vibration equipment	Drilling machine (14), scoop tram (LHD) (10), and roof cutter and scaling vehicle (9)	High	99	Medium	High
Weight average (sum of [1] x [2]) / sum of [1]					1.95 (Medium)

Remarks:
[1] Classified by Chaudhary et al. (2015); Eger et al. (2013); Mandal et al. (2013); Scarlett and Stayner (2005, p. 10 and 13); Teschke et al. (1999)
[2] Based on equipment and employee lists in ASEAN Potash Mining PLC (2014a, chap. 4)
[3] Other site vehicles include only the vehicles regularly used during the operation. Personnel transporters are not included.

The rating of the impact of respiratory diseases is high, and the impact of noise-induced hearing loss and musculoskeletal disorders are rated as medium. The aggregated value of these ratings using an equal weight of 0.33 is 2.33, so the level of the impacts of occupational diseases on workers is rated as medium.

5.3.1.2 Harmful working conditions

Exposure to heat and a lack of oxygen are assessed as follows.

(1) Exposure to heat

The impact of heat is assessed in the underground mine and above ground operations.

Apparent temperature. The 30-year (1982-2011) average temperature and humidity of Chaiyapoom province are 27.2°C and 69.6% (Thailand's Meteorological Department, 2012). Thus, the apparent temperature in the above-ground working area is around 30°C and plus 9°C for outdoor work (Occupational Safety and Health Administration, n.d.). However, the processing plant has several heat sources, comprising hot leaching units and crystallizers (105°C), evaporators (135°C), dryers, and a co-generation system. The temperatures close to these sources are assumed to be 10°C more than the above-ground apparent temperature (i.e. 40°C). The temperature in the underground mine is affected by air auto-compression, geothermal gradient, heat from diesel equipment and explosives, human metabolism, and thermal water (Torres and Singh, 2011). The effect of these factors are calculated following the explanation in Torres and Singh (2011) as follows.

According to the mining plan, the mine is located around 200 meters under the surface. This means the temperature should elevate by 1.96°C from air auto-compression as the air auto-compression generally raises the temperature by 0.98°C every 100 meters of vertical shaft (Torres and Singh, 2011).

The effect of geothermal gradient (Δt) is calculated from the equation:

$$\Delta t = [\lambda \cdot P \cdot (L-h_n)^2] / [g_g [\lambda \cdot P \cdot (L-h_n)+2000 \cdot \rho_a \cdot C_e \cdot Q]]$$

where, λ = heat transfer coefficient calculated from $k \cdot N_{db}/d$[1], P = perimeter of the underground opening's cross-section (m), L = length affected by geothermal gradient (m), h_n = depth of thermal neutral zone (m), g_g = geothermal gradient (m/°C), ρ_a = air density (kg/m^3), C_e = specific heat of air (kJ/m·°C), Q = air flow rate (m^3/s). The values of λ = 0.1115, P = 70 m, L = 7,000 m, h_n = 15 m, g_g = 40 m/°C, ρ_a = 1.1774 kg/m^3, C_e = 1.0057 kJ/m·°C, and Q = 24,130 m^3/s are used in the formula, yielding the Δt of 0.5°C.

The effect of diesel engine on temperature (Δt) is calculated from the equation:

$$\Delta t = (f_m \cdot f_t \cdot q_d \cdot P_d) / (\rho_a \cdot C_e \cdot Q)$$

where, f_m = mechanical efficiency, f_t = equipment utilization efficiency, q_d = equivalent energy released by diesel fuel (2.9 kW/kW), P_d = equipment power (kW), ρ_a = air density

---

[1] K = thermal conductivity (W/m·°C), N_{db} = Dittus and Boelter coefficient calculated from $[((f/8) \cdot (V \cdot d/\mu) \cdot (\rho_a \cdot C_e \cdot \mu/K))/(1.07+12.7(f/8)^{0.5}(Pr^{0.67}-1))]$, where f=friction coefficient of the underground wall (kg/m^3), V=average air velocity (m/s), d=underground opening diameter (m), μ=air kinematic viscosity (kg/m·s) (Torres and Singh, 2011).

(kg/m^3), C_e = specific heat of air (kJ/m·°C), and Q = air flow rate (m^3/s). Using f_m = 80% (assumed), f_t = 60% (assumed), ρ_a = 1.1774 kg/m^3, C_e = 1.0057 kJ/m·°C, and Q = 24,130 m^3/s in the formula yields the Δt of 0.5°C.

The effect of explosives (Δt) is calculated from the following equation:

$$\Delta t = (E_e \cdot q_e) / (86{,}400 \cdot \rho_a \cdot C_e \cdot Q)$$

where, E_e = calorific energy of explosive (kJ/kg), q_e = amount of explosives (kg/day), ρ_a = air density (kg/m^3), C_e = specific heat of air (kJ/m·°C), and Q = air flow rate (m^3/s). Using E_e = 3,900 kJ/kg (ANFO), q_e = 4,500 kg/day, ρ_a = 1.1774 kg/m^3, C_e = 1.0057 kJ/m·°C, and Q = 24,130 m^3/s in the formula yields the Δt of 0.01°C (which is negligible).

The effect of human metabolism (Δt) is calculated from the equation:

$$\Delta t = (q_h \cdot n) / (\rho_a \cdot C_e \cdot Q)$$

where, q_h = human heat release (kW/person), n = number of worker per shift, ρ_a = air density (kg/m^3), C_e = specific heat of air (kJ/m·°C), and Q = air flow rate (m^3/s). Using q_h = 0.21 and 0.32 kW/person for low and high metabolic groups, n = 119 and 36 for low and high metabolic groups, ρ_a = 1.1774 kg/m^3, C_e = 1.0057 kJ/m·°C, and Q = 24,130 m^3/s in the formula yields the Δt of 0.001°C (which is negligible).

The effect of thermal water is considered as irrelevant because the mine is isolated from groundwater. Together, the air temperature in the underground mine should value around 30.2°C in average. Assuming no change in humidity, the apparent temperature is estimated according to Table 4.3 at approximately 35°C, which is rated as medium temperature (thus likelihood).

Metabolic rate. Activities in the mine, the processing plant, and the waste storage facility are divided into three categories based on the information by Malchaire (n.d.) and Stewart (1981). Low metabolic activities include machine controlling, inspection, fitting, driving, and desk work. Medium metabolic activities comprise equipment installation and destallation and driving or operating machines in difficult conditions. High metabolic activities are rarely carried out in this case because of the use of machinery.

Ventilation. Ventilation in the processing plant is determined by indoor air velocity. Applying the value of 0.25 m/s, which is the standard value for indoor air movement, the effect of ventilation is moderate, and the likelihood of heat exposure is rated as medium. Outdoor ventilation is rated by the wind speed. The 30-year (1982-2011) average wind speed in Chaiyapoom province was 1.8 knots or 0.93 m/s (Thailand's Meteorological

Department, 2012), so the heat exposure likelihood is rated as low. The criteria for air velocity in this underground mine are 0.1-0.3 m/s at the working face. The low value (0.1 m/s) is used for rating. The effect of ventilation is considered low and is rated as a medium likelihood of heat exposure.

The details of the assessment of heat impact on worker are shown in Table 5.12. The impact of heat on workers is rated as medium.

Table 5.12: Assessment of the impact of heat on workers

Worker group	Likelihood							Consequence		Impact [7]
	Apparent temperature		Metabo-lic rate	Air velocity		Sum		No. of worker[1] (men/day)		
	Value	Rating [1]	Rating [2]	Value	Rating [3]	Value $([1]x[2]x[3])^{0.33}$	Rating [4]	Value [5]	Rating [6]	
Underground mine										
-Low meta-bolic activity	35°C	Med	Low	0.1 m/s	Med	1.59	Low	357	High	Med
-Med. meta-bolic activity	35°C	Med	Med	0.1 m/s	Med	2.00	Med	107	Med	Med
Above-ground operation										
-Low meta-bolic activity	30°C	Low	Low	0.25 m/s	Med	1.26	Low	399	High	Med
-Med. meta-bolic activity	30°C	Low	Med	0.25 m/s	Med	1.59	Low	67	Med	Low
-Low meta-bolic activity	40°C	High	Low	0.25 m/s	Med	1.82	Med	64[2]	High	High
-Low meta-bolic activity	39°C	Med	Low	0.93 m/s	Low	1.26	Low	14[3]	Low	Low
Weighted average of all worker groups (sum of ([5] x [7]) / sum of [5]										1.98 (Med)

Remarks:
[1] Based on the workers' information in ASEAN Potash Mining PLC (2014a, pp. 4-204-4–208)
[2] Assuming 50% of the worker at the processing plant operate close to heat sources
[3] Assuming 50% of the worker at the waste facility work outdoor

(2) Lack of oxygen

Likelihood. Likelihood is determined by the presence of asphyxiant gases and ventilation conditions as follows.

- *Presence of asphyxiant gases*
    - *Strata gases.* The exploration report did not state any findings about gas anomalies in the deposit. However, the document of the World Bank (1987, p. 5 and 11) stated that the carnallite deposit "*seemed to be gas-bearing*." The drilling of a shaft pilot hole showed a hydrogen content of about 30%. It was also argued that the opinions on gas problems were based on those of inexperienced staff and only one core sample containing 70 cubic centimeters

of gas per 1,000 cubic centimeters of ore (or approximately 0.04 m^3/t). Despite this uncertainty on the gas issue, the presence of gas is regarded as a possibility, and a rating of low gas content (likelihood) is assigned.

  - *Explosives.* The use of explosives was estimated at 4,500 kilograms per day (ASEAN Potash Mining PLC, 2014a), so gas released from explosives is rated as medium.
  - *Diesel engine.* According to the equipment list, the total power of diesel equipment is 9,650 kilowatts (ASEAN Potash Mining PLC, 2014a). Thus, the presence of gas is rated as medium.

  The presence of strata gases is rated as low, the use of explosives as medium, and the use of diesel engine as medium. The sum of these ratings uses an equal weight of 0.33 and values 1.67, so the presence of ashyxiant gases is rated as medium presence (and likelihood).

- *Ventilation condition.* The mining plan (ASEAN Potash Mining PLC, 2014a, pp. 4–167) states that the air velocity at the underground working face with gas must be maintained at not less than 0.5 m/s. Therefore, the effect of ventilation is considered moderate and is rated as a medium likelihood.

The geometric mean of the rating of the presence of gas (medium) and that of the ventilation condition (medium) is 2, so the likelihood of workers' exposure to gas is rated as medium.

Consequence. The workers that might be exposed to ashphyxiant gases are those operating the exploration and production faces, including the operators of production drilling machines (12 units), continuous miners (6 units), scaling vehicles (2 units), roof-cutting vehicles (5 units), roof-bolter (3 units), load-haul-dumps (9 units), raise-boring units (2 units), exploration drilling units (11 units, 2 persons per unit), as well as inspectors (6 vehicles) and surveyors (5 persons) (Based on ASEAN Potash Mining PLC, 2014a, chap. 4). The number of exposed workers is 216 per day, so the consequence is rated as high.

The geometric mean of the rating of likelihood (medium) and that of consequence (high) is 2.45, so the impact of oxygen deficiency on workers is rated as high.

The impact rating of heat exposure is medium, and that of oxygen deficiency is high. Summating both ratings using the weight of 0.5 for each component yields the value 2.5, which means the impact of harmful working conditions is rated as high.

5.3.1.3 Accidents

Five forms of accidents, namely, fire and explosions, gas outburst, rockburst, an inrush of water or semi-solids, and ground failure are used to measure the impacts of accidents as follows.

(1) Fire and explosions

Likelihood. The presence of fuel, oxygen, and ignition sources determine the likelihood of fire and explosions.

- *Presence of fuel.* The presence of fuel is considered in terms of quantity and sensitivity. Fuels used in the project will consist of diesel for vehicles and mobile equipment, oil and grease for machinery in the mine and processing plant, bituminous coal for cogeneration systems, and explosives for production in the underground mine. Potential gas in the deposit was identified as inflammable gas; therefore, it is not included in the consideration. According to the company's document (ASEAN Potash Mining PLC, 2014b, pp. 5-133-5–134), the project plans to hold a stock of 100,000 liters of diesel and 22,000 kilograms of explosives in the above-ground storage areas and 3,000 kilograms of explosives underground. It is assumed that the diesel tank in the underground mine is 5,000 liters large and 5 containers (1,000 liters) of oil and grease are stored in the warehouse area underground. It is also assumed that 10 containers (2,000 liters) of oil and grease and 3,000 tonnes (3-day stock) of coal are stored above-ground.
- *Presence of oxidizing agent.* Air velocity and the distance of oxidizing agents to flammable substances determine the presence of oxidizing agents.
    - *Air velocity.* Air velocity above ground outdoor is assumed to be equal to wind speed. The 30-year (1982-2011) weather statistics indicate that Chaiyapoom province has an average wind speed of 1.8 knots or 0.93 m/s (Thailand's Meteorological Department, 2012). The above-ground, indoor air velocity is assumed to be 0.25 m/s. The criteria for air velocity in the underground mine are not below 0.1-0.3 m/s at the working face and not more than 6 m/s in the conveyor drift. Accordingly, the presence of oxygen is rated as medium at the above-ground facility, low at the working face, and high at the conveyor drift.
    - *Distance to flammable substance.* An important oxidizing agent besides ventilating air in the mine is compressed air, which is used in mining equipment and maintenance section. According to the facility plan (ASEAN Potash Mining

PLC, 2014a, chap. 8), the maintenance areas above ground and underground are located more than 100 meters away from fuel storage and explosives storage facilities as well as from the production area. As a result, the distance to flammable substances is rated as high for the presence of diesel engines at the fuel and explosive storage facilities and maintenance area and as low for other cases.

- *Presence of ignition source.* Ignition sources include friction in handling and mobile equipment, electrical sparking from electrical equipment and welding, explosives, and spontaneous combustion of coal. These ignition sources are located more than 200 meters away from fuel and explosive storage facilities, so the presence of ignition sources is rated as low.

Consequence. The consequence at different fuel sources are explained as follows.

- *Bituminous coal.* The company's document did not specify the location of the coal storage area. It is assumed that the storage area is next to the cogeneration unit, in which coal is used. The facilities located within 100 meters of the expected coal stockpile consist of shaft building 2 (personnel transport shaft), shower building, cogeneration unit, and main power distribution station. In the worst case, the number of affected workers in the shaft building and the shower building should be equal the number of underground workers in two shifts, which is 302, plus that of the cogeneration unit and main power distribution station. As a result, the consequence is rated as high.
- *Diesel.* A fire or explosion incident at the above-ground diesel storage facility would affect surrounding facilities. The facilities located within 100 meters comprise a lorry garage, water treatment facility, lorry-loading facility, fire extinguishing facility, and product storage buildings. Assuming five workers per facility, the number of workers that might be affected by a fire incident at the diesel tank is 25 persons, which is rated as a medium consequence. In the underground mine, the diesel tank is in an isolated room between the underground office and the cleaning area. Assuming that assistant managers, safety staff, and quality and environmental staff work in the office and that 5 persons work in the cleaning area, the number of affected workers is 22. Accordingly, the consequence of an incident at the underground diesel tank is rated as medium.
- *Oil and grease.* It is assumed that oil and grease are stored in the warehouse, which is located next to the maintenance building and the shaft building 1. The number of maintenance staff in the processing plant is 24 per shift, and that of operators in the

shaft building 1 is estimated at 10 per shift. The consequence is thus rated as medium. In the underground mine, oil and grease is expected to be stored close to the maintenance area. The number of affected workers is estimated from the number of maintenance staff, which is around 30 per shift. Accordingly, the consequence is rated as medium.

- *Explosives.* The above-ground explosive storage area is located in an isolated area, maintaining a distance of more than 100 meters from other facilities. In the underground mine, explosives are stored in an isolated room in the facility area, more than 100 meters away from other facilities. Together with the fact that only limited personnel are allowed to enter the explosives storage area, the number of affected workers, if any incident occurs, is limited and should not exceed 5. Accordingly, the consequence is rated as low for the explosive storage.

Figure 5.6 shows the location of flammable substances and facilities. The assessment details are summarized in Table 5.13. The weighted-average impact rating of fire and explosions on workers indicates a medium impact level.

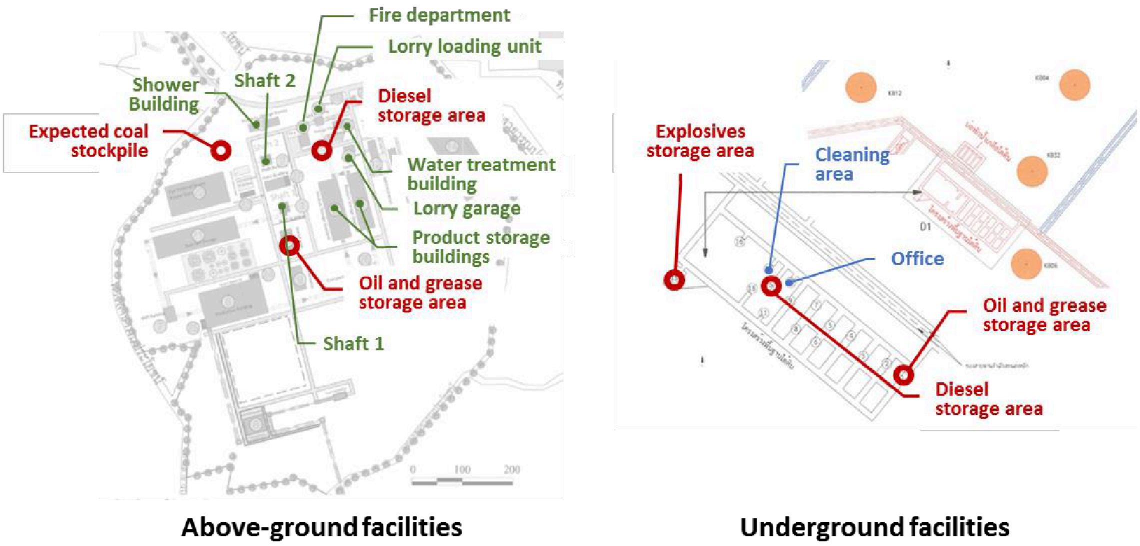


Figure 5.6: Location of flammable substances and facilities (Adapted from ASEAN Potash Mining PLC, 2014a, 2014b, pp. 2–166)

(2) Gas outburst

Likelihood. Likelihood is determined by the presence of gas, geological structure, and mining depth as follows.

Table 5.13: Assessment of the impact of fire and explosion on workers

Fuel	Likelihood								Consequence: No. of worker [9]	Impact $([8]x[9])^{0.5}$ [10]
	Fuel			Oxidizing agent			Ignition source [7]	Sum $([3]x[6]x[7])^{0.33}$ [8]		
	Amount [1]	Sensitivity [2]	Sum $([1]x[2])^{0.5}$ [3]	Air velocity [4]	Distance to fuel [5]	Sum ([4]+[5]) x0.5 [6]				
Mine										
Diesel	201 kg (Med)	High	High	0.1 m/s (Low)	Low	Low	Low	Low	22 (Med)	Low
Oil and grease	900 kg (Med)	Low	Low	0.1 m/s (Low)	Med	Med	Low	Low	30 (Med)	Low
Explosives	3 t (High)	High	High	0.1 m/s (Low)	Low	Low	Low	Low	5 (Low)	Low
Above-ground area										
Bituminous coal	3,000 t (High)	Low	Med	0.25 m/s (Low)	Low	Low	Low	Low	312 (High)	Med
Diesel	85 t (High)	High	High	0.93 m/s (Med)	Low	Med	Low	Med	25 (Med)	Med
Oil and grease	1.8 t (High)	Low	Med	0.25 m/s (Low)	Low	Low	Low	Low	34 (Med)	Low
Explosives	22 t (High)	High	High	0.25 m/s (Low)	Low	Low	Low	Low	5 (Low)	Low
Weighted sum of impact ratings using no. of worker as weights (sum of ([9] x [10]) / sum of [9])										1.77 (Med)

- *Presence of gas.* As mentioned previously, a document of the World Bank (1987, pp. 5, 11) indicated that the deposit "*seemed to be gas-bearing*" and the drilling of a shaft pilot hole showed a hydrogen content of about 30%. However, it was argured that this information might be based on the estimation of inexperienced staff and only one core sample, which contained 70 cubic centimeters of gas per 1,000 cubic centimeters of ore. The gas content of 7% by volume (0.04 m^3/t) is used to represent the worst condition, so the presence of gas is rated as low (a low likelihood).
- *Geological structure.* The geological structure of this project is characterized by evaporite strata, mainly rock salt and potash intervened by clastic and thin clay layers. The structure of the deposit is identified as a concentric zonal deformation, which is formed by the combination of synclines and anticlines (see Figure 5.7) and is considered as the highest degree of folding (Jeremic, 1994, p. 27). Thus, the structure is rated as intensely folded or faulted (a high likelihood).
- *Mining depth.* The mining area is 100 and 300 meters below ground. Since the values range in low and medium depth, the higher value is used for the assessment. Thus, the depth is rated as a medium depth (and likelihood).

The presence of gas is rated as low, the geological structure as high, and the mining depth as medium. The geometric mean of these ratings is 1.82, so the likelihood is rated as medium.

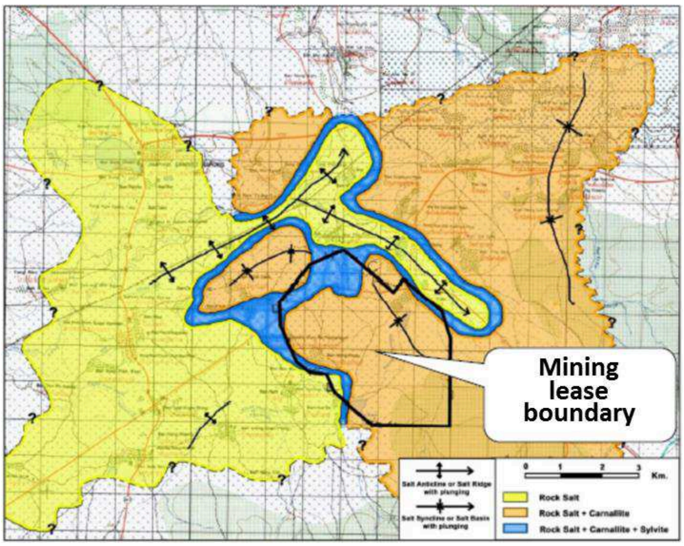


Figure 5.7: Geological structure of Bamnet Narong deposit (ASEAN Potash Mining PLC, 2014a; Suwanich, 2007)

Consequence. The workers at risk of being harmed if an outburst occurs are those operating at the exploration and production faces, including the operators of production drilling machines (12 units), continuous miners (6 units), scaling vehicles (2 units), roof-cutting vehicles (5 units), roof-bolters (3 units), load-haul-dumps (9 units), raise-boring units (2 units), exploration drilling units (11 units, 2 persons per unit) as well as inspectors (6 vehicles) and surveyors (5 persons). The number of exposed workers is 72 per shift, so the consequence is rated as medium.

The likelihood and the consequence are rated as medium. The geometric mean of both ratings is 2, so the impact of a gas outburst on workers is rated as medium.

(3) Rockburst

Likelihood. The likelihood of rockburst is determined by the rock properties and stress in the surrounding rock as follows.

- *Rock properties.* The type of rock and discontinuities determine the rock properties.
    - *Type of rock.* The testing result of the project's rock properties did not contain information about uniaxial compressive strength and tensile strength. Thus, this assessment refers to the carnallitite properties in German literature. The uniaxial compressive strength was 123 kilopound per square centimeters (kp/cm^2), and the tensile strength was 8.1 kp/cm^2 (Gimm and Pforr, 1968, p. 180). The brittleness is equal to 15.2. Consequently, the likelihood of rockburst from the type of rock is rated as medium.

- *Discontinuities.* As explained in the assessment of gas outburst impacts, the structure of the deposit is characterized by the concentric zonal deformation, so the discontinuities are classified as intensely folded or faulted, which is rated as a high likelihood.

The type of rock rating is medium, and discontinuities rating is high. The geometric mean of both ratings is 2.45, so the rock property is rated as high.

- *Stress in surrounding rock.* Stress in the surrounding rock is assessed from the mining depth, opening design, extraction ratio, and advance rate as follows.
  - *Mining depth.* The project operates at a level of 100-300 meters. This level is considered a medium depth and is rated as medium stress.
  - *Opening design.* The tunnel cross section of this project has a rectangular shape. The main conveyor drift is 6.0 meters wide and 4.5 meters high. The ratio between width and height of the opening is thus 1.3, which is rated as medium stress. The production room is 15 meters wide, and its height varies from 5 to 25 meters. The width to height ratio ranges between 0.6 and 3. The highest ratio is used to represent the worst case, so a value of 3 is used in the consideration. The stress due to the opening design is rated as high.
  - *Extraction ratio.* The calculation in the mining plan shows that the resource of potash ores within the project area is 304.2 million tonnes, and their mineable reserve is 117.3 million tonnes. Consequently, the extraction ratio is 38.6%, which is rated as medium.
  - *Advance rate.* The panel is extracted in two patterns: room and pillar and long pillar. In the room and pillar panel, there are 12 production rooms intermitted by 11 pillars between 2 crosscuts. The room and the pillars are 15 and 20 meters wide, respectively. Advancing through 1 pillar and 1 crosscut (35 meters in total) requires a total extraction distance within the panel of 640 meters (35x12 + 20x11). Accordingly, the panel advance rate of 1 meter is equivalent to 18.3 meters linear advance rate. The minimum cross section of the opening is 15 meters wide and 4 meters thick. At the production rate of 1,500 tonnes per hour (capacity of the main conveyor drift) and density of 1.66 tonnes per cubic meters, the linear advance rate is estimated at 15.1 meters per hour or 271 meters per day (assuming 6 working hours per shift), which is equal to a panel advance

rate of 14.8 meters per day. Since the panel advance rate is <15 meters per day, a medium advance rate (and stress) is assigned.

In the long pillar panel, there are 12 production rooms intermitted by 11 long pillars. The room and the pillars are 15 and 20 meters wide, respectively. Advancing through 1 pillar along the whole panel (400 meters) requires a total extraction distance within the panel of 4,800 meters (400x12). Accordingly, a panel advance rate of 1 meter is equivalent to 12 meters (4,800/400) linear advance rate. The minimum cross section of the opening is 15 meters wide and 14 meters high. The panel advance rate is estimated at 22.6 meters per day, which is rated as a high advance rate (and stress).

The high rating is used to represent the stress level caused by the advance rate.

The stress level caused by the mining depth is rated as medium, the opening design as high, the extraction ratio as medium, and the advance rate as high. The geometric mean of these ratings is 2.45, so the stress in the surrounding rock is rated as high level.

Both the rock properties and stress in the surrounding rock are rated as high. The geometric mean of both ratings is 3, so the likelihood of rockburst is rated as high.

Consequence. The workers that might be affected by a rockburst incident are those operating at the exploration and production faces, including the operators of production drilling machines (12 units), continuous miners (6 units), scaling vehicles (2 units), roof-cutting vehicles (5 units), roof-bolters (3 units), load-haul-dumps (9 units), raise-boring units (2 units), exploration drilling units (11 units, 2 persons per unit) as well as inspectors (6 vehicles) and surveyors (5 persons). The number of exposed workers is 72 per shift, so the consequence is rated as medium.

The likelihood is rated as high, and the consequence is rated as medium. The geometric mean of both ratings is 2.45, so the impact of rockburst on workers is rated as high.

(4) Inrush of water or semi-solids

Likelihood. The likelihood of an inrush is considered from the presence of water or semi-solid and mass movement potentials as follows.

- *Presence of water or semi-solid*
  - *Distance to the adjacent water or semi-solid source.* In the project area, there is no adjacent or abandoned mine. The tailing dam is located 7 kilometers away from the underground mine site. Hence, these sources of water or semi-solids are considered irrelevant. Possible sources of water and semi-solids include backfilled slurry, groundwater, and strata connecting borehole. The area backfilled by tailing slurry is separated by a safety pillar, which is 50 meters wide (ASEAN Potash Mining PLC, 2014a, pp. 4–88), so the distance to backfilled slurry is rated as medium. Groundwater is located at a level of 15-40 meters from ground level (Siam Tech Group, n.d.), and a 20-meter-thick brine layer lies approximately 60 meters deep (ASEAN Potash Mining PLC, 2014a). They are separated from the mine openings by the layer of impermeable salt of not less than 6.5 meters. The rating of high likelihood is assigned to groundwater source. Another source of water is the boreholes connecting to water strata as well as shafts and decline. These boreholes are sealed and their surroundings are kept undisturbed at a radius of 50 meters. Likewise, the shafts and the decline have 150-meter and 50-meter buffer distances, respectively (ASEAN Potash Mining PLC, 2014a, pp. 4–94). Consequently, their distances are rated as medium, high, and medium, respectively.
  - *Water or semi-solid capacity.* The capacity of backfilled slurry is estimated from the volume of the mine opening in one panel. The volume in room-and-pillar and long-pillar panels ranges between 0.6 and 1.8 million cubic meters, so a high rating is assigned. In case the groundwater strata are the source of water, the water yield in the project area is 2-10 cubic meters per hour (Siam Tech Group, n.d., pp. 2–32), which is a low yield. Together with the fact that water strata are limitless, a medium rating is assigned to the capacity.
- *Mass movement potential*
  - *Discontinuities.* As explained in the assessment of gas outburst impacts, the structure of the deposit is characterized by the concentric zonal deformation, so this indicator is rated as intensely folded or faulted (a high likelihood).
  - *Effect of ground subsidence.* In this project, the maximum horizontal strain in the mining lease area is estimated at 2.31×10^{-7} (ASEAN Potash Mining PLC, 2014a). Thus, the effect of ground subsidence is rated as low.

Consequence. The workers that might be affected by an inrush are those operating in one panel as it is assumed that the inrush can be limited by the safety pillars of the production panel. The number of exposed workers is estimated from the available number of production drilling machines (12 units), scaling vehicles (2 units), roof-cutting vehicles (5 units), roof-bolters (3 units), load-haul-dumps (9 units), raise-boring units (2 units), inspectors (6 vehicles), surveyors (5 persons), and 10 maintenance staffs. The total number is 54 persons, so the consequence is rated as medium.

Table 5.14 summarizes the assessment of the likelihood and the consequence of an inrush. The negative impacts (risks) of inrush from backfilled slurry, groundwater, and borehole are rated as high, high, and medium, respectively. The sum of these ratings which uses an equal weight of 0.33 is 2.67, so the impact of water or semi-solid inrush on workers is rated as high.

Table 5.14: Assessment of the impact of water or semi-solid inrush on workers

Component	Reference no.	Backfilled slurry	Groundwater	Borehole
Likelihood $([2] \times [5])^{0.5}$	[1]	High	High	Medium
Presence of water or semi-solid $([3] \times [4])^{0.5}$	[2]	High	High	Medium
-Distance of water source	[3]	50 m (Medium)	6.5 m (High)	50 m (Medium)
-Water or semi-solid capacity	[4]	High	Medium	Medium
Mass movement potentials $([6] \times [7])^{0.5}$	[5]	Medium	Medium	Medium
-Geological structure	[6]	High	High	High
-Effect of ground subsidence	[7]	Low	Low	Low
Consequence	[8]	54 men/shift (Medium)	54 men/shift (Medium)	54 men/shift (Medium)
Impact: $([1] \times [8])^{0.5}$	[9]	High	High	Medium
Average		2.67 (High)		

(5) Ground failure

Likelihood. The likelihood of ground failure is determined by geological characteristics and design parameters.

- *Geological characteristics*
    - *Rock strength.* The testing result of the project's rock property did not contain information about uniaxial compressive strength. Thus, this assessment refers to the carnallitite properties in German literature, indicating the uniaxial compressive strength of 123 kilopound per square centimeters (or 12.1 MPa) (Gimm and Pforr, 1968, p. 180). Consequently, the strength is low, and the failure likelihood is rated as high.

- *Geological structure.* As explained in the assessment of gas outburst impacts, the structure of the deposit is characterized by the concentric zonal deformation, so this indicator is rated as intensely folded or faulted (a high likelihood).
- *Water factors.* According to the mass balance data in the mining plan, the input ore contains 20.2% H_2O in the ore crystal and 0% liquid content (ASEAN Potash Mining PLC, 2014a). Because the water content is 0%, a rating of low water content (and low likelihood) is assigned.

The failure likelihood due to rock strength is rated as high, geological structure as high, and water factors as low. The geometric mean of these ratings is 2.08, so the geological characteristics are rated as a medium failure likelihood.

- *Design parameters.* Design parameters are viewed under the aspects of safety, opening design, and extraction ratio as follows.
  - *Factor of safety.* According to the mine design, the extraction patterns which are varied in the opening height have a safety factor between 2.4 and 6.5 (ASEAN Potash Mining PLC, 2014a, chap. 4). The values lie in the range of low and medium, so the worse value (a medium likelihood) is used for this assessment.
  - *Opening design.* According to the mining plan (ASEAN Potash Mining PLC, 2014a, chap. 4), the main conveyor drift is 6.0 meters wide and 4.5 meters high. The width and height ratio of the opening is thus 1.3, which is considered medium stress (a medium likelihood). The plan also states that the production room is 15 meters wide, and its height ranges from 5-25 meters. This results in a width and height ratio between 0.6 and 3. The high value is used to represent the worst-case design, so the design is rated as a high likelihood.
  - *Extraction ratio.* The calculation in the mining plan (ASEAN Potash Mining PLC, 2014a, chap. 4) shows that the resource of potash ores within the project area is 304.2 million tonnes, and their mineable reserve is 117.3 million tonnes. Consequently, the extraction ratio is 38.6%, which is rated as medium.

The factor of safety is rated as medium, the opening design as high, and the extraction ratio as medium. The geometric mean of these ratings is 2.29, so the design parameters are rated as a medium failure likelihood.

Both the geological characteristics and the design parameters are rated as medium. The geometric mean of both ratings is 2, so the likelihood of ground failure is rated as medium.

Consequence. The workers that might be affected by a ground failure incident are those operating in one panel due to the presence of the safety pillars. The number of exposed workers is estimated from the available number of production drilling machines (12 units), scaling vehicles (2 units), roof-cutting vehicles (5 units), roof-bolters (3 units), load-haul-dumps (9 units), raise-boring units (2 units), inspectors (6 vehicles), surveyors (5 persons), and 10 maintenance staffs. The total number is 54 persons, so the consequence is rated as medium.

Both the likelihood and the consequence are rated as medium. The geometric mean of both ratings is 2, so the impact of ground failure on workers is rated as medium.

The impact of accidents on workers is determined by the ratings of fire and explosions (medium), gas outburst (medium), rockburst (high), an inrush of water or semi-solids (high), and ground failure (medium). The total value of these ratings using an equal weight of 0.2 is 2.4, so the impact of accidents on workers is rated medium.

The overall rating of the mining's negative impacts on workers is derived from the ratings of occupational diseases (medium), harmful working conditions (high), and accident (medium). The sum value of these ratings using an equal weight of 0.33 is 2.33, so the negative impacts of mining on workers are rated as medium.

5.3.2 Negative impacts on communities

The negative impacts of the mining project on communities are considered from the changes in health and safety, access to assets, and vulnerability to external changes as follows.

5.3.2.1 Health and safety

The impacts on community health and safety are viewed from the risk of accidents and pollution.

(1) Risk of accidents

The accident risk from a failure of the waste storage facility and sinkhole is determined as follows.

(1.1) Failure of waste storage facility

Likelihood. There are two types (sections) of waste storage facility: waste dump and tailing dam. The likelihood of failure is determined by the following parameters:

- *Type of material*
    - *Waste dump.* Waste material in the waste dump consists mainly of rock salt (sodium chloride). Due to a lack of data, the properties of salt tailing in Saskatchewan are used for the assessment. The salt tailing, which contained 90% NaCl, had a similar gradation to that of uniform medium to coarse sand and 115-700 MPa of deformation moduli (Pufahl and Fredlund, 1988). Consequently, the material is classified as a high quality waste material and is rated as a low likelihood.
    - *Tailing dam.* The mining plan shows that the tailing dam will be constructed with building dam walls on the slightly sloping area (ASEAN Potash Mining PLC, 2014a, chap. 7). The dam can be classified as a ring-dyke water retention dam, so a low likelihood rating is assigned.
- *Facility height*
    - *Waste dump.* The waste pile is designed to have a maximum height of 20 meters. Thus, the rating of a low height is assigned to this indicator.
    - *Tailing dam.* The tailing dam is designed to be 20 meters high, so the medium rating is applied.
- *Slope angle*
    - *Waste dump.* According to the mining plan, the wall slope of the dump pile's embankment will be 1:2 or 30°. Accordingly, the slope angle is rated as a medium angle (and likelihood).
    - *Tailing dam.* The slope of a tailing dam embankment is designed to have a vertical to horizontal ratio of 1:2 (30°), so the slope angle is considered gentle and is rated as a medium likelihood.
- *Seismic condition.* According to the earthquake risk zone in Figure 4.3, the project area is located in the low intensity zone (zone 0-1). Thus, the seismic condition is rated as low.
- *Amount of rainfall.* The maximum annual rainfall according to the 30-year (1982-2011) weather statistics at Bamnet Narong weather station is 1,388 millimeters per year (Siam Tech Group, n.d., pp. 2–5). Consequently, the amount of rainfall is rated as a low level.

- *Foundation conditions.* The foundation of the site area is formed by the quaternary sediment with an average thickness of less than 20 meters over the tertiary sediment of the Phu Thok formation, which comprises a 200-350 meter-thick layer of brick-red claystone and sandstone with cross-bedding (ASEAN Potash Mining PLC, 2014a, pp. 3–32; Hansen et al., 2016). An engineering test of soil samples in the project area indicates that the sediment layer has 1-8.5 meters of topsoil consisting of clay and silty clay, and that under the topsoil lies 1.5-meter-thick soft to stiff silty clay, 2.5-meter-thick medium to very dense sand, and hard silty clay, respectively (ASEAN Potash Mining PLC, 2014a, chap. 8). The ground will be compacted on the surface for 600 millimeters and double lined with 1.5-millimeter HDPE. The presence of a clay layer would classify the foundation as weak. However, the use of a liner will reduce the possibility of adverse pore pressure. Accordingly, the foundation conditions are rated as medium.
- *Water content in waste*
    - *Waste dump.* The salt tailing sent to the waste dump will contain 13% moisture (ASEAN Potash Mining PLC, 2014a, pp. 6–26), so the water content is rated as medium.
    - *Tailing dam.* The mineral processing mass balance shows that the brine tailing will contain 99.6% by weight or 99.7% by volume of liquid (ASEAN Potash Mining PLC, 2014a, p. Appendix D-11). Therefore, the tailing is identified as a high liquid content.

Consequence. The community located closest to the dump boundary is Moo 6 Ban Kok Saew, with a population of 531. However, the center of the village is located more than 500 meters away from the dump boundary, and only a few houses are scattered in the specified range. Accordingly, the consequence is rated as low. In case of tailing dam, the community located within 1 kilometer from the dam is Moo 7 Ban Nong Dong in Bamnet Narong district, Chaiyapoom, which has a population of 448, so the consequence is rated as medium.

The aggregation of the likelihood and the consequence ratings is shown in Table 5.15. The sum of the impact ratings of both sections of the waste facility using an equal weight of 0.5 yields the value of 1.2, so the impact of a waste facility failure on communities is rated as low.

Table 5.15: Assessment of the impact of waste facility failure on communities

Indicator	Waste dump		Tailing dam	
	Value	Rating	Value	Rating
Likelihood	1.35	Low	1.57	Low
-Type of material	Good quality	Low	Water retention	Low
-Facility height	20 m	Low	20 m	Medium
-Slope angle	30°	Medium	30°	Medium
-Seismic condition	Zone 0-1	Low	Zone 0-1	Low
-Amount of rainfall	1,388 mm/year	Low	1,388 mm/year	Low
-Foundation conditions	Intermediate	Medium	Intermediate	Medium
-Water content in waste	13%	Medium	Liquid	High
Consequence	<100	Low	448	Medium
Impact	1.00	Low	1.41	Low
Average	1.0 (Low)			

(1.2) Sinkhole

Likelihood. Likelihood is determined by the presence of sinkhole-related geology or structures and the presence of water.

- *Presence of sinkhole-related geology or structures.* The geological structure of the project area is not characterized by carbonate rocks. There is no abandoned mine within the area that would be the cause of ground subsidence. However, the deposit itself is made of evaporite minerals, which are soluble substances and can contribute to the occurrence of sinkhole structures. Thus, this indicator is rated as highly related to sinkhole structures.
- *Presence of water*
    - *Amount of rainfall.* The average annual rainfall according to the 37-year (1975-2011) weather statistics at Bamnet Narong weather station is 904.1 millimeters per year (Siam Tech Group, n.d., pp. 2–10). Consequently, the amount of rainfall is rated as low level.
    - *Groundwater velocity.* According to the data for shaft development, the hydraulic transmissivity in the unconfined aquifer is 345 square meters per day. Assuming the effect of a hydraulic head is negligible, this value can be converted into a groundwater velocity of 0.000345 meters per day per square kilometer, which is classified as low velocity (and likelihood).

  Both the amount of rainfall and the groundwater velocity are rated as low. Summating both ratings using an equal weight of 0.5 gives the value of 1.0, so the presence of water is rated as low.

The presence of sinkhole-related geology or structures is rated as high, and the presence of water is rated as low. The geometric mean of both ratings is 1.73, so the likelihood is rated as medium.

Consequence. The amount of population that might be affected by an incident is estimated from the number of inhabitants in the project area. The communities within the assessment boundary and their population are shown in Table 5.16. The total population is 5,399 people, so the consequence is rated as high.

Table 5.16: Communities within the mining lease area

No.	Community	Village	Sub-district	District	Population
1	Ban Hua Bueng	Moo 1	Ban Tan	Bamnet Narong, Chaiyapoom	764
2	Ban Tan	Moo 4	Ban Tan		596
3	Ban Kok Pet	Moo 8	Ban Tan		284
4	Ban Hua Bueng	Moo 11	Ban Tan		273
5	Ban Hua Talae	Moo 1	Hua Talae		603
6	Ban Nong Pra Doo	Moo 4	Hua Talae		939
7	Ban Kao	Moo 8	Hua Talae		607
8	Ban Hua Sapan	Moo 10	Hua Talae		285
9	Ban Hua Talae	Moo 11	Hua Talae		437
10	Ban Sawang Sri Pattana	Moo 22	Ban Pet		611
Total					5,399 (High)

Source: ASEAN Potash Mining PLC (2014b, pp. 3-223-3-245–66)

The ratings of the likelihood and the consequence of a sinkhole occurrence are medium and high, respectively. Their geometric mean is 2.45, so the negative impact of a sinkhole is rated as high.

The impact of an accident on communities is determined by the rating of the waste storage facility failure (low) and that of the sinkhole (high). The sum of both ratings using an equal weight of 0.5 is 2, so the impact of an accident on communities is rated as medium.

(2) Pollution

The impacts of pollution on communities are considered from air, water (and sediment), and soil pollution as follows.

(2.1) Air pollution

Likelihood. The likelihood of exposure is assessed from the release of pollutants and pollutant dilution.

- *Release of pollutants.* The amount and rating of particulate matter (PM10), sulfur dioxide, nitrogen dioxide, carbon monoxide, arsenic, cadmium, lead, and mercury released from the project are summarized in Table 5.17. The sum of these ratings with an equal weight for the mining compound is rated as medium pollutant release and for the waste storage facility as low pollutant release.

Table 5.17: Amount of air pollutants released by the project

Pollutant	Unit	Rating criteria			Mining lease area		Waste facility	
		Low	Medium	High	Amount	Rating	Amount	Rating
PM10	t/year	<7.3	7.3-14.6	>14.6	2,274	High	0.1	Low
SO_2	t/year	<22.8	22.8-45.6	>45.6	3,039	High	-	-
NOx	t/year	<7.3	7.3-14.6	>14.6	1,000	High	-	-
CO	t/year	<1,825	1,825-3,650	>3,650	271	Low	-	-
Ozone	t/year	<21.9	21.9-43.8	>43.8	-	-	-	-
Benzene	t/year	<0.9	0.9-1.8	>1.8	0.03	Low	-	-
Arsenic	kg/year	<1.1	1.1-2.2	>2.2	1.08	Low	-	-
Cadmium	kg/year	<0.9	0.9-1.8	>1.8	0.33	Low	-	-
Lead	kg/year	<91.3	91.3-182.5	>182.5	1.24	Low	-	-
Mercury	kg/year	<3.7	3.7-7.3	>7.3	0.11	Low	-	-
Average						1.67 Med		1 Low

- *Pollutant dilution*
  - *Wind speed.* The 30-year (1982-2011) average wind speed in Chaiyapoom province was 1.8 knots or 0.93 m/s (Thailand's Meteorological Department, 2012). It is considered as a low speed with less contribution to dilution and is rated as a high exposure likelihood.
  - *Topography.* The topography of the project area as well as of the waste storage area is a flat terrain. Its elevation ranges between 200 and 250 meters above sea level, and the average gradient is less than 1%. The topography is preferable for pollutant dispersion, so the exposure likelihood is rated as low.
  - *Average rain days per year.* The 30-year (1982-2011) weather record of Chaiyapoom province showed that the average rain days per year was 101 days (Siam Tech Group, n.d., pp. 2–5). Consequently, a medium rating is assigned to this indicator.

The wind speed rating is high, the topography rating is low, and the average rain days per year rating is medium. Their geometric mean is 1.82, so the pollutant dilution is rated as medium.

The likelihood is derived from the ratings of the release of pollutants and pollutant dilution. For the mining lease compound, their ratings are both medium. Their geometric mean is 2, so the likelihood is rated as medium. For the waste facility area, the release of pollutants is rated as low, and the pollutant dilution is rated as medium. Their geometric mean is 1.41, so the likelihood is rated as low.

Consequence. The number of people living within 5 kilometers of the project area and of the waste facility area is shown in Table 5.18. There are 16,099 and 5,985 inhabitants respectively that live near the mining and processing area and near the waste storage facility. The former is rated as high and the latter as medium

Table 5.18: Number of population within 5 kilometers of the mining lease and from waste facility areas

No.	Community	Village	Sub-district	District	Province	Population
Mining lease and 5 kilometers around						
1	Ban Hua Bueng	Moo 1	Ban Tan	Bamnet Narong	Chaiyapoom	764
2	Ban Tha Sala	Moo 2	Ban Tan	Bamnet Narong	Chaiyapoom	403
3	Ban Kratoompra	Moo 3	Ban Tan	Bamnet Narong	Chaiyapoom	270
4	Ban Tan	Moo 4	Ban Tan	Bamnet Narong	Chaiyapoom	596
5	Ban Wang Ka Arm	Moo 5	Ban Tan	Bamnet Narong	Chaiyapoom	663
6	Ban Kok Pet	Moo 8	Ban Tan	Bamnet Narong	Chaiyapoom	284
7	Ban Nong Yai Bood	Moo 9	Ban Tan	Bamnet Narong	Chaiyapoom	263
8	Ban Hua Bueng	Moo 11	Ban Tan	Bamnet Narong	Chaiyapoom	273
9	Ban Tan Pattana	Moo 12	Ban Tan	Bamnet Narong	Chaiyapoom	396
10	Ban Hua Talae	Moo 1	Hua Talae	Bamnet Narong	Chaiyapoom	603
11	Ban Hua Sa	Moo 2	Hua Talae	Bamnet Narong	Chaiyapoom	679
12	Ban Koom	Moo 3	Hua Talae	Bamnet Narong	Chaiyapoom	791
13	Ban Nong Pra Doo	Moo 4	Hua Talae	Bamnet Narong	Chaiyapoom	939
14	Ban Kao	Moo 8	Hua Talae	Bamnet Narong	Chaiyapoom	607
15	Ban Noan Sang	Moo 9	Hua Talae	Bamnet Narong	Chaiyapoom	459
16	Ban Hua Sapan	Moo 10	Hua Talae	Bamnet Narong	Chaiyapoom	285
17	Ban Hua Talae	Moo 11	Hua Talae	Bamnet Narong	Chaiyapoom	437
18	Ban Hua Sa Mai	Moo 12	Hua Talae	Bamnet Narong	Chaiyapoom	433
19	Ban Kok Sawang	Moo 4	Ban Pet	Bamnet Narong	Chaiyapoom	738
20	Ban Kloy	Moo 5	Ban Pet	Bamnet Narong	Chaiyapoom	382
21	Ban Tong Kam Ping	Moo 6	Ban Pet	Bamnet Narong	Chaiyapoom	555
22	Ban Don Ta Ying	Moo 9	Ban Pet	Bamnet Narong	Chaiyapoom	245
23	Ban Kok Faek	Moo 12	Ban Pet	Bamnet Narong	Chaiyapoom	349
24	Ban Non Tong Lang	Moo 13	Ban Pet	Bamnet Narong	Chaiyapoom	229
25	Ban Kam Ping Pattana	Moo 15	Ban Pet	Bamnet Narong	Chaiyapoom	509
26	Ban Kok Sawang Wattana	Moo 18	Ban Pet	Bamnet Narong	Chaiyapoom	447
27	Ban Sawang Sri Pattana	Moo 22	Ban Pet	Bamnet Narong	Chaiyapoom	611
28	Ban Hin Tang	Moo 4	Ban Chuan	Bamnet Narong	Chaiyapoom	568
29	Ban Na	Moo 1	Ban Kham	Chaturat	Nakon Ratchasima	1,099
30	Ban Kham	Moo 2	Ban Kham	Chaturat	Nakon Ratchasima	798
31	Ban Nong Luk Chang	Moo 3	Ban Kham	Chaturat	Nakon Ratchasima	424
Sum						16,099 (High)
Waste facilities and 5 kilometers around						
1	Ban Kao Din	Moo 5	Hua Talae	Bamnet Narong	Chaiyapoom	805
2	Ban Kok Saew	Moo 6	Hua Talae	Bamnet Narong	Chaiyapoom	531
3	Ban Nong Dong	Moo 7	Hua Talae	Bamnet Narong	Chaiyapoom	448
4	Ban Nong Kok	Moo 8	Ban Pet	Bamnet Narong	Chaiyapoom	526
5	Ban Nong Nae	Moo 1	Nong Krad	Dan Khun Tod	Nakon Ratchasima	478
6	Ban Nong Krad	Moo 3	Nong Krad	Dan Khun Tod	Nakon Ratchasima	620
7	Ban Nong Bua Kok	Moo 1	Ban Praeng	Dan Khun Tod	Nakon Ratchasima	436
8	Ban Fai Boad	Moo 2	Ban Praeng	Dan Khun Tod	Nakon Ratchasima	479
9	Ban Non Sa-Ard	Moo 3	Ban Praeng	Dan Khun Tod	Nakon Ratchasima	554
10	Ban Nong Prue	Moo 9	Ban Praeng	Dan Khun Tod	Nakon Ratchasima	662
11	Ban Samnak Piman	Moo 12	Kud Piman	Dan Khun Tod	Nakon Ratchasima	446
Sum						5,985 (Medium)

Source: ASEAN Potash Mining PLC (2014b, pp. 3-223-3–245)

Two factors determine the impact of air pollution on the community. For the mining compound, the impact level is derived from a medium likelihood and a high consequence and is rated as high. For the waste storage facility area, the impact level is derived from a low likelihood and a medium consequence and is rated as low. Summating the impact ratings of both parts using an equal weight of 0.5 yields the value of 2, so the impact of air pollution on the community is rated as medium.

(2.2) Water pollution

The impacts of water (and sediment) pollution on communities are considered from the planned discharge and undesired release of pollutants.

(2.2.1) Planned discharge of water pollutants

The project does not plan to discharge any water from its process to the natural water body. Only run-off water from the project compound and treated household water are drained into the sewage system. The discharge of arsenic, cadmium, lead, mercury, uranium, and cyanide is negligible (if any). As a result, the discharge of pollutant is considered irrelevant.

(2.2.2) Undesired release of water pollutants

The impacts of an undesired release of pollutants on communities are assessed from leaching and contamination from mine drainage, seepage from the waste facility, and failure of the waste facility as follows.

(2.2.2.1) Leaching and contamination from mine drainage

The mining project deals mainly with potash and salt, which are not acid-generating substances. Therefore, leaching and contamination from (acid) mine drainage is considered irrelevant.

(2.2.2.2) Seepage from waste facility

Likelihood. Likelihood is determined by the seepage potential and the pollutant dilution.

- *Seepage potential.* Seepage potential is considered based on the data in the mining plan (ASEAN Potash Mining PLC, 2014a, chap. 7) as follows.
    - o *Capacity of waste facility.* The waste dump and the tailing dam are designed to have a capacity of 14.4 and 13.8 million cubic meters, respectively. The rating of high is thus assigned to both facilities.
    - o *Water content in wastes.* Waste material in the dump pile will be made of sodium chloride containing 13% of brine. Accordingly, the water content is rated as medium. Tailing in the tailing dam will mainly be magnesium chloride brine, containing more than 99% liquid. The liquid content is rated as high.
    - o *Control measures.* The wall and the foundation of both waste dump and tailing dam will be at least 30 and 60 centimeters thick, respectively. The wall and the bottom of the facility will be lined with two layers of 1.5-

millimeter-thick HDPE. A drainage system made of sand layer and pipe network will be installed as well as barrier walls and trenches to capture overflowing water (see Figure 5.8) (ASEAN Potash Mining PLC, 2014a, pp. 7–9). Both seepage prevention and capture measures are present, so the control measures are considered effective and rated as having a low seepage potential.

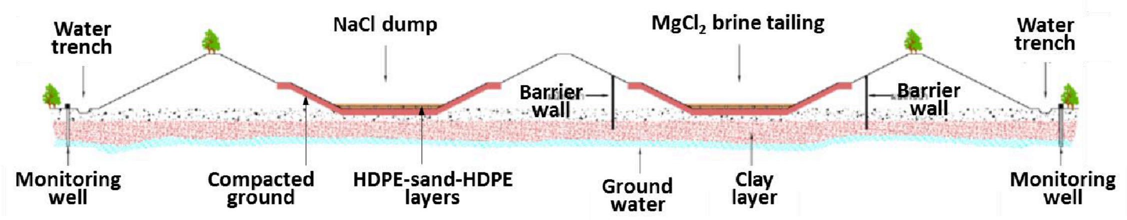


Figure 5.8: Seepage prevention measures in the waste storage facility (Adapted from ASEAN Potash Mining PLC, 2014a, pp. 7–10)

- *Presence of water*
    - *Amount of rainfall.* The maximum annual rainfall according to the 30-year (1982-2011) weather statistics at Bamnet Narong weather station was 1,388 millimeters per year (Siam Tech Group, n.d., pp. 2–5). Consequently, the amount of rainfall is rated as a low level.
    - *Depth of groundwater.* According to the hydrogeological data, groundwater is found at a depth of 20-30 meters in an unconsolidated sedimentary aquifer and 15-40 meters in a hard rock aquifer. Lying less than 50 meters deep, the groundwater is considered to have a medium depth.
- *Waste management after closure.* According to the mining plan, the waste material within the dump pile and the brine within the tailing dam will be backfilled entirely into the mine opening. The area will be cleaned, leveled, and reforested with local plant species. These measures are identified as the removal of waste material to dry areas, so this indicator is rated as having a low seepage potential.

- *Exposure potential.* Exposure potential is determined by the pollutant concentration and the pollutant dilution as follows.
    - *Pollutant concentration.* Substances in the waste storage facility will mainly be salt components. The solid waste will be 100% NaCl with 13% liquid (containing 504 g/L of salt components), and the tailing brine will contain

454 g/L of salt components (i.e. KCl, NaCl, $MgCl_2$, $CaCl_2$, and $CaSO_4$) and 0.3% solid (of which 63.7% is solid salt components) (ASEAN Potash Mining PLC, 2014a, p. Appendix D-4, D-11). Therefore, the main property to be assessed is salinity. Because the waste and tailing substances are highly-concentrated salts, the rating of high salinity is applied.

- *Pollutant dilution.* According to the data for shaft development in the mining plan (ASEAN Potash Mining PLC, 2014a, p. Appendix D-4, D-11), the hydraulic transmissivity in the unconfined aquifer is 345 square meters per day. Assuming the effect of the hydraulic head is negligible, this value can be converted into a groundwater velocity of 0.000345 meters per day per square kilometer, which is low in velocity and dilution ability. Thus, the exposure likelihood dilution is rated as high.

Consequence. The population living within 5 kilometers of the waste storage facility is estimated at 5,985 (see Table 5.18), so the consequence to the affected population is rated as medium.

The ratings of the likelihood and the consequence of seepage from the waste dump and the tailing dam are summarized in Table 5.19. The total impact ratings of both facilities using an equal weight of 0.5 is equal to 2, so the impact of seepage from the waste storage facility on communities is rated as medium.

Table 5.19: Assessment of the impact of seepage from the waste storage facility on communities

Component	Reference no.	Waste dump		Tailing dam	
		Value	Rating	Value	Rating
Likelihood ([2] x [10])$^{0.5}$	[1]	1.73	Medium	1.73	Medium
Seepage potential ([3]x[4]x[5]x[6]x[9])$^{0.2}$	[2]	1.43	Low	1.55	Low
-Capacity of waste storage facility	[3]	14.4 Mm^3	High	13.8 Mm^3	High
-Water content in waste	[4]	13%	Medium	99.8%	High
-Control measures	[5]	Prevent and capture	Low	Prevent and capture	Low
-Presence of water ([7]x0.67)+([8]x0.33)	[6]	1.33	Low	1.33	Low
Amount of rainfall	[7]	1,388 mm	Low	1,388 mm	Low
Depth of groundwater table	[8]	15-40 m	Medium	15-40 m	Medium
-Waste management after closure	[9]	Backfill	Low	Backfill	Low
Exposure potential ([11]x[12])$^{0.5}$	[10]	3	High	3	High
-Pollutant concentration	[11]	100% NaCl	High	454 g/L salt	High
-Pollutant dilution: groundwater velocity	[12]	0.3 mm/day	High	0.3 mm/day	High
Consequence	[13]	5,985	Medium	5,985	Medium
Impact ([1] x [13])$^{0.5}$	[14]	2	Medium	2	Medium
Averaged impact rating		2 (Medium)			

(2.2.2.3) Failure of waste storage facility

Likelihood. The likelihood is determined by the failure potential of the waste storage facility and the dilution potential of pollutants as follows.

- *Failure potential.* The failure potential is determined by the type of material, the facility height, slope angle, seismic condition, amount of rainfall, foundation conditions, and the water content in wastes. The ratings of these indicators were explained in section 5.3.2.1(1.1) and are also applied in this section. The failure potential ratings of the waste dump and the tailing dam are both low.
- *Exposure potential.*
    - *Pollutant concentration.* The substances in the waste storage facility will mainly be salt components. The solid waste will be 100% NaCl with 13% liquid (containing 504 g/L of salt components) while the tailing brine will contain 454 g/L salt components (i.e. KCl, NaCl, $MgCl_2$, $CaCl_2$, and $CaSO_4$) and 0.3% solid (of which 63.7% is solid salt components) (ASEAN Potash Mining PLC, 2014a, p. Appendix D-4, D-11). Therefore, the main property to be assessed is salinity. Because the waste and tailing substances are highly-concentrated salts, a high salinity rating is applied.
    - *Dilution potential.* There are two canals located within 3 kilometers of the waste storage facility, namely, Nong Dong canal and Kratoom Lai canal (Huatalae Local Administration Office, n.d.). These canals are classified as streams, so a low likelihood rating is applied.

Consequence. The number of people living within 5 kilometers from the waste storage facility is estimated at 5,985 (see Table 5.18), so the consequence in terms of affected population is rated as medium.

The likelihood and the consequence ratings of human exposure to pollutants caused by the failure of the waste dump and tailing dam are summarized in Table 5.20. The sum of the impact ratings of both facilities using an equal weight of 0.5 is equal to 1.0, so the impact of a waste storage facility failure on communities is rated as low.

Table 5.20: Assessment of the impact of waste storage facility failure on communities

Indicator	Reference no.	Waste dump		Tailing dam	
		Value	Rating	Value	Rating
Likelihood $([2]x[10])^{0.5}$	[1]	1.41	Low	1.41	Low
Failure potential Geometric mean of [3] to [9]	[2]	1.35	Low	1.57	Low
-Type of material	[3]	Good quality	Low	Water retention	Low
-Facility height	[4]	20 m	Low	20 m	Medium
-Slope angle	[5]	30°	Medium	30°	Medium
-Seismic condition	[6]	Zone 0-1	Low	Zone 0-1	Low
-Amount of rainfall	[7]	1,388 mm/year	Low	1,388 mm/year	Low
-Foundation conditions	[8]	Intermediate	Medium	Intermediate	Medium
-Water content in waste	[9]	13%	Medium	Liquid	High
Exposure potential $([11]x[12])^{0.5}$	[10]	1.73	Medium	1.73	Medium
-Pollutant concentration: salinity	[11]	100% NaCl	High	454 g/L salt	High
-Dilution potential	[12]	Stream	Low	Stream	Low
Consequence	[13]	5,985	Medium	5,985	Medium
Impact $([1]x[13])^{0.5}$	[14]	1.41	Low	1.41	Low
Average		1.0 (Low)			

The impact level of an undesired release of water pollutants is derived from the sum of the ratings of leaching and contamination from mine drainage (irrelevant), seepage from the waste facility (medium), and failure of the waste facility (low) using an equal weight of 0.33. The sum value is 1, so the impact of an undesired release of water pollutants is rated as low.

The impacts of water pollution on communities are determined by the sum of the ratings of a planned discharge of water pollutants (irrelevant) and an undesired release of water pollutants (low) using the weight of 0.67 and 0.33, respectively. The total value equals 0.33, so a low rating is assigned to the impacts of water pollution on communities.

(2.3) Soil pollution

Direct soil contamination and indirect soil contamination through dust deposition determine the impacts of soil pollution on communities.

Direct contamination. Possible sources of direct soil contamination are ashes from coal combustion in the co-generation unit. However, the ashes will be managed by a competent waste management company. Thus, the impact of direct contamination is rated as irrelevant.

Indirect contamination.

- Likelihood. The release of pollutants and the pollutant dilution determine the likelihood of indirect soil contamination as follows:
    - *Release of pollutants.* The releases of heavy metals are estimated in the project's mass flow (in 5.1.4.1) and are summarized in Table 5.21. The release of pollutants from the mining compound is rated as low.

Table 5.21: Amount of indirect soil contaminants released by the project

Pollutant	Unit	Rating criteria			Mining lease area	
		Low	Medium	High	Amount	Rating
Arsenic	kg/year	<0.7	0.7-1.4	>1.4	1.08	Med
Cadmium	kg/year	<6.8	6.8-13.5	>13.5	0.33	Low
Lead	kg/year	<73	73-146	>146	1.24	Low
Mercury	kg/year	<4.2	4.2-8.4	>8.4	0.11	Low
Averaged rating					1.25	Low

- *Pollutant dilution.* The rating of pollutant dilution was assessed in 5.3.2.1(2.1). The same rating (medium) is applied in this part.

The likelihood is derived from the ratings of the release of pollutants (low) and the pollutant dilution (medium). Their geometric mean is 1.41, so the likelihood is rated as low.

Consequence. The population size living within 5 kilometers of the project area (see Table 5.18) is 16,099, so the consequence is rated as high.

The ratings of the likelihood and the consequence are low and high, respectively. Their geometric mean is 1.73, so the impact of indirect soil contamination on communities is rated as medium.

The soil pollution rating is derived from the sum of the ratings of direct contamination (irrelevant) and indirect contamination (medium) using an equal weight of 0.5. The sum value is 1, so the impact of soil pollution on communities is considered low.

The impacts of pollution on communities are determined by the sum of the impact ratings of air pollution (medium), water pollution (low), and soil pollution (low) using an equal weight of 0.33. The total value is equal 1.33, so a low rating is assigned to the impacts of pollution on communities.

The impacts of mining on community health and safety are derived from the ratings of the impacts of accidents (medium) and pollution (low). Adding both ratings with an equal weight of 0.5 yields a value of 1.5, so a medium rating is assigned to the impacts of mining on community health and safety.

5.3.2.2 Community's access to livelihood assets

The negative impacts of a mining project on the community's access to livelihood assets are assessed from the access to natural and physical assets.

(1) Access to natural assets

The impacts on community access to natural assets are assessed from the competing uses of water, land, and forest as follows.

(1.1.1) Competing water use

The impacts of competing water use are determined by the effects of water abstraction and lowered water level.

(1.1.1.1) *Water abstraction*

Likelihood. According to the mining plan (ASEAN Potash Mining PLC, 2014a), the project will annually abstract 3.3 million cubic meters of water from Lam Kan Choo reservoir, which has a storage capacity of 42.6 million cubic meters. The study of the water supply in the same document indicates that the average water runoff was 66.8 million cubic meters per year, whereas the average water demand from the reservoir was 67.1 million cubic meters per year, of which 82% was for agriculture and 11% was for household and industrial uses. This means, the water available for additional use is approximately 33.8 million cubic meters. The ratio of the abstraction quantity to the available water supply (runoff and 80% of storage capacity) equals 0.10, so the likelihood is rated as low.

Consequence. The water from Lam Kan Choo reservoir is used by people living along Lam Kan Choo canal in 12 sub-districts, namely, Kok Pet Pattana, Ban Pet, Koh Manao, Koak Reng Rom, Ban Chuan, Ban Tan, Hua Talae, Ban Kham, Nong Doan, Kood Nam Sai, Ban Kok, and Nong Bua Yai (Royal Irrigation Department, n.d.). It was estimated that the reservoir could supply water to around 7,600 hectares of agricultural land. The total population in these 12 sub-districts in 2015 was 77,347 (Department of Public Administration, 2016). In order to estimate the consequence, it is assumed that the entire population of these sub-districts relies on the Lam Kan Choo canal. The employment statistics in the Northeastern region of Thailand show that 65.1% of the workforce was in the agricultural sector, 5.97% in manufacturing, 28.64% in services, and 0.29% unemployed (Bank of Thailand, 2011). The number of affected population is adjusted by these proportions. The consequence is calculated as shown in Table 5.22.

The likelihood is rated as low, and the consequence is rated as high. The geometric mean of both ratings is 1.73, so the impact of competing water use is rated as medium.

Table 5.22: Amount of affected population with the consideration of occupation type

Occupation type	Occupation weight [1]	No. of population [2]	Adjusted no. of population [1] x [2]
Agriculture	1	50,353	50,353
Manufacturing	0.67	4,618	3,094
Services and others	0.33	22,376	7,384
Sum		77,347	60,831 (High)

(1.1.1.2) Lowered water level

Likelihood. The likelihood of the water level sinking is determined by the depth of the mine and the distance of ground subsidence.

- *Depth of mine.* The working area is between 100 and 300 meters deep. However, this project involves the extraction of soluble minerals, so water must be prevented from entering the mine openings. Hence, the groundwater level should not be affected by the operation and is considered as irrelevant.
- *Distance of ground subsidence.* The maximum distance of subsidence was estimated at 16 centimeters, so the effect of subsidence is rated as low.

The total rating of the mine depth (irrelevant) and of the ground subsidence depth (low) using an equal weight of 0.5 is 0.5, so the likelihood is rated as low.

Consequence. The consequence of a lowered water level on communities is determined by the affected population and type of household. The affected inhabitants are those living within the mining lease area and the 5-kilometer surrounding. They are estimated from the number of households, the average residents per household, and the kind of occupation from the survey stated in the environmental impact assessment report (ASEAN Potash Mining PLC, 2014b, pp. 3-223-3–245). The size and occupation type of the affected population is shown in Table 5.23. The rating high is assigned to the consequence.

The ratings of the likelihood and the consequence of a lowered water level are low and high, respectively. The impact of a lowered water level is rated as medium.

The impact of water abstraction and that of a lowered water level are both rated as medium. Adding both ratings with an equal weight of 0.5 yields the value 2, so the impact of competing water use is rated as medium.

Table 5.23: Amount of population within 5 kilometers from mining lease with the consideration of occupation type

Village		Affected population by occupation			Adjusted no. of population
		Agriculture (weight = 1)	Manufacturing (weight = 0.67)	Services & others (weight = 0.33)	
Ban Tan sub-district					
Moo 1	Ban Hua Bueng	294	0	470	451
Moo 2	Ban Tha Sala	288	0	115	326
Moo 3	Ban Kratoom Pra	216	0	54	234
Moo 4	Ban Tan	417	60	119	497
Moo 5	Ban Wang Ka Arm	331	0	331	441
Moo 8	Ban Kok Pet	284	0	0	284
Moo 9	Ban Nong Yai Bood	175	0	88	204
Moo 11	Ban Hua Bueng	219	0	55	237
Hua Talae sub-district					
Moo 1	Ban Hua Talae	302	60	241	422
Moo 2	Ban Hua Sa	370	0	309	473
Moo 3	Ban Koom	426	61	304	568
Moo 4	Ban Nong Pradoo	587	0	352	704
Moo 8	Ban Kao	546	0	61	566
Moo 9	Ban Non Sang	459	0	0	459
Moo 10	Ban Hua Sapan	285	0	0	285
Moo 11	Ban Hua Talae	291	0	146	340
Moo 12	Ban Hua Sa Mai	325	0	108	361
Ban Pet sub-district					
Moo 4	Ban Kok Sawang	316	105	316	491
Moo 5	Ban Kloy	273	55	55	328
Moo 6	Ban Tong Kam Ping	555	0	0	555
Moo 9	Ban Don Ta Ying	245	0	0	245
Moo 12	Ban Kok Faek	300	0	50	317
Moo 13	Ban Non Tong Lang	229	0	0	229
Moo 15	Ban Kam Ping Pattana	458	0	51	475
Moo 18	Ban Kok Sawang Wattana	280	0	168	336
Moo 22	Ban Sawang Sri Pattana	333	0	278	426
Ban Chuan sub-district					
Moo 4	Ban Hin Tang	426	0	142	473
Ban Kham sub-district					
Moo 1	Ban Na	481	0	618	687
Moo 2	Ban Kham	399	0	399	532
Moo 3	Ban Nong Look Chang	283	0	141	330
Sum		10,562	341	5,197	12,277 (High)

(1.2) Competing land use

Likelihood. The land acquired by the mining project includes that of the mining compound, the waste storage facility area, and the area for the pipeline installation as shown in Figure 5.9. According to the company's plan (ASEAN Potash Mining PLC, 2014a, pp. 8–4, 2014b, pp. 3-194-3–195), the acquired area for the mining compound is 50.72, which are all residential areas or agricultural land. The acquired area for the waste facility and the pipeline installation is 444.32 hectares, of which 1.4 hectares are forest and the rest is residential areas or agricultural land. The total residential or agricultural areas acquired by the project is 93.64 hectares, so the likelihood is rated as low.

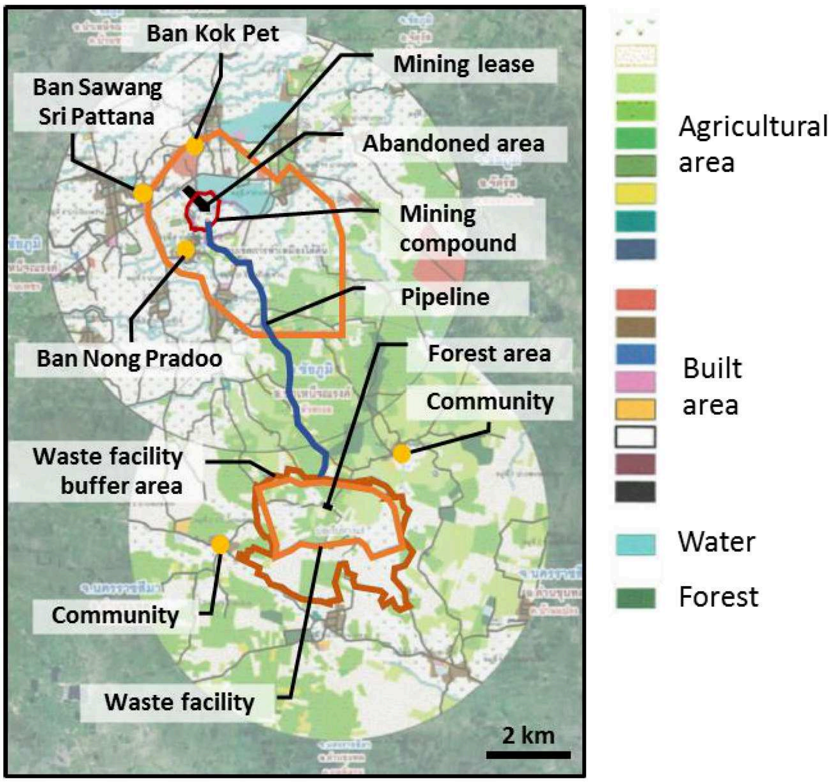


Figure 5.9: Land use in the project area (ASEAN Potash Mining PLC, 2014b, pp. 3–195)

Consequence. The affected population in the mining compound area is calculated from the number of land deeds in the mining compound (57 deeds (ASEAN Potash Mining PLC, 2014b, pp. 3-194-3–195)), which is assumed to represent the number of affected households, and the average number of residents per household of the area. For the waste storage facility area, the data of the deeds is not available. Consequently, it is estimated from the average area per land deed of the mining compound, which is equal to 0.89 hectares per deed. The waste facility and pipeline area is 444.32 hectares, so the estimated number of affected households is 395. The average population per household of Hua Talae sub-district is 3.61, so the number of affected people in the mining compound area and that in the waste facility (including pipeline) are 206 and 1,426. It is assumed that all of them work in the farming sector because the area consists mainly of agricultural land. The adjusted population size is 1,632, which is rated as a low consequence.

Both the likelihood and the consequence are rated as low. Their geometric mean is 1, so the impact of competing land use is rated as low.

(1.3) Competing forest use

Likelihood. The mining compound consists of approximately 40 hectares of abandoned land[2], and the waste facility area has 1.4 hectares of forest area (ASEAN Potash Mining PLC, 2014b, pp. 3-194-3–195). Both areas are rated as a low likelihood.

Consequence. Because the forest and the abandoned areas are relatively small, the affected population is limited to the vicinity. It is estimated from the population living in 1 kilometer of the abandoned area and the forest areas according to the survey data in the EIA report (ASEAN Potash Mining PLC, 2014b, pp. 3-194-3–195). The communities located within 1 kilometer of the abandoned area include Moo 22 Ban Sawang Sri Pattana (Ban Pet sub-district), Moo 4 Ban Nong Pradoo (Hua Talae sub-district), and Moo 8 Ban Kok Pet (Ban Tan sub-district) (see Figure 5.9). Their total population is 1,834, of which 1,204 are in primary occupation and 630 are in tertiary occupation or unemployed. The adjusted population size is 1,031, which is rated as low. The community closest to the waste facility area is located farther than 1 kilometer from the forest area, so the population is counted as zero.

In the mining compound, the ratings of both likelihood and consequence are low. Their geometric mean is 1, so the impact of competing forest use is rated as low. The impact of the waste storage facility area is considered irrelevant. Aggregating both ratings with a weighted sum using an equal weight of 0.5, the overall impact of competing forest use is rated as low.

The impact level of the community's access to natural assets is derived from the impact ratings of a rival use of water (medium), land (low), and forest (low). The sum of these ratings using an equal weight of 0.33 is 1.33, so the rating low is assigned to the mining impacts on the community's access to natural assets.

(2) Access to physical assets

The impacts on the community's access to physical assets are assessed from the competing uses of road, rail, healthcare, and education.

Road. The project compound is located next to the main transport route from Lopburi to Nakon Ratchasima provinces – Highway 205. According to the vehicle counting carried

[2] estimated from the map due to a lack of detailed information

out by the company on weekdays and weekends (ASEAN Potash Mining PLC, 2014b, pp. 3-213-3–214, 5–108), the total number of vehicles on weekdays was 188 passenger car equivalents per hour in the Lopburi direction and 234 passenger car equivalents per hour in the Nakon Ratchasima direction and on weekends 206 passenger car equivalents per hour in the Lopburi direction and 241 passenger car equivalents per hour in the Nakon Ratchasima direction. It was estimated that the highway has a capacity for 2,000 passenger car equivalents per hour. The presence of the project would increase the ratio of traffic on weekdays to the highway capacity from 0.09 to 0.10 in the Lopburi direction and from 0.12 to 0.13 in the Nakon Ratchasima direction. During the weekend, the ratio would increase from 0.10 to 0.11 in the Lopburi direction and from 0.12 to 0.13 in the Nakon Ratchasima direction. Table 5.24 shows the traffic data and calculation in this assessment. Since the traffic-road capacity ratio is in a range of less than 0.35, the impact of mining on road traffic is rated as low.

Table 5.24: Current and estimated future traffic in the main highway next to the project compound (Adapted from ASEAN Potash Mining PLC, 2014b, pp. 5-107-5–113)

Vehicle type	PCE factor[1]	PCU/12 hours[2]				Additional PCU/8 hours	
		Weekdays		Weekends		Develop-ment	Opera-tion
		Loburi direction	Nakon Ratchasima direction	Loburi direction	Nakon Ratchasima direction		
Bicycle and tricycle	0.25	2	4	1	2		
Motorcycle and motored-tricycle	0.3	302	316	408	511		
Passenger car	1	455	431	467	383		
Small bus	1	40	59	44	54	29	7
Medium bus	1	3	4	3	4		
Large bus	1.5	13	15	13	17		5
Small truck	1.3	841	1165	844	1117		
Medium truck	1.5	87	100	82	110		
Large truck	1.7	60	72	69	83	72	
Truck with >10 wheels	2	140	149	204	199	1	38
Others	1.3	32	82	51	86		
Capacity (PCE/hour)		2,000	2,000	2,000	2,000		
Average PCE/hour		188	234	206	241	19	11
Average PCE/hour (worst case), development		207	253	225	260		
Average PCE/hour (worst case), operation		199	245	217	252		
T/C ratio[3], current		0.09	0.12	0.10	0.12		
T/C ratio, development		0.10	0.13	0.11	0.13		
T/C ratio, operation		0.10	0.12	0.11	0.13		

Remarks:
[1] PCE (passenger car equivalent) factor is the weight applied to different type of vehicle
[2] The PCE is divided by 12 hours, which are the period of traffic counting.
[3] T/C = traffic/capacity

Rail. It is planned to transport 2,200 tonnes of potash daily by rail to the port in Chonburi province. This export amount will require 2 transports per day. The route, which extends over 354 kilometers, can be divided into 7 sections. Table 5.25 shows the capacity and current traffic of each transport section. The data shows that the section Lam Narai-Ban Chong Tai is the transport bottleneck for it has the least remaining capacity (i.e. 2 trains per day). The additional transport required by the project will cause the ratio of rail transport per day to the remaining transport capacity at the bottleneck to be 1.0, so the mining impact on rail traffic is rated as medium.

Table 5.25: Capacity and current rail traffic along the route to the port (ASEAN Potash Mining PLC, 2014b, pp. 11–8)

Section	Distance (km)	Capacity (train/day)	Current traffic (train/day)	Remaining capacity (train/day)
Bamnet Narong - Lam Narai	83	47	30	17
Lam Narai - Ban Chong Tai	81	36	34	2
Ban Chong Tai - Kaeng Koi	4	137	38	99
Kaeng Koi - Klong Sib Kao	82	31	15	16
Klong Sib Kao - Chacheongsao	25	62	15	47
Chacheongsao - Sriracha	70	108	79	29
Sriracha - Laem Chabang	9	184	47	137
Total	354		258	

Healthcare. The community's access to healthcare was assessed in 5.2.2.2(5) (positive contribution). The change in the ratio of population to medical staff due to the presence of the mining project was estimated at -0.3%, so the mining impact on the community's access to healthcare is rated as low.

Education. The community's access to education was assessed in 5.2.2.2(6) (positive contribution). The change in the ratio of student to teacher due to the presence of the mining project was estimated at -3.5%, so the mining impact on the community's access to education is rated as low.

The competing use of road is rated as low, rail as medium, healthcare as low, and education as low. The sum of these four ratings using an equal weight of 0.25 is 1.25, so a low rating is assigned to the mining impacts on the community's access to physical assets.

The impact ratings of the access to natural assets and the access to physical assets are both low. The sum of both ratings using an equal weight of 0.5 is 1, so the low rating is assigned to the impacts on the community's access to assets.

5.3.2.3 Vulnerability to external changes

Community's vulnerability to external changes is considered from the vulnerability to floods, vulnerability to droughts, and dependency on mining as follows.

(1) Vulnerability to floods

The impact on the community's vulnerability to floods is determined by the effect of subsidence and that of sediment release to waterway.

Effect of subsidence

- *Likelihood.* Likelihood is determined by the current state of flooding potential and the distance of ground subsidence as follows.
    - *Current state of flooding potential.* The area of concern is the area within the mining lease boundary because the effect of subsidence is limited to that boundary. The area within this boundary identified by the Department of Disaster Prevention and Mitigation (2012a) in 2011 as a flood-prone area is Moo 10 Ban Hua Sapan in Hua Talae sub-district. The risk level was identified as medium, and the damage area was estimated to be >160 hectares. The flooding potential calculated from this information is 4 (medium area and medium risk), so the current state of the flooding potential is rated as medium
    - *Distance of ground subsidence.* The project's maximum subsidence was estimated at 16 centimeters (ASEAN Potash Mining PLC, 2014a, chap. 4), so this parameter is rated as low.

  The current flooding potential is rated as medium, and the distance of ground subsidence is rated as low. The geometric mean of both ratings is 1.41, so the likelihood of floods is rated as low.
- *Consequence.* The affected population is represented by those living within 2 kilometers of the flood-prone area (i.e. Moo 10 Ban Hua Sapan). The communities located in the specified range, their population, and their types of occupation are shown in Table 5.26. The consequence is rated as medium.

The ratings of the likelihood and the consequence of the effect of subsidence on the community's vulnerability to floods are low and medium, respectively. Their geometric mean is 1.41, so the effect of subsidence is rated as low.

Table 5.26: Amount and occupation of population who might be affected by floods due to ground subsidence

Village		Affected population by occupation			Adjusted number of affected population
		Agriculture (weight = 1)	Manufacturing (weight = 0.67)	Services & others (weight = 0.33)	
Hua Talae sub-district					
Moo 2	Ban Hua Sa	370	0	309	473
Moo 3	Ban Koom	426	61	304	568
Moo 4	Ban Nong Pradoo	587	0	352	704
Moo 8	Ban Kao	546	0	61	566
Moo 9	Ban Non Sang	459	0	0	459
Moo 10	Ban Hua Sapan	285	0	0	285
Sum		2,673	61	1,026	3,056 (Med)

Source: Adapted from ASEAN Potash Mining PLC (2014b)

Effect of the sediment release to waterway. According to the mining plan, the company does not plan to release any process water and wastes, and only run-off water from the site and household wastewater will be discharged to the sewage system (ASEAN Potash Mining PLC, 2014a). The effect of sediment is thus considered irrelevant.

The rating of the effect of subsidence is low, and that of the effect of sediment release to the waterway is irrelevant. The sum of both ratings using an equal weight of 0.5 is 0.5, so the mining impact on the community's vulnerability to floods is rated as low.

(2) Vulnerability to droughts

Likelihood. The likelihood of being vulnerable to droughts is determined by the current state of drought potential and the effect of a lowered water table as follows.

- *Current state of drought potential.* The area of concern is the area within the mining lease and its 5-kilometer surrounding. The drought-prone areas within this boundary and their risk ratings are shown in Table 5.27. The current state of drought potential is rated as high.
- *Effect of lowered water table.* The effect of a lowered water table is determined by the mine's depth and the distance of ground subsidence.
    - o *Depth of mine.* The depth of the working area is between 100 and 300 meters. However, this project involves the extraction of soluble minerals, so water must be prevented from entering the mine openings. Thus, the groundwater level should not be affected by the operation and is considered as irrelevant.

Table 5.27: Assessment of the current state of drought potential

Village no.	Village name	Sub-district	Risk rating[1]	Area[2] (Hectare)
Moo 2	Ban Tha Sala	Ban Tan	Very low	322
Moo 3	Ban Kratoom Pra	Ban Tan	Very low	215
Moo 4	Ban Tan	Ban Tan	Very low	455
Moo 1	Ban Hua Talae	Hua Talae	Very low	451
Moo 4	Ban Kok Sawang	Ban Pet	Very low	500
Moo 5	Ban Kloy	Ban Pet	Very low	276
Moo 6	Ban Tong Kam Ping	Ban Pet	Very low	382
Moo 9	Ban Don Ta Ying	Ban Pet	Very low	171
Moo 12	Ban Kok Faek	Ban Pet	Very low	248
Moo 13	Ban Non Tong Lang	Ban Pet	Very low	163
Moo 18	Ban Kok Sawang Pattana	Ban Pet	Very low	320
Moo 1	Ban Na	Ban Kham	Very low	432
Moo 3	Ban Nong Look Chang	Ban Kham	Very low	341
Moo 5	Ban Wang Ka Arm	Ban Tan	High	516
Moo 8	Ban Kok Pet	Ban Tan	High	226
Moo 2	Ban Hua Sa	Hua Talae	High	514
Moo 3	Ban Koom	Hua Talae	High	593
Moo 4	Ban Nong Pradoo	Hua Talae	High	706
Moo 8	Ban Kao	Hua Talae	High	457
Moo 9	Ban Non Sang	Hua Talae	High	336
Moo 10	Ban Hua Sapan	Hua Talae	High	216
Moo 15	Ban Kam Ping Wattana	Ban Pet	High	351
Moo 4	Ban Hin Tang	Ban Chuan	High	273
Sum			Very low	4,276 (High)
			High	4,188 (High)
Calculated current state of drought potential			12 (High)	

Remarks:
[1] According to the Department of Disaster Prevention and Mitigation (2012b)
[2] Estimated from the average area per household except the area in Ban Kham sub-district, of which actual data are available; data are obtained from the websites of Local Administration Organizations (sub-district).

- *Distance of ground subsidence.* The maximum distance of subsidence was estimated at 16 centimeters, so the effect of subsidence is rated as low.

The sum of the rating of the depth of mine (irrelevant) and the distance of ground subsidence (low) using an equal weight of 0.5 is 0.5, so the likelihood is rated as low.

Likelihood is determined by the ratings of the current state of drought potential (high) and the effect of a lowered water table (low). The geometric mean of both ratings is 1.73, which is a medium rating.

Consequence. The affected population are those living in the drought-prone area within the mining lease boundary and its 5-kilometer surrounding. The size and the types of occupation of the affected population are shown in Table 5.28. A medium rating is assigned to the consequence.

The ratings of the likelihood and the consequence of the community's vulnerability to droughts are both medium. Their geometric mean is 2, so the impact level of the community's vulnerability to droughts is rated as medium.

Table 5.28: Amount and occupation of population potentially affected by drought

Village		Sub-district	Affected population by occupation[1]			Adjusted number of affected population
			Agriculture (weight=3)	Manufac-turing (weight=2)	Services and others (weight=1)	
Moo 2	Ban Tha Sala	Ban Tan	288	0	115	326
Moo 3	Ban Kratoom Pra	Ban Tan	216	0	54	234
Moo 4	Ban Tan	Ban Tan	417	60	119	497
Moo 1	Ban Hua Talae	Hua Talae	302	60	241	422
Moo 4	Ban Kok Sawang	Ban Pet	316	105	316	491
Moo 5	Ban Kloy	Ban Pet	273	55	55	328
Moo 6	Ban Tong Kam Ping	Ban Pet	555	0	0	555
Moo 9	Ban Don Ta Ying	Ban Pet	245	0	0	245
Moo 12	Ban Kok Faek	Ban Pet	300	0	50	317
Moo 13	Ban Non Tong Lang	Ban Pet	229	0	0	229
Moo 18	Ban Kok Sawang Pattana	Ban Pet	280	0	168	336
Moo 1	Ban Na	Ban Kham	481	0	618	687
Moo 3	Ban Nong Look Chang	Ban Kham	283	0	141	330
Moo 5	Ban Wang Ka Arm	Ban Tan	331	0	331	441
Moo 8	Ban Kok Pet	Ban Tan	284	0	0	284
Moo 2	Ban Hua Sa	Hua Talae	370	0	309	473
Moo 3	Ban Koom	Hua Talae	426	61	304	568
Moo 4	Ban Nong Pradoo	Hua Talae	587	0	352	704
Moo 8	Ban Kao	Hua Talae	546	0	61	566
Moo 9	Ban Non Sang	Hua Talae	459	0	0	459
Moo 10	Ban Hua Sapan	Hua Talae	285	0	0	285
Moo 15	Ban Kam Ping Wattana	Ban Pet	458	0	51	475
Moo 4	Ban Hin Tang	Ban Chuan	426	0	142	473
Sum			8,355	341	3,427	9,727 (Med)

Source: Adapted from ASEAN Potash Mining PLC (2014b)
Remarks: [1] Estimated from the number of household and the average population per household of the sub-district

(3) Dependency on mining

The impacts of the community's dependency on mining are determined by the employment dependency and the local spending by the mining project as follows.

Employment dependency. The total workforce in Bamnet Narong district in 2014 was 27,340 (Department of Public Administration, 2016). It is expected that the mining project will employ 1,008 full-time employees during its operation phase, 938 of which will be operators, general staff, and foremen (ASEAN Potash Mining PLC, 2014a, pp. 4-2-4-4–208). Assuming all of the 938 employees are local, the total workforce in the region will increase to 27,410 and the ratio of employment by the mining project to the local workforce will be 3.4%, so the employment dependency is rated as low.

Local spending of mining project. In 2014, the gross provincial product (GPP, nominal) of Chaiyapoom province valued 55,383 million Baht (1,705 million USD), and the GPP per capita valued 57,774 Baht (1,779 USD) (Bank of Thailand, 2016; Office of the National Economic and Social Development Board, 2015). The annual operating and transport costs that would be spent by the mining company during the full operation years were estimated at approximately 134 million USD, of which 37% was maintenance costs, 31% energy costs, 15% labor costs, 12% transport costs to river ports, and 5% others (ASEAN Potash Mining PLC, 2014a, chap. 14). Assuming 80% (which is a high proportion of local procurement spending based on the data of some multinational mining companies) of labor, maintenance, transport, and miscellaneous costs are disbursed to local suppliers and contractors, the local spending will be 74 million USD per year. The ratio of local mine spending to economy size will be around 4.3%. The dependency on local spending of the mining project is thus rated as low.

Both the employment dependency and the local spending by the mining project are rated as low and are summated with an equal weight of 0.5. The impact level of the community's dependency on mining is rated as low.

Vulnerability to floods is rated as low, vulnerability to droughts as medium, and dependency on mining as low. The sum of these ratings using an equal weight of 0.33 is 1.33, so a low rating is assigned to the impacts on the community's vulnerability to external changes.

The level of mining impacts on communities is derived from the impact ratings of the community's health and safety (low), access to livelihood assets (low), and vulnerability to external changes (low). The sum of these ratings using an equal weight of 0.33 is 1, so the mining impacts on communities are rated as low.

5.3.3 Negative impacts on the environment

The negative impacts of mining on the environment are viewed from the standpoint of habitat loss and pollution.

5.3.3.1 Habitat loss

The impacts of habitat loss are determined by terrestrial and aquatic habitat losses.

(1) Terrestrial habitat loss

The impacts of terrestrial habitat loss are viewed from the standpoint of the loss of land cover and the effect of ground subsidence as follows.

(1.1) Loss of land cover

Likelihood. The loss period and the loss area determine the extent of land cover loss. The areas that will undergo land cover changes include the mining compound, the waste facility area, areas for installing tailing and water pipelines, and rails. Since these areas are connected, they are considered together in one calculation. The details of area loss and loss period are shown in Table 5.29. The extent of land cover loss is rated as high.

Table 5.29: Assessment of the extent of land cover loss

Land cover loss, by period of change	Score [1]	Area[1] (Hectare)	Area rating [2]	[1] x [2]
No change or temporary loss (≤1 year)	0	1.27	Low	0
-Water pipeline		1.27		
Short-term loss (>1-≤3 years)	1	-	-	0
Medium-term loss (>3-≤10 years)	2	-	-	0
Long-term loss (>10 years)	3	470.82	Medium	6
-Mining compound		50.72		
-Waste facility		308.00		
-Tailing pipeline		96.08		
-Rail		16.02		
Sum		472.09		6 (High)

Remark: [1] Data from ASEAN Potash Mining PLC (2014a, 2014b, sec. Appendix 2-3, Appendix 2-5)

Consequence. The presence of species is determined by species vulnerability and the number of species found in the area. The assessment for the mining compound and the waste storage facility area was carried out in 5.2.2.3. The presence of species in the mining lease and that in the waste storage facility are both rated as low. A low consequence, which is an average of both ratings, is thus applied.

The likelihood of land cover loss is rated as high, whereas the consequence is rated as low. The geometric mean of both ratings is 1.73, so the impact level of the loss of land cover is rated as medium.

(1.2) Effect of ground subsidence

Likelihood. There is no detailed information of horizontal strain caused by the project. However, the result of a ground subsidence assessment reported in the mining plan indicates that the maximum horizontal strain in the mining lease area is 2.31×10^{-7} (ASEAN Potash Mining PLC, 2014a, chap. 4). Applying this value to the entire mining lease area (1,553 hectares), the area rating is high and the horizontal strain is rated as low. The geometric mean of both rating is 1.73, so the likelihood is rated as medium.

Consequence. The presence of species in the mining compound was assessed in 5.2.2.3. It was rated as low.

The likelihood is rated as medium, and the consequence is rated as low. The geometric mean of both ratings is 1.41, so the impact level of the effect of ground subsidence is rated as low.

The impacts of terrestrial habitat loss are determined by the rating of the loss of land cover (medium) and that of the effect of ground subsidence (low). The sum of both ratings using the weights of 0.67 and 0.33 is 1.67, so the impacts of terrestrial habitat loss are rated as medium.

(2) Aquatic habitat loss

The impacts of aquatic habitat loss are assessed from the direct removal of the water body and indirect water disruption.

(2.1) Direct removal of water body

According to the land use data in the EIA report (ASEAN Potash Mining PLC, 2014b, pp. 3-194-3–195), there will be no removal of natural water body in the mining compound and the waste facility area. Accordingly, the extent of water body removal is rated as irrelevant.

(2.2) Indirect water disruption

According to the mining plan, the project will not involve any water blockage, water diversion, damming, and discharge of sediment. As a result, the effect of indirect water disruption is considered irrelevant.

Both the direct removal of water body and the indirect water disruption are rated as irrelevant. Accordingly, the impacts of aquatic habitat loss are rated as irrelevant.

The impacts of habitat loss are determined by the ratings of terrestrial habitat loss (medium) and aquatic habitat loss (irrelevant). The sum of both ratings with an equal weight of 0.5 is 1, so the impact level of habitat loss is rated as low.

5.3.3.2 Pollution

The impacts of pollution are assessed from air pollution, and water pollution, and soil pollution as follows.

(1) Air pollution

Likelihood. The likelihood of exposure is assessed from the release of pollutants and the pollutant dilution.

- *Release of pollutants.* The amount and rating of sulfur dioxide, nitrogen dioxide, and ground-level ozone as estimated in the project's mass flow (in 5.1.4.1) are summarized in Table 5.30. The pollutant release rate is rated as high.

Table 5.30: Amount of air pollutants released by the project

Pollutant	Unit	Rating criteria			Mining compound	
		Low	Medium	High	Amount	Rating
SO_2	t/year	<22.8	22.8-45.6	>45.6	3,039	High
NOx	t/year	<7.3	7.3-14.6	>14.6	1,000	High
Ozone	t/year	<21.9	21.9-43.8	>43.8	-	-
Average						3 (High)

- *Pollutant dilution.* The effect of pollutant dilution is determined by wind speed, topography, and average rain days per year. The pollutant dilution was assessed in 5.3.2.1(2.1) and was rated as medium.

The ratings of the release of pollutants and pollutant dilution are high and medium, respectively. The geometric mean of both ratings is 2.45, so the likelihood is rated as high.

Consequence. The presence of species in the mining compound was assessed in 5.2.2.3. It was rated as low.

The likelihood of exposure to air pollution is rated as high, and the consequence is rated as low. The geometric mean of both ratings is 1.73, so the level of air pollution impacts on the environment is rated as medium.

(2) Water pollution

The impacts of water (and sediment) pollution are viewed from the standpoint of a planned discharge and an undesired release of pollutants as follows.

(2.1) Planned discharge of water pollutants

The project does not plan to discharge any water from its process to the natural water body. Only run-off water from the project compounds and treated household water will be drained into the sewage system. The discharge of arsenic, cadmium, lead, mercury, uranium, cyanide, suspended solid, acidity-alkalinity, salinity, and heat is negligible (if any). As a result, the discharge of pollutants is considered irrelevant.

(2.2) Undesired release of water pollutants

The impacts of an undesired release of pollutants to water are assessed regarding leaching and contamination from mine drainage, seepage from the waste facility, and failure of the waste facility.

(2.2.1) Leaching and contamination from mine drainage

The mining project deals mainly with potash and salt, which are not acid-generating substances. Thus, leaching and contamination from mine drainage is considered irrelevant.

(2.2.2) Seepage from waste facility

Likelihood. Likelihood is determined by the seepage potential and the exposure potential. It was assessed in 5.3.2.1(2.2.2.2). Similar data is applied in this part.

Consequence. There is no data on fish, so the assessment is based on indirect information. According to the study by Nachaiperm et al. (2006), 88 fish species were found in the Chi river, which is the main river connected to the waterway in the project area. The data of the Thailand's Office of Natural Resources and Environmental Policy and Planning (2005) also indicate that none of the endangered fish species was found in Chaiyapoom province. Assuming 50% of the fish species are present in the project area, the number of fish species used for the assessment is 44, all of which are in the category of unthreatened species. Likewise, the survey data shows that 9 aquatic plant species were found in the area, but there was no information regarding their abundance. It is thus assumed that all are highly abundant. Table 5.31 shows the assessment of the presence of aquatic species in the project area. A low rating is assigned to the waste facility and its 5-kilometer surrounding area

Table 5.31: Presence of aquatic species in the waste facility and its 5-kilometer surrounding area

Vulnerability	Vulnerability rating [1}	No. of species			Adjusted no. of species	Rating
		LA	MA	HA		
Unthreatened species	1	5	3	55	58.7	Low
Potentially threatened species	2	0	0	0	0.0	Irrelevant
Threatened species	3	0	0	0	0.0	Irrelevant
Average using vulnerability rating as weights						Low

Remarks: LA = low abundance (weight = 0.33)
MA = medium abundance (weight = 0.67)
HA = high abundance (weight = 1)

The ratings of the likelihood and the consequence of seepage from the waste dump and the tailing dam are summarized in Table 5.32. The impact of seepage from the waste facility on the environment is rated as low.

(2.2.3) Failure of waste storage facility

Likelihood. Likelihood is determined by the failure potentials of the waste storage facility and the exposure potential of pollutants. They were assessed in 5.3.2.1(1.1) and 5.3.2.1(2.2.2.3). The failure potentials of the waste dump and the tailing dam were both rated as medium; their exposure potentials were rated as low.

Consequence. Consequence is determined by the presence of species. It was assessed in 5.3.3.2(2.2.2) and a low rating is applied.

Table 5.32: Assessment of the impact of seepage from the waste facility on the environment

Component	Reference no.	Waste dump		Tailing dam	
		Value	Rating	Value	Rating
Likelihood ([2] x [10])$^{0.5}$	[1]	1.73	Medium	1.73	Medium
Seepage potential ([3]x[4]x[5]x[6]x[9])$^{0.2}$	[2]	1.43	Low	1.55	Low
-Capacity of waste storage facility	[3]	14.4 Mm^3	High	13.8 Mm^3	High
-Water content in waste	[4]	13%	Medium	99.8%	High
-Control measures	[5]	Prevent and capture	Low	Prevent and capture	Low
-Presence of water ([7]x0.67)+([8]x0.33)	[6]	1.33	Low	1.33	Low
Amount of rainfall	[7]	1,388 mm	Low	1,388 mm	Low
Depth of groundwater table	[8]	15-40 m	Medium	15-40 m	Medium
-Waste management after closure	[9]	Backfill	Low	Backfill	Low
Exposure potential ([11] x [14])$^{0.5}$	[10]	3	High	3	High
-Pollutant concentration ([12]+[13]) x 0.5	[11]	3	High	3	High
Salinity	[12]	100% NaCl	High	454 g/L salt	High
Heat	[13]	-	-	45°C	High
-Pollutant dilution: groundwater velocity	[14]	0.3 mm/day	High	0.3 mm/day	High
Consequence	[15]		Low		Low
Impact ([1] x [15])$^{0.5}$	[16]	1.41	Low	1.41	Low
Averaged impact		1 (Low)			

The ratings of likelihood and consequence are summarized in Table 5.33. The sum of the impact ratings of both facilities using an equal weight of 0.5 is equal to 1, so the impact of the waste storage facility failure on the environment is rated as low.

Table 5.33: Assessment of the impact of the waste storage facility failure on the environment

Indicator	Waste dump		Tailing dam	
	Value	Rating	Value	Rating
Likelihood	1.41	Low	1.41	Low
Failure potential	1.35	Low	1.57	Low
-Type of material	Good quality	Low	Water retention	Low
-Facility height	20 m	Low	20 m	Medium
-Slope angle	30°	Medium	30°	Medium
-Seismic condition	Zone 0-1	Low	Zone 0-1	Low
-Amount of rainfall	1,388 mm/year	Low	1,388 mm/year	Low
-Foundation conditions	Intermediate	Medium	Intermediate	Medium
-Water content in waste	13%	Medium	Liquid	High
Exposure potential	1.73	Medium	1.73	Medium
-Pollutant concentration: salinity	100% NaCl	High	454 g/L salt	High
-Dilution potential	Stream	Low	Stream	Low
Consequence: presence of species		Low		Low
Impact	1	Low	1	Low
Average	1 (Low)			

The impacts of an undesired release of water pollutants on the environment are derived from the sum of the ratings of leaching and contamination from mine drainage (irrelevant), seepage from the waste facility (low), and failure of the waste facility (low) using an equal weight of 0.33. The sum value is 0.67, so the impact level is rated as low.

The impacts of water (and sediment) pollution on the environment are determined by the sum of the ratings of a planned discharge (irrelevant) and an undesired release (low) using the weight of 0.67 and 0.33, respectively. The sum value is 0.33, so the impacts of water pollution on the environment are rated as low.

(3) Soil pollution

The impact of soil pollution on the environment is determined by the likelihood and the consequence of dust deposition as follows:

Likelihood. Likelihood is assessed from the release of pollutants and the pollutant dilution.

- *Release of pollutants.* The amount and rating of arsenic, cadmium, lead, and mercury as estimated in the project's mass flow (in 5.1.4.1) are summarized in Table 5.21. The release of pollutants is rated as low.
- *Pollutant dilution.* The effect of pollutant dilution is determined by wind speed, topography, and average rain days per year. The pollutant dilution was assessed in 5.3.2.1(2.1) and was rated as medium.

The ratings of the release of pollutants and pollutant dilution are low and medium, respectively. The geometric mean of both ratings is 1.41, so the likelihood is rated as low.

Consequence. The presence of species is evaluated by the number the mammal, bird, reptile, amphibian, and plant species in the mining lease and its 5-kilometer surrounding area. Table 5.34 shows the assessment of the presence of species in the mining lease and 5-kilometer surrounding area. The indicator is rated as low.

Table 5.34: Presence of species in the mining lease and its 5-kilometer surrounding area

Vulnerability	Vulnerability rating [1}	No. of species			Adjusted no. of species	Rating
		LA	MA	HA		
Unthreatened species	1	66	28	280	58.7	Low
Potentially threatened species	2	5	1	0	0.0	Irrelevant
Threatened species	3	3	0	0	0.0	Irrelevant
Average using vulnerability rating as weights						Low

Remarks: LA = low abundance (weight = 0.33)
MA = medium abundance (weight = 0.67)
HA = high abundance (weight = 1)

Both the likelihood and the consequence of dust disposition are rated as low. The geometric mean of both ratings is 1, so the impact of soil pollution on the environment is rated as low.

The impact ratings of air pollution (medium), water pollution (low), and soil pollution (low) determine the impacts of pollution. The sum of these three ratings using an equal weight of 0.33 is 1.33, so the impacts of pollution on the environment are rated as low.

The impacts of the mining project on the environment are determined by the ratings of habitat loss (low) and pollution (low). The sum of both ratings using an equal weight of 0.5 is 1, so the negative impacts on the environment are rated as low.

5.3.4 Negative impacts on shareholders

The negative impacts of the mining project on shareholders are determined by rate of return and project risk. Project risk is determined by exploration risk, technology and method, price volatility, social conflicts, and company's reputation as follows.

Exploration risk. For this project, intensive explorations were carried out. The deposit was explored through 76 drill-holes over 156 square kilometers, in which 15.5 square kilometers of the mining lease contain 36 drill-holes. The drill-hole spacing varied from less than 0.5 to about 2 kilometers as shown in Figure 5.10. According to the GSC Paper 88-21 (a Standardized Coal Resource/Reserve Reporting System for Canada), a suggested drill-hole spacing of <0.8, 0.8-1.6, and 1.6-4.8 kilometers denotes the level of confidence in measured, indicated, and inferred resources for flat lying or gently dipping deposits (Mackintosh, 2011). These values are used as a reference for the assessment since the characteristics of coal seam and low complex potash seam are comparable. They indicate that the level of confidence in the exploration data ranges between measured and indicated resources. Therefore, the exploration risk of this project is rated as medium.

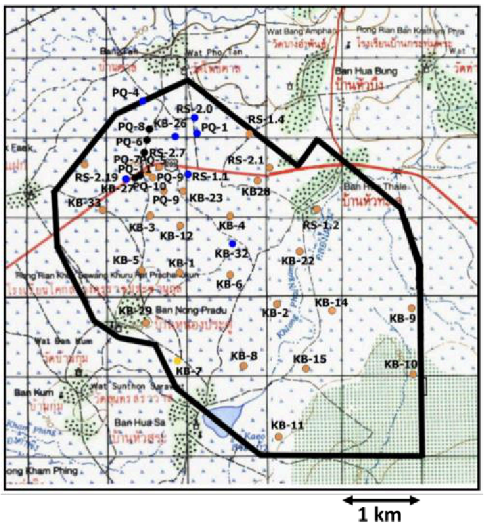


Figure 5.10: Location of exploration drill-holes (ASEAN Potash Mining PLC, 2014a, pp. 3–40)

Technology and methods. The mining method applied in this project is room and pillar with drilling and blasting techniques, which is a common method for underground mining. The method is applied in potash projects in many countries such as Germany and the U.S.A. (Buja, 2013; Herne and McGuire, 2001; Livingstone et al., 2001). The processing method is hot leaching, which is well-known to the global potash industry and is commercially applied for carnallite production in Germany and Jordan (United Nations Industrial Development Organization and International Fertilizer Development Center, 1998, p. 147). However, Thailand currently has no experience with potash mining, and this project is a pioneer in potash mining and processing in the country. As a result, the technology and methods are rated as medium risk.

Price volatility. Price volatility of muriate of potash (MOP) is calculated from the standard deviation of the monthly percentage price changes over 10 years (2006-2015) which is then annualized by multiplying a square root of 12. The result shows an average annual volatility of 23%, which is rated as medium volatility. The price and the calculation of price volatility can be found in Appendix D.

Social conflict. The project has met with few problems with public acceptance regarding the mining plan. However, the application for constructing a coal-fired cogeneration plant appears to raise public concern. A local group of fewer than 100 protesters are refusing approval due to health and environmental concerns. Due to the presence of this opposition group, a high conflict level is assigned as a score for calculation.

Company's reputation. A company's reputation is determined by its trustworthiness, environmental performance, financial performance, and employee's trust. The project belongs to the ASEAN Potash Mining PLC (or newly named ASEAN Potash Chaiyaphum PLC), which began its activities in 1991. The main shareholders are the government of Thailand and five other ASEAN countries as well as Thai and foreign companies. The shares held by private companies are not dominated by one company alone and the ASEAN Potash Mining PLC has not carried out any mining activities besides this project, so the company is considered a new company. Accordingly, the community's trustworthiness, environmental performance, and employee's trust is rated as a low risk. The financial performance is rated as a high risk. The sum of these four ratings using an equal weight of 0.25 is 1.5, so the company's reputation is rated as medium.

Exploration risk, technology and methods, price volatility, and company's reputation are rated as medium, and social conflicts are rated as high. Summating these ratings using an equal weight of 0.2 yields the value of 2.2, so the project risk is rated as medium.

The feasibility study shows that the project's rate of return is 18.98% (ASEAN Potash Mining PLC, 2014a, chap. 14). Applying the criteria for medium-risk projects, a medium impact level (business failure potential) is applied.

5.3.5 Result aggregation

The negative impacts of the mining project are rated from the impact ratings of workers (medium), communities (low), the environment (low), and shareholders (medium). Their ratings are aggregated by summation using an equal weight of 0.25. The total value is 1.5, so the negative impacts of the project are rated as medium.

5.4 Data aggregation into the necessity-impacts matrix

According to the assessment in the previous sections, the necessity of the mining project development is rated as medium, and the negative impacts of the project are also rated as medium. Putting these two values in the necessity-impacts matrix, we can identify the project priority as medium (see Table 5.35).

Table 5.35: Necessity-impacts matrix of the potash mining project

Negative impacts Necessity of development	Low	Medium	High
High (vital for society)	High priority	High priority	Medium priority
Medium (not absolutely necessary but can positively contribute to society)	High priority	Medium priority	Low priority
Low (not really necessary)	Medium priority	Low priority	Low priority

6 Result discussion

The result discussion is presented in two parts. The first part is the summary of the assessment results of the case study and a discussion on their validity. The second part depicts how the framework can be integrated into the existing administration system and how the results can be connected to the key mineral policy issues.

6.1 Assessment results of the case study

The assessment of the new underground potash mining project in Bamnet Narong, Thailand according to the new assessment framework shows that the project's development priority is classified as medium, derived from medium development necessity and medium negative impacts. Figure 6.1 and Figure 6.2 summarize the ratings of the necessity of the project development and the negative impacts, respectively.

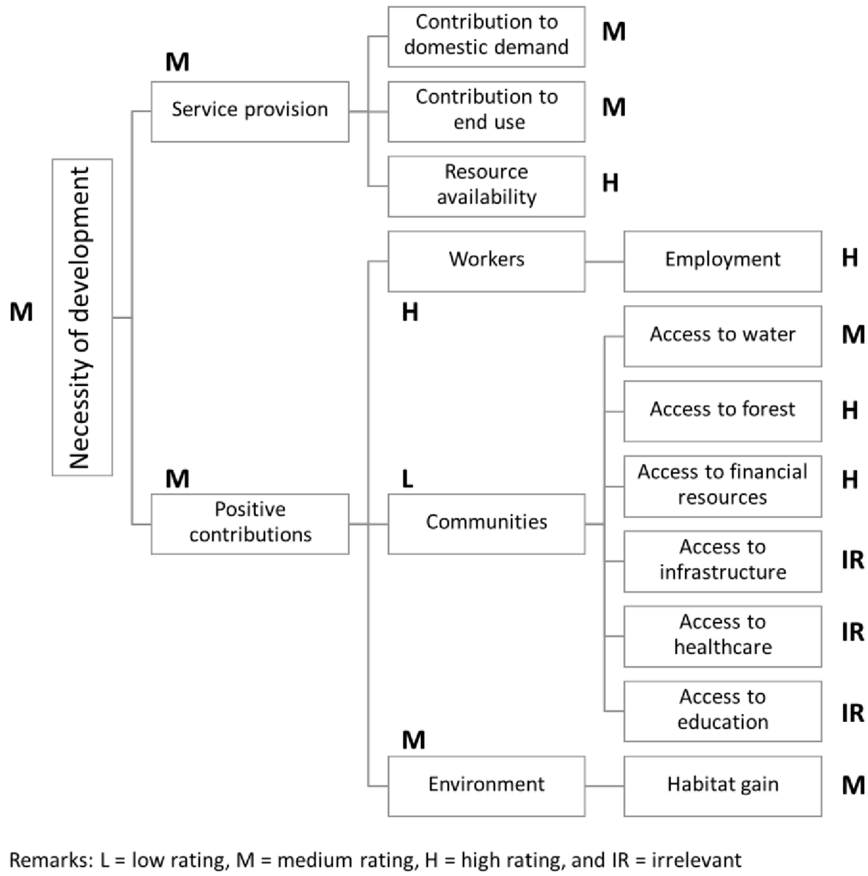
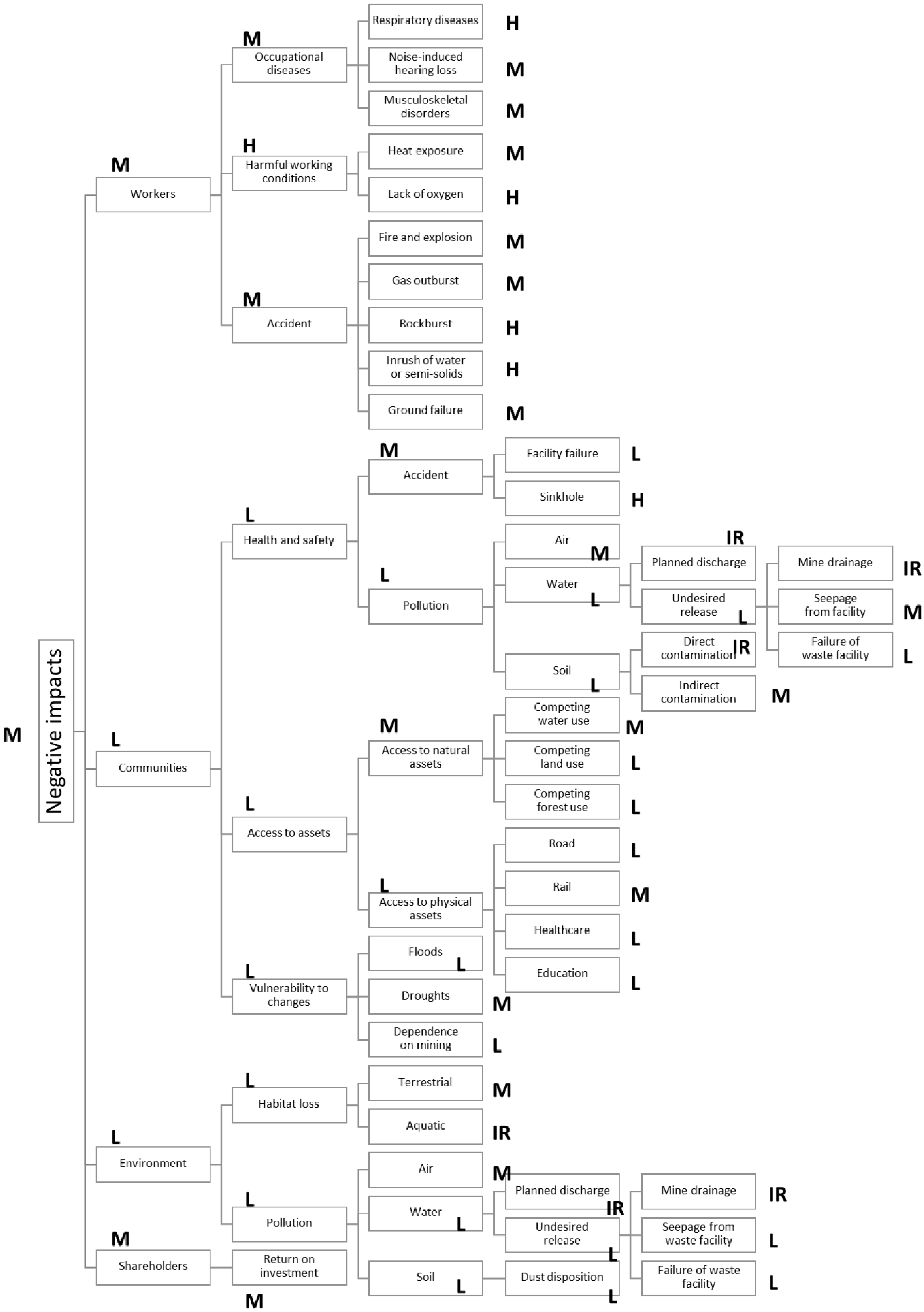


Figure 6.1: Summary of the ratings of the necessity of project development



Remarks: L = low rating, M = medium rating, H = high rating, and IR = irrelevant

Figure 6.2: Summary of the ratings of the negative impacts

The medium rating of the development necessity is derived from the medium rating of both service provision and positive contributions. The medium rating of the service provision results from the medium contribution to domestic demand, the medium contribution to end use, and high resource availability. It shows that the new project can reduce the import of raw material moderately. An increased domestic supply can lead to an increased export of potassium. The current low-level potassium export is likely to grow but the growth will not be drastic. The high rating of resource availability indicates that the resource is still abundant and can supply the needs for a long time, so the development should not cause any raw material shortage or depletion in the near future.

The positive contributions are rated as high, derived from the high rating of the contributions to worker's well-being, low rating of the contributions to community's well-being, and medium rating of the contributions to environmental wellness. The main contributions come from full-time employment. This is not an unexpected result because the scale of this project is large compared to quarries, in which the majority of Thailand's mining activities take place (Department of Primary Industries and Mines, 2016b). It is interesting to see that the contributions to community's and environmental well-being are ranked as low and medium, respectively. The results show that the project can contribute significantly to access to water, forest, and financial resources. However, the contributions in terms of infrastructure and basic services are irrelevant. The documents submitted to the government and other publicized project documents do not state any concrete social investment and development plans regarding these issues. At the same time, the habitat gain that the project might induce is moderate despite a significant reforested area. This is because the reforested area is relatively low in diversity. The low to medium ratings of the contributions to community's and environmental well-being imply the insufficient concerns and actions of the mining project about bringing forth constructive changes and improvements.

The medium rating of the negative impacts results from the medium rating of the impacts on workers and shareholders and the low ratings of the impacts on communities and the environment.

The medium rating of the negative impacts on workers is a consequence of the high risk of harmful working conditions and the medium risks of occupational diseases and accidents. The medium impact rating of occupational diseases is derived from the high risk of respiratory diseases and the moderate risks of hearing problems and musculoskeletal disorders. Diesel exhausts mainly in the underground mine and respirable particulate matters are the key sources for these diseases. The high rating of harmful working conditions is derived from the moderate risk of heat illness and high risk of asphyxiation. The moderate accident rating is obtained from the high risks of rockburst and water inrush and the medium risks of fire and explosion, gas outburst, and ground failure. These ratings are in the expected ranges. They reflect the fact that the problems of respiratory diseases, heat illnesses, asphyxiation, as well as accidents are not uncommon in underground mining (Donoghue, 2004a; Silverman et al., 2012) and that the operating conditions according to the mine design such as mine depth and geological characteristics are not harsh.

The negative impacts on communities are rated as low. The rating is derived from the low ratings of health and safety, access to assets, and vulnerability to changes. In the health and safety issue, the low rating is derived from a medium risk of accidents and low risk of health issues from pollution. The main source of accidents is sinkholes, which result from the type of minerals. The low risk of pollution is mainly influenced by the medium rating of air pollution, which mainly results from diesel exhausts and respirable dust in the mine and combustion gases from the coal-fueled cogeneration plant, and the end-product processing and handling in the processing plant. Contamination can also arise from soil pollution through dust deposition and water pollution through an undesired release of pollutants, especially possible seepage in the waste storage facility.

The low rating of the negative impacts on the community's access to assets is derived from the low ratings of access to natural assets and access to physical assets. Most of the issues are rated as low. Two of them have medium impacts, including competing water use and railroads. The impact of competing water use is moderate. However, because a large percentage of the population works in the agricultural sector, the competitive use of water has a significant impact. The competitive use of infrastructure and services, on the other hand, has a low impact because the project will cause only slight changes in demand relative to the remaining capacity of the infrastructure. Furthermore, the company tries to compensate the additional need for services by recruiting and providing new resources. However, the compensation efforts do not fully alleviate the additional demand.

The low rating of the negative impacts on the community's vulnerability to changes is based on the low ratings of the vulnerability to floods and the dependency on mining and the medium rating of the vulnerability to droughts. The vulnerability to droughts requires more concerns because many parts of the project area are identified as drought-prone and the consequence of mining on water availability can enhance the effect of droughts.

The low rating of the negative impacts on the environment results from low risks of habitat loss and biodiversity damages from pollution. The removal of land cover for a long period is the main factor of habitat loss, but the impact level is not high because of the low presence of species in the area. The effects of pollution on the environment result mainly from air pollution. This result is in line with the expectation because the project does not plan to discharge water and waste materials, and the main emissions are the acidic gases from fossil fuel combustion.

The medium rating of the negative impacts on shareholders is obtained from the moderate risk of business failure. This results from the fact that the project expects a moderate rate of return under high risks, especially with regards to social conflicts.

The assessment results are informative and can be used for many purposes. However, the question may arise how reasonable and meaningful they are. The Sustainable Measures private consulting (2010) identified four characteristics of effective indicators, namely, being relevant, easy to understand, reliable, and based on accessible data. These characteristics are used to consider the effectiveness of the assessment framework as follows.

Relevant. Being relevant means that the assessment results show the information the assessor needs to know. This assessment framework responds to the research questions how the worthiness of the development of a new mining project can be assessed based on Buddhist ethics. The relevance of the framework to the Buddhist idea of worthiness can be explained in terms of what, who, when, and where as follows.

- *What.* The components related to the well-being of humans and the environment, especially those components conducive to improving or worsening suffering conditions ascertain the impacts. They are determined by both the anticipated consequences and the risks of intentional and unintentional events that bear on the well-being of humans and the environment.
- *Who.* The positive and negative consequences of the proposed mining project are determined in relation to the key stakeholders and the environment. This reflects the

correction of self-interest-oriented perspective in the available assessment methods and makes the assessment more compatible with the government's objectives of satisfying the collective needs of the public (Gildenhuys, 2004, p. 369).

- *When.* The positive and negative impacts are assessed using the project lifetime as a time frame with special emphasis on the impacts during the operation phase. The significant impacts that occur in other phases are included with an additional description of the time frame such as rehabilitation after mine closure and ground subsidence. The study stretches over the primary periods of the key impacts, thus providing a comprehensive and objective assessment.
- *Where.* The impacts are determined both on the national and the local level. The spatial boundaries vary according to the subject matter. In most cases, the local-level area is limited to where activities take place such as the mining area, processing area, and tailing facility. Broader boundaries are applied when movement of substances are involved (such as pollution). The assessment should cover the area that is most critically affected by the project, so that an overall view of the framework includes a spatial look at the project's worthiness.

Owing to the characteristics mentioned above, the assessment framework reflects the Buddhist view of worthiness and provides comprehensive, objective information for the governmental decision-making as well as the subsequent project administration.

Easy to understand. The framework consists of a set of related topics. The aggregated score specifies the level of consequence relative to the specified topics. The aggregated score provides a rough idea about the presence and the magnitude of consequences of the specified issues, which can be compared with that of different development alternatives. Together, its compositional details, i.e. the ratings of the components within its hierarchy, prevent the informants from being misled by any reductionism effects. These details are also aggregated and presented in a rating form, so it is simple not only for the assessor but also for non-experts to understand the overview and the assessment results.

Reliable. The assessment of anticipated and possible impacts of the project is based on the risk assessment concept. The risk-based approaches are established upon scientific information and are likely to be scientifically defensible (National Research Council, 1999, p. 81). Moreover, the components in the assessment are structured in a hierarchy following the Analytic Hierarchy Process (AHP), of which the hierarchical structure provides a systematic decomposition of a problem in decision-making (Saaty, 2008). The components are assessed from the indicators, which are identified as causes or influential factors or possible effects aggregated in a hierarchical structure. Using a hierarchical structure also reduces the compensation effects in the rating aggregation by summating the ratings and re-rated them level by level. In addition, most of the criteria for rating these indicators are set with reference to empirical, scientific, standard, or statistical values, and the framework uses the data from reasonable sources such as engineering design documents, statistical records, and survey data. As a result, the assessment framework is scientifically reliable.

Based on accessible data. The assessment framework involves a number of parameters and contains a large set of criteria. The main sources of information are the mining plan and the EIA report officially submitted by the company to the government. Although the data are obtained from the company, they must be reviewed by the governmental agencies. As a result, the data correctness is generally reliable to a certain degree. Other sources are statistical data such as economic data, social structure and population, and weather records as well as technical studies which provide geological and hydrological data. Most of the data are accessible to the government. It is possible that some data are unavailable, especially for the assessment of smaller-scale projects or those using simple production methods. The absence of assessment data signifies that the past studies might be insufficient and requires the government and companies to acquire more data for planning and manangement purposes. On the other hand, the government has an option to use data from other projects as references. Accordingly, the assessment framework is considered reasonable in terms of data accessibility.

6.2 Implementation of the framework

Knowing the characteristics of the assessment framework, we can attempt to answer the last sub-research question 'how can the assessment be integrated in the current administration system?' The primary objective of this assessment framework was to help the government make a decision on the development of new mining projects. Accordingly, the framework should be integrated in the mining lease approval stage, which also includes the approval of the mining plan and the EIA report – the main information sources of the assessment. Conducting the assessment at this stage is beneficial to the governmental administration in many ways. The assessment results can be used to support the approval decision-making process. Understanding the mining consequences and development priorities of the project can help identify the necessary management preparations for the project. These include provisions for dealing with the positive and negative impacts brought about by the proposed project. The assessment data will also help examine the choices of the design parameters. Moreover, the assessment framework can be used to compare development options and help identify the weaknesses in the mining plan and the EIA report. Through an iterative process and adjustment, more complete documents can be obtained. Additionally, the assessment results can be used for communicating with stakeholders and enhancing their collaboration with the company. With respect to stakeholder groups, the results can be used separately for different target groups. When stakeholders have a better understanding of the development objectives and the impacts they would face, they can better communicate and collaborate with the company to achieve their mutual goals.

The use of the assessment results is not limited to the early stage of the project. It can also be useful for the government and the company as a basis for defining management strategies during the operation and post-closure stages for strengthening compliance, preventing or controlling what will cause physical suffering to others, promoting well-being, preparing for uncertainties and risks, and promoting continuous improvement. These strategies are linked to certain policy issues. The important ones include operation control, mining revenue management, post-mining management, and public participation.

Operation control. The assessment results identify the extent of negative impacts of the project. The key idea of the operation control is to reduce the negative impacts through legal compliance. Basically, the company must conform to the imposed rules, regulations, and norms. The impact (risk) ratings of sub-components and indicators inform which issues require special attention. The government can focus its efforts on monitoring, controlling, and improving the ratings of more critical issues. Following the risk treatment options (International Standard Organization, 2009), the measures to avoid, reduce, share, or accept the risks must be identified and imposed under the continuous improvement process. The results of the case study can be used as an example. The negative impacts on workers are rated as medium. The main risk of occupational diseases results from the amount of pollutant release, factors affecting exposure, and number of workers. Measures to avoid risks, such as changing the design and machinery, to reduce risks such as using protection equipment or implementing capacity building programs, to share risks such as arranging a working schedule, and to accept risks such as health monitoring programs, must be considered and specified as part of the requirements.

Mining revenue management. Revenue management is in the focus of the public, especially for a large-scale mining project. Because mining can provide a huge amount of revenue to the communities (International Institute of Environment and Development, 2002, p. 201), efficient management can ensure meaningful spending and the transformation of financial capital to other forms of capitals necessary for the well-being of people and the environment. The assessment results identify how much a mining project contributes to the well-being of workers, communities, and the environment. They also contain information about the conditions of the local communities and ecosystem. The information can help gauge the needs for improving the communities' welfare and advise on which issues the revenue should be spent. The results of the case study can be used as an example. The results show that the project will contribute slightly to moderately to the well-being of the communities and environment. There will be no significant improvement in the community's access to infrastructure and basic services. Since the project will increase the community's access to financial resources from royalties considerably and, according to the measures in the EIA report (ASEAN Potash Mining PLC, 2014b), from the special community funding, the investment for improving the habitat conditions and the community's access to natural resources, infrastructure, and services should be prioritized. Moreover, the data on flood and drought vulnerability in the negative impact assessment shows that many communities are vulnerable to floods and droughts and the majority of the communities rely significantly on natural resources. Improving the flood and drought conditions should be at the top of the investment list. Since the local administration is responsible for managing the revenue, basic requirements on how to spend the money must be specified so that the prioritized development issues are accomplished.

Post-mining management. Post-mining management is another important issue affecting the well-beings of internal and external stakeholders. Subjects to be considered in the post-mining planning are mainly safety and health, environmental damage, and local economy. The assessment provides post-mining data about habitat gain-loss, access to assets, dependency on mining, vulnerability to change, unintentional release of water pollutants, and the community's health and safety (especially regarding accidents). This data helps to identify the weaknesses in the current post-mining management plan so that additional measures can be specified and financial resources for implementation can be secured. The results of the case study can be used as an example. They show that the project will cause a net loss of habitat and an increase in potential accidents. The vulnerability to droughts might also be elevated. In terms of economics, the effects of mine closure might not be critical owing to the low dependency on mining. This information implies that the post-mining plan should put more emphasis on developing habitats and improving the safety of the communities (regarding potential accidents). Possible schemes should be integrated in the plan to mitigate vulnerability to natural hazards and to strengthen the community's livelihood.

Public participation. Sufficient information increases the capacity and understanding of stakeholders in public participation and prevents them from fears and mistrust (The Chamber of Mines of South Africa, 2002). The assessment framework provides an overview of what the stakeholders should expect from the development of a mining project. It can be used to promote the understanding of mutual objectives and cooperation between company and stakeholders. The results based on an equal attention to the impacts on different stakeholders provide a ground for open dialogs. When the advantages and disadvantages of different parties are considered, trust can be created and participation can be enhanced. The assessment results can also be used for communicating and increasing the roles of stakeholders during the development. Along with the continuous improvement process, communication with the public can promote efficient cooperation and successful development on a local level.

All in all, the details of the policy issues and strategies mentioned above reflect one main goal, i.e. to affirm and raise the project development's priority (worthiness). This is achieved either by enhancing the necessity of the development or by reducing negative impacts. In this case, both parts are equally important and should be emphasized as they will improve the project development priority as shown in Figure 6.3.

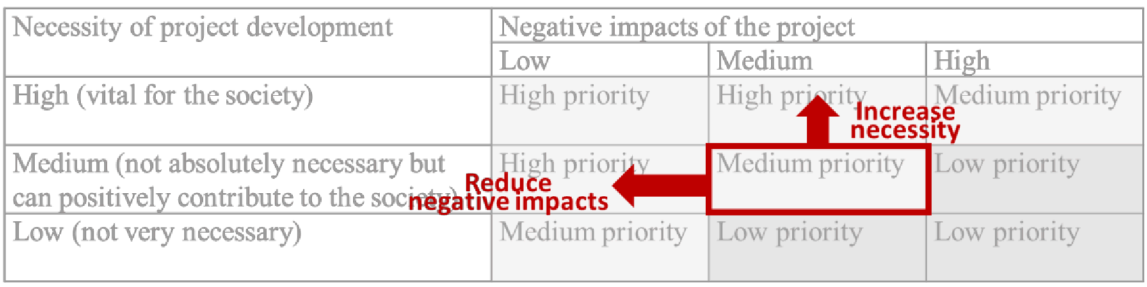


Figure 6.3: Objective of mineral policy and development strategies

In addition to the project-level management, the information regarding service provision can also be useful for strategic planning and managing mineral resources at a macro level. **Figure** 6.4 illustrates the possible applications of the assessment framework and its results by the government during the project life cycle.

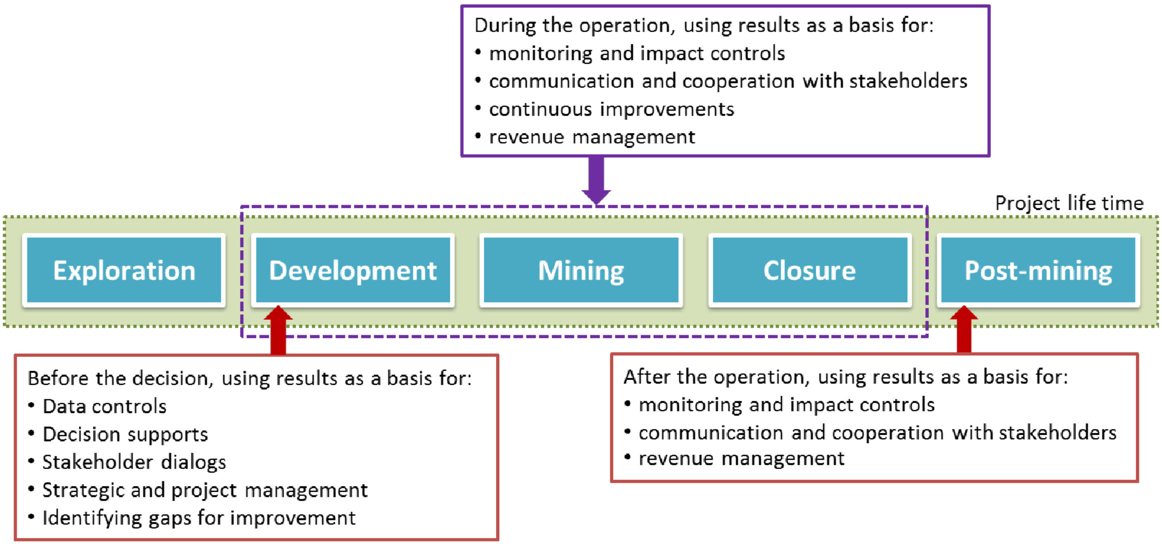


Figure 6.4: Possible applications of the assessment framework and its results by the government

In practice, the staff arrangement for implementing this assessment framework is another important aspect that the governments need to consider. It can be done in different ways but is more preferable that the mining authority or a third party carries out this assessment since it should make the assessment results neutral and credible. If the authority is responsible for this task, it can also benefit from the framework since the framework can facilitate the reviews of plan and reporting documents. Establishing an assessment team can be a good option to implement this assessment framework because of the interdisciplinary characteristic of the framework. It is recommended that the assessors should have a scientific background because the assessment involves some judgement and assumptions. Having a scientific background can help them to be more aware of the limitations and able to make reasonable judgments if necessary.

This assessment framework is supposed to be applicable to surface and underground mining projects in general. Although it is based on Buddhist principles, the idea can be applied in general and is not specific to only for the Buddhist countries or Thailand because Buddhist principles contribute to the improvements of the assessment approaches by making information more neutral and emphasizing the reduction of suffering and the increase of public well-beings. Accordingly, it should be applicable to other countries with different cultures, with some criteria adjustments. Rather than the method itself, what determines whether the framework should be applied to other contexts or not depends on the development objectives of those countries and the purpose of their uses.

7 Conclusions and recommendations

This study was motivated by the problem concerning mineral management in Thailand. The authorities responsible for granting mining leases face the difficulties of evaluating new mining projects and communicating their decisions to other stakeholders. The problems are displayed through the resistance in society by those who oppose new mining projects. A further issue is inefficient administration among different governmental agencies. These problems result partly from the current decision-making procedure for granting mining leases. The key tool applied during the mining project approval procedure is the environmental impact assessment (EIA). Although it improves project approval process especially in terms of the comprehensiveness of impact-related information and helps identify the project's consequences on certain aspects, it does not provide any indication as to whether the project is in the interest of the government or the public.

The objective of this study is to create a tool that can help Thai authorities and mining stakeholders to consider the worthiness of new mining projects. An assessment framework for new mining projects is developed with reference to the sustainable development concept, in which the project's significance for the economy, ecology, and society is considered. A cultural perspective of the implementation of the concept is also taken into account when the framework is established, so as to ensure the framework's applicability and compatibility to the context of Thailand. Buddhist principles, the foundation of Thai values, are used to identify the implementation weaknesses of the sustainable development concept that might be problematic in non-Western, non-industrialized contexts such as in Thailand. The key weaknesses identified from the Buddhist perspective are (1) the pursuance of self-interest that can lead to profit-oriented behavior and (2) the reductionist perspective that can cause misleading understanding about the project consequences. The assessment framework establishes two attributes which help overcome these weaknesses. The first attribute is the inclusion of the interests of stakeholders instead of those of the shareholders only. The second attribute is the ability to present neutral, fact-based, holistic information regarding the consequences of mining projects.

The assessment framework determines the worthiness of a mining project in terms of project development priority through a necessity-impacts matrix. Necessity refers to the essential importance for developing the mining project, and impacts refer to the negative impacts of the mining project. Each component is determined from a set of parameters arranged in a hierarchy. This structural arrangement is inspired by the idea of Analytical Hierarchy Process (AHP) – a decision-supporting framework, in which the elements affecting decisions are organized into a hierarchy. The necessity is considered from service provision and the positive contribution to workers, communities, and the environment. The positive contribution to shareholders is not considered as a separate component due to the limitation of data, but part of the contribution is implied in other topics such as the contribution to workers. The impacts are determined in relation to workers, communities, the environment, and shareholders. The components, parameters, as well as sub-parameters are assessed using the risk concept and are rated as irrelevant, low, medium, or high. Their scores are subsequently aggregated up the hierarchy by summation. The final ratings of the necessity and the impacts are entered into the matrix to rank the project development priority.

The new assessment framework was validated by applying it to the case of a new underground potash mining project in Bamnet Narong, Chaiyapoom province, Thailand. According to the mining plan (ASEAN Potash Mining PLC, 2014a), this project is designed to have a production capacity of 7.8 tonnes carnallite ore per year using the room-and-pillar mining method and the drilling and blasting technique. The ore will be processed in the processing plant, which will apply a hot crystallization process to produce 95% KCl at the rate of 1.1 million tonnes per year. Wastes from the processing plant consisting of NaCl and $MgCl_2$ brine will be stored in the tailing dam, which consists of NaCl dump and $MgCl_2$ dam compartments located next to each other. The waste materials will gradually be backfilled into the mining voids during the operation period, and all of them will be kept underground at the end of the project. The project was assessed using the data from the EIA report and the mining plan officially submitted to the government as the main information sources.

The assessment result shows that the project development priority is moderate. It denotes a medium rating for both the necessity of the project development and the negative impacts. The medium rating of the necessity of development is derived from the medium rating of both the service provision and the positive contributions. The medium rating of the service provision results from the medium contribution to domestic demand, the medium contribution to end use, and the high resource availability. The high rating of the positive contributions is derived from the high contribution to worker's well-being, the low contribution to community's well-being, and the medium contribution to environmental wellness. The medium rating of the negative impacts results from the medium impacts on workers, the low impacts on communities and the environment, and the medium impacts on shareholders.

Decisions based on the assessment results are more objective compared to those of the current concessional process since the data on the positive and negative consequences of the new mining project as well as the interests of stakeholders are taken into account. The results are useful to the decision-making process in both aggregated and detailed forms. The aggregated form provides a comprehensive rating of the positive and negative consequences and a comparable priority ranking, which can facilitate communication among stakeholders. The detailed form allows the authorities as well as the stakeholders to identify influential parameters and cope with them in a more efficient way since their causal factors are also identified and assessed.

The assessment framework can be integrated into the current administration system. This tool can facilitate various functions in the mining lease approval process, which consists of various procedures such as the approval of the mining plan, the approval of EIA, the acquirement of land use rights, the attainment of the community's opinions, and public hearing. During the approval of the mining plan and of the EIA, it can help officials check whether the data submitted by the mining company is complete. The assessment results are useful for comparing alternatives, not only when selecting the design and process but also when identifying environmental as well as health and safety measures during the project life cycle. They can also facilitate the communication among government officials on the approval committee and among stakeholders during the public involvement process and during the operation and post-closure phases. The results help define management strategies such as the management of mining revenue, post-mining management, and public participation. Despite different application stages and activities, the uses of the assessment results serve one main goal, i.e. to affirm and raise the project development's priority (worthiness). This is achieved either by enhancing the necessity of the development or by reducing negative impacts or by both.

The assessment framework provides some strong points in terms of methodology and quality of the results. Firstly, it allows a neutral evaluation of the project's consequences. This is because the framework uses facts and scientific information to assess the impacts. Furthermore, it examines the impacts on stakeholders and not only the profit for shareholders. The impacts on the well-being of workers, communities, the environment, and shareholders are taken into account with equal importance. Moreover, the stakeholders' well-being is determined by the conditions that influence the state of well-being and not its level at a certain point of time. This helps reduce the appropriation by business interests because when the conditions influencing the state of well-being are improved, this improvement tends to last longer and can even be developed further. Unlike the former case, a change in the level of well-being at a certain point of time might just be temporary and resulting from the pursuit of individual interests such as a business objective. For example, the local communities might obtain extra services such as temporary healthcare services or educational programs, which improve the community well-being indicator during the project life but this well-being might not last once the mine has closed.

The second strength of this assessment framework is its comprehensiveness. The assessment components consist of a variety of issues that emerge when a mining project is developed. Most issues are related to the local impacts. The assessment results of these components are aggregated through a hierarchy into two rating values, the necessity of development and negative impacts. Using a matrix to identify the development priority allows the consideration of both components without summing up the positive and the negative values, which can mislead the overview understanding. The results provide information about the overall impacts of the entire project as well as the information about the impacts on certain groups of stakeholders or those concerning specific issues. The comprehensiveness of the assessment results also provides application advantages, especially with regards to identifying key problems and revealing improvement disparities. The case study provides obvious examples for this. For instance, the results regarding pollution show that air pollution is the main contributor to pollution problems or the results on positive contributions indicate that the mining project has a low contribution to the environment and communities, which shows a need for improvements.

Another advantage of this framework is that the assessment results can be used for management purposes. Because the impacts are mostly assessed in terms of risk and the assessment is carried out based on a certain set of components and criteria, the assessment results are comparable. Consequently, the framework can be used to compare different development options or different projects in addition to identifying the development priority of the project. Moreover, the identified risks provide the possibility to treat them in line with the risk management concept, i.e. by avoiding, reducing, sharing or transferring, or accepting the risks (International Standard Organization, 2009).

Despite its strengths, the assessment framework has some limitations, of which assessors and the users of the results should be aware. It is undeniable that this assessment framework contains reductionist characteristics and relative information, which can cause misunderstanding. The most important limitation is data uncertainty. The uncertainty is caused by many factors such as the inconsistency of data, the source of data, and the availability of data. This assessment framework deals with a large amount and different aspects of information. Because the framework includes all the key effects of the project, it involves information on technical, social, environmental, and economic dimensions. Although most of the data are available in the key information sources (i.e. mining plan, EIA report, and statistical databases), there might still be inconsistencies. There might be chronological inconsistencies because the data are available in different years or different periods of a year, so the data requires adjustments or comments to ensure that the assumptions are clear. The data derived from different studies might also contain uncertainties and inconsistencies because they are based on different data and assumptions and many of them are not derived from the Thailand's cases. For example, the estimation of emissions in the case study is calculated from the emission factors developed by the U.S. Environmental Protection Agency (1995) and the emission standard of the European Union (ECOpoint Inc., 2016). The conditions in these studies might differ from those of the actual case, and the study results that are the basis for identifying the emission factors are only some samples of the data. The fact that the estimated value might deviate substantially from the actually measured emissions should not be neglected, and the measured data from the actual case should be used as much as possible to avoid any uncertainty.

Data availability is another important source of uncertainty. Because the assessment is carried out at an early stage of the project, some data cannot be obtained and its related impacts cannot be included in the assessment. An important example is the data about social changes. Because human society is dynamic, it is difficult to predict the changes induced by a mining project such as the number of migrant workers not employed by the mining company, the number of businesses that might be attracted by the project, the number of social problems induced by the mining project, etc. Some estimations in the assessment such as an increasing number of students and a growing population are based on certain assumptions. To reduce the uncertainty of the estimation, it would be helpful to collect and compile statistical or empirical data of mining projects in Thailand in order to develop a set of reference values. This is a recommendation for a future study which would strengthen the effectiveness of the implementation of the assessment framework.

Data aggregation can also be a source of misunderstanding. The ratings of key components are derived from the aggregated ratings of their sub-components. The aggregation is mainly done by a weighted sum method, which is based on numerical addition. The weighted sum method has disadvantages such as its assumption of cardinal utility function (Pomerol and Barba-Romero, 2000, p. 78). It presupposes that criteria are neutral and that different alternatives have comparable, substitutable values, so their values can be summated. This weakness also influences the results of the rating aggregation and must be made clear. For example, components with irrelevant ratings can reduce the weighted sum value of the ratings. If the irrelevant component is present and is aggregated with other ratings, the overall rating including the irrelevant rating is lower than the overall one when the irrelevant rating is excluded. The irrelevant rating will be compensated by the ratings of other components. The lower score can give an impression that the overall impact is lower than it is in reality. For example, the average of two irrelevant impacts and one high impact results in a low impact average. Without looking at the details, the importance of the high impact will be overlooked. This might lead to an inefficient use of data and misinformed actions. Despite this danger, this framework still includes the irrelevant ratings in the aggregation in order to make the results comparable. The overall rating obtained from the assessment is a relative value to the specified set of criteria. To prevent any misunderstanding caused by the reductionist approach, result users should always consider the aggregated ratings together with the detailed ratings in the hierarchy. When using the assessment results, one should be aware of the scope of the information. This is because the assessment framework is a generic framework, designed to cover the major issues of positive and negative impacts of mining projects. Some issues are not included in the assessment. The heavy metals evaluated in the study are the four most important substances: arsenic, cadmium, lead, and mercury. However, if a project deals with other heavy metals such as nickel or copper, the impacts from these substances might be significant but might be neglected because they are not dealt with in the framework. In these cases, this framework leaves room for adjustments. Additional risks or components can be added to the related subjects or components in the hierarchy. The scope and/or criteria can also be adjusted to make them more logical or related to the project's conditions. To do so, it is important that the alteration is based on reasonable grounds.

Future research projects should bear the aforementioned limitations of this new assessment framework in mind. One of the possible improvements is the adjustment of the data aggregation procedure. In this assessment, the ratings of different components in the hierarchy are aggregated at each level so that they are in a comparable, communicable form and easy to understand, but the results are still affected by reductionism. In fact, this method is one of the possible ways for data aggregation. This poses a question for future observations as to how different the outcomes from different aggregation methods may be. In addition, the weakness of the weighted sum method mentioned earlier should not be ignored. A possible way to reduce the effect of irrelevance is to separate the framework into different sub-categories, for example, underground and surface mines. An improvement in this part would help increase reliability of the model. In addition, carrying out empirical researches to identify the values of the data which are difficult to predict, such as the social impacts, in order to attain reliable reference values for future estimation would improve the implementation efficiency of this framework since they can help reduce uncertainties in the assessment results.

Another issue that should be emphasized is related to the static characteristic of the assessment. The assessment uses specific values, for example, the mass flow of the project is based on the data at full production and the substance flow of potassium is based on the data in 2012. Possible changes during the operation such as a change in production rate due to market conditions and its subsequent changes in emissions are not taken into account. Although it is adequate to provide a preliminary idea about the consequences of the project, it would be conducive to similar assessments in future or for other applications to improve data collections so that they include the temporal aspects. In addition to the static nature, the assessment does not consider the operation term. Some data such as that on emissions is measured annually, thereby not including the influence of a project's duration. As a consequence, some results do not show the differences between short-term and long-term projects. Users need to be aware of this limitation, and this aspect should be emphasized in the future improvements. In addition, some of the criteria are based on recent statistical data such as those of the status of current end use (under service provision). They should be reviewed from time to time and adjusted if necessary. Related policies should also be taken into account.

Another useful improvement would be the extension of the assessment framework and its applications. This assessment framework is designed for use at a pre-development stage. However, the components and the structure of the framework can also be applied during the operation stage. To do so, the assessment criteria need to be adjusted so that the actual data can be used and the model can show changes and reflect a project's performance.

The assessment framework developed in this study is not only a tool to assist the Thai government in its decision-making but also a starting point for implementing good practices in mining project management. Identifying risks and impacts will develop an understanding of what everyone should expect from a mining project and how to gear towards that vision. Together with the understanding, tools and practical guidelines as well as regulations, which are important components in terms of action, must be developed in order to facilitate and promote the increase of necessity and to diminish the negative impacts. Putting the understanding and the action together, the entire framework for assessment and implementation can systematically and continuously guide the conduct of mining projects towards a firm, efficient path and allow the projects to contribute to the sustaining well-being of humans and the environment.

8 Bibliography

Ahluwalia, V.K., 2015. Environmental Studies, 2nd ed. The Energy and Resources Institute (TERI), New Delhi.

Alcamo, J., Ash, N.J., Butler, C.D., Callicott, J.B., Capistrano, D., Carpenter, S.R., Castilla, J.C., Chambers, R., Chopra, K., Cropper, A., Daily, G.C., Dasgupta, P., Groot, R. de, Dietz, T., Duraiappah, A.K., Gadgil, M., Hamilton, K., Hassan, R., Lambin, E.F., Lebel, L., Leemans, R., Jiyuan, L., Malingreau, J.-P., May, R.M., McCalla, A.F., McMichael, T. (A. J.., Moldan, B., Mooney, H., Naeem, S., Nelson, G.C., Wen-Yuan, N., Noble, I., Zhiyun, O., Pagiola, S., Pauly, D., Percy, S., Pingali, P., Prescott-Allen, R., Reid, W. V., Ricketts, T.H., Samper, C., Scholes, R. (Bob), Simons, H., Toth, F.L., Turpie, J.K., Watson, R.T., Wilbanks, T.J., Williams, M., Wood, S., Shidong, Z., Zurek, M.B., 2003. Ecosystems and Human Well-being: A Framework for Assessment. Island Press, Washington D.C.

Alsharedah, Y.A., 2015. Slope Stability Enhancement of an Upstream Tailings Dam: Laboratory Testing and Numerical Modelling. The University of Western Ontario.

ASEAN Potash Chaiyaphum PLC, 2016. ASEAN Potash Chaiyaphum Public Company Limited: Corporate Social Responsibility [WWW Document]. URL http://apot.co.th/2015/CSR.php (accessed 11.16.16).

ASEAN Potash Mining PLC, 2014a. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.

ASEAN Potash Mining PLC, 2014b. Environmental Impact Assessment, Bamnet Narong Potash Project. Bangkok.

Atlas Copco, 2010. Exploration Drilling, First Edition [WWW Document]. URL http://www.podshop.se/content/10/opensearchresult.aspx?file=6991+1722+01_l.pdf (accessed 11.16.16).

Australian Safety and Compensation Council, 2006. Occupational Respiratory Diseases in Australia.

Awuah-Offei, K., Adekpedjou, A., 2011. Application of life cycle assessment in the mining industry. Int. J. Life Cycle Assess. 16, 82–89. doi:10.1007/s11367-010-0246-6

Bank of Thailand, 2016. Average Exchange Rate of Commercial Bank in Bangkok, Yearly Rate [WWW Document]. URL http://www2.bot.or.th/statistics/ReportPage.aspx?reportID=123&language=th (accessed 11.16.16).

Bank of Thailand, 2015. Employment Statistics, as per 30 June 2015 [WWW Document]. URL http://www2.bot.or.th/statistics/ReportPage.aspx?reportID=638&language=th, 15-7-2015 (accessed 7.15.15).

Bank of Thailand, 2011. Employment Statistics (New Set), Northeastern Region, 2010 [WWW Document]. URL http://www2.bot.or.th/statistics/ReportPage.aspx?reportID=725&language=th (accessed 11.26.16).

Barker, J.R., Tingey, D.T., 1992. The effects of air pollution on biodiversity: a synopsis, in: Barker, J.R., Tingey, D.T. (Eds.), Air Pollution Effects on Biodiversity. Springer Science+Business Media, New York.

Bartels, S.F., Chen, H.Y.H., Wulder, M.A., White, J.C., 2016. Trends in post-disturbance recovery rates of Canada's forests following wildfire and harvest. For. Ecol. Manage. 361, 194–207. doi:10.1016/j.foreco.2015.11.015

Bauer, E.R., Kohler, J.L., n.d. Cross-sectional Survey of Noise Exposure in the Mining Industry.

Bell, F.G., 1999. Geological Hazards: Their Assessment, Avoidance and Mitigation. E & FN Spon, London and New York.

Bell, F.G., Stacey, T.R., Genske, D.D., 2000. Mining subsidence and its effect on the environment: some differing examples. Environ. Geol. 40, 135–152. doi:10.1007/s002540000140

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., Courchamp, F., 2012. Impacts of climate change on the future of biodiversity. Ecol. Lett. 15, 365–377. doi:10.1111/j.1461-0248.2011.01736.x

Bieniawski, Z.T., 1992. Ground control, in: Hartman, H.L. (Ed.), SME Mining Engineering Handbook. Colorado, pp. 897–911.

Bieniawski, Z.T., 1989. Engineering Rock Mass Classifications. Wiley, New York.

Blake, W., Hedley, D.G.F., 2003. Rockbursts: Case Studies from North American Hard-rock Mines. Society for Mining, Metallurgy, and Exploration, Inc., Littleton, Colorado.

Blight, G.E., Fourie, A.B., 2004. A Review of catastrophic flow failures of deposits of mine waste and municipal refuse, in: Picarelli (Ed.), Proceedings of International Workshop "Occurrence and Mechanisms of Flow-Lik Landslides in Natural Slopes and Earthfills." Patron, Bologna, Sorrento, pp. 19–36.

Borquez, G. V., Thompson, J. V., 1990. Feasibility studies, in: Kennedy, B.A. (Ed.), Surface Mining. Society for Mining, Metallurgy, and Exploration, Inc., Littleton, Colorado, pp. 396–423.

Bradshaw, V., 2006. Human comfort and health requirements, in: The Building Environment: Active and Passive Control Systems. Wiley, pp. 3–37.

Brady, B.H.G., Brown, E.T., 1985. Rock Mechanics: For Underground Mining. George Allen & Unwin, London.

Brazda, L.L., Thornburg, H.A., 1990. 4.3 Financial aspects, in: Kennedy, B.A. (Ed.), Surface Mining. Society for Mining, Metallurgy, and Exploration, Colorado, pp. 424–451.

Bröring, U., Wiegleb, G., 2005. Assessing biodiversity in SEA, in: Michael Schmidt, João, E., Albrecht, E. (Eds.), Implementing Strategic Environmental Assessment. Springer-Verlag, Berlin/Heidelberg, pp. 523–538. doi:10.1007/3-540-27134-1_36

Brown, E.T., Hoek, E., 1978. Technical note: Trends in relationships between measured in-situ stresses and depth. Int. J. Rock Mech. Min. Sci. 15, 211–215.

Buddhatasa Bhikku, 1983. The Four Noble Truth from Buddha's Words: Beginning Part, 2nd ed. Dhammatan Foundation, Chaiya.

Buja, H.O., 2013. Ingenieurhandbuch Bergbautechnik: Lagerstätten und Gewinnungstechnik, 1st ed. Beuth, Berlin.

Bullock, R.L., 2011. Mineral property feasibility studies, in: Darling, P. (Ed.), SME Mining Engineering Handbook. Society for Mining, Metallurgy, and Exploration, Inc., Littleton, Colorado, pp. 227–261.

Cai, M., 2016. Prediction and prevention of rockburst in metal mines – A case study of Sanshandao gold mine. J. Rock Mech. Geotech. Eng. 8, 204–211. doi:10.1016/j.jrmge.2015.11.002

Call, R.D., Savely, J.P., 1990. Open pit rock mechanics, in: Kennedy, B.A. (Ed.), Surface Mining. Society for Mining, Metallurgy, and Exploration, Inc., Littleton, Colorado, pp. 860–882.

Canter, L., Sadler, B., 1997. A Tool Kit for Effective EIA Practice - Review of Methods and Perspectives on Their Application, A Supplementary Report of the International Study of the Effectiveness of Environmental Assessment.

Canter, L.W., 1999. Sources, effects, and fate of pollutants, in: Liu, D.H.F., Liptak, B.G. (Eds.), Air Pollution. CRC Press, pp. 3–19.

Cantor, M., 2011. Development for the Past, Present, and Future: Defining and Measuring Sustainable Development (No. Paper 305), Senior Honors Projects.

Capoferri, S., 2014. The financial evaluation of 25 major iron ore projects using risk-adjusted discount rates. London.

Carney, D. (Ed.), 1998. Sustainable Rural Livelihoods: What Contribution Can We Make? London.

Caudle, R.D., Clark, G.B., 1955. Stresses around Mine Openings in Some Simple Geologic Structures (No. 430), Illinois Engineering Experiment Station Bulletin.

CCSG Associates, 2004. Overburdened: Understanding the Impacts of Mineral Extraction on Women's Health in Mining Communities. Ottawa, Ontario.

Chalermlarp, S., Kiatwongthong, N., 2004. The Study on Mining Problem Cases for Policy Recommendation. Bangkok.

Chambers, R., Conway, G.R., 1991. Sustainable rural livelihood: practical concept for the 21st century, IDS Discussion Paper 296. Institute of Development Studies, Brighton.

Chaudhary, D.K., Bhattacherjee, A., Patra, A.K., Chau, N., 2015. Whole-body Vibration Exposure of Drill Operators in Iron Ore Mines and Role of Machine-Related, Individual, and Rock-Related Factors. Saf. Health Work 6, 268–278. doi:10.1016/j.shaw.2015.06.004

Chazdon, R.L., 2003. Tropical forest recovery: legacies of human impact and natural disturbances. Perspect. Plant Ecol. Evol. Syst. 6, 51–71.

Colorado Division of Minerals and Geology, 2002. Best Practices in Abandoned Mine Land Reclamation: The Remediation of Past Mining Activities. State of Colorado, Denver.

Cordes, J., 2000. Normative and Philosophical Perspectives on the Concept of Sustainable Development, in: Otto, J.M., Cordes, J. (Eds.), Sustainable Development and the Future of Mineral Investment. United Nations Environment Programme.

Cristescu, R.H., Frère, C., Banks, P.B., 2012. A review of fauna in mine rehabilitation in Australia: Current state and future directions. Biol. Conserv. 149, 60–72. doi:10.1016/j.biocon.2012.02.003

Cronjé, F., Reyneke, S., Van Wyk, D., 2013. Local communities and health disaster management in the mining sector. Jàmbá J. Disaster Risk Stud. 5. doi:10.4102/jamba.v5i2.78

Crowson, P., 2009. The Resource Curse: A Modern Myth?, in: Richards, J.P. (Ed.), Mining, Society, and a Sustainable World. Springer-Verlag Berlin Heidelberg, Berlin, Heidelberg, pp. 3–36. doi:10.1007/978-3-642-01103-0

Davies, M., Lupo, J., Martin, T., McRoberts, E., Musse, M., Ritchie, D., 2010. A dewatered tailings practice - trends and observations (Presentation). AMEC Earth & Environmental.

Department of Agricultural Extension, 2011. Number of District, Sub-district, Village, Municipality, Local Administration Office, And Area, By Province, 2011 [WWW Document]. URL http://www.agriinfo.doae.go.th/year54/general/village54.pdf (accessed 10.25.16).

Department of Disaster Prevention and Mitigation, 2012a. Flood- and Mud Slide-prone Area 2010-2011, Regional Office 5: Nakon Ratchasima [WWW Document]. URL http://www.rtrc.in.th/ewt_dl.php?nid=1562 (accessed 11.27.16).

Department of Disaster Prevention and Mitigation, 2012b. Drought-prone Area 2007, Lower Northeastern Thailand [WWW Document]. URL http://www.rtrc.in.th/more_news.php?cid=138&filename=index (accessed 11.27.16).

Department of Economic Development, Job, Transport and Resources, Victoria, A., 2016. Management of tailings storage facilities [WWW Document]. Miner. Guidel. Codes Pract. URL http://earthresources.vic.gov.au/earth-resources-regulation/licensing-and-approvals/minerals/guidelines-and-codes-of-practice/management-of-tailings-storage-facilities (accessed 2.4.17).

Department of Groundwater Resources, 2016. Thailand's Groundwater Level Situation 2015. Bangkok.

Department of Local Administration, 2016. Central Database System of Local Administration Organization, Chaiyapoom 2015 [WWW Document]. URL http://info.dla.go.th/public/surveyInfo.do (accessed 11.15.16).

Department of Local Administration, n.d. Standard for Small Reservoirs and Dams.

Bangkok.

Department of Mineral Resources, 2015. Geological and Georesource Status Report 2015. Bangkok.

Department of Mineral Resources, 2001. Maps of Mineral Resources [WWW Document]. URL http://www.dmr.go.th/download/webmap/Rkst.pdf (accessed 4.2.15).

Department of Primary Industries and Mines, 2016a. Royalty Rates and Announced Prices of Minerals [WWW Document]. URL http://www.dpim.go.th/minerals-minerals/mp002.php (accessed 12.27.16).

Department of Primary Industries and Mines, 2016b. Thailand's Mineral Statistics Database [WWW Document]. URL http://www7.dpim.go.th/stat/index.php (accessed 11.10.16).

Department of Primary Industries and Mines, 2016c. Mineral Statistics of Thailand 2011-2015. Bangkok.

Department of Primary Industries and Mines, 2015a. Thailand's Mineral Statistics Database [WWW Document]. URL http://www7.dpim.go.th/stat/ (accessed 7.31.15).

Department of Primary Industries and Mines, 2015b. Thailand's Mining Lease Database [WWW Document]. URL http://www.dpim.go.th/webservices/con_report.php (accessed 1.29.16).

Department of Primary Industries and Mines, 2007. Mineral Resource in Thailand 2007 [WWW Document]. URL http://www1.dpim.go.th/dpimdoc/ores/ (accessed 1.28.17).

Department of Primary Industries and Mines, Department of Mineral Resources, 2009. Thailand's mineral resources and reserves, Internal Document. Bangkok.

Department of Public Administration, 2016. Official Statistics Registration Systems [WWW Document]. URL http://stat.bora.dopa.go.th/stat/statnew/statTDD/ (accessed 11.10.16).

Department of Public Administration, n.d. Thailand's Local Administration [WWW Document]. URL http://pab.dopa.go.th/mmenu1.html (accessed 12.24.16).

Department of Water Resources, 2013. Groundwater Situation in Bangkok Metropolitan Region in 2012. Bangkok.

Doley, D., Audet, P., Mulligan, D.R., 2012. Examining the Australian context for post-mined land rehabilitation: Reconciling a paradigm for the development of natural and novel ecosystems among post-disturbance landscapes. Agric. Ecosyst. Environ. 163, 85–93. doi:10.1016/j.agee.2012.04.022

Donoghue, A.M., 2004a. Occupational health hazards in mining: an overview. Occup. Med. (Chic. Ill). 54, 283–289. doi:10.1093/occmed/kqh072

Donoghue, A.M., 2004b. Heat Illness in the U.S. Mining Industry. Am. J. Ind. Med. 45, 351–356. doi:10.1002/ajim.10345

Donoghue, A.M., 2000. Heat exhaustion in a deep underground metalliferous mine. Occup.

Environ. Med. 57, 165–174. doi:10.1136/oem.57.3.165

Dowling, R., Kittelson, W., Zegeer, J., Skabardonis, A., 1997. Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications. National Academy Press, Washington D.C.

Drysdale, D., 2011. An Introduction to Fire Dynamics, 3rd ed. Wiley.

Dunn, A., 2004. Great Companies, Great Chart: Effective Stock Trading Techniques to Beat the Markets. iUniverse Inc., New York, Lincoln, Shanghai.

ECOpoint Inc., 2016. Emission Standards, EU: Nonroad Engines [WWW Document]. URL https://www.dieselnet.com/standards/eu/nonroad.php (accessed 1.22.17).

Eger, T., Kociolek, A., Dickey, J., 2013. Comparing Health Risks to Load-Haul-Dump Vehicle Operators Exposed to Whole-Body Vibration Using EU Directive 2002/44EC, ISO 2631-1 and ISO 2631-5. Minerals 3, 16–35. doi:10.3390/min3010016

Environmental Law Alliance Worldwide, 2010. Guidebook for Evaluating Mining Project EIAs, 1st ed. Environmental Law Alliance Worldwide, Eugene, OR.

Environmental Law Institute, 2003. Conservation Thresholds for Land Use Planners. Environmental Law Institute, Washington D.C.

Ernst & Young Australia, 2016. Extractives Sector Reporting in Australia: Research Report.

European Commission, 2013. Science for Environmental Policy, In-depth Report, Soil Contamination: Impacts on Human Health (No. Issue 5), Science for Environmental Policy.

European Commission, 2006. Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques on Emissions from Storage.

European Environment Agency, 2012. Environmental Indicator Report 2012: Ecosystem Resilience and Resource Efficiency in a Green Economy in Europe. European Environment Agency, Copenhagen. doi:10.2800/4874

European Parliament, 2002. Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) (sixteenth individual Directive within. European Union.

EY, 2015. Business Risks Facing Mining and Metals 2015-2016: Moving from the Back Seat to the Driver's Seat.

Faling, H., Xiaoming, L., 1993. Re-analysis of the rockburst mechanism and discussion on the gradation of the rockburst intensity, in: Aydan, O., Kawamoto, T., Pasamehmetoglu, A.G., Whittaker, B.N. (Eds.), Assessment and Prevention of Failure Phenomena in Rock Engineering. Balkema, Rotterdam, p. 581.

FAO Forestry Department, 2010. Global Forest Resources Assessment 2010: Terms and Definitions. Rome.

Fernando, J.L., 2003. The Power of Unsustainable Development: What is to be Done? Ann. Am. Acad. Pol. Soc. Sci. 590, 6–34. doi:10.1177/0002716203258283

Focazio, M.J., Reilly, T.E., Rupert, M.G., Helsel, D.R., 2002. Assessing Ground-Water Vulnerability to Contamination: Providing Scientifically Defensible Information for Decision Makers, Circular 1224.

Fonseca, A., McAllister, M.L., Fitzpatrick, P., 2014. Sustainability reporting among mining corporations: a constructive critique of the GRI approach. J. Clean. Prod. 84, 70–83. doi:10.1016/j.jclepro.2012.11.050

Forestry Research Center, 2013. Biodiversity of Mae Horpra Forest Plantation, Chiang Mai.

Foster, G., Burgess, M., n.d. Assessment of Vibration Exposure in the Mining Industry.

Foster, S., Hirata, R., 1988. Groundwater Pollution Risk Assessment: A Methodology Using Available Data.

Gajigo, O., Dhaou, M. Ben, 2015. Economies of Scale in Gold Mining (No. 222). Abidjan.

Gaughan, P.A., 2011. Mergers, Acquisitions, and Corporate Restructurings, 5th ed. John Wiley & Sons, Inc., New Jersey.

Gibson, R.E., 2000. Favouring the higher test: contributions to sustainability as the central criterion for reviews and decisions under the Canadian Environmental Assessment Act. J. Environ. Law Pract. 10, 39–54.

Gilbert, A.J., 1997. The legal bases of federal environmental control of mining, in: Marcus, J.J. (Ed.), Mining Environmental Handbook: Effects of Mining on the Environment and American Environmental Control on Mining. Imperial College Press.

Gildenhuys, J.S.H., 2004. The Philosophy of Public Administration- A Holistic Approach: An Introduction for Undergraduate Students. Sun Press, Stellenbosch.

Gimm, W., Pforr, H., 1968. Gebirgsmechanik im Salzbergbau, in: Gimm, W. (Ed.), Kali- Und Steinsalz-Bergbau, Band I: Aufschluß Und Abbau von Kali- Und Steinsalzlagerstätten. VEB Deutscher Verlag für Grundstoffindustrie, Leipzig.

Global Reporting Initiative, 2015. Sustainability Disclosure Database [WWW Document]. URL http://database.globalreporting.org/search (accessed 10.24.16).

Global Reporting Initiative, 2013a. GRI Sustainability Reporting Standards: Reporting Principles and Standard Disclosures. Global Reporting Initiative, Amsterdam.

Global Reporting Initiative, 2013b. G4 Sector Disclosure: Mining and Metals. Global Reporting Initiative, Amsterdam.

Global Reporting Initiative, 2013c. G4 Sustainablility Reporting Guidelines. Amsterdam.

Global Reporting Initiative, n.d. Linking G4 and the UN Guiding Principles. Amsterdam.

Google Maps, 2016. Thailand [WWW Document]. URL https://www.google.com/maps/ (accessed 12.24.16).

Government of Ontario, 2016. R.R.O. 1990, Reg. 854: Mines and Mining Plants, under Occupational Health and Safety Act, R.S.O. 1990, c. O.1. Government of Ontario, Canada.

Graham, S., 2006. The sustainable development discourse: a view through the social constructivist lens. SPARC BC News 14–17.

Guha-Sapir, D., Hoyois, P., Below, R., 2015. Annual Disaster Statistical Review 2014 – The Numbers and Trends. Brussels.

Hakami, B.A., 2016. Waste disposal and landfill: information needs. Int. J. Civ. Eng. Technol. 7, 241–247.

Hansen, B.T., Wemmer, K., Eckhardt, M., Putthapiban, P., Assavapatchara, S., 2016. Isotope Dating of the Potash and Rock Salt Deposit at Bamnet Narong, NE-Thailand. Open J. Geol. 6, 875–894. doi:10.4236/ojg.2016.68067

Hasse, I., 2003. Basic atmospheric structure and concepts: Beaufort wind scale, in: North, G.R., Pyle, J.A., Zhang, F. (Eds.), Encyclopedia of Atmospheric Sciences, Volume 1. AP, pp. 1–6.

Health and Safety Executive, 2005. Control Back-pain Risks from Whole-body Vibration.

Health and Safety Executive, n.d. The Prevention and Control of Fire and Explosion in Mines. London.

Health and Safety Executive, n.d. Storage of Flammable Liquids in Process Areas, Workrooms, Laboratories and Similar Working Areas [WWW Document]. URL http://www.hse.gov.uk/fireandexplosion/storageflammliquids.htm (accessed 1.31.17b).

Health Information System Development Office, 2013. Thailand Health 2013. Nakon Pathom.

Herne, V., McGuire, T., 2001. Mississippi Potash, Inc.'s, underground operations, in: Hustrulid, W.A., Bullock, R.L. (Eds.), Underground Mining Methods: Engineering Fundamentals and International Case Studies. Society of Mining, Metallurgy, and Exploration, Inc., Littleton, Colorado.

Hofstede, G., Hofstede, G.J., Minkov, M., 2010. Cultures and Organizations, Software of the Mind, Intercultural Cooperation and its Importance for Survival. McGraw-Hill.

Huatalae Local Administration Office, n.d. Development Strategic Plan 2008-2012 [WWW Document]. URL http://www.huatalae.go.th/fileupload/1252551-2555.doc (accessed 11.25.16).

Hulshof, C., Veldhuijzen van Zanten, B., 1987. Whole-body vibration and low-back pain. Int. Arch. Occup. Environ. Health 59, 205–220. doi:10.1007/BF00377733

Humphreys, D., 2011. Pricing and trading in metals and minerals, in: Darling, P. (Ed.), SME Mining Engineering Handbook. Society for Mining, Metallurgy, and Exploration, Colorado, pp. 49–64.

Hunt, A.P., 2011. Symptoms of heat illness in surface mine workers. Queensland

University of Technology.

Hunt, A.P., Parker, A.W., Stewart, I.B., 2013. Symptoms of heat illness in surface mine workers. Int. Arch. Occup. Environ. Health 86, 519–527. doi:10.1007/s00420-012-0786-0

Huntington, S.P., 1997. After twenty years: the future of the third wave. J. Democr. 8, 3–12.

Hyett, D., 2010. Environmental risk assessment in environmental impact assessment – optional or mandatory?, in: IAIA10 Conference Proceedings, The Role of Impact Assessment in Transitioning to the Green Economy. 30th Annual Meeting of the International Association for Impact Assessment, Geneva, Switzerland.

Iannacchione, A., Prosser, L., Esterhuizen, G., Bajpayee, T.S., 2006. Assessing Roof Fall Hazards for Underground Stone Mines: A Proposed Methodology, in: SME Annual Meeting. St. Louis, MO.

Industry & Investment NSW, Queensland Department of Mines and Energy, 2009. Managing Musculoskeletal Disorders: A Practical Guide to Preventing Musculoskeletal Disorders in the NSW Mining and Extractives Industry.

Inoue, S., 1997. Putting Buddhism to Work: A New Approach to Management and Business. Kodansha International Ltd., Tokyo.

International Association for Impact Assessment, 2009. What Is Impact Assessment? [WWW Document]. URL http://www.iaia.org/uploads/pdf/What_is_IA_web.pdf (accessed 11.11.16).

International Council on Mining & Metals, 2003. 10 Principles [WWW Document]. URL http://www.icmm.com/document/1319 (accessed 3.16.16).

International Council on Mining and Metals, 2012a. In Brief: The Role of Mining in National Economies, Mining's Contribution to Sustainable Development. London.

International Council on Mining and Metals, 2012b. Water Management in Mining: a Selection of Case Studies. London.

International Council on Mining and Metals, 2010. Good Practice Guidance on Health Impact Assessment. London.

International Council on Mining and Metals, 2006. Good Practice Guidance for Mining and Biodiversity. International Council on Mining and Metals, London.

International Institute for Sustainable Development, 2002. Seven Questions to Sustainability How to Assess the Contribution of Mining and Minerals Activities. International Institute for Sustainable Development, Winnipeg.

International Institute of Environment and Development, 2002. Breaking New Ground: Mining, Minerals and Sustainable Development. Earthscan, London.

International Labour Organization, 1995a. Safety and Health in Mines Recommendation. International Labour Organization, Geneva.

International Labour Organization, 1995b. Safety and Health in Mines Recommendation. International Labour Organization, Geneva, 82nd ILC session (22 June 1995).

International Standard Organization, 2009. ISO 31000:2009 Risk Management - Principles and Guidelines.

International Standard Organization, 2006. ISO 14040: Environmental Management - Life Cycle Assessment - Principles and Framework, 2nd ed. International Standard Organization.

International Standard Organization, 2004. ISO 8996:2004 Ergonomics of the Thermal Environment -- Determination of Metabolic Rate. International Standard Organization.

International Union for Conservation of Nature and Natural Resources, 2012. IUCN Red List Categories and Criteria, Version 3.1, 2nd ed. International Union for Conservation of Nature and Natural Resources, Gland and Cambridge.

JEMA Agro, 2006. Manual Bucket Elevator T53/T54/T55 [WWW Document]. URL http://www.jema.as/media/T53_T54_T55_-_NON_ZONE_Engelsk.pdf (accessed 11.16.16).

Jenkins, H., Obara, L., 2008. Corporate social responsibility (CSR) in the mining industry - the risk of community dependency, in: Proceedings of the 2008 Centre for Resource Research Conference. Centre for Resource Research Conference, Queen's University Belfast, Belfast.

Jensen, R.C., 2014. Hierarchies of hazard control: A proposal to resolve different lists, Advances in Safety Management and Human Factors. AHFE Conference.

Jeremic, M.L., 1994. Rock Mechanics in Salt Mining. Balkema, Rotterdam.

Jimeno, C.L., Jimeno, E.L., Carcedo, F.J.A., 1995. Drilling and Blasting of Rocks. Taylor & Francis Group, London and New York.

Johnson, D.L., Papadopoulos, P., Watfa, N., Takala, J., 2001. Exposure criteria, occupational exposure levels, in: Goelzer, B., Hansen, C.H., Sehrndt, G.A. (Eds.), Occupational Exposure to Noise: Evaluation, Prevention and Control. World Health Organization, Dortmund, pp. 79–102.

Johnson, R.E., 2001. Shareholder Value: A Business Experience. Butterworth-Heinemann, Oxford.

Joyce, S.A., MacFarlane, M., 2001. Social Impact Assessment in the Mining Industry: Current Situation and Future Directions (No. 46), Mining, Minerals and Sustainable Development.

Kaushik, A., Kaushik, C.P., 2006. Perspectives in Environmental Studies, 2nd ed. New Age International Publishers.

Kemp, D., Bond, C.J., Franks, D.M., Cote, C., 2010. Mining, water and human rights: making the connection. J. Clean. Prod. 18, 1553–1562. doi:10.1016/j.jclepro.2010.06.008

Komin, S., 1991. National character in the Thai nine value clusters, in: Psychology of the Thai People: Values and Behavioral Patterns. National Institute of Development Administration (NIDA), Bangkok, pp. 191–197.

Kouame, K.A.J., Jiang, F., Zhu, S., Feng, Y., 2017. Overview of rock burst research in China and its application in Ivory Coast. Int. J. GEOMATE 12, 204–211. doi:10.21660/2017.29.67564

Kunimatsu, S., Pathak, K., 2012. Vibration-Related Disorders Induced by Mining Operations and Standardization of Assessment Process. MAPAN - J. Metrol. Soc. India 27, 241–249. doi:10.1007/s12647-012-0035-8

Kwata, M.G., 2014. Comparison of Methods for Measurement of Dust Deposition in South African Mining Sectors. University of Pretoria.

Lama, R., Saghafi, A., 2002. Overview of Gas Outbursts and Unusual Emissions, in: 2002 Coal Operators' Conference. The AusIM /Illawarra Branch, pp. 74–88.

Langston, J.D., Lubis, M.I., Sayer, J.A., Margules, C., Boedhihartono, A.K., Dirks, P.H.G.M., 2015. Comparative development benefits from small and large scale mines in North Sulawesi, Indonesia. Extr. Ind. Soc. 2, 434–444. doi:10.1016/j.exis.2015.02.007

Lapalme, L.-A., 2003. The Social Dimension of Sustainable Development and the Mining Industry: A Background Paper. Ottawa, Ontario.

Laurence, D., 2006. Optimisation of the mine closure process. J. Clean. Prod. 14, 285–298. doi:10.1016/j.jclepro.2004.04.011

Li, J.C., 2008. Environmental Impact Assessment in Developing Countries: An Opportunity for Greater Environmental Security? (No. 4), Working paper. Falls Church, VA.

Li, T., Xiao, X., Shi, Y., 2006. Comprehensive Integrated Methods of Rockburst Prediction in Underground Engineering (No. 594), IAEG 2006 Paper. London.

Livingstone, P., Purcell, J., Morehouse, D., Waugh, D., 2001. Mining at IMC Potash Carlsbad, in: Hustrulid, W.A., Bullock, R.L. (Eds.), Underground Mining Methods: Engineering Fundamentals and International Case Studies. Society for Mining, Metallurgy, and Exploration, Inc., Littleton, Colorado.

Lloyd, M.V., Barnett, G., Doherty, M.D., Jeffree, R.A., John, J., Majer, J.D., Osborne, J.M., Nichols, O.G., 2002. Managing the Impacts of the Australian Minerals Industry on Biodiversity. London.

Lottermoser, B., 2007. Mine Wastes: Characterization, Treatment and Environmental Impacts, 2nd ed. Springer-Verlag Berlin Heidelberg.

Mackintosh, D., 2011. Let the Discussion Begin: Are Potash Technical Reports Meeting the Intent of NI 43-101? [WWW Document]. Stand. Guidel. Resour. Reserv. URL http://web.cim.org/standards/MenuPage.cfm?sections=185,331&menu=349 (accessed 11.25.16).

MacMahon, J.A., Holl, K.D., 2001. Ecological restoration, a key to conservation biology's future, in: Soulé, M.E., Orians, G.H. (Eds.), Conservation Biology: Research Priorities for the Next Decade. Island Press, Washington DC, pp. 245–269.

Mafuta, R.K., Fytas, K., Paraszczak, J., Laflamme, M., 2014. Impact of diesel equipment on ventilation in Quebec underground mines, in: Drebenstedt, C., Singhal, R. (Eds.), Mine Planning and Equipment Selection: Proceedings of the 22nd MPES Conference, Dresden, Germany, 14th-19th October 2013. Springer International Publishing Switzerland, Switzerland, pp. 571–579.

Malchaire, J., n.d. Ergonomics of the Thermal Environment: Determination of Metabolic Rate.

Mandal, B., Pal, A., Sishodiya, P., 2013. Vibration characteristics of mining equipment used in Indian mines and their vibration hazard potential. Int. J. Environ. Health Eng. 2, 45. doi:10.4103/2277-9183.122440

Matsuoka, M., 2005. The Buddhist Concept of the Human Being: From the Viewpoint of the Philosophy of the Soka Gakkai. J. Orient. Stud. 15.

Maury, V., 1993. An overview of tunnel, underground excavation and borehole collapse mechanisms, in: Hudson, J.A. (Ed.), Comprehensive Rock Engineering: Principles, Practice, and Projects; Volume 4: Excavation, Support and Monitoring. Pergamon Press, Exeter, pp. 369–412.

Mborah, C., Bansah, K.J., Boateng, M.K., 2015. Evaluating Alternate Post-Mining Land-Uses: A Review. Environ. Pollut. 5, 14. doi:10.5539/ep.v5n1p14

McBride, D.I., 2004. Noise-induced hearing loss and hearing conservation in mining. Occup. Med. (Chic. Ill). 54, 290–296. doi:10.1093/occmed/kqh075

McCarthy, P.L., Dorricott, M.G., 2011. Dewatering underground operations, in: Darling, P. (Ed.), SME Mining Engineering Handbook. Society for Mining, Metallurgy, and Exploration Inc., Littleton, Colorado, pp. 765–780.

McPherson, M.J., 2008. Ventilation planning, in: Subsurface Ventilation Engineering. Mine Ventilation Services (MVS).

Meixler, M.S., 1999. Water body identification, in: Bain, M.B., Stevenson, N.J. (Eds.), Aquatic Habitat Assessment: Common Methods. American Fisheries Society, Bethesda, Maryland, pp. 35–45.

Meybeck, M., Friedrich, G., Thomas, R., Chapman, D., 1996a. Rivers, in: Chapman, D. (Ed.), Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring. UNESCO/WHO/UNEP.

Meybeck, M., Kuusisto, E., Mäkelä, A., Mälkki, E., 1996b. Water quality, in: Bartram, J., Ballance, R. (Eds.), Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes. United Nations Environment Programme and World Health Organization.

Michael P. Davies, Lighthall, P.C., Rice, S., Martin, T.E., 2002. Design of tailings dams and impoundments, in: Keynote Address Tailings and Mine Waste Practices, SME, AGM, Phoenix, 2002.

Minerals Council of Australia, 2015. The Whole Story: Mining's Contribution to the Australian Community. Forrest.

Ministry of Education, 2014. Thailand's Education Statistics Year 2012-2013. Bangkok.

Ministry of Industry, 2002. Ministerial Regulation on Number of Employment and Permanent Assets of Medium and Small Enterprises B.E. 2545. Office of the Council of State, Thailand.

Ministry of Interior, 1996. Cabinet's Resolution, Criteria for Village Establishment on 14 May B.E. 2539. Ministry of Interior, Thailand.

Ministry of Public Health, 2016a. Report on Public Health Resource 2015. Nonthaburi.

Ministry of Public Health, 2016b. GIS: Public Health Resource [WWW Document]. URL http://gishealth.moph.go.th/healthmap/gmap.php#result (accessed 11.16.16).

Misra, S.G., Mani, D., 2009. Soil Pollution. A.P.H. Publishing Corporation, New Delhi.

Moneva, J.M., Archel, P., Correa, C., 2006. GRI and the camouflaging of corporate unsustainability. Account. Forum 30, 121–137. doi:10.1016/j.accfor.2006.02.001

Mooiman, M.B., Sole, K.C., Dinham, N., 2016. The precious metals industry: global challenges, responses, and prospects, in: Izatt, R.M. (Ed.), Metal Sustainability: Global Challenges, Consequences, and Prospects. John Wiley & Sons, Ltd., Chichester, West Sussex, pp. 361–396.

Munn, R.E. (Ed.), 1979. Environmental Impact Assessment, 2nd ed. Scientific Committee On Problems of the Environment (SCOPE).

Nachaiperm, J., Nuengsit, S., Chuenchom, C., 2006. Structure and distribution of fish community in Chi river, in: Abstract in the Fishery Conference 2006. Department of Fisheries and Southeast Asian Fisheries Development Center, Bangkok, pp. 167–168.

National Oceanic and Atmospheric Administration, n.d. National Weather Service [WWW Document]. NWS Heat Index. URL http://www.nws.noaa.gov/om/heat/heat_index.shtml (accessed 11.5.16).

National Research Council, 1999. Environmental Cleanup at Navy Facilities: Risk-Based Methods. National Academy Press, Washington D.C.

National Research Council, Institute of Medicine, 2007. Mining Safety and Health Research at NIOSH: Reviews of Research Programs of the National Institute for Occupational Safety and Health. The National Academic Press, Washington D.C.

National Statistics Office, 2014. Need for Capacity Building of Thai People: Education Level of the Population Older Than 15 in B.E. 2557 [WWW Document]. URL http://service.nso.go.th/nso/nsopublish/themes/files/elderlyworkFullReport57-1.pdf (accessed 11.10.16).

National Statistics Office, 2010. Population And Housing Census 2010. Bangkok.

Nee, P.W., 2014. Key Facts on Thailand: Essential Information on Thailand. The Internationalist, Boston.

Nelson, G., 2013. Occupational respiratory diseases in the South African mining industry. Glob. Health Action 6. doi:10.3402/gha.v6i0.19520

Nelson, M.G., 2011. Mine economics, management, and law, in: Darling, P. (Ed.), SME Mining Engineering Handbook. Society for Mining, Metallurgy, and Exploration Inc., Littleton, Colorado, pp. 297–307.

Netbood, K., 2009. A Survey of Biodiversity in Huai Sai Khao Arboretum, Phrae Province. Phrae.

New South Wales Government, 2012. Guideline for the Use of Cost Benefit Analysis in Mining and Coal Seam Gas Proposals. New South Wales Government.

Newton, G.W., 2009. Bankruptcy and Insolvency Accounting, Volume One: Practice and Procedure, 7th ed. John Wiley & Sons, Inc., New Jersey.

Northey, S.A., Mudd, G.M., Saarivuori, E., Wessman-Jääskeläinen, H., Haque, N., 2016. Water footprinting and mining: Where are the limitations and opportunities? J. Clean. Prod. 135, 1098–1116. doi:10.1016/j.jclepro.2016.07.024

NSW Department of Trade and Investment, 2015. NSW Code of Practice: Inundation and Inrush Hazard Management.

Nyantumbu, B., Barber, C.M., Ross, M., Curran, A.D., Fishwick, D., Dias, B., Kgalamono, S., Phillips, J.I., 2006. Hand-arm vibration syndrome in South African gold miners. Occup. Med. (Chic. Ill). 57, 25–29. doi:10.1093/occmed/kql089

Occupational Safety and Health Administration, 2016. Occupational Safety and Health Standards: Flammable Liquids, 29 CFR 1910.106.

Occupational Safety and Health Administration, 2013. Section III: Chapter 5 Noise [WWW Document]. OSHA Tech. Man. URL https://www.osha.gov/dts/osta/otm/new_noise/index.html (accessed 1.31.17).

Occupational Safety and Health Administration, n.d. Using the Heat Index: A Guide for Employers. Washington D.C.

OECD, 2008. Handbook on Constructing Composite Indicators: Methodology and User Guide. OECD Publishing, Paris.

Office of Agricultural Economics, 2016. Agricultural Statistics of Thailand 2015. Bangkok.

Office of Natural Resources and Environmental Policy and Planning, 2005. Thailand's Red Data: Fishes [WWW Document]. URL http://chm-thai.onep.go.th/RedData/PDF/Fishs.pdf (accessed 11.29.16).

Office of the Basic Education Commission, 2016. Education Management Information System: EMIS [WWW Document]. URL http://data.bopp-obec.info/emis/index.php (accessed 11.16.16).

Office of the National Economic and Social Development Board, 2015. Gross Provincial Product at Current Market Prices by Industrial Origin, Chaiyaphum Province: 2005-2014 [WWW Document]. URL http://service.nso.go.th/nso/web/statseries/tables/43600_Chaiyaphum/E11116-48-

57.xls

Office of the National Economic and Social Development Board, 2014. National Income of Thailand 2014, Chain Volume Measures. Bangkok.

Office of the National Economic and Social Development Board, 2011. The Eleventh National Economic and Social Development Plan. Office of the National Economic and Social Development Board, Bangkok.

Office of the National Economic and Social Development Board, 2006. The Tenth National Economic and Social Development Plan (2007-2011). Office of the National Economic and Social Development Board, Bangkok.

Office of the National Economic and Social Development Board, 2001. The Ninth National Economic and Social Development Plan (2002-2006). Office of the National Economic and Social Development Board, Bangkok.

Office of the National Economic and Social Development Board, 1996. The Eighth National Economic and Social Development Plan (1997-2001). Office of the National Economic and Social Development Board, Bangkok.

Office of the National Economic and Social Development Board, 1991. The Seventh National Economic and Social Development Plan (1992-1996). Office of the National Economic and Social Development Board, Bangkok.

Office of the National Economic and Social Development Board, 1986. The Sixth National Economic and Social Development Plan (1987-1991). Office of the National Economic and Social Development Board, Bangkok.

Office of the National Economic and Social Development Board, 1981. The Fifth National Economic and Social Development Plan (1982-1986). Office of the National Economic and Social Development Board, Bangkok.

Office of the National Economic and Social Development Board, 1976. The Fourth National Economic and Social Development Plan (1977-1981). Office of the National Economic and Social Development Board, Bangkok.

Office of the National Economic and Social Development Board, 1971. The Third National Economic and Social Development Plan (1972-1976). Office of the National Economic and Social Development Board, Bangkok.

Office of the National Economic and Social Development Board, 1966. The Second National Economic and Social Development Plan (1967-1971). Office of the National Economic and Social Development Board, Bangkok.

Office of the National Economic and Social Development Board, 1963. The First National Economic Development Plan (Phase 2) (1964-1966). Office of the National Economic and Social Development Board, Bangkok.

Office of the National Economic and Social Development Board, 1960. The First National Economic Development Plan (Phase 1) (1961-1963). Office of the National Economic and Social Development Board, Bangkok.

Office of the National Economics and Social Development Board, 2015. National Income of Thailand 2015, Chain Value. Bangkok.

Office of the National Economics and Social Development Board, 2007. Sufficiency Economy Implications and Applications. Office of the National Economics and Social Development Board, Bangkok.

Orman, M., Peevers, R., Sample, K., 2011. Waste piles and dumps, in: Darling, P. (Ed.), SME Mining Engineering Handbook. Society for Mining, Metallurgy, and Exploration Inc., Littleton, Colorado, pp. 667–680.

Oxford University Press, 2016. Oxford Dictionaries: Buddhism [WWW Document]. URL http://www.oxforddictionaries.com/definition/english/buddhism (accessed 3.17.16).

Parsons, K., 2003. Human Thermal Environment, The Effects of Hot, Moderate and Cold Temperatures on Human Health, Comfort and Performance, 2nd ed. CRC Press, New York.

Payutto, P.A., 2016. Part I Dictionary of Numerical Dhamma, in: Dictionary of Buddhism. Global Education for Peace Foundation.

Payutto, P.A., 2012a. Dictionary of Buddhism, 23rd ed. Dhammatankusoljit Foundation, Bangkok.

Payutto, P.A., 2012b. Buddhadhamma (Extended Version). Dharma Centre, Chulalongkorn University, Bangkok.

Payutto, P.A., 2005. Buddhist Economics. Dhammaintrend, Bangkok.

Payutto, P.A., 2003. Sustainable Development, 9th ed. Komol Keemthong Foundation Publishing, Bangkok.

Pearce, D.W., 2006. Introduction: valuing environments in the rich world, in: Environmental Valuation in Developed Countries: Case Studies. Edward Elgar Publishing, Glos, pp. 1–11.

Petkova, V., Lockie, S., Rolfe, J., Ivanova, G., 2009. Mining developments and social impacts on communities: Bowen basin case studies. Rural Soc. 19, 211–228.

Piteau Associates Engineering Ltd., 1991. Mined Rock and Overburden Piles: Investigation and Design Manual, Interim Guidelines. British Columbia Mine Dump Committee, British Columbia.

Pomerol, J.-C., Barba-Romero, S., 2000. Multicriterion Decision in Management: Principles and Practice. Kluwer Academic Publishers, Boston, Dordrecht, London.

Poulin, L., 2006. Estimating volumes of air through various engines in an urban setting. C. Bull. SCMO 34, 116–124.

Pufahl, D.E., Fredlund, D.G., 1988. Lateral movements and material properties of a potash tailings pile in Saskatchewan Canada, in: Van Zyl, D.J.A., Vick, S.G. (Eds.), Proceedings of the Hydraulic Fill Structures ’88, ASCE, Geotechnical Specialty Conference. Fort Collins, pp. 956–970.

Ramsar Convention Secretariat, 2012. Information Sheet on Ramsar Wetlands (RIS), 2009-

2012 Version. Gland.

Rao, M.N., Sultana, R., Kota, S.H., 2017. Solid and Hazardous Waste Management: Science and Engineering. Elsevier, Chennai.

Read, J., Stacey, P., 2009. Guidelines for Open Pit Slope Design. CSIRO Publishing.

Righettini, G., Mousset-Jones, P., 2004. Ventilation savings with fuel cell vehicles, in: Bandopadhyay, S., Ganguli, R. (Eds.), Mine Ventilation: Proceedings of the 10th US / North American Mine Ventilation Symposium, Anchorage, Alaska, USA, 16-19 May 2004. Taylor & Francis Group, London, pp. 433–443.

Ross, M.H., 2004. Occupational respiratory disease in mining. Occup. Med. (Chic. Ill). 54, 304–310. doi:10.1093/occmed/kqh073

Royal Institute, 1982. Thailand's Geography Encyclopedia. Royal Institute, Bangkok.

Royal Irrigation Department, n.d. Lam Kan Choo Reservoir [WWW Document]. Proj. Water Distrib. Maint. Up. Chi Watershed, Reg. Off. 6. URL http://upperchiwater2.blogspot.de/p/blog-page_23.html (accessed 11.26.16).

Royal Thai Government Gazette, 2016. Regulation of the Department of Primary Industries and Mines on the Procedure for Mining Lease Application, Issuance, Extension, and Transfer B.E. 2558. Gazette Book 133, Section 10 D, Thailand.

Royal Thai Government Gazette, 2011. Occupational Safety, Health and Environment Act B.E. 2554. Royal Thai Government Gazette, Thailand.

Royal Thai Government Gazette, 2009a. Subdistrict Councils and Subdistrict Administrative Organisations Act, B.E. 2537, Amended in B.E. 2552. Office of the Council of State, Thailand.

Royal Thai Government Gazette, 2009b. Municipal Act B.E. 2496 (Resolved to Issue 13 B.E. 2552). Office of the Council of State, Thailand.

Royal Thai Government Gazette, 2008. Order No. 436/2498 on Authorizing Local Officer to Specify the Explosive Storage Conditions in the Permits. p.182, Thailand.

Royal Thai Government Gazette, 2002. Amending Ministry, Sub-Ministry and Department Act B.E. 2545. Thailand.

Royal Thai Government Gazette, 1999. Determining Plan and Process of Decentralization Act B.E. 2542. Royal Thai Government Gazette, Thailand.

Royal Thai Government Gazette, 1998. Labour Protection Act B.E. 2541. Royal Thai Government Gazette, Thailand.

Royal Thai Government Gazette, 1996. Announcement of the Ministry of Sciences, Technology, and Environment, Issue 3 (B.E. 2539), Standard for Controlling Wastewater Discharge from Factories and Industrial Estates. Thailand.

Royal Thai Government Gazette, 1992a. National Environmental Protection and Promotion Act B.E. 2535. Royal Thai Government Gazette, Thailand.

Royal Thai Government Gazette, 1992b. Hazardous Substances Act B.E. 2535. Royal Thai

Government Gazette, Thailand.

Royal Thai Government Gazette, 1991. State Administration Act B.E. 2534. Thailand.

Royal Thai Government Gazette, 1967. Mineral Act B.E. 2510. Royal Thai Government Gazette, Thailand.

Royal Thai Government Gazette, 1947. Guns, Munitions, Explosive Devices, Fireworks and Improvise Guns Act, B.E. 2490. Royal Thai Government Gazette, Thailand.

Runge, I.C., 1998. Mining Economics and Strategy. Society for Mining, Metallurgy, and Exploration, Colorado.

Saaty, T.L., 2008. Decision making with the analytic hierarchy process. Int. J. Serv. Sci. 1, 83–98.

Safe Work Australia, 2011. Draft, Code of Practice, Ground Control for Underground Mines.

Sakamornsnguan, K., Kretschmann, J., Tabtieng, W., 2015. A Comparison of the Mining Administration System of Germany and Thailand, in: 5th International Symposium: Mineral Resources and Mine Development. Institute of Mining Engineering I, Aachen, pp. 173–188.

Sanchaisuriya, P., Vongpralub, T., Sommart, K., Pholsen, S., Laopaiboon, B., 2012. Wildlife surveying in plant genetics conservation project under the royal initiation of her royal highness princess Maha Chakri Sirindhorn of Juraphorn Dam. Khon Kaen Agr. J. 40, 522–525.

Scarlett, A.J., Stayner, R.M., 2005. Whole-body Vibration on Construction, Mining and Quarrying machines: Evaluation of Emission and Estimated Exposure Levels. London.

Schumacher, E.F., 1973. Small is Beautiful: Economics as if People Mattered. Blond and Briggs, London.

Scoones, I., 1998. Sustainable Rural Livelihoods: A Framework for Analysis, IDS Working Paper No. 72. Sussex.

Seangtharathip, P., Vijittakolchai, C., Duangchantrasiri, S., 2015. Wildlife Biodiversity in Khao Sanam Preng Wildlife Sanctuary, Kampaeng Phet Province. Wildl. Yearb. 15 353–375.

Secretariat of the Convention on Biological Diversity, 2014. Global Biodiversity Outlook 4: A Mid-term Assessment of Progress towards the Implementation of the Strategic Plan for Biodiversity 2011-2020. Montreal.

Secretariat of the Convention on Biological Diversity Netherlands, Commission for Environmental Assessment, 2006. Biodiversity in Impact Assessment, Background Document to CBD Decision VIII/28: Voluntary Guidelines on Biodiversity-Inclusive Impact Assessment (No. 26), CBD Technical Series. Montreal.

Senécal, P., Goldsmith, B., Conover, S., Sadler, B., Brown, K., 1999. Principles of Environmental Impact Assessment Best Practice [WWW Document]. Int. Assoc.

Impact Assess. Inst. Environ. Assessment, UK. URL http://www.iaia.org/uploads/pdf/principlesEA_1.pdf (accessed 11.11.16).

Serkin, G., 2015. Frontier: Exploring the Top Ten Emerging Markets of Tomorrow. John Wiley & Sons, Ltd.

Shubina, E.A., Lukyanov, V.G., 2016. Stimulation of commercial coal seam methane production aimed at improving mining technology. IOP Conf. Ser. Earth Environ. Sci. 43, 12098. doi:10.1088/1755-1315/43/1/012098

Siam Tech Group, n.d. Final Report: Project on Water Supply Procurement for a Potash Mine in Bamnet Narong, Chaiyapoom.

Silverman, D.T., Samanic, C.M., Lubin, J.H., Blair, A.E., Stewart, P.A., Vermeulen, R., Coble, J.B., Rothman, N., Schleiff, P.L., Travis, W.D., Ziegler, R.G., Wacholder, S., Attfield, M.D., 2012. The diesel exhaust in miners study: A nested case-control study of lung cancer and diesel exhaust. JNCI J. Natl. Cancer Inst. 104, 855–868. doi:10.1093/jnci/djs034

Singer, D.A., Kouda, R., 1999. Examining risk in mineral exploration. Nat. Resour. Res. 8, 111–122. doi:10.1023/A:1021838618750

Singh, M.M., 1992. Mine subsidence, in: Hartman, H.L. (Ed.), SME Mining Engineering Handbook, Vol. I. Society for Mining, Metallurgy, and Exploration, Inc., Littleton, Colorado, pp. 938–971.

Singh, N., MacDonald, A.J., 2001. Extraction of a wide ore body at depth in the SV2/3 area at Placer Dome Western Areas Joint Venture, in: Hustrulid, W.A., Bullock, R.L. (Eds.), Underground Mining Methods: Engineering Fundamentals and International Case Studies. Society for Mining, Metallurgy, and Exploration Inc., Littleton, Colorado, pp. 179–186.

Singh, R.N., 1986. Mine inundation. Int. J. Mine Water 5, 1–28.

Sivakumar, R., 2010. Introduction to Environmental Science and Engineering, 2nd ed. Tata McGraw Hill Education Private Limited, New Delhi.

Sivaraksa, S., 2009. The Wisdom of Sustainablity: Buddhist Economics for the 21st Century, 1st ed. Koa Books and Silkworm Books, Hawai'i and Chiang Mai.

Śledzik, K., 2013. Financial and non-financial value drivers in shareholder value creation process. SSRN Electron. J. doi:10.2139/ssrn.2257767

Steffen, O.K.H., Contreras, L.F., Terbrugge, P.J., Venter, J., 2006. A risk evaluation approach for pit slope design, in: 42nd U.S. Rock Mechanics Symposium and 2nd U.S.-Canada Rock Mechanics Symposium. American Rock Mechanics Association, San Francisco.

Stegmann, F.J., 2004. Economic Liberalism, Marxism and Critical Judgement (No. 1), St Augustine Paper Volume 5. Johannesburg.

Stephens, C., Ahern, M., 2002. Worker and Community Health Impacts Related to Mining Operations Internationally: A Rapid Review of the Literature. London.

Stephens, T., 2010. Manual on Small Earth Dams: A Guide to Siting, Design and Construction. Food and Agriculture Organization of the United Nations, Rome.

Stewart, J.M.M., 1981. Heat transfer and limiting physiological criteria as a basis for the setting of heat stress limits. J. South. African Inst. Min. Metall. 81, 239–251.

Stewart, P., Ramezanzadeh, A., Knights, P., 2006. Benchmark drill and blast and mechanical excavation advance rates for underground hard-rock mine development, in: Australian Mining Technology Conference 26-27 September 2006. pp. 41–63.

Sustainable Europe Research Institute, 2014. Visualising Global Material Flows [WWW Document]. URL http://www.materialflows.net/data/datadownload/ (accessed 7.6.15).

Sustainable Measures, 2010. Characteristics of effective indicators [WWW Document]. Sustain. Indic. 101. URL http://www.sustainablemeasures.com/node/92 (accessed 12.3.16).

Suter, A.H., 1998. 47.2 The Nature and Effects of Noise, in: Stellman, J.M. (Ed.), Encyclopaedia of Occupational Health and Safety. International Labour Organization, Geneva.

Suwanich, P., 2007. Mineral Geology of Potash and Rock Salt Deposits in Thailand. Bangkok.

Suyana, Y., 2009. A Survey of Biodiversity in Chor Hae Arboretum, Muang District, Phrae Province. Phrae.

Szczepanska, J., Twardowska, I., 2004. Mining waste, in: Twardowska, I., Allen, H.E., Kettrup, A.F., Lacy, W.J. (Eds.), Solid Waste: Assessment, Monitoring and Remediation. pp. 319–385.

Tanchev, L., 2014. Dams and Appurtenant Hydraulic Structures, 2nd ed. CRC Press, Boca Raton, Florida.

Teschke, K., Nicol, A.-M., Davies, H., Ju, S., 1999. Whole Body Vibration and Back Disorders among Motor Vehicle Drivers and Heavy Equipment Operators: A Review of the Scientific Evidence. Vancouver.

Thailand's Meteorological Department, 2016. Thailand weather report 2015. Bangkok.

Thailand's Meteorological Department, 2013. Thailand's Climate [WWW Document]. URL http://www.tmd.go.th/info/knowledge_weather02_n.html (accessed 11.7.16).

Thailand's Meteorological Department, 2012. Thirty-year Weather Statistics, Chaiyapoom Meteorological Station. Bangkok.

The Chamber of Mines of South Africa, 2002. Public Participation Guidelines for Stakeholders in the Mining Industry. Marshalltown.

The Harris Poll, 2017. Harris Poll Reputation Quotient: Six Dimensions of Reputation [WWW Document]. URL http://www.theharrispoll.com/reputation-quotient (accessed 4.11.17).

Torres, V.F.N., Singh, R.N., 2011. Thermal state and human comfort in underground mining, in: Bernardes, M.A.D.S. (Ed.), Developments in Heat Transfer. InTech, Rijeka, pp. 589–610. doi:10.5772/19944

Torries, T.F., 1998. Evaluating Mineral Projects: Applications and Misconceptions. Society of Mining, Metallurgy, and Exploration, Inc., Littleton.

Tripathi, N., Singh, R.S., 2010. Underground coal mine subsidence impacts forest ecosystem, in: Project Environmental Clearance: Engineering and Management Aspects. Wide Publishing.

Tripathy, D.P., 2007. Noise Pollution. A.P.H. Publishing Corporation, New Delhi.

U.S. Congress, 1985. Preventing Illness and Injury in the Workplace. U.S. Congress, Office of Technology Assessment, Washington D.C.

U.S. Department of Health and Human Services, 1998. Criteria for a Recommended Standard: Occupational Noise Exposure, Revised Criteria 1998. Cincinnati, Ohio.

U.S. Department of Transportation, 2006. Construction equipment noise levels and ranges, in: Construction Noise Handbook. U.S. Department of Transportation, Washington D.C.

U.S. Environmental Protection Agency, 1995. AP-42, Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. Washington D.C.

U.S. Environmental Protection Agency, 1994. Technical Report: Design and Evaluation of Tailings Dams. Washington D.C.

UK Government, 2014. Resource Nationalism: A Horizon Scanning Research Paper by the Resources Demand and Supply Resource Nationalism Community of Interest.

UNEP-GEMS/Water Programme, 2008. Water Quality for Ecosystem and Human Health, 2nd ed. United Nations Environment Programme Global Environment Monitoring System (GEMS)/ Water Programme, Burlington, Ontario.

United Nations, 2016. Progress towards the Sustainable Development Goals: Report of the Secretary-General.

United Nations, 2012. The Future We Want. Rio de Janeiro.

United Nations, 2010. Best Practice Guidance for Effective Methane Drainage and Use in Coal Mines (No. 31), ECE energy series. New York and Geneva.

United Nations, 2007. Indicators of Sustainable Development: Guidelines and Methodologies, Third Edit. ed. New York.

United Nations, 1993. Agenda 21: Earth Summit – The United Nations Programme of Action from Rio. New York.

United Nations, 1992. Convention on Biological Diversity.

United Nations, 1987. Our Common Future: Report of the World Commission on Environment and Development. Switzerland.

United Nations, 1972. Report of the United Nations Conference on the Human Environment. Stockholm.

United Nations Industrial Development Organization, International Fertilizer Development Center (Eds.), 1998. Fertilizer raw materials and reserves, in: Fertilizer Manual. The Netherlands.

Van Zyl, D., Sassoon, M., Digby, C., Fleury, A.-M., Kyeyune, S., 2002. Mining for the Future, Appendix A: Large Volume Waste (No. 31).

Vick, S.G., 1990. Planning, Design, and Analysis of Tailings Dams. BiTech, Vancouver.

Vingård, E., Elgstrand, K., 2013. Safety and health in mining, in: Torén, K. (Ed.), Occupational Safety and Health in Mining: Anthology on the Situation in 16 Mining Countries. University of Gothenburg, Gothenburg, pp. 1–22.

Vutukuri, V.S., Lama, R.D., 1986. Environmental Engineering in Mines. Cambridge University Press, New York.

Vutukuri, V.S., Singh, R.N., 1995. Mine inundation-case histories. Mine Water Environ. 14, 107–130. doi:10.1007/BF02914857

Wagner, M., Wellmer, F.-W., 2009. A hierarchy of natural resources with respect to sustainable development, in: Richards, J.P. (Ed.), Mining, Society, and a Sustainable World. Springer-Verlag Berlin Heidelberg, Berlin, Heidelberg, pp. 91–121.

Waltham, A.C., 1994. Foundations of Engineering Geology. E & FN Spon, London and New York.

Wang, H.Y., Chateil, B., 2007. Numerical simulation of wind-aided flame spread over horizontal surface of condensed fuel in a confined channel. Int. J. Eng. Performance-Based Fire Codes 9, 65–77.

Weidema, B.P., 2006. The Integration of Economic and Social Aspects in Life Cycle Impact Assessment. Int. J. Life Cycle Assess. 11, 89–96. doi:10.1065/lca2006.04.016

Weir, E., 2005. Hand-arm vibration syndrome. Can. Med. Assoc. J. 172, 1001–1002. doi:10.1503/cmaj.045314

Whyatt, J., Varley, F., 2008. Catastrophic failures of underground evaporite mines, in: Peng, S.S., Mark, C., Finfinger, G.L., Tadolini, S.C., Khair, A.W., Heasley, K.A., Luo, Y. (Eds.), Proceedings of the 27th International Conference on Ground Control in Mining (ICGCM), July 29-31, 2008. West Virginia University, Morgantown, pp. 113–122.

Wickham, G. E. Tiedemann, H.R., Skinner, E.H., 1972. Support determination based on geologic predictions, in: Lane, K.S., Garfield, L.A. (Eds.), North American Rapid Excav. Tunneling Conf., Chicago. Soc. Min. Engrs., Am. Inst. Min. Metall. Petrolm Engrs., New York, pp. 43–64.

Williams, D.J., 2014. Mine site rehabilitation - laying geotechnical foundations, in: Weiersbye, I.M., Fourie, A.B., Tibbett, M. (Eds.), The Book of Proceedings of the 9th International Conference on Mine Closure: Mine Closure 2014. Sandton, Johannesburg.

Williams, D.J., 2000. Assessment of embankment parameters, in: Hustrulid, W.A., McCarter, M.K., Van Zyl, D.J.A. (Eds.), Slope Stability in Surface Mining. Society for Mining, Metallurgy, and Exploration, Inc., Littleton, Colorado, pp. 275–284.

Wisner, B., Blaikie, P., Cannon, T., Davis, I., 2003. At Risk: Natural Hazards, People's Vulnerability and Disasters, 2nd ed. Routledge, London and New York.

Wood, C., 2003. Environmental Impact Assessment: A Comparative Review, 2nd ed. Pearson Education Limited, Essex.

World Bank, 1987. Project Completion Report: Thailand - Potash Engineering Project (Loan 1947-TH). Washington D.C.

World Commission on Environment and Development, 1987. Food 2000: Global Policies for Sustainable Agriculture, A Report of the Advisory Panel on Food Security, Agriculture, Forestry, and Environment Submitted to the World Commission on Environment and Development. London and New Jersey.

Xing, Z., Chu, L., 2011. Research on constructing composite indicator of objective well-being from China mainland, in: Proceedings of the 58th World Statistical Congress. International Statistical Institute, Dublin, Ireland, pp. 3081–3097.

Xue, S., Wang, Y.C., Xie, X., 2010. Numerical modeling of outbursts of coal and gas with a coupled simulator, in: Zegong, L., Kicki, J., Xinzhu, H., Shujie, Y., Guanglong, D., Sobczyk, E.J. (Eds.), Mine Safety and Efficient Exploitation Facing Challenges of the 21st Century, International Mining Forum 2010. Taylor & Francis Group, London, pp. 33–39.

Zipf Jr., R.K., 2001. Pillar design to prevent collapse of room-and-pillar mines, in: Hustrulid, W.A., Bullock, R.L. (Eds.), Underground Mining Methods: Engineering Fundamentals and International Case Studies2. Society for Mining, Metallurgy, and Exploration Inc., Littleton, Colorado, pp. 493–512.

Zsolnai, L., 2009. Buddhist Economics for Business, in: Ethical Prospects. Springer Netherlands, Dordrecht, pp. 89–99. doi:10.1007/978-1-4020-9821-5_5

Appendix A: Summary of components and rating criteria

Table A-1 and A-2 summarize the assessment criteria of the necessity of a mining project development and the negative impacts of the mining project, respectively.

Table A-1: Components and criteria for assessing the necessity of a mining project development

No.	Components	Rating criteria			
		Irrelevant	Low	Medium	High
A	**Necessity for mining project development (1 x 0.67) + (2 x 0.33)**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
1.	**Service provision (1.1 + 1.2 + 1.3) x 0.33**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
1.1	Contribution to domestic demand: annual production rate / current total non-domestic input		<0.33 or >1.20	0.33-0.67	>0.67-1.20
1.2	Contribution to end use (1.2.1 + 1.2.2) x 0.5	0	>0-<1.5	1.5-<2.5	2.5-3
1.2.1	Status of current end use: current mineral export / current total output of the same substance		>0.50	0.25-0.50	<0.25
1.2.2	Increase in mineral export: increase in planned export / current mineral export				
	-Non-bulk minerals		>0.15	0.05-0.15	<0.05
	-Bulk minerals		>0.25	0.10-0.25	<0.10
1.3	Resource availability: project's resource / domestic resource of the same mineral				
	-Non-bulk minerals		>0.1	0.01-0.1	<0.01
	-Bulk minerals		>0.005	0.0005-0.005	<0.0005
2.	**Positive contributions of mining project to the society (2.1 + 2.2 + 2.3) x 0.33**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
2.1	**Positive contributions to workers: number of employment**		**<1,250 employee-year**	**1,250-5,000 employee-year**	**>5,000 employee-year**
2.2	**Positive contributions to communities (Sum of 2.2.1 to 2.2.6) x 0.17**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
2.2.1	Access to water $((1) \times (2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood: increase in water storage capacity	0	>0-0.5 Mm^3	0.5-1 Mm^3	>1 Mm^3
(2)	Consequence: affected population	0	>0-<2,000	2,000-10,000	>10,000
2.2.2	Access to forest $((1) \times (2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood: reforested area - deforested area	≤0	>0-<0.5 hectares	0.5-48.0 hectares	>48.0 hectares
(2)	Consequence: affected population	0	>0-<2,000	2,000-10,000	>10,000
2.2.3	Access to financial resources $((1) \times (2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood: expected annual locally-allocated royalty / current local revenue	≤0	>0-<0.1	0.1-0.5	>0.5
(2)	Consequence: affected population	0	>0-<2,000	2,000-10,000	>10,000
2.2.4	Access to infrastructure	0	>0-<1.5	1.5-<2.5	2.5-3

No.	Components	Rating criteria			
		Irrelevant	Low	Medium	High
	(Sum of (1) to (3) x 0.33				
(1)	Number of people benefited from the improved transport networks	0	>0-<2,000	2,000-10,000	>10,000
(2)	Number of people benefited from the improved water and energy distribution systems	0	>0-<2,000	2,000-10,000	>10,000
(3)	Number of people benefited from the improved waste disposal facilities	0	>0-<2,000	2,000-10,000	>10,000
2.2.5	Access to healthcare: positive change of population / medical staff	≤0	>0-<5%	5-15%	>15%
2.2.6	Access to education: positive change of population / teaching staff	≤0	>0-<5%	5-10%	>10%
2.3	**Positive contributions to the environment: habitat gain** **$(2.3.1 \times 2.3.2)^{0.5}$**	**0**	**1-<1.67**	**1.67-<2.33**	**2.33-3**
2.3.1	Likelihood: reforested area / deforested area	≤0	>0-<0.5 hectares	0.5-48.0 hectares	>48.0 hectares
2.3.2	Consequence: presence of species Average (2a) to (2c) only if relevant, using the rating of (1) as weights		1-<3	3-<6	6-18
(1)	Vulnerability		Unthreatened species	Potentially threatened species	Threatened species
(2)	Number of species Actual number of species x (2.1)				
(2a)	-Unthreatened species	0	1-100	101-500	>500
(2b)	-Potentially threatened species	0	1-5	6-10	>10
(2c)	-Threatened species	0	1-5	6-10	>10
(2.1)	Species abundance weight		0.33	0.67	1

Table B-2: Components and criteria for assessing negative impacts

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
B	**Negative impacts** **(1 + 2 + 3 + 4) x 0.25**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
1.	**Workers** **(1.1 + 1.2 + 1.3) x 0.33**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
1.1	**Occupational disease** **(1.1.1 + 1.1.2 + 1.1.3) x 0.33**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
1.1.1	**Respiratory diseases** **$((1) \times (2))^{0.5}$; weighted sum of different hazard groups using the adjusted no. of exposed workers of each hazard group as weights**	**0**	**1-<1.67**	**1.67-<2.33**	**2.33-3**
(1)	Likelihood: release amount	8-hour TWA	>0-<1.5	1.5-<2.5	2.5-3
	Respirable dust[1]	5 mg/m^3	<456 kg/year	456-913 kg/year	>913 kg/year
	Silica dust (crystalline silica)[1]	0.025 mg/m^3	<2.3 kg/year	2.3-4.6 kg/year	>4.6 kg/year
	Coal dust (>5% respirable quartz)[1]	0.1 mg/m^3	<9.1 kg/year	9.1-18.3 kg/year	>18.3 kg/year
	Diesel exhausts[2]				
	-Nitrogen dioxide	6 mg/m^3	<547 kg/year	547-1,095 kg/year	>1,095 kg/year
	-Sulfur dioxide	13 mg/m^3	<1,186 kg/year	1,186-2,373 kg/year	>2,373 kg/year
	-Carbon dioxide	9,000 mg/m^3	<821 t/year	821-1,643 t/year	>1,643 t/year
	-Carbon monoxide	55 mg/m^3	<5 t/year	5-10 t/year	>10 t/year

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
	Asbestos[1]	0.1 fiber/cm^3	<9.1 Tera-fiber/year	9.1-18.3 Tera-fiber/year	>18.3 Tera-fiber/year
	Radon progeny[3]	14 mJ-h/m^3	<1.3 MJ-h/year	1.3-2.6 MJ-h/year	>2.6 MJ-h/year
	Heavy metals[1]				
	-Arsenic	10 µg/m^3	<0.9 kg/year	0.9-1.8 kg/year	>1.8 kg/year
	-Cadmium (respirable dust)	2 µg/m^3	<183 g/year	183-365 g/year	>365 g/year
	-Lead	50 µg/m^3	<4.6 kg/year	4.6-9.1 kg/year	>9.1 kg/year
	-Mercury	25 µg/m^3	<2.3 kg/year	2.3-4.6 kg/year	>4.6 kg/year
(2)	Consequence: number of exposed workers with weight		<20 men/day	20-150 men/day	>150 men/day
1.1.2	**Noise-induced hearing loss ((1) x (2))$^{0.5}$; weighted sum of different exposure groups using the adjusted no. of exposed workers of each exposure group as weights**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
(1)	Extent of exposure	rare presence in the proximity of the hazard	short or non-frequent presence in high noise intensity zone or occasional presence in medium noise intensity zone	a frequent presence of workers in medium noise intensity zone or occasionally presence in high noise intensity zone	a regular presence of workers in medium noise intensity zone or a frequent to regular presence in high noise intensity zone
(1.1)	Noise intensity zone classification		<80 dBA	80-90 dBA	>90 dBA
(2)	Consequence: number of exposed workers		<20 men/day	20-150 men/day	>150 men/day
1.1.3	**Musculoskeletal disorders ((1) x (2))$^{0.5}$; Weighted sum of different hazard groups using the no. of exposed worker of each hazard group as weights**	**0**	**1-<1.67**	**1.67-<2.33**	**2.33-3**
(1)	Likelihood: vibration level		1-<3	3-<6	6-9
	-Hand-held vibration tools		<2.5 m/s^2	2.5-5.0 m/s^2	>5.0 m/s^2
	-Mobile equipment		<0.50 m/s^2	0.50-1.15 m/s^2	>1.15 m/s^2
(2)	Consequence: number of exposed workers		<20 men/day	20-150 men/day	>150 men/day
1.2	**Harmful working conditions (1.2.1 + 1.2.2) x 0.5**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
1.2.1	**Exposure to heat ((1) x (2))$^{0.5}$; Weighted sum of different hazard groups using the no. of exposed worker of each hazard group as weights**	**0**	**1-<1.67**	**1.67-<2.33**	**2.33-3**
(1)	Likelihood ((1.1) x (1.2) x (1.3))$^{0.33}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Apparent temperature		<32.8°C	32.8-39.4°C	>39.4°C
(1.2)	Type of activities (by metabolic rate)		≤130 W/m^2	>130-200 W/m^2	>200 W/m^2
(1.3)	Ventilation (by air velocity)		>0.5 m/s	0.1-0.5 m/s	<0.1 m/s
(2)	Consequence: number of exposed workers		<20 men/day	20-150 men/day	>150 men/day
1.2.2	**Lack of oxygen ((1) x (2))$^{0.5}$**	**0**	**1-<1.67**	**1.67-<2.33**	**2.33-3**
(1)	Likelihood	0	1-<1.67	1.67-<2.33	2.33-3

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
	$((1.1) \times (1.2))^{0.5}$				
(1.1)	Presence of asphyxiant gases ((1.1.1) + (1.1.2) + (1.1.3)) x 0.33	0	>0-<1.5	1.5-<2.5	2.5-3
(1.1.1)	Strata gases	0	>0-<4 m^3/t	4-8 m^3/t	>8 m^3/t
(1.1.2)	Use of explosives		<1,500 kg/day	1,500-15,000 kg/day	>15,000 kg/day
(1.1.3)	Use of diesel engines		<2,500 kW	2,500-13,500 kW	>13,500 kW
(1.2)	Ventilation condition: air velocity		1-4 m/s	0.3-1 or >4 m/s	<0.3 m/s
(2)	Consequence: number of exposed workers		<20 men/day	20-150 men/day	>150 men/day
1.3	**Accidents** **(Sum of 1.3.1 to 1.3.5) x 0.2**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
1.3.1	**Fire and explosions** **$((1) \times (2))^{0.5}$; sum of different sources with an equal weight**	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood $((1.1) \times (1.2) \times (1.3))^{0.33}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Presence of fuel $((1.1.1) \times (1.1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1.1)	Quantity		200 kg	200-2,000 kg	>2,000 kg
(1.1.2)	Sensitivity		Materials that must be preheated to create ignition	Materials that require moderate heating before it is ignited	Materials that can be ignited under almost all normal temperature conditions; very flam-mable gases; very volatile flammable liquids
(1.2)	Presence of oxidizing agent ((1.2.1) + (1.2.2)) x 0.5	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
(1.2.1)	Air velocity		<0.4 m/s	0.4-1.5 m/s	>1.5 m/s
(1.2.2)	Distance to flammable substance		>100 m	10-100 m	<10 m
(1.3)	Presence of ignition sources in the proximity of flammable substance				
	-Gaseous flammable substance		>200 m	100-200 m	<100 m
	-Solid and liquid flammable substance		>100 m	10-100 m	<10 m
(2)	Consequence: number of workers potentially harmed		<20 men/shift	20-150 men/shift	>150 men/shift
1.3.2	**Gas outburst** **$((1) \times (2))^{0.5}$**	**0**	**1-<1.67**	**1.67-<2.33**	**2.33-3**
(1)	Likelihood $((1.1) \times (1.2) \times (1.3))^{0.33}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Presence of gases: gas content		>0-<4 m^3/t	4-8 m^3/t	>8 m^3/t
(1.2)	Geological structure		Massive to slightly folded or faulted	Moderately folded or faulted	Intensively folded or faulted
(1.3)	Mining depth		<250 m	250-700 m	>700 m
(2)	Consequence: number of workers potentially harmed		<20 men/shift	20-150 men/shift	>150 men/shift
1.3.3	**Rockburst** **$((1) \times (2))^{0.5}$**	**0**	**1-<1.67**	**1.67-<2.33**	**2.33-3**
(1)	Likelihood $((1.1) \times (1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Rock properties $((1.1.1) \times (1.1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
(1.1.1)	Type of rock: brittleness coefficient		>26.7	14.5-26.7	<14.5
(1.1.2)	Discontinuities		Massive to slightly folded or faulted	Moderately folded or faulted	Intensively folded or faulted
(1.2)	Stress in surrounding rock (Multiplication of (1.2.1) to (1.2.4))$^{0.25}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.2.1)	Mining depth		<250 m	250-700 m	>700 m
(1.2.2)	Opening design: width-to-height ratio		<0.5	0.5-1.0	>1.0
(1.2.3)	Extraction ratio		<38%	38-75%	>75%
(1.2.4)	Advance rate				
	-Drilling and blasting		<7 m/day	7-15 m/day	>15 m/day
	-Mining with other methods		<10 m/day	10-30 m/day	>30 m/day
(2)	Consequence: number of workers potentially harmed		<20 men/shift	20-150 men/shift	>150 men/shift
1.3.4	**Inrush of water or semi-solids ((1) x (2))$^{0.5}$**	**0**	**1-<1.67**	**1.67-<2.33**	**2.33-3**
(1)	Likelihood ((1.1) x (1.2))$^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Presence of water or semi-solid ((1.1.1) x (1.1.2))$^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1.1)	Distance to the adjacent water or semi-solid source		>100 m	50-100 m	<50 m
(1.1.2)	Water or semi-solid capacity		<9,000 m^3	9,000-27,000 m^3	>27,000 m^3
(1.2)	Mass movement potential ((1.2.1) x (1.2.2))$^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.2.1)	Discontinuities		Massive to slightly folded or faulted	Moderately folded or faulted	Intensively folded or faulted
(1.2.2)	Effect of ground subsidence: horizontal strain		<$5x10^{-3}$	$5x10^{-3}$-$10x10^{-3}$	>$10x10^{-3}$
(2)	Consequence: number of workers potentially harmed		<20 men/shift	20-150 men/shift	>150 men/shift
1.3.5	**Ground failure ((1) x (2))$^{0.5}$**	**0**	**1-<1.67**	**1.67-<2.33**	**2.33-3**
(1)	Likelihood ((1.1) x (1.2))$^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Geological characteristics ((1.1.1) x (1.1.2) x (1.1.3))$^{0.33}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1.1)	Rock strength		>100 MPa	25-100 MPa	<25 MPa
(1.1.2)	Geological structure		Massive to slightly folded or faulted	Moderately folded or faulted	Intensively folded or faulted
(1.1.3)	Water content		0-20%	20-60%	60-100%
(1.2)	Design parameters				
(a)	Surface mining ((a1) x (a2))$^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(a1)	Factor of safety		>1.3	1-1.3	<1
(a2)	Seismic condition: DMR's earthquake risk zone		0-1	2A	2B
(b)	Underground mining ((b1) x (b2) x (b3))$^{0.33}$	0	1-<1.67	1.67-<2.33	2.33-3
(b1)	Factor of safety		>3	1.8-3	<1.8
(b2)	Opening design: width-to-height ratio		<0.5	0.5-1.0	>1.0
(b3)	Extraction ratio		<38%	38-75%	>75%
(2)	Consequence: number of workers potentially harmed		<20 men/shift	20-150 men/shift	>150 men/shift
2.	**Communities (2.1 + 2.2 + 2.3) x 0.33**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
2.1	**Health and safety (2.1.1 + 2.1.2) x 0.5**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
2.1.1	**Risk of accident (2.1.1.1 + 2.1.1.2) x 0.5**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
2.1.1.1	Waste facility failure $((1) \times (2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood (Multiplication of (1.1) to $(1.7))^{0.14}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Type of material				
	-Waste dump		Strong, durable material with <10% fines	Material with moderate strength, variable durability, and 10-25% fines	Weak material subject to slaking or degradation and >25% fines
	-Tailing dam: type of dam		Water retention	Downstream or centerline	Upstream
(1.2)	Facility height				
	-Waste dump		>0-<50 m	50-100 m	>100 m
	-Tailing dam		>0-<10 m	10-30 m	>30 m
(1.3)	Slope angle				
	-Waste dump		>0-<26°	26-45°	>45°
	-Tailing dam		>0-<20°	20-35°	>35°
(1.4)	Seismic condition (Seismic zone according to DMR[1])		0-1	2A	2B
(1.5)	Amount of rainfall: maximum annual rainfall in a 30-year period		>0-1,500 mm/year	>1,500-2,000 mm/year	>2,000 mm/year
(1.6)	Foundation condition		Materials as strong as or stronger than waste rock, not subject to adverse pore pressures, and no adverse geological structure	Foundation materials being intermediate between competent and weak, foundation soils gain strength with consolidation , and adverse pore pressure dissipate loading rate controlled	Limited bearing capacity, soft soils; subject to adverse pore pressures, groundwater; and shear strength sensitive to strain, liquefaction potential
(1.7)	Water content in wastes				
	-Waste dump		<10%	10-30%	>30%
	-Tailing dam		Cake or dry tailing	Thickened or paste	Slurry or liquid
(2)	Potentially affected population		>0-<200	200-600	>600
2.1.1.2	Sinkhole $((1) \times (2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood $((1.1) \times (1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Presence of sinkhole-related geology or structures	No presence of sinkhole-related geology or structures			Presence of karst geology, soluble minerals, or old mine with potential subsidence or collapse
(1.2)	Presence of water	0	>0-<1.5	1.5-<2.5	2.5-3

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
	((1.2.1) + (1.2.2)) x 0.5				
(1.2.1)	Amount of rainfall: average annual rainfall in a 30-year period		>0-1,500 mm/year	>1,500-2,000 mm/year	>2,000 mm/year
(1.2.2)	Groundwater velocity		<0.1 m/day	>0.1-1 m/day	>1 m/day
(2)	Potentially affected population		>0-<200	200-600	>600
2.1.2	**Pollution (2.1.2.1 + 2.1.2.2 + 2.1.2.3) x 0.33**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
2.1.2.1	Air pollution $((1) \times (2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood $((1.1) \times (1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Release of pollutants Sum of related pollutants with an equal weight	Air emission standard[4,5]	>0-<1.5	1.5-<2.5	2.5-3
	-Particulate matter (PM10)	40 $\mu g/m^3$	<7.3 t/year	7.3-14.6 t/year	>14.6 t/year
	-Sulfur dioxide	125 $\mu g/m^3$	<22.8 t/year	22.8-45.6 t/year	>45.6 t/year
	-Nitrogen dioxide	40 $\mu g/m^3$	<7.3 t/year	7.3-14.6 t/year	>14.6 t/year
	-Carbon monoxide	10 mg/m^3	<1,825 t/year	1,825-3,650 t/year	>3,650 t/year
	-Ozone	120 $\mu g/m^3$	<21.9 t/year	21.9-43.8 t/year	>43.8 t/year
	-Benzene	5 $\mu g/m^3$	<0.9 t/year	0.9-1.8 t/year	>1.8 t/year
	-Lead	0.5 $\mu g/m^3$	<91.3 kg/year	91.3-182.5 kg/year	>182.5 kg/year
	-Arsenic	6 ng/m^3	<1.1 kg/year	1.1-2.2 kg/year	>2.2 kg/year
	-Cadmium	5 ng/m^3	<0.9 kg/year	0.9-1.8 kg/year	>1.8 kg/year
	-Mercury	1 $\mu g/m^3$	<3.7 kg/year	3.7-7.3 kg/year	>7.3 kg/year
(1.2)	Pollutant dilution $((1.2.1) \times (1.2.2) \times (1.2.3))^{0.33}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.2.1)	Wind speed		>5 m/s	1-5 m/s	<1 m/s
(1.2.2)	Topography		Flat terrain and the topography that facilitate air flow horizontally and vertically	Topography that interrupts air flow such as that occupied with buildings	Valley topography which is more likely to have temperature inversion and other topography that tends to have problems with atmospheric stability
(1.2.3)	Average rain days per year		>150 days/year	100-150 days/year	<100 days/year
(2)	Consequence: potentially affected population		>0-<2,000	2,000-10,000	>10,000
2.1.2.2	Water pollution (2.1.2.2.1 x 0.67) + (2.1.2.2.2 x 0.33)	0	>0-<1.5	1.5-<2.5	2.5-3
2.1.2.2.1	Planned discharge of water pollutants $((1) \times (2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood $((1.1) \times (1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Pollutant discharge Sum of the ratings of related pollutants using an equal weight	Water quality standard[6] (human)	>0-<1.5	1.5-<2.5	2.5-3
	-Arsenic	0.01 mg/L	<2.7 kg/year	2.7-5.5 kg/year	>5.5 kg/year
	-Cadmium	0.003 mg/L	<0.8 kg/year	0.8-1.6 kg/year	>1.6 kg/year

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
	-Mercury	0.006 mg/L	<1.6 kg/year	1.6-3.3 kg/year	>3.3 kg/year
	-Lead	0.01 mg/L	<2.7 kg/year	2.7-5.5 kg/year	>5.5 kg/year
	-Uranium	0.015 mg/L	<4.1 kg/year	4.1-8.2 kg/year	>8.2 kg/year
	-Cyanide	0.07 mg/L	<19.2 kg/year	19.2-38.3 kg/year	>38.3 kg/year
(1.2)	Pollutant dilution				
	-Surface water		Stream or shallow lake (≤30 m)	River	Deep lake (>30 m),
	-Underground water		Bank filtration and karst	Alluvial aquifers	Sedimentary or deep aquifers
(2)	Consequence: potentially affected population		>0-<2,000	2,000-10,000	>10,000
2.1.2.2.2	Undesired release of water pollutants ((1) + (2) + (3)) x 0.33	0	>0-<1.5	1.5-<2.5	2.5-3
(1)	Leaching and contamination from mine drainage $((1.1) \times (1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Likelihood $((1.1.1) \times (1.1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1.1)	Presence of pollutant		Presence of both acid-generating substances (i.e. sulfide minerals) and neutralizing substances such as carbonate and silicate minerals	Presence of acid-generating substances without (or with insignificant amount of) neutralizing substances	Presence of both acid-generating substances and heavy metals, regardless of neutralizing substances
(1.1.2)	Presence of water ((1.1.2.1) + (1.1.2.2)) x 0.5	0	>0-<1.5	1.5-<2.5	2.5-3
(1.1.2.1)	Amount of rainfall: average annual rainfall in a 30-year period		>0-1,500 mm/year	>1,500-2,000 mm/year	>2,000 mm/year
(1.1.2.2)	Groundwater velocity		<0.1 m/day	0.1-1 m/day	>1 m/day
(1.2)	Consequence: potentially affected population		>0-<2,000	2,000-10,000	>10,000
(2)	Seepage and leakage in waste facility $((2.1) \times (2.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(2.1)	Likelihood $((2.1.1) \times (2.1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(2.1.1)	Seepage potential (Multiplication of (2.1.1.1) to $(2.1.1.5))^{0.2}$	0	>0-<1.5	1.5-<2.5	2.5-3
(2.1.1.1)	Capacity of waste facility		>0-<0.02 Mm^3	0.02-0.05 Mm^3	>0.05 Mm^3
(2.1.1.2)	Water content in waste				
	-Waste dump		<10%	10-30%	>30%
	-Tailing dam		Cake or dry tailing	Thickened or paste	Slurry or liquid
(2.1.1.3)	Control measures		Presence of seepage prevention and capture measures	Presence of either prevention or capture measures	Neither prevention nor capture measures are implemented
(2.1.1.4)	Presence of water ((a) x 0.67) + ((b) x 0.33)	0	>0-<1.5	1.5-<2.5	2.5-3

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
(a)	Amount of rainfall: maximum annual rainfall in a 30-year period		>0-1,500 mm/year	>1,500-2,000 mm/year	>2,000 mm/year
(b)	Depth of groundwater table		>100 m	10-100 m	<10 m
(2.1.1.5)	Waste management after closure		Removal of waste material to dry area	Storage of waste material in wet area with an adequate implementation of capping, water diversion and erosion prevention	Storage of waste material in wet area without or with inadequate application of capping, water diversion and erosion prevention measures
(2.1.2)	Exposure potential $((2.1.2.1) \times (2.1.2.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(2.1.2.1)	Pollutant concentration Sum of the ratings of related pollutants using an equal weight	Water quality standard	>0-<1.5	1.5-<2.5	2.5-3
	-Arsenic[6]	0.01 mg/L	<5 µg/L	5-10 µg/L	>10 µg/L
	-Cadmium[6]	0.003 mg/L	<1.5 µg/L	1.5-3.0 µg/L	>3.0 µg/L
	-Lead[6]	0.006 mg/L	<3 µg/L	3-6 µg/L	>6 µg/L
	-Mercury[6]	0.01 mg/L	<5 µg/L	5-10 µg/L	>10 µg/L
	-Uranium[6]	0.015 mg/L	<8 µg/L	8-15 µg/L	>15 µg/L
	-Cyanide[6]	0.07 mg/L	<35 µg/L	35-70 µg/L	>70 µg/L
	-Acidity-alkalinity	pH 5.5-9.0	pH 5.5-9.0	pH 3-5 or 9.5-10.5	pH <3 or >10.5
	-Salinity	1 g/L	<0.5 g/L	0.5-1.0 g/L	>1.0 g/L
(2.1.2.2)	Pollutant dilution: groundwater velocity		>1 m/day	0.1-1 m/day	<0.1 m/day
(2.2)	Consequence: potentially affected population		>0-<2,000	2,000-10,000	>10,000
(3)	Failure of waste facility $((3.1) \times (3.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(3.1)	Likelihood $((3.1.1) \times (3.1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(3.1.1)	Failure potential	See 2.1.1.1 (1)			
(3.1.2)	Exposure potential $((3.1.2.1) \times (3.1.2.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(3.1.2.1)	Pollutant concentration Sum of the ratings of related pollutants using an equal weight	Water quality standard	>0-<1.5	1.5-<2.5	2.5-3
	-Arsenic[6]	0.01 mg/L	<5 µg/L	5-10 µg/L	>10 µg/L
	-Cadmium[6]	0.003 mg/L	<1.5 µg/L	1.5-3.0 µg/L	>3.0 µg/L
	-Lead[6]	0.006 mg/L	<3 µg/L	3-6 µg/L	>6 µg/L
	-Mercury[6]	0.01 mg/L	<5 µg/L	5-10 µg/L	>10 µg/L
	-Uranium[6]	0.015 mg/L	<8 µg/L	8-15 µg/L	>15 µg/L
	-Cyanide[6]	0.07 mg/L	<35 µg/L	35-70 µg/L	>70 µg/L
	-Acidity-alkalinity	pH 5.5-9.0	pH 5.5-9.0	pH 3-5 or 9.5-10.5	pH <3 or >10.5
	-Salinity	1 g/L	<0.5 g/L	0.5-1.0 g/L	>1.0 g/L
(3.1.2.2)	Dilution potential: type of water body present within 3 kilometers from waste facility		Stream or shallow lake (≤30 m)	River	Deep lake (>30 m)
(3.2)	Consequence: potentially affected population		>0-<2,000	2,000-10,000	>10,000
2.1.2.3	Soil pollution $((1) + (2)) \times 0.5$	0	>0-<1.5	1.5-<2.5	2.5-3
(1)	Direct contamination $((1.1) \times (1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
(1.1)	Likelihood $((1.1.1) \times (1.1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1.1)	Polluted area		<5 hectares	5-20 hectares	>20 hectares
(1.1.2)	Type of land use		Industrial and commercial purposes	Residential or other purposes that might allow pollutants to reach some groups of land users	Agriculture or other purposes that might cause direct or indirect exposure to a large group of people
(1.2)	Consequence: pollutant concentration[6]	Soil quality standard[8]			
	-Arsenic	3.9 mg/kg	<2.0 mg/kg	2.0-3.9 mg/kg	>3.9 mg/kg
	-Cadmium	37 mg/kg	<18.5 mg/kg	18.5-37.0 mg/kg	>37.0 mg/kg
	-Lead	400 mg/kg	<200 mg/kg	200-400 mg/kg	>400 mg/kg
	-Mercury	23 mg/kg	<11.5 mg/kg	11.5-23.0 mg/kg	>23.0 mg/kg
(2)	Indirect contamination $((2.1) \times (2.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(2.1)	Likelihood $((2.1.1) \times (2.1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(2.1.1)	Release of pollutants	Soil quality standard[8]			
	-Arsenic	3.9 mg/kg	<0.7 kg/year	0.7-1.4 kg/year	>1.4 kg/year
	-Cadmium	37 mg/kg	<6.8 kg/year	6.8-13.5 kg/year	>13.5 kg/year
	-Lead	400 mg/kg	<73 kg/year	73-146 kg/year	>146 kg/year
	-Mercury	23 mg/kg	<4.2 kg/year	4.2-8.4 kg/year	>8.4 kg/year
(2.1.2)	Pollutant dilution $((2.1.2.1) \times (2.1.2.2) \times (2.1.2.3))^{0.33}$	0	1-<1.67	1.67-<2.33	2.33-3
(2.1.2.1)	Wind speed		>5 m/s	1-5 m/s	<1 m/s
(2.1.2.2)	Topography		Flat terrain and the topography that facilitate air flow horizontally and vertically	Topography that interrupts air flow such as that occupied with buildings	Valley topography which is more likely to have temperature inversion and other topography that tends to have problems with atmospheric stability
(2.1.2.3)	Average rain days per year		>150 days/year	100-150 days/year	<100 days/year
(2.2)	Consequence: potentially affected population		>0-<2,000	2,000-10,000	>10,000
2.2	**Access to assets (2.2.1 + 2.2.2) x 0.5**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
2.2.1	**Access to natural assets (2.2.1.1 + 2.2.1.2 + 2.2.1.3) x 0.33**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
2.2.1.1	Competing water use	0	>0-<1.5	1.5-<2.5	2.5-3

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
	((1) + (2)) x 0.5				
(1)	Water abstraction $((1.1) \times (1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Likelihood: abstraction quantity / supply	0	>0-0.5	>0.5-1	>1
(1.2)	Consequence: adjusted number of affected population		<2,000	2,000-10,000	>10,000
(2)	Lowered water level $((2.1) \times (2.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(2.1)	Likelihood ((2.1.1) + (2.1.2)) x 0.5	0	>0-<1.5	1.5-<2.5	2.5-3
(2.1.1)	Depth of mine	unrelated or 0-50 m	>50-100 m	>100-150 m	>150 m
(2.1.2)	Distance of ground subsidence		>0-<0.3 m	0.3-2.4 m	>2.4 m
(2.2)	Consequence: adjusted number of affected population		<2,000	2,000-10,000	>10,000
2.2.1.2	Competing land use $((1) \times (2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood: residential and agricultural area acquired by mining project		<100 hectares	100-1,000 hectares	>1,000 hectares
(2)	Consequence: adjusted number of affected population		<2,000	2,000-10,000	>10,000
2.2.1.3	Competing forest use $((1) \times (2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood: Forest and abandoned area acquired by mining project		<100 hectares	100-1,000 hectares	>1,000 hectares
(2)	Consequence: adjusted number of affected population		<2,000	2,000-10,000	>10,000
2.2.2	**Access to physical assets (Sum of 2.2.2.1 to 2.2.2.4) x 0.25**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
2.2.2.1	Road: expected vehicle number / road capacity	0	>0-0.6	>0.6-1.0	>1.0
2.2.2.2	Rail: rail transport per day / remaining transport capacity at bottleneck	0	>0-0.6	>0.6-1.0	>1
2.2.2.3	Healthcare: change in ratio of population to medical staff	Positive change-indifferent	<5% decrease	5-15% decrease	>15% decrease
2.2.2.4	Education: change in ratio of student and educator in the area	Positive change-indifferent	<5% decrease	5-10% decrease	>10% decrease
2.3	**Vulnerability to external changes (2.3.1 + 2.3.2 + 2.3.3) x 0.33**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
2.3.1	**Floods $((1) \times (2))^{0.5}$**	**0**	**1-<1.67**	**1.67-<2.33**	**2.33-3**
2.3.1.1	Effect of subsidence $((1) \times (2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood $((1.1) \times (1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Current state of flooding potential Sum of ((1.1.1) x (1.1.2))		>0-<3	3-<6	6-18
(1.1.1)	Area		<100 hectares	100-1,000 hectares	>1,000 hectares
(1.1.2)	DDPM risk rating		Low	Medium	High
(1.2)	Effect of ground subsidence: maximum subsidence		>0-<0.3 m	0.3-2.4 m	>2.4 m
(2)	Consequence: adjusted number of affected population		<2,000	2,000-10,000	>10,000
2.3.1.2	Effect of sediment release to waterway $((1) \times (2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood	0	1-<1.67	1.67-<2.33	2.33-3

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
	((1.1) x (1.2))$^{0.5}$				
(1.1)	DDPM risk rating (flooding risk at water bank category)		Low	Medium	High
(1.2)	Release of sediment to waterway ((1.2.1) x (1.2.2))$^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.2.1)	Annual release of suspended solid	0	>0-<13.7 t/year	13.7-27.3 t/year	>27.3 t/year
(1.2.2)	Type of water channel		Water channel with turbulent flow or high fluid force or bedform enhancing flow strength	Water channel with characteristic s between low and high rating	Water channel with laminar flow or low fluid force or bedform that promotes smooth flow
(2)	Consequence: adjusted number of affected population		<2,000	2,000-10,000	>10,000
2.3.2	**Droughts ((1) x (2))$^{0.5}$**	**0**	**1-<1.67**	**1.67-<2.33**	**2.33-3**
(1)	Likelihood ((1.1) x (1.2))$^{0.5}$	**0**	**1-<1.67**	**1.67-<2.33**	**2.33-3**
(1.1)	Current state of drought potential Sum of ((1.1.1) x (1.1.2))		>0-<3	3-<6	6-18
(1.1.1)	Area		<100 hectares	100-1,000 hectares	>1,000 hectares
(1.1.2)	DDPM risk rating		Low	Medium	High
(1.2)	Effect of lowered water level ((1.2.1) + (1.2.2)) x 0.5	0	>0-<1.5	1.5-<2.5	2.5-3
(1.2.1)	Depth of mine	unrelated or 0-50 m	>50-100 m	>100-150 m	>150 m
(1.2.2)	Distance of ground subsidence		>0-<0.3 m	0.3-2.4 m	>2.4 m
(2)	Consequence: adjusted number of affected population		<2,000	2,000-10,000	>10,000
2.3.3	**Dependency on mining (4.2.1 + 4.2.2) x 0.5**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
(1)	Employment dependency: mine employment / local workforce		>0-<5%	5-15%	>15%
(2)	Local spending of mining project: local mine spending / economy size		>0-<5%	5-15%	>15%
3.	**Environment (3.1 + 3.2) x 0.5**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
3.1	**Habitat loss (3.1.1 + 3.1.2) x 0.5**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
3.1.1	**Terrestrial habitat loss (3.1.1.1 x 0.67) + (3.1.1.2 x 0.33)**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
3.1.1.1	Loss of land cover ((1) x (2))$^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood Sum of ((1.1) x (1.2))		>0-<3	3-<6	6-18
(1.1)	Area		>0-<50 hectares	50-1,000 hectares	>1,000 hectares
(1.2)	Loss period	≤1 year	>1-≤3 years	>3-≤10 years	>10 years
(2)	Consequence: presence of species Average (2.2a) to (2.2c) only if relevant, using the rating of (2.1) as weights		1-<3	3-<6	6-18
(2.1)	Vulnerability		Unthreatened species	Potentially threatened species	Threatened species
(2.2)	Adjusted number of species No. of species x (2.2.1)				
(2.2a)	-Unthreatened species		1-100	101-500	>500
(2.2b)	-Potentially threatened species		1-5	6-10	>10

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
(2.2c)	-Threatened species		1-5	6-10	>10
(2.2.1)	Species abundance weight		0.33	0.67	1
(c)	-Threatened species		1-5	6-10	>10
3.1.1.2	Effect of ground subsidence $(3.1.2.1 \times 3.1.2.2)^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood Sum of ((1.1) x (1.2))		>0-<3	3-<6	6-18
(1.1)	Area		<50 hectares	50-1,000 hectares	>1,000 hectares
(1.2)	Horizontal strain		$>0-<5x10^{-3}$	$5x10^{-3}$-$10x10^{-3}$	$>10x10^{-3}$
(2)	Consequence: presence of species	See 3.1.1.1(2)			
3.1.2	**Aquatic habitat loss** **(3.1.1 x 0.67) + (3.1.2 x 0.33)**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
3.1.2.1	Direct removal of water body $(3.2.1.1 \times 3.2.1.2)^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood Sum of ((1.1) x (1.2))		>0-<3	3-<6	6-18
(1.1)	Area		>0-<1 hectares	1-8 hectares	>8 hectares
(1.2)	Loss period	≤1 year	>1-≤3 years	>3-≤10 years	>10 years
(2)	Consequence: presence of species	See 3.1.1.1(2)			
3.1.2.2	Indirect water disruption $((1) \times (2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood		Activities that can cause a minor, temporary disruption to downstream water body	Activities that can cause a temporary significant loss or long-term minor disruption to downstream water body or a combination of up to three minor disruptions	Activities that can cause a significant, long-term loss of downstream water body or a combination of more than three different activity types
(2)	Consequence: presence of species	See 3.1.1.1(2)			
3.2	**Pollution** **(3.2.1 + 3.2.2 + 3.2.3) x 0.33**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
3.2.1	**Air pollution** $\mathbf{((1) \times (2))^{0.5}}$	**0**	**1-<1.67**	**1.67-<2.33**	**2.33-3**
(1)	Likelihood $((1.1) \times (1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Release of pollutants Sum of related pollutants with an equal weight	Air emission standard[4]	>0-<1.5	1.5-<2.5	2.5-3
	-Sulfur dioxide	125 μg/m³	<22.8 t/year	22.8-45.6 t/year	>45.6 t/year
	-Nitrogen dioxide	40 μg/m³	<7.3 t/year	7.3-14.6 t/year	>14.6 t/year
	-Ozone	120 μg/m³	<21.9 t/year	21.9-43.8 t/year	>43.8 t/year
(1.2)	Pollutant dilution $((1.2.1) \times (1.2.2) \times (1.2.3))^{0.33}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.2.1)	Wind speed		>5 m/s	1-5 m/s	<1 m/s
(1.2.2)	Topography		Flat terrain and the topography that facilitate air flow horizontally and vertically	Topography that interrupts air flow such as that occupied with buildings	Valley topography which is more likely to have temperature inversion and other

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
					topography that tends to have problems with atmospheric stability
(1.2.3)	Average rain days per year		>150 days/year	100-150 days/year	<100 days/year
(2)	Consequence: presence of species	See 3.1.1.1(2)			
3.2.2	**Water pollution (3.2.2.1 x 0.67) + (3.2.2.2 x 0.33)**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
3.2.2.1	Planned discharge of water pollutants $((1) \times (2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1)	Likelihood $((1.1) \times (1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Pollutant discharge Sum of related pollutants with an equal weight	Water quality standard (aquatic)	>0-<1.5	1.5-<2.5	2.5-3
	-Arsenic[7]	150 µg/L	<2.7 kg/year	2.7-5.5 kg/year	>5.5 kg/year
	-Cadmium[7]	0.72 µg/L	<0.8 kg/year	0.8-1.6 kg/year	>1.6 kg/year
	-Lead[7]	2.5 µg/L	<2.7 kg/year	2.7-5.5 kg/year	>5.5 kg/year
	-Mercury[7]	0.77 µg/L	<1.6 kg/year	1.6-3.3 kg/year	>3.3 kg/year
	-Uranium[6]	0.015 mg/L	<4.1 kg/year	4.1-8.2 kg/year	>8.2 kg/year
	-Cyanide[6]	0.07 mg/L	<19.2 kg/year	19.2-38.3 kg/year	>38.3 kg/year
	-Suspended solid	0.05 µg/L	<25 mg/L	25-50 mg/L	>50 mg/L
	-Acidity-alkalinity	pH 5.5-9.0	pH 5.5-9.0	pH 3-5 or 9.5-10.5	pH <3 or >10.5
	-Salinity[9]	1 g/L	<273.8 t/year	273.8-574.5 t/year	>574.5 t/year
	-Heat[10]	40°C	<30°C	30-40°C	>40°C
(1.2)	Pollutant dilution				
	-Surface water		Stream or shallow lake (≤30 m)	River	Deep lake (>30 m),
	-Underground water		Bank filtration and karst	Alluvial aquifers	Sedimentary or deep aquifers
(2)	Consequence: presence of species	See 3.1.1.1(2)			
3.2.2.2	Undesired release of water pollutants ((1) + (2) + (3)) x 0.33	0	>0-<1.5	1.5-<2.5	2.5-3
(1)	Leaching and contamination from mine drainage $((1.1) \times (1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Likelihood $((1.1.1) \times (1.1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1.1)	Presence of pollutant		Presence of both acid-generating substances (i.e. sulfide minerals) and neutralizing substances such as carbonate	Presence of acid-generating substances without (or with insignificant amount of) neutralizing substances	Presence of both acid-generating substances and heavy metals, regardless of neutralizing substances

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
			and silicate minerals		
(1.1.2)	Presence of water ((1.1.2.1) + (1.1.2.2)) x 0.5	0	>0-<1.5	1.5-<2.5	2.5-3
(1.1.2.1)	Amount of rainfall: average annual rainfall in a 30-year period		>0-1,500 mm/year	>1,500-2,000 mm/year	>2,000 mm/year
(1.1.2.2)	Groundwater velocity		<0.1 m/day	0.1-1 m/day	>1 m/day
(1.2)	Consequence: presence of species	See 3.1.1.1(2)			
(2)	Seepage from waste facility $((2.1) \times (2.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(2.1)	Likelihood $((2.1.1) \times (2.1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(2.1.1)	Seepage potential (Multiplication of (2.1.1.1) to (2.1.1.5))$^{0.2}$	0	1-<1.67	1.67-<2.33	2.33-3
(2.1.1.1)	Capacity of waste facility		>0-<0.02 Mm^3	0.02-0.05 Mm^3	>0.05 Mm^3
(2.1.1.2)	Water content in wastes				
	-Waste dump		<10%	10-30%	>30%
	-Tailing dam		Cake or dry tailing	Thickened or paste	Slurry or liquid
(2.1.1.3)	Control measures		Presence of seepage prevention and capture measures	Presence of either prevention or capture measures	Neither prevention nor capture measures are implemented
(2.1.1.4)	Presence of water ((a) x 0.67) + ((b) x 0.33)	0	>0-<1.5	1.5-<2.5	2.5-3
(a)	Amount of rainfall: maximum annual rainfall in a 30-year period		>0-1,500 mm/year	>1,500-2,000 mm/year	>2,000 mm/year
(b)	Depth of groundwater table		>100 m	10-100 m	<10 m
(2.1.1.5)	Waste management after closure		Removal of waste material to dry area	Storage of waste material in wet area with an adequate implementati on of capping, water diversion and erosion prevention	Storage of waste material in wet area without or with inadequate application of capping, water diversion and erosion prevention measures
(2.1.2)	Exposure potential $((2.1.2.1) \times (2.1.2.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(2.1.2.1)	Pollutant concentration	Water quality standard			
	-Arsenic[6]	0.01 mg/L	<5 µg/L	5-10 µg/L	>10 µg/L
	-Cadmium[6]	0.003 mg/L	<1.5 µg/L	1.5-3.0 µg/L	>3.0 µg/L
	-Lead[6]	0.006 mg/L	<3 µg/L	3-6 µg/L	>6 µg/L
	-Mercury[6]	0.01 mg/L	<5 µg/L	5-10 µg/L	>10 µg/L
	-Uranium[6]	0.015 mg/L	<8 µg/L	8-15 µg/L	>15 µg/L
	-Cyanide[6]	0.07 mg/L	<35 µg/L	35-70 µg/L	>70 µg/L
	-Acidity-alkalinity	pH 5.5-9.0	pH 5.5-9.0	pH 3-5 or 9.5-10.5	pH <3 or >10.5
	-Salinity	1 g/L	<0.5 g/L	0.5-1.0 g/L	>1.0 g/L
(2.1.2.2)	Pollutant dilution: groundwater velocity		<0.1 m/day	0.1-1 m/day	>1 m/day
(2.2)	Consequence: presence of species	See 3.1.1.1(2)			
(3)	Failure of waste facility $((3.1) \times (3.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
(3.1)	Likelihood $((3.1.1) \times (3.1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(3.1.1)	Failure potential	See 2.1.1.1(1)			
(3.2.1)	Exposure potential $((3.2.1.1) \times (3.2.1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(3.2.1.1)	Pollutant concentration	Water quality standard			
	-Arsenic[6]	0.01 mg/L	<5 µg/L	5-10 µg/L	>10 µg/L
	-Cadmium[6]	0.003 mg/L	<1.5 µg/L	1.5-3.0 µg/L	>3.0 µg/L
	-Lead[6]	0.006 mg/L	<3 µg/L	3-6 µg/L	>6 µg/L
	-Mercury[6]	0.01 mg/L	<5 µg/L	5-10 µg/L	>10 µg/L
	-Uranium[6]	0.015 mg/L	<8 µg/L	8-15 µg/L	>15 µg/L
	-Cyanide[6]	0.07 mg/L	<35 µg/L	35-70 µg/L	>70 µg/L
	-Acidity-alkalinity	pH 5.5-9.0	pH 5.5-9.0	pH 3-5 or 9.5-10.5	pH <3 or >10.5
	-Salinity	1 g/L	<0.5 g/L	0.5-1.0 g/L	>1.0 g/L
(3.2.1.2)	Dilution potential: type of water body present within 3 kilometers from waste facility		Stream or shallow lake (≤30 m)	River	Deep lake (>30 m)
(3.2)	Consequence: presence of species	See 3.1.1.1(2)			
3.2.3	**Soil pollution** **((1) + (2)) x 0.5**	**0**	**>0-<1.5**	**1.5-<2.5**	**2.5-3**
(1)	Likelihood $((1.1) \times (1.2))^{0.5}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.1)	Release of pollutants	Soil quality standard[8]			
	-Arsenic	3.9 mg/kg	<0.7 kg/year	0.7-1.4 kg/year	>1.4 kg/year
	-Cadmium	37 mg/kg	<6.8 kg/year	6.8-13.5 kg/year	>13.5 kg/year
	-Lead	400 mg/kg	<73 kg/year	73-146 kg/year	>146 kg/year
	-Mercury	23 mg/kg	<4.2 kg/year	4.2-8.4 kg/year	>8.4 kg/year
(1.2)	Pollutant dilution $((1.2.1) \times (1.2.2) \times (1.2.3))^{0.33}$	0	1-<1.67	1.67-<2.33	2.33-3
(1.2.1)	Wind speed		>5 m/s	1-5 m/s	<1 m/s
(1.2.2)	Topography		Flat terrain and the topography that facilitate air flow horizontally and vertically	Topography that interrupts air flow such as that occupied with buildings	Valley topography which is more likely to have temperature inversion and other topography that tends to have problems with atmospheric stability
(1.2.3)	Average rain days per year		>150 days/year	100-150 days/year	<100 days/year
(2)	Consequence: presence of species	See 3.1.1.1(2)			
4.	**Shareholders**				
4.1	**Rate of return**				
	-Low risk project		>15%	5-15%	<5%
	-Medium risk project		>20%	10-20%	<10%
	-High risk project		>25%	15-25%	<15%
4.1.1	Project risk level (Sum of 4.1.1.1 to 4.1.1.5) x 0.2	0	>0-<1.5	1.5-<2.5	2.5-3

No.	Components	Rating Criteria			
		Irrelevant	Low	Medium	High
4.1.1.1	Exploration risk		Measured resources	Indicated resources	Inferred resources
4.1.1.2	Technology and methods		Widely applied at commercial scale and are familiar to local operators	Globally known but have never or rarely been applied within the country or similar cases	Newly developed or applied in other fields and whose applications in mining field and/or at commercial scale are still limited
4.1.1.3	Price volatility: 10-years annualized volatility		0-<10%	10-30%	>30%
4.1.1.4	Social conflict		No opposition or minor concerns	Presence of opposition group but the majority gives consent to the project	Presence of strong opposition group or a large number of active protesters
4.1.1.5	Company's reputation (Sum of (a) to (d)) x 0.25	0	>0-<1.5	1.5-<2.5	2.5-3
(a)	Community's trust		No involvement in any scandals or legal violation conducts during the last 10 years or being a newly founded company	No involvement in any scandals or legal violation conducts during the last 3 years but having problem within the last 10 years	Involvement in any related scandals or legal violation conducts during the last 3 years
(b)	Environmental performance				
(c)	Employee's trust				
(d)	Financial performance: net profit margin		>15%	5-15%	<5%

Remarks:

[1] Occupational Safety and Health Administration, 2016. Permissible Exposure Limits – Annotated Tables [WWW Document]. URL https://www.osha.gov/dsg/annotated-pels/index.html (accessed 11.13.16).

[2] National Institute for Occupational Safety and Health, 1988. Carcinogenic Effects of Exposure to Diesel Exhaust [WWW Document]. Curr. Intell. Bull. 50. URL https://www.cdc.gov/niosh/docs/88-116/ (accessed 11.13.16).

[3] U.S. Department of Health and Human Services, 2012. 8. Regulations, Advisories, and Guidelines, in: Toxicological Profile for Radon.

[4] European Commission, 2016. Air Quality Standards [WWW Document]. URL http://ec.europa.eu/environment/air/quality/standards.htm (accessed 11.14.16).

[5] World Health Organization, 2000. Air Quality Guidelines for Europe (No. 91), WHO Regional Publications, European Series. Copenhagen.

[6] World Health Organization, 2006. Guidelines for Drinking-water Quality, First Addendum, Volume 1 Recommendations, 3rd ed. World Health Organization, Geneva.

[7] U.S. Environmental Protection Agency, 2016. National Recommended Water Quality Criteria - Aquatic Life Criteria Table [WWW Document]. URL https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table (accessed 11.14.16).

[8] Pollution Control Department, 2016. Soil Quality Standards for Habitat and Agriculture [WWW Document]. URL http://www.pcd.go.th/info_serv/en_reg_std_soil01.html (accessed 11.14.16).

[9] McCevoy, P., Goonan, P., 2003. Salinity is not necessarily bad for biodiversity: case studies of invertebrates from South Australian streams and River Murray wetlands, Records of the South Australian Museum No. 7.

[10] Using different criteria for classifying the ratio (i.e. 0.75 instead of 0.5) because the range of temperature change that can affect the ecosystem is narrow

Appendix B: Mass flow calculation for the operation phase of the case study

The mass flow of the operation is considered from the inputs and the outputs at three main project facilities: underground mine, mineral processing plant, and waste storage facility.

(1) Mine

(1.1) Inputs

The key inputs of mining process include ores, backfilled materials, energy, water, and explosives.

(1.1.1) Ores

The amount of ores entering the study boundary refers to the production rate. The production rate at full operation is used for the calculation. According to the mining plan, the company plans to annually produce around 7.19 million tonnes of potash ores at the average grade of 14.78%K_2O and 0.08 million tonnes of rock salt[1].

(1.1.2) Backfilled materials

Backfilled materials are NaCl (solid) and $MgCl_2$ (brine) tailings from the waste storage facility. Their average quantities during the full production years (production year 6-17) are 3.05 million tonnes per year and 1.93 million cubic meters or 2.53 million tonnes per year, respectively[2].

(1.1.3) Energy

The energy required in the underground mine is derived from electricity and fuel. The mining plan mentions that the electricity requirement of the underground mine is 17.7 megawatts (MW) or 136 gigawatts-hour (GWh) per year[3]. The generation of electricity is

---

[1] p. 4-105 and p. 4-111, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok. Use the average value of the full production period (production year 6-17)

[2] p. 4-108, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.

[3] p. 9-1, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok. Assume 24 working hours per day and 320 days per year.

considered as part of the mineral processing plant since the electricity is generated from a coal-fired cogeneration unit, located on the plant compound and supplying steam and electricity to the plant. The diesel requirement of the mine is estimated from the machinery list as shown in Table B-1; it accounts for 7,565 tonnes per year.

Table B-1: Estimated diesel requirement of the mine

Diesel vehicle	Amount (unit)	Power (kW)	Working hour (hours/ year/unit)[a]	Assumed utilization rate	Diesel consumption rate (gallon/ 100 bhp-hr)[b]	Diesel consumption (tonnes/year)
Development and production						
Scaling vehicle	2	147	4,570	80%	5.57	240.96
Roof cutting vehicle	5	147	4,570	80%	5.57	602.39
Scoop tram (LHD) diesel	2	168	4,570	80%	5.57	275.38
Roof bolter	3	129	4,570	80%	5.57	317.18
Site vehicle	6	121	4,570	80%	5.89	629.20
Personnel transporter	6	122	857	15%	5.89	118.95
Utility vehicle	3	122	3,427	60%	5.89	237.90
Oiler vehicle	3	128	1,142	20%	5.89	83.20
Forklift platform	4	173	3,427	60%	5.89	449.80
Blasting production						
Large hole drilling carriage	3	45	571	10%[c]	5.57	18.44
Dual boom jumbo	5	75	571	10%[c]	5.57	51.22
Explosives load vehicle	3	82	571	10%[c]	5.57	33.81
Scoop tram (LHD) diesel	2	320	4,570	80%	5.57	703.12
Bench drill	4	67	571	10%[c]	5.57	36.88
Backfill						
Scaling vehicle	1	110	4,570	80%	5.57	120.48
Roof cutting vehicles	1	110	4,570	80%	5.57	120.48
Scoop tram (LHD) diesel	1	125	4,570	80%	5.57	137.69
Roof bolter	1	96	4,570	80%	5.57	105.73
Forklift	2	45	3,427	60%	5.89	78.00
Multi purpose mine vehicle	3	90	3,427	60%	5.89	234.00
Crane	2	90	1,714	30%	5.89	78.00
Aereal work platform	2	47	1,714	30%	5.89	40.95
Site vehicle	1	91	3,427	60%	5.89	79.30
Personnel transporter	1	90	4,570	80%	5.89	104.87
Maintenance and general						
Craftsmen vehicle	9	69	857	15%	5.89	136.01
Site vehicles	5	56	4,570	80%	5.89	325.00
Transport vehicle	9	69	3,427	60%	5.89	544.05
Multi purpose mine vehicle	2	90	3,427	60%	5.89	156.00
Carriageway-construction-vehicle	5	204	4,570	80%	5.89	1,182.99
Forklift	3	45	3,427	60%	5.89	117.00
Lifting ramp (aereal work platform)	5	47	3,427	60%	5.89	204.75
Ambulance	1	69	24[d]		5.89	0.42
Fire fighter vehicle	1	69	24[d]		5.89	0.42
Total						7,564.54

Remarks:

[a] Calculate from operation time or cycle time, 85% availability, and utilization rate between 10-80%.

[b] Use the diesel consumption rates of 5.89, 5.89, and 5.57 gallons per 100 brake horsepower-hour for vocational vehicles with light heavy-duty (LHD), medium heavy-duty (MHD), and heavy heavy-duty (HHD) diesel engines, respectively. The values are derived from ECOpoint Inc., 2016. Emission Standards, EU: Nonroad Engines [WWW Document]. URL https://www.dieselnet.com/standards/eu/nonroad.php (accessed 1.22.17).

[c] Referred to the movement by diesel engine

[d] Assume working once a month and two hours per time.

(1.1.4) Water

The inflows of water to the mining area come from water in ores, backfilled materials, and water for personal use. The total amount of water fed to the mining area is 3.38 million tonnes per year. The calculation is shown in Table B-2.

Table B-2: Estimated amount of water inflows to the mining area

Flow description	Flow rate (10^6 t/year)[a]	Composition[b]				Total water (10^6 t/year)
		% solid (by weight)	% water in solid	Water in liquid (g/L)	Liquid density (g/L)	
Ores: carnallite	7.19	0%	20.2%			1.45
Backfilled materials						
- NaCl tailing	3.05	87.23%[c]	0%	818.2[c]	1,263.5[c]	0.25
- $MgCl_2$ tailing	2.53	0.37%	36.4%	859.6	1,313.7	1.65
Water for personal uses	0.02[d]					0.02
Total						3.38

Remarks:

[a] p. 4-105, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok. Use the average values during the full production years (production year 6-17).

[b] Assume the properties of the backfilled materials similar to those of the tailings discharged from the mineral processing plant; feed rates are derived from the annual amount of backfilled materials.

[c] Average value of all the NaCl tailing flows in the mineral processing plant

[d] p.10-2, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.

(1.1.5) Explosives

It is estimated in the mining plan that the explosives used in the mine production consist of high explosive 69 tonnes per year, ANFO 1,381 tonnes per year, and non-electric detonator approximately 168,500 sets per year. The estimation is shown in Table B-3.

Table B-3: Estimation of annual explosives requirement

	Unit	Burn cut	Benching	Total
Blasted ores[a]	10^6 t/year	0.73	4.36	5.09
Powder factor[b]	kg/t	0.7	0.2	
Required explosive	t/year	508.8	872.2	1,381.0
- High explosive	t/year	25.4	43.6	69.1
- ANFO	t/year	483.4	828.6	1,312.0
- Non-electric detonator	set/year	91,488	77,050	168,538

Remarks:

[a] Calculated from the average annual production rate during the full production year (production year 6-17) and the proportion of ore produced from different blasting patterns. The average production is 7.27 million tonnes per year (comprising 7.19 million tonnes carnallite and 0.08 million tonnes halite). The proportions of produced ores from development (using continuous miners), from opening less than 8 meters high (burn cut), and from opening as high as or higher than 8 meters (benching) are 30%, 10%, and 60% of total blasted ores, respectively. The value is derived from p. 4-105 and pp. 5-18-5-19, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.

[b] Ch. 5, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok

(1.2) Outputs

The mine outputs consist mainly of ores and wastes, emissions, and water.

(1.2.1) Ores and wastes

The average amounts of carnallite and halite during the full production year (production year 6-17) are 7.19 and 0.08 million tonnes per year [4].

(1.2.2) Emissions

The emissions from the mine include exhaust gases from diesel combustion engines, gases from blasting, and particulate matter from transport vehicles and material handling.

(1.2.2.1) Exhaust gases from diesel combustion engines

The estimation of the exhaust gases from diesel combustion engines in the mine is shown in Table B-4.

Table B-4: Estimated amount of exhaust gases from diesel combustion engines in the mine

Diesel vehicle	Amount (unit)	Power (kW)	Operation time (hours/ year)[a]	Emission factor (g/kWh)[b]				Emission (tonnes/year)			
				CO	HC	NOx	PM	CO	HC	NOx	PM
Development and production											
Scaling vehicle	2	147	4,570	5.0	1.0	6.0	0.3	5.01	1.00	6.01	0.30
Roof cutting vehicle	5	147	4,570	5.0	1.0	6.0	0.3	12.53	2.51	15.03	0.75
Scoop tram (LHD) diesel	2	168	4,570	5.0	1.0	6.0	0.3	5.73	1.15	6.87	0.34
Roof bolter	3	129	4,570	5.0	1.0	6.0	0.3	6.60	1.32	7.92	0.40
Site vehicle	6	121	4,570	5.0	1.0	6.0	0.3	12.37	2.47	14.85	0.74
Personnel transporter	6	122	857	5.0	1.0	6.0	0.3	2.34	0.47	2.81	0.14
Utility vehicle	3	122	3,427	5.0	1.0	6.0	0.3	4.68	0.94	5.61	0.28
Oiler vehicle	3	128	1,142	5.0	1.0	6.0	0.3	1.64	0.33	1.96	0.10
Forklift platform	4	173	3,427	5.0	1.0	6.0	0.3	8.85	1.77	10.62	0.53
Blasting production											
Large hole drilling carriage	3	45	571	5.0	1.3	7.0	0.38	0.10	0.12	0.54	0.03
Dual boom jumbo	5	75	571	5.0	1.3	7.0	1.07	0.28	0.33	1.49	0.09
Explosives load vehicle	3	82	571	5.0	1.0	6.0	0.70	0.14	0.17	0.84	0.04
Scoop tram (LHD) diesel	2	320	4,570	3.5	1.0	6.0	10.24	2.92	5.79	17.55	0.58

[4] p. 4-105, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.

Diesel vehicle	Amount (unit)	Power (kW)	Operation time (hours/ year)[a]	Emission factor (g/kWh)[b]				Emission (tonnes/year)			
				CO	HC	NOx	PM	CO	HC	NOx	PM
Bench drill	4	67	571	5.0	1.3	7.0	0.4	0.77	0.20	1.07	0.06
Backfill											
Scaling vehicle	1	110	4,570	5.0	1.0	6.0	0.3	2.51	0.50	3.01	0.15
Roof cutting vehicles	1	110	4,570	5.0	1.0	6.0	0.3	2.51	0.50	3.01	0.15
Scoop tram (LHD) diesel	1	125	4,570	5.0	1.0	6.0	0.3	2.86	0.57	3.44	0.17
Roof bolter	1	96	4,570	5.0	1.0	6.0	0.3	2.20	0.44	2.64	0.13
Forklift	2	45	3,427	5.0	1.3	7.0	0.4	1.53	0.40	2.15	0.12
Multi purpose mine vehicle	3	90	3,427	5.0	1.0	6.0	0.3	4.60	0.92	5.52	0.28
Crane	2	90	1,714	5.0	1.0	6.0	0.3	1.53	0.31	1.84	0.09
Aereal work platform	2	47	1,714	5.0	1.3	7.0	0.4	0.81	0.21	1.13	0.06
Site vehicle	1	91	3,427	5.0	1.0	6.0	0.3	1.56	0.31	1.87	0.09
Personnel transporter	1	90	4,570	5.0	1.0	6.0	0.3	2.06	0.41	2.47	0.12
Maintenance and general											
Craftsmen vehicle	9	69	857	5.0	1.3	7.0	0.4	2.67	0.70	3.74	0.21
Site vehicles	5	56	4,570	5.0	1.3	7.0	0.4	6.39	1.66	8.95	0.51
Transport vehicle	9	69	3,427	5.0	1.3	7.0	0.4	10.70	2.78	14.98	0.86
Multi purpose mine vehicle	2	90	3,427	5.0	1.0	6.0	0.3	3.07	0.61	3.68	0.18
Carriageway construction vehicle	5	204	4,570	3.5	1.0	6.0	0.2	16.29	4.65	27.92	0.93
Forklift	3	45	3,427	5.0	1.3	7.0	0.4	2.30	0.60	3.22	0.18
Lifting ramp	5	47	3,427	5.0	1.3	7.0	0.4	4.03	1.05	5.64	0.32
Ambulance	1	69	24	5.0	1.3	7.0	0.4	0.01	0.00	0.01	0.00
Fire fighter vehicle	1	69	24	5.0	1.3	7.0	0.4	0.01	0.00	0.01	0.00
Total								140.53	32.22	188.41	8.97

Remarks:
[a] Estimated from assumed availability and utilization rate.
[b] Based on the EU Directive 97/68/EC and its amendments; source: ECOpoint Inc., 2016. Emission Standards, EU: Nonroad Engines [WWW Document]. URL https://www.dieselnet.com/standards/eu/nonroad.php (accessed 1.22.17).

(1.2.2.2) Gases from blasting

The amount of gases from blasting is estimated from the amount of explosives and emission factors as shown in Table B-5.

Table B-5: Estimated amount of gases from blasting

Explosive	Amount (tonnes/ year)[a]	Emission factor (kg/Mg)[b]					Emission (tonnes per year)				
		CO	NO_X	CH_4	SO_2	H_2S	CO	NO_X	CH_4	SO_2	H_2S
ANFO	1,312.0	34	8	0	1	0	44.6	10.5	0.0	1.3	0.0
Dynamite, gelatin	69.1	52	26	0.3	1	2	3.6	1.8	0.0	0.1	0.1
Total							48.2	12.3	0.0	1.4	0.1

Remarks:
[a] Using daily explosive requirement specified in the mining plan (Table 5.1-5.5) and assuming 320 working days per year
[b] Table 11.9-2 and 13.3-1 in U.S. Environmental Protection Agency, 1995. AP-42, Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. Washington D.C.

(1.2.2.3) Particulate matter from production and material handling

The amounts of particulate matter from production and material handling and from vehicle transport are estimated from operation parameters and emission factors as shown in Table B-6 and Table B-7, respectively.

Table B-6: Estimated amount of particulate matter from production and material handling

Activity	Operating parameter			Emission factor[a]			Emission (tonnes/year)[b]	
	Description	Value	Unit	TSP	PM10	Unit	TSP	PM10
Drilling	No. of drill-holes per year	168,538	holes/year	0.59	0.31	kg/hole	99.4	52.2
Blasting	Blasting area per year: benching method	150	m^2/blast	0.00022 x (blasting area per blast)$^{1.5}$	0.000114 x (blasting area per blast)$^{1.5}$	kg/blast	0.8	0.4
		1,101	blast/year					
	Blasting area per year: burn cut method	120	m^2/blast					
		482	blast/year					
Scaling	Working hours [c]	4,570	hours/year	2.6 x silt content$^{1.2}$ / moisture content$^{1.3}$; use silt content 10% and moisture content 2%	0.34 x silt content$^{1.5}$ / moisture content$^{1.4}$; use silt content 10% and moisture content 2%	kg/hour/ equipment	229.4	55.9
	No. of equipment	3	units					
Excavating	Working hours [c]	571	hours/year				57.4	14.0
	No. of equipment	6	units					
Road grading	Working hours [c]	4,570	hours/year				382.4	93.1
	No. of equipment	5	units					
Bolting	No. of rock bolt	1,137,503[d]	holes/year	0.59	0.31	kg/hole	628.6	330.3
Loading	Ore amount	22,714	tonnes/day	0.74 x 0.0016 x (wind speed / 2.2)$^{1.3}$ / (%moisture in material / 2)$^{1.4}$; use wind speed in tunnel 6 m/s and in shaft 10 m/s and moisture content 2%	0.35 x 0.0016 x (wind speed / 2.2)$^{1.3}$ / (%moisture in material / 2)$^{1.4}$; use wind speed in tunnel 6 m/s and in shaft 10 m/s and moisture content 2%	kg/Mg	31.7	15.0
Unloading to crusher	Ore amount	22,714	tonnes/day				31.7	15.0
Belt transporting	No. of transfer points	4	points				126.9	60.0
Shaft transporting	No. of transfer points	2	points				123.2	58.3
Crushing	Ore amount	22,714	tonnes/day	0.2	0.02	kg/tonne	1,453.7	145.4
Total							3,165.2	839.6

Remarks:

[a] Table 11.9-2 and 13.2-2 in U.S. Environmental Protection Agency, 1995. AP-42, Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. Washington D.C.; Table 3 in The Department of Sustainability, Environment, Water, Population and Communities, 2012. National Pollutant Inventory Emission Estimation Technique Manual for Mining Version 3.1. Canberra.

[b] Assuming 320 working days per year

[c] Working hours is estimated from availability and utilization rates. The production rate and machine specification are also taken into account.

[d] Estimated from mining area and the use of rock bolt of 4 bolt per square meters. The values are obtained from table 4-37 and p. 4-149 in ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.

Table B-7: Estimated amount of particulate matter from vehicle transport

Vehicle	Amount (unit)	Tramming speed (km/h)[a]	Weight (tonnes)	VMT[b]	Emission (t/year)[c]	
					TSP	PM10
Development and production						
Continuous miner	6	0.95	127	326	1.91	0.54
Discontinuous haulage systems	12	-	-	-	-	-
Scaling vehicle	2	11.5	25	10,528	29.66	8.47
Roof cutting vehicles	5	11.5	25	26,321	74.14	21.18
Scoop tram (LHD) diesel	2	10.0	23.7	34,342	51.70	25.86
Roof bolter	3	5.8	22.7	7,896	21.30	6.09
Site vehicle	6	30.0	2.1	822,528	404.71	141.84
Personnel transporter	6	26.4	6	135,717	64.26	21.94
Utility vehicle	3	26.4	6	271,434	128.51	43.89
Oiler vehicle	3	15.0	14.4	51,408	112.98	32.28
Forklift platform	4	15.0	12	205,632	416.31	118.95
Blasting production						
Large hole drilling carriage	3	10.8	14.5	18,507	40.80	11.66
Dual boom jumbo	5	8.6	34	24,676	79.82	22.81
Explosives load vehicle	3	15.0	25	25,704	72.40	20.69
Scoop tram (LHD) diesel	2	10.0	76.8	27,382	127.81	36.52
Scoop tram (LHD) electric	5	10.0	76.8	68,455	319.53	91.30
Bench drill	4	15.0	25	34,272	96.54	27.58
Raise boring unit	2	-	-	-	-	-
Backfill						
Scaling vehicle	1	11.5	25.0	5,264	14.83	4.24
Roof cutting vehicles	1	11.5	25.0	5,264	14.83	4.24
Scoop tram (LHD) diesel	1	10.0	23.7	17,171	45.25	12.93
Roof bolter	1	5.8	22.7	2,632	7.10	2.03
Forklift	2	15.0	12.0	102,816	208.15	59.47
Multi purpose mine vehicle	3	15.0	14.4	154,224	338.93	96.84
Crane	2	15.0	14.4	51,408	112.98	32.28
Aereal work platform	2	15.0	14.4	51,408	112.98	32.28
Site vehicle	1	19.8	6.0	67,859	29.46	9.49
Personnel transporter	1	30.0	2.1	137,088	67.45	23.64
Maintenance and general						
Craftsmen vehicles	9	26.4	6.0	203,576	96.39	32.92
Site vehicles	5	30.0	2.1	685,440	337.25	118.20
Transport vehicles	9	26.4	6.0	814,303	385.54	131.66
Multi purpose mine vehicle	2	15.0	14.4	102,816	225.95	64.56
Carriageway-construction-vehicle	5	15.0	25.0	342,720	965.40	275.83
Forklift	3	15.0	12.0	154,224	312.23	89.21
Lifting ramp	5	15.0	14.4	257,040	564.88	161.40
Ambulance	1	26.4	6.0	634	0.30	0.10
Total					5,882.59	1,783.02

Remarks:

[a] Tramming speed is estimated from the assumed speed in percentage of the speed in specification.

[b] Vehicled kilometers travelled per year

[c] Emissions are calculated from the formula from Table 13.2-2, in U.S. Environmental Protection Agency, 1995. AP-42, Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. Washington D.C. and the formula in The Department of Sustainability, Environment, Water, Population and Communities, 2012. National Pollutant Inventory Emission Estimation Technique Manual for Mining Version 3.1. Canberra as shown below.

TSP (in kg/VKT) for:

- Light duty vehicle (<11.8 t) $1.69 \times ((\text{silt content} / 12) \times (\text{speed}/48)^{0.3} / (\text{moisture} / 0.5)^{0.3}) - 0.0013$
- Heavy duty vehicle (≥11.8 t) $(0.4536 / 1.6093) \times 4.9 \times (\text{silt content} / 12)^{0.7} * (\text{weight in tonnes} \times 1.1023/3)^{0.45}$

PM10 (in kg/VKT) for:

- Light duty vehicle (<11.8 t) $0.51 \times ((\text{silt content} / 12) \times (\text{speed} / 48)^{0.5} / (\text{moisture} / 0.5)^{0.2}) - 0.0013$
- Heavy duty vehicle (≥11.8 t) $(0.4536 / 1.6093) \times 1.5 \times (\text{silt content} / 12)^{0.9} \times (\text{weight in tonnes} \times 1.1023 / 3)^{0.45}$

Assume the moisture content at the road surface of 6% and the silt content of 8.5% for underground haul road and 10% for surface haul road. These values are based on the mid-value of the moisture at industrial road surface mentioned in Table 13.2.2-3 and the average silt content of haul road from/to pit in stone quarry and coal mining and of the in-plant road in stone quarry in Table 13.2.2-1 in the same document (AP-42).

(1.2.3) Water

Water outputs of the mine include water in ores, wastewater from personal use, evaporated water, and water from backfill sites.

(1.2.3.1) Water in ores

The amount of water flowing out of the mining process with ores is equal to that in extracted ore, which is 1.45 million tonnes per year.

(1.2.3.2) Wastewater from personal uses

The wastewater from personal use is assumed to be equal to the input water for personal use, which is 23,670 tonnes per year.

(1.2.3.3) Evaporated water

The amount of evaporated water is calculated from the evaporation at the underground pond. Another source of evaporated water in the mine is the water used for road grading, but this is assumed to be negligible because most of the water tends to bind with salt and remain in the road structure. Based on the information in the mining plan, the area of the underground brine pond is estimated at 5,000 square meters. An evaporation rate of 1,309.7 millimeters per year is applied. It is derived from an annual average pan evaporation rate of 1,871 millimeters per year[5] and a lake evaporation factor of 0.7[6]. The calculated amount of water evaporated from the underground pond is 6,548.5 tonnes per year.

(1.2.3.4) Water from backfill sites

The amount of water obtained from the backfilled areas is estimated from the rate of brine pumped out from the collecting pond to the backfill-material-mixing unit. A rate of 307 cubic meters per hour, which is the design capacity of the pump and the duct, is used for the calculation. It is also assumed that the composition of the brine from the backfill site is similar to that of the brine output from the mineral processing plant (water content in liquid 859.6 grams per liter, liquid volume per solid volume 192.6/193.2[7]), the amount of returning water from backfill is 263.1 tonnes per hour or 2.02 million tonnes per year.

---

[5] p. 8-6, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.

[6] Sheet 10, Golder Associates, 2011. Report on Guidance Document on Water and Mass Balance Models for the Mining Industry. Whitehorse, Yukon.

[7] p. 4-155 and appendix D11, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.

(2) Mineral processing plant

(2.1) Inputs

The inputs to mineral processing plant mainly consist of ores, energy, and water.

(2.1.1) Ores

The flow rate of ores into the mineral processing plant is 7.19 million tonnes, which is the average feed rate during the full production period (production year 6-17)[8].

(2.1.2) Energy

According to the information in the EIA report [9], the mineral processing plant and other above-ground activities require electricity of 31.2 megawatts (MW) or 25.8 gigawatt-hour (GWh) per year and steam of 46,806 tonnes per year. The electricity is supplied by a cogeneration unit, of which the designed capacity is 40 MW, and by the local electricity grid. It is planned to fuel the cogeneration unit with 1,000 tonnes of coal per day (or 345,000 tonnes per year) and biomass. Besides electricity, fuel oil is used in two burners. Adjusted by a factor of 90.8% of planned working hours to correspond to the ore feed rate, the requirements for coal and fuel for burners are 313,260 and 6,319 tonnes per year, respectively. The calculation of the fuel requirement is shown below:

Dryer feed[10]: wet KCl 1,075,524 t/year, water 5% by weight, 17°C

Dryer output[12]: dried KCl 818,152 t/year, moisture 0.2% by weight, 100°C (assumed)

Amount of water removed per tonne feed = 48.1 kilograms

Heat required for 1 kilogram feed = heat to raise the temperature ($q_{17\text{ to }100°C}$) + latent heat for vaporization ($q_{\text{liquid to steam at }100°C}$)

Calculate heat requirement from the equation: $q = m \cdot c \cdot \Delta T$ and $q = m \cdot L$

where, q = heat (kJ), m = mass (kg), c = specific heating value (kJ/kg/Kelvin), ΔT = temperature difference (Kelvin), and L = latent heat of vaporization (kJ/kg/Kelvin)

$q_{17\text{ to }100°C} = q_{KCl} + q_{water}$

---

[8] p. 4-111, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.

[9] p. 2-400, ASEAN Potash Mining PLC, 2014. Environmental Impact Assessment, Bamnet Narong Potash Project. Bangkok.

[10] Use 6,975 working hours per year to correspond to the ore feed rate and data from Appendix D14-1 and D14-2, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.

q_{KCl} = 1.022×10^9 kg/year x 0.695 kJ/kg/Kelvin x (373-290) Kelvin

q_{water} = 5.378×10^7 kg/year x 4.184 kJ/kg/Kelvin x (373-290) Kelvin

Thus, $q_{17 \text{ to } 100°C}$ = $5.894 \times 10^{10} + 1.867 \times 10^{10}$ = 7.761×10^{10} kJ

$q_{\text{liquid to steam at } 100°C}$ = 48.1 kg/t feed x 1.076×10^6 t feed/year x 2,257 kJ/kg/Kelvin

= 1.168×10^{11} kJ/year

Minimum heat required = 1.944×10^{11} kJ/year

Assume 85% efficiency, heat requirement = 2.287×10^{11} kJ/year

Assume fuel oil heating value = 33,654.5 kJ/liter

Required amount of fuel oil = 6,794,835 liters/year

Use SG = 0.93 t/m^3, required amount of fuel oil = 6,319 t/year

(2.1.3) Water

Water inputs of the mineral processing plant include rainfall runoff, water in ores, water for processing and steam generation, and water for personal and miscellaneous uses.

(2.1.3.1) Rainfall runoff

The rainfall runoff in the mineral processing plant compound (including the mine access area) is estimated at 379,737 cubic meters (tonnes) per year as shown in Table B-8 below.

Table B-8: Rainfall runoff in the mineral processing plant and the mine access compounds

Facility	Area (m^2)[a]	Rainfall in the facility (m^3/year)[b]	Share of area type[c]			Runoff (m^3/year)			
			Natural ground	Prepared ground	Water retaining area	Natural ground	Prepared ground	Water retaining area	Sum
Processing plant	507,200	458,560	20%	78%	2%	62,679	286,535	10,849	360,063
Decline access	27,200	24,592	-	100%	-	0	19,673	0	19,673
Total									379,737

Remarks:

[a] Data from the mining plan

[b] Calculated from the average rainfall of 904.1 millimeter per year

[c] The following runoff coefficients are applied: 0.7 for natural ground (including waste pile), 0.8 for prepared ground, and 1 for water retaining area. The coefficients are based on the information by Golder Associates, 2011. Report on Guidance Document on Water and Mass Balance Models for the Mining Industry. Whitehorse, Yukon. The share of area type in processing plant is assumed based on the information about project's area in the mining plan.

(2.1.3.2) Water in ores

The ores containing 20.2% moisture in the structure are to be fed into the mineral processing plant at the rate of 7.19 million tonnes per year, which are around 90.8% of the designed capacity. Thus, the amount of water in the ore structure input to the plant equals 1.45 million tonnes per year.

(2.1.3.3) Water for processing and steam generation

According to the mining plan[11], the water fed into the process consists of new water and reused water. Based on the design capacity, the amount of new water feed is 176.4 tonnes per hour, and that of reused water feed is 361.7 tonnes per hour. In addition, the plant requires water for steam generation at the rate of 173.6 tonnes per hour. Using the working time of 6,975 hours per year for the processing plant and steam generation, which corresponds to the average production rate, the annual feed of water to the process is 3.75 million tonnes, of which 1.23 million is new water feed and 2.52 million is reused feed, and the annual water feed for steam generation is 1.21 million tonnes

(2.1.3.4) Water for personal and miscellaneous uses

The amount of water for personal use in the mineral processing plant and above-ground activities is estimated at 23,136 cubic meters per year, and that for miscellaneous uses is 21,120 cubic meters per year[12].

(2.2) Outputs

The outputs of the mineral processing plant consist of products and wastes, emissions from the combustion of machinery and cogeneration unit, particulate matter from process and material handling, and water.

(2.2.1) Products and wastes

The products from the mineral processing plant are potassium chloride (KCl) in standard form and as granulated products. They are produced at the rate of 0.82 and 0.20 million tonnes per year, respectively. The wastes generated from the mineral processing plant are tailings and ashes from the cogeneration unit. Tailings consist of two types of material: NaCl (solid) and $MgCl_2$ (brine). They are generated at an average rate of 3.81 and 3.54 million tonnes per year, respectively[13]. The ashes from the cogeneration unit are estimated

---

[11] p. 10-2, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.

[12] p. 10-2-10-3, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.

[13] Estimated from flow rates in mass balance in Appendix D, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok. Use 6,975 working hours per year, corresponding to the production rate.

based on the information about the ash content. Assuming 10% of coal is turned into fly ash and bottom ash, the amount of ashes is estimated at 31,326 tonnes per year[14].

(2.2.2) Emissions from combustion

(2.2.2.1) Machinery

In the mineral processing plant, no diesel or gasoline engines are used. The main sources of combustion exhaust gases are the two burners in the product dryer. The amount of fuel oil required by the burner is 6,319 tonnes per year. Using the emission factor of fuel oil provided by the U.S. Environmental Protection Agency (EPA), the key emissions are estimated in Table B-9.

Table B-9: Estimated emissions of the substances of concern from burners

Substance	Emission factor			Emission (t/year)
	Value	Unit	Remark	
PM10	0.0052	kg/Mg fuel oil	a	3.29×10^{-2}
CO	6.00×10^{-1}	kg/m^3 fuel oil	b	4.08
SO_2	9.00	kg/m^3 fuel oil	b, c	61.15
NO_x	2.40	kg/m^3 fuel oil	b	16.31
Benzene	6.67×10^{-2}	kg/m^3 fuel oil	d	1.74×10^{-4}
Arsenic	1.58×10^{-4}	kg/m^3 fuel oil	e	1.08×10^{-3}
Cadmium	4.78×10^{-5}	kg/m^3 fuel oil	e	3.25×10^{-4}
Lead	1.81×10^{-4}	kg/m^3 fuel oil	e	1.23×10^{-3}
Mercury	1.36×10^{-5}	kg/m^3 fuel oil	e	9.21×10^{-5}

Remarks:

[a] Table 11.16-4 in U.S. Environmental Protection Agency, 1995. AP-42, Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. Washington D.C.

[b] Use the value of fuel oil no.4, boiler <100 BTU, combustor in Table 1.3-1 in U.S. Environmental Protection Agency, 1995. AP-42, Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. Washington D.C.

[c] Emission factor is calculated from 150 x S x 0.12 kg/m^3, where S = percentage sulfur content. Assume S = 0.5%

[d] Use the value of fuel oil no.4, combustor in Table 1.3-3 in U.S. Environmental Protection Agency, 1995. AP-42, Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. Washington D.C.

[e] Use the value of fuel oil no.6, combustor in Table 1.3-11 in U.S. Environmental Protection Agency, 1995. AP-42, Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. Washington D.C.

(2.2.2.2) Cogeneration unit

The cogeneration unit supplies electricity to both the underground mine and the above-ground facilities. The information in the EIA report[15] indicates that the cogeneration unit

---

[14] The EIA report (p. 2-401) indicates that the coal should contain 1-12% ash content. The example in the literature shows that the ash can be generated at the rate of 11.17% by weight of the coal feed (Lee, S.-H., Kim, J.-S., Lee, J.-W., Lee, S.-H., Lee, S.-H., Jeon, E.-C., 2011. A Study of the Bituminous Coal Oxidation Factor in Large Scale Boilers for Estimating GHG Emissions. Asian J. Atmos. Environ. 5, 189–195. doi:10.5572/ajae.2011.5.3.189)

[15] p. 2-401, ASEAN Potash Mining PLC, 2014. Environmental Impact Assessment, Bamnet Narong Potash Project. Bangkok.

will mainly be fired by bituminous coal with calorific value 5,500-6,500 kilocalories per kilogram (kcal/kg), moisture 8-15%, ash content 1-12%, and total sulfur 0.1-1.5%, and biomass such as rubber wood. The emissions from the cogeneration unit can be estimated from a coal feed rate of 313,324 tonnes per year (90.8% of 345 operating days per year) and the coal quality above as shown in Table B-10.

Table B-10: Estimated emissions from the cogeneration unit

Emission	Emission factor[a]			Emission (t/year)
	Value	Unit	Remark	
PM10	0.96	kg/t coal	b	300.73
CO	2.50×10^{-1}	kg/t coal		78.32
SO_2	9.5	kg/t coal	c	2,976.97
NO_x	2.5	kg/t coal	d	783.15
Benzene	3.4	kg/PJ		2.67×10^{-2}
Arsenic	2.10×10^{-4}	kg/PJ	e	1.65×10^{-6}
Cadmium	2.60×10^{-5}	kg/PJ	e	2.04×10^{-7}
Lead	2.10×10^{-4}	kg/PJ	e	1.65×10^{-6}
Mercury	2.43×10^{-9}	kg/PJ	f	7.61×10^{-7}

Remarks:

[a] Table 5 and 6 in The Department of Sustainability, Environment, Water, Population and Communities, 2012. National Pollutant Inventory Emission estimation technique manual for Fossil Fuel Electric Power Generation Version 3.0. Canberra.

[b] Use the value for electrostatic precipitator (ESP) plant

[c] Emission factor is calculated from 19 x S (formulae for bituminous coal), where S = percentage sulfur content of coal as fired. Assume S = 0.5%

[d] Use the value for fluidized bed, circulating

[e] Factors based on coal feed, as fired, andd apply to controlled coal combustion for boilers utilising electrostatic precipitators or fabric filters

[f] Emission factor is calculated from C x 8.1 x 10^{-4} (value for fabric filter and ESP plant); where C = concentration of metal in the coal (ppm by mass or mg/kg (as received basis)). Assume C = 0.03 mg/kg, referring to the value of Indonesian sub-bituminous coal in p. 6, Tsinghua University, 2011. Reducing Mercury Emissions from Coal Combustion in the Energy Sector. Beijing.

(2.2.3) Particulate matter from material handling

The estimation of particulate matter emitted from material handling in the mineral processing plant is shown in Table B-11.

Table B-11: Estimated emissions from material handling in the mineral processing plant

Activity	Operating parameter		Emission factor (kg/Mg)[b]		Emission (t/year)		Emission (t/year), after bag filter[c]	
	No. of point	Flow (t/h)[a]	TSP	PM10	TSP	PM10	TSP	PM10
Ore storage, conveyor to pile	4	1,031.0	6.77×10^{-6}	3.20×10^{-6}	0.19	9.22×10^{-2}	1.95×10^{-3}	9.22×10^{-4}
Ore storage, from pile	3	1,031.0	6.77×10^{-6}	3.20×10^{-6}	0.15	6.91×10^{-2}	1.46×10^{-3}	6.91×10^{-4}
Ore crushing, hopper & feeder	3	1,031.0	6.77×10^{-6}	3.20×10^{-6}	0.15	6.91×10^{-2}	1.46×10^{-3}	6.91×10^{-4}
Ore crushing, screening	2	515.5	8.00×10^{-2}	6.00×10^{-2}	575.29	431.47	5.75	4.31
Ore crushing, hammer mill	2	257.8	0.60		2,157.33	0.00	21.57	0.00
Ore crushing, handling transfer	4	257.8	4.33×10^{-3}	2.05×10^{-3}	31.16	14.74	0.31	0.15
Product drying, dryer	2	77.1	9.80	5.90	10,540.14	6,345.59	105.40	63.46
Product drying, vibrating screen	2	77.1	8.00×10^{-2}	6.00×10^{-2}	86.04	64.53	0.86	0.65
Product drying, handling transfer	4	34.9	4.33×10^{-3}	2.05×10^{-3}	4.21	1.99	4.21×10^{-2}	1.99×10^{-2}
Product drying, handling transfer	4	34.9	4.33×10^{-3}	2.05×10^{-3}	4.21	1.99	4.21×10^{-2}	1.99×10^{-2}
Product drying, dryer	2	17.4	9.80	5.90	2,382.13	1,434.14	23.82	14.34
Product drying, mixer	2	17.4	4.33×10^{-3}	2.05×10^{-3}	1.05	4.98×10^{-1}	1.05×10^{-2}	4.98×10^{-3}
Product drying, crusher	2	34.9	1.40	8.00×10^{-2}	680.61	38.9	6.81	0.39
Product compaction, handling transfer	1	117.3	4.33×10^{-3}	2.05×10^{-3}	3.55	1.68	3.55×10^{-2}	1.68×10^{-2}
Product compaction, handling transfer	1	109.3	4.33×10^{-3}	2.05×10^{-3}	3.30	1.56	3.30×10^{-2}	1.56×10^{-2}
Product compaction, compacting machine	1	109.3	4.33×10^{-3}	2.05×10^{-3}	3.30	1.56	3.30×10^{-2}	1.56×10^{-2}
Product compaction, crusher	1	109.3	0.20	2.00×10^{-2}	152.47	15.25	1.52	0.15
Product compaction, handling transfer	2	109.3	6.00×10^{-2}	3.00×10^{-2}	91.48	45.74	9.15×10^{-1}	4.57×10^{-1}
Product compaction, vibrating feeder & 2-deck vibrating screen	1	190	8.00×10^{-2}	6.00×10^{-2}	106.02	79.51	1.06	7.95×10^{-1}
Product compaction, mashing machine 130 t/h	1	110	4.33×10^{-3}	2.05×10^{-3}	3.33	1.57	3.33×10^{-2}	1.57×10^{-2}
Product compaction, vibrating screen 130 t/h	1	110	8.00×10^{-2}	6.00×10^{-2}	61.38	46.03	6.14×10^{-1}	4.60×10^{-1}
Product compaction, crusher	1	50	0.60		209.25	0.00	2.09	0.00
Product compaction, handling transfer	1	80	4.33×10^{-3}	2.05×10^{-3}	2.42	1.14	2.42×10^{-2}	1.14×10^{-2}
Product storage, standard, handling transfer	4	117.3	4.33×10^{-3}	2.05×10^{-3}	14.18	6.71	1.42×10^{-1}	6.71×10^{-2}
Product storage, standard, handling transfer	4	116.6	4.33×10^{-3}	2.05×10^{-3}	14.10	6.67	1.41×10^{-1}	6.67×10^{-2}
Product storage, compacted, handling transfer	4	29.3	4.33×10^{-3}	2.05×10^{-3}	3.54	1.68	3.54×10^{-2}	1.68×10^{-2}
Product storage, compacted, handling transfer	4	29.1	4.33×10^{-3}	2.05×10^{-3}	3.52	1.66	3.52×10^{-2}	1.66×10^{-2}
Truck loading, handling transfer	4	72.9	4.45×10^{-2}	2.11×10^{-2}	90.47	42.79	9.05×10^{-1}	4.28×10^{-1}
Rail loading, handling transfer	4	72.9	4.45×10^{-2}	2.11×10^{-2}	90.47	42.79	0.90	0.43
Total					17,315.42	8,630.42	173.15	86.30

Remarks:

[a] Appendix D in ASEAN Potash Mining PLC, 2014. Environmental Impact Assessment, Bamnet Narong Potash Project. Bangkok.

[b] Table 13.2-4 in U.S. Environmental Protection Agency, 1995. AP-42, Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. Washington D.C.

[c] Assume 99% dust removal by bag filter

(2.2.4) Water

Water outputs from the mineral processing plant include the water released from the process, evaporation, the discharge of rainfall runoff, and wastewater.

(2.2.4.1) Water released from the process

The amount of water emitted from the process with products and tailings is estimated from the flow compositions shown in Table B-12. Next to that, water is released as steam from the cogeneration unit. It is assumed that the steam output is equal to the input water for steam generation (1,210,837 tonnes per year).

Table B-12: Estimated water quantity released from the mineral processing plant

Flow description	Flow rate and composition from mass balance[a]						Total water	
	Feed (t/h)	Total solid (t/h)	Moisture in solid (%)	Total liquid (t/h)	H_2O in liquid (g/L)	Liquid density (g/L)	t/h	t/year[b]
KCl product	146.7	146.7	0.2	-	-	-	0.29	2,046
Vapor from dryer				7.4			7.4	51,614
NaCl tailing								
- Flow 1	397.4	348.8	0	48.6	826.7	1,260.9	31.8	222,249
- Flow 2	137.4	117.8	0	19.6	798.3	1,266.9	12.4	86,142
- Flow 3	10.8	9.4	0	1.4	801.6	1,305.6	0.9	5,995
$MgCl_2$ tailing	507.9	1.9	36.4	506.0	859.6	1,313.7	331.8	2,314,157
Total								2,682,203

Remarks:
[a] Appendix D in ASEAN Potash Mining PLC, 2014. Environmental Impact Assessment, Bamnet Narong Potash Project. Bangkok.
[b] Use 6,975 working hours per year, corresponding to the production rate.

(2.2.4.2) Evaporated water

Water evaporated from the mineral processing plant is calculated from the water storage area in the plant compound. The water pool in the plant compound is 7.5 Rai or 12,000 square meters. Applying the evaporation rate of 1,309.7 millimeters per year, derived from the annual average pan evaporation rate of 1,871 millimeters per year and an assumed lake evaporation rate of 70% of pan evaporation rate[16], the evaporation at the mill pond is estimated at 15,716.4 cubic meters (tonnes) per year.

[16] p. 8-6, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok; Sheet 10, Golder Associates, 2011. Report on Guidance Document on Water and Mass Balance Models for the Mining Industry. Whitehorse, Yukon.

(2.2.4.3) Discharged rainfall runoff

The water from rainfall runoff is assumed to be equal to the rainfall runoff input (379,737 tonnes per year) since it is not specially handled and discharged to the sewage system.

(2.2.4.4) Wastewater for personal and miscellaneous uses

The wastewater from personal and miscellaneous uses is assumed to be equal to the input water for the same purposes (44,256 tonnes per year) since it is collected and treated in the compound and discharged to the sewage system.

(3) Waste storage facility

(3.1) Inputs

The inputs of the waste storage facility are mainly tailing and water. The calculation of both inputs is explained below.

(3.1.1) Tailings

Tailings entering the waste storage facility consist of solid NaCl tailing (salt) and liquid $MgCl_2$ tailing (brine). Their amounts are equal to those of the tailing outputs from the mineral processing plant, i.e. 3,805,487 tonnes of NaCl and 3,542,534 tonnes $MgCl_2$ per year.

(3.1.2) Water

Water inputs come into the waste storage facility with the tailings and from rainfall runoff.

(3.1.2.1) Water in tailing

The amount of water discharged with tailings from the mineral processing plant to the waste storage facility was estimated in the output of the mineral processing plant. The amount of water in NaCl tailing is 314,386 tonnes per year and that in $MgCl_2$ tailing is 2,314,157 tonnes per year.

(3.1.2.2) Water from rainfall runoff

The amount of water from rainfall runoff is calculated from the facility area, rainfall rate, and runoff factor as shown in Table B-13.

Table B-13: Estimation of rainfall runoff in the waste facility area

Facility	Area (m^2)[a]	Rainfall in the facility (m^3/year)[b]	Share of area type[c]			Runoff (m^3/year)			
			Natural ground	Prepared ground	Water retaining area	Natural ground	Prepared ground	Water retaining area	Sum
Waste dump	976,000	882,402	100%	-	-	617,681	0	0	617,681
Tailing dam	928,000	839,005	-	-	100%	0	0	839,005	839,005
Extension pond	1,176,000	1,063,221	100%	-	-	744,255	0	0	744,255
Remaining of the waste facility	1,363,200	1,232,469	-	100%	-	0.0	985,975	0	985,975
Total									3,186,916
- Retained runoff									1,456,686
- Discharged runoff									1,730,230

Remarks:
[a] p. 7-7 and p. 7-9, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.
[b] Calculated from the average rainfall of 904.1 millimeters per year, derived from weather statistics
[c] The following runoff coefficients are applied: 0.7 for natural ground (including waste pile), 0.8 for prepared ground, and 1 for water retaining area. The coefficients are based on the information by Golder Associates, 2011. Report on Guidance Document on Water and Mass Balance Models for the Mining Industry. Whitehorse, Yukon. The share of area type in processing plant is assumed based on the information about project's area in the mining plan.

(3.2) Outputs

The outputs of the waste storage facility consist of the waste materials sent to the backfill site, emissions, and water.

(3.2.1) Waste materials sent to the backfill site

The waste materials sent to the backfill site consist of NaCl tailing and $MgCl_2$ brine from the waste storage facility. Their average quantities during the full production years (production year 6-17) are 3.05 million tonnes per year and 1.93 million cubic meters or 2.53 million tonnes per year, respectively[17].

(3.2.2) Emissions

The main emissions of the waste storage facility are particulate matter from erosion and material handling. Table B-14 shows the estimated amount of particulate matter from the waste dump.

[17] p. 4-108, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.

Table B-14: Estimated emissions from the waste dump

Activity	Operating parameter[a]			Emission factor (kg/Mg)[b]		Emission (t/year)	
	Description	Value	Unit	TSP	PM10	TSP	PM10
Loading	Point	3	point	0.00013	0.00006	0.0906	0.0429
	Feed	234,240	t/year				
Wind erosion	Area	976,000	m^2	0.36121[c]	0.18061[d]	0.0353	0.0176
Total						0.1259	0.0605

Remarks:
[a] ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.
[b] Table 13.2-4 in U.S. Environmental Protection Agency, 1995. AP-42, Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. Washington D.C. and Appendix 1.1.17 in The Department of Sustainability, Environment, Water, Population and Communities, 2012b. National Pollutant Inventory Emission Estimation Technique Manual for Mining Version 3.1. Canberra.
[c] Calculated from 1.9 x (% silt content / 1.5) x 365 x ((365 - no. of day per year when rainfall is >0.25 mm) / 235) x (percentage of time that wind speed is >5.4 m/s at the mean height of the stockpile / 15); Assume silt content = 10%, no. of day per year when rainfall is >0.25 mm = 89.6 days (referring to the Thai Meteorological Department's statistics in 2013 that rainfall days in Chaiyapoom was 112 days and assuming 80% is >0.25 mm), and percentage of time that wind speed is >5.4 m/s (19.44 km/h) at the mean height of the stockpile = 10%.
[d] Calculated from 50% of TSP

(3.2.3) Water

The water outputs of the waste storage facility include water in the backfilled materials, evaporated water, and the discharge of rainfall runoff.

(3.2.3.1) Water in the backfilled materials

The amount of water in the backfilled materials is estimated from the backfilling rate and tailing composition. The flows of NaCl and $MgCl_2$ are 3.05 and 2.53 million tonnes per year [18]. Assuming the compositions of the backfilled materials are like those of the tailings from the mineral processing plant, the amounts of water in both flows are 8.3% (average of all NaCl tailing outflows from the mineral processing plant) and 65.2% water by weight. Therefore, the estimated amount of water sent to the backfill site is 1.90 million tonnes per year, of which 0.25 and 1.65 million tonnes are in NaCl and $MgCl_2$, respectively.

(3.2.3.2) Evaporated water

The amount of water evaporated from the waste storage facility is calculated from the evaporation at the NaCl waste dump and $MgCl_2$ tailing dam. Based on the information in the mining plan, the waste dump and the tailing dam cover the area of 976,000 and 928,000 square meters, respectively. The evaporation rate is estimated at 1,309.7 millimeters per

[18] p. 4-108, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.

year. This value is derived from the annual average pan evaporation rate of 1,871 millimeters per year[19] and a lake evaporation factor of 0.7[20]. The calculated amount of water evaporated from the facility is 2.49 million tonnes per year (1.28 million from the dump and 1.22 million from the dam).

(3.2.3.3) Discharged rainfall runoff

The water from rainfall runoff is assumed to be equal to the rainfall runoff input at the extension pond and the remaining area of the waste storage facility since the runoff is not specially handled and discharged to the sewage system. The amount of discharged runoff estimated in the input section was 1.73 million tonnes per year.

(4) Summary of inputs and outputs

(4.1) Mine

Inflow	Quantity	Unit	Outflow	Quantity	Unit
Ores			Ores and wastes		
- Carnallite	7.19×10^6	t	- Carnallite	7.19×10^6	t
(Water)	(1.45×10^6)	(t)	(Water)	(1.45×10^6)	(t)
- Halite	7.73×10^4	t	- Halite	7.73×10^4	t
Energy			Emissions		
- Electricity	135.9	GWh	- PM10, total	1,887	t
- Diesel	7,565	t	(Engine combustion)	(9)	(t)
Water for personal uses	23,670	t	(Production)	(95)	(t)
Backfilled materials			(Vehicle transport)	(1,783)	(t)
- NaCl tailing	3.05×10^6	t	- CO	189	t
(Water)	(251,834)	(t)	- SO_2	1	t
- $MgCl_2$ tailing	2.53×10^6	t	- NO_x	201	t
(Water)	(1.65×10^6)	(t)	Returning brine		t
Explosive			- $MgCl_2$	1.96×10^6	t
- ANFO	1,312	t	(Water)	(1.29×10^6)	(t)
- High explosive	69	t	Water		
			- Wastewater	23,670	t
			- Evaporated water	6,549	t

[19] p. 8-6, ASEAN Potash Mining PLC, 2014. Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC. Bangkok.
[20] Sheet 10, Golder Associates, 2011. Report on Guidance Document on Water and Mass Balance Models for the Mining Industry. Whitehorse, Yukon.

(4.2) Mineral processing plant

Inflow	Quantity	Unit	Outflow	Quantity	Unit
Ore			Product		
- Carnallite	7.19 x 10^6	t	- KCl	1.02x 10^6	t
(Water)	(1.45 x 10^6)	(t)	(Water)	(2,046)	(t)
Energy			Tailings		t
- Bituminous coal	313,260	t	- NaCl	3.81 x 10^6	t
- Fuel oil	6,319	t	(Water)	(3.14 x 10^5)	(t)
- Electricity	62.7	GWh	- $MgCl_2$	3.54 x 10^6	t
Water		t	(Water)	(2.31 x 10^6)	(t)
- Rainfall runoff	3.80 x 10^5	t	Ashes	31,326	t
- Process water: new	1.23 x 10^6	t	Emissions		
- Process water: reused	2.52 x 10^6	t	- PM10, total	387	t
- Steam generation	1.21 x 10^6	t	(Cogeneration unit)	(301)	(t)
- Personal and miscelleneous uses	44,256	t	(Burners)	(3.29 x 10^{-2})	(t)
			(Material handling)	(86)	(t)
			- CO	82	t
			- SO_2	3,038	t
			- NO_x	799	t
			- Benzene	2.69 x 10^{-2}	t
			- Arsenic	1.08 x 10^{-3}	t
			- Cadmium	3.25 x 10^{-4}	t
			- Lead	1.23 x 10^{-3}	t
			- Mercury	9.29 x 10^{-5}	t
			Water		t
			- Evaporated water	15,716	t
			- Rainfall runoff	3.80 x 10^5	t
			- Wastewater	44,256	t
			- Process water: reused	2.52 x 10^6	t
			- Steam	1.21 x 10^6	t
			- Vapor from dryer	5.68 x 10^5	t

(4.3) Waste storage facility

Inflow	Quantity	Unit	Outflow	Quantity	Unit
Tailings		t	Backfilled materials		
- NaCl	3.81 x 10^6	t	- NaCl tailing	3.05 x 10^6	t
(Water)	(3.14 x 10^5)	(t)	(Water)	(251,834)	(t)
- $MgCl_2$	3.54 x 10^6	t	- $MgCl_2$ tailing	2.53 x 10^6	t
(Water)	(2.31 x 10^6)	(t)	(Water)	(1.65 x 10^6)	(t)
Water			Emissions		
- Rainfall runoff	3.19 x 10^6	t	- PM10	(6.05 x 10^{-2})	(t)
			Water		t
			- Evaporated water	2.49 x 10^6	t
			- Rainfall runoff	1.73 x 10^6	t

Appendix C: Flows of potassium in the Thai economy

The data about the flows of potassium in the Thai economy is gathered from statistical data and data on potassium contents of the related substances found in literature. The data is compiled using the mass balance principle and presented as potassium stocks and flows of potash-related components within the boundary of Thailand during a one-year period. The statistical data on the commodity's production, trade, and consumption in 2012 are used as a basis for the calculation. The data of other years is used if those in 2012 are not available. The input and output structures as well as their components and calculation method are shown in Table C-1. The results are summarized in Table C-2.

Table C-1: Structure and calculation formula of the potassium stocks and flows

Flow	Component	Calculation*
Inputs		
1. Ore extraction	Potash ores	Annual production[a,b,c,d] x Average grade[b,c,d]
2. Import		
2.1 Fertilizers	Single fertilizer	Import amount[e] x K_2O content
	Mixed fertilizers	Import amount[e] x K_2O content
2.2 Chemicals	Potassium nitrate	Import amount[f] x K_2O content
	Potassium hydroxide	Import amount[f] x K_2O content
	Potassium carbonate	Import amount[f] x K_2O content
	Potassium phosphate	Import amount[f] x K_2O content
	Potassium permanganate	Import amount[f] x K_2O content
2.3 Goods		
2.3.1 Agricultural products		
- Key crops	food crops, cassava, raw materials of animal feeds	Import amount[g] x K_2O content
- Tree products and vegetables	- fruits: orange, apple, and grape	Import amount[g] x K_2O content
	- vegetables: potato, garlic and shallot	Import amount[g] x K_2O content
- Oil plants	soy bean	Import amount[g] x K_2O content
2.3.2 Processed foods	Fish (tuna), meat (cattle), dairy products, seasoning products, tea and coffee, and cocoa products	Import amount[g] x K_2O content
2.3.3 Industrial products	Soap and detergent	Import amount[f] x K_2O content
3. Reuse		
3.1 Household wastes	Municipal wastes	Waste amount[h] x K_2O content
	Human excretion	Assume 50% reuse (See Wastes)
3.2 Industrial wastes	Wastewater from food processing	Assume 10% sludge in wastewater and 100% sludge reuse (See Wastes)
	Food processing wastes	Assume 50% reuse (See Wastes)
3.3 Agricultural wastes		
- Biomass	Plant biomass	
- Animal excretion	Animal excretion	Assume 50% reuse (See Wastes)
Outputs		
4. Export		
4.1 Fertilizers	Single fertilizer	Export amount[e] x K_2O content
	Mixed fertilizers	Export amount[e] x K_2O content
4.2 Chemicals	Potassium nitrate	Export amount[f] x K_2O content

Flow	Component	Calculation*
	Potassium hydroxide	
	Potassium carbonate	
	Potassium phosphate	
	Potassium permanganate	
4.3 Goods		
4.3.1 Agricultural products		
- Key crops		Export amount[g] x K_2O content
- Tree products and vegetables		Export amount[g] x K_2O content
- Oil plants		Export amount[g] x K_2O content
- Other animal products		Export amount[g] x K_2O content
4.3.2 Processed foods		
4.3.3 Industrial products	Soap and detergent	Export amount[f] x K_2O content
	Tyre	Export amount[g] x K_2O content
5. Wastes		
5.1 Mining wastes	Overburden and tailings	Amount generated[b,c,d] x K_2O content[b,c,d]
5.2 Household wastes	Municipal wastes	Waste amount[h] x K_2O content
	Urban wastewater	Wastewater generation per person per day[i] x Population[j] x Day per year x K_2O content
	Human excretion	Population[j] x Average K_2O in excretion rate[k]
5.3 Industrial wastes		
5.3.1 Industrial wastewater		
- Food processing	Canned pineapple and juice, dairy products, meat, flour, oil, sugar	Product amount[l] x Wastewater ratio[m,n] x K_2O content
- Textile	textile industry	Product amount[l] x Wastewater ratio[o] x K_2O content
5.3.2 Food processing waste	Fruit and vegetable (canned pineapple, juice, and dried vegetables) Meat (Pork and chicken) Fish and seafood Oil production	Product amount[l] x Waste ratio x K_2O content
5.4 Agricultural wastes		
5.4.1 Biomass	Rice husk, bagasse, corn cob, palm's empty fruit bunch, palm fiber, palm shell, slab rubber wood, rubber wood chips and sawdust, tree parts (loss and pruned)	Product amount[g,p] x Waste ratio x K_2O content
5.4.2 Animal excretion	Animal excretion	Livestock population[l] x Average K_2O in excretion per animal[q]
6. Losses	Runoff leaching and soil erosion	Assume 30% of K_2O in fertilizer applied in the same year[r]

Remarks:
* K_2O contents are obtained from chemical analyses in different studies. The values reported in the literature is assumed to represent the potassium contents of Thailand's products. For items that contain different types of subitems, the K_2O contents are derived from average values of the major subitems.

[a] Department of Primary Industries and Mines, "Thailand's Mineral Statistics Database," 2015. [Online]. Available: http://www7.dpim.go.th/stat/. [Accessed: 31-Jul-2015].

[b] ASEAN Potash Mining PLC, "Underground Mining Plan, Mining Lease Application No. 1/2547, Mining Lease Mark No. 31708, ASEAN Potash Mining PLC.," Bangkok, 2014.

[c] Asia Pacific Potash Corporation, "Environmental Impact Assessment, APPC, Udon Thani Potash Project," Bangkok, 2014.

[d] Thai Kali, "Environmental Impact Assessment, Thai Kali Potash Project, Nakon Ratchasima," Bangkok, 2014.

[e] Department of Agriculture, "Statistics Related to Fertilizer Act," 2012. [Online]. Available: http://www.doa.go.th/ard/FileUpload/Fertilizer/fertilizer_static/33grade55.pdf. [Accessed: 31-Jul-2015].

[f] Ministry of Commerce, "Thailand's Trade Statistics," 2015. [Online]. Available: http://www2.ops3.moc.go.th. [Accessed: 15-Jul-2015].

[g] Office of Agricultural Economics, Basic Data: Agricultural Economy 2013. Bangkok: Office of Agricultural Economics, 2013.

[h] P. Silapasuwan, "Municipal Solid Waste : The Significant Problem of Thailand," Bangkok, 2014.

[i] Department of Water Resources, "Research Strategy on Water Management," 2013. [Online]. Available: http://www.dwr.go.th/contents/files/article/article_th-15102013-104217-468260.docx. [Accessed: 31-Jul-2015].

[j] Department of Public Administration, "Official Statistics Registration Systems," 2012. [Online]. Available: http://stat.dopa.go.th/stat/statnew/upstat_age.php. [Accessed: 31-Jul-2015].

[k] D. Del Porto and C. Steinfeld, The Composting Toilet System Book. Concord, Mass.: Center for Ecological Pollution Prevention, 2000 and J.-O. Drangert, J. Bew, and U. Winblad, Ecological sanitation: Proceedings from Sida Sanitation Workshop, Balingsholm, Sweden. Balingsholm, Sweden, 1997.
[l] Office of Industrial Economics, "Industrial Statistics Database," 2015. [Online]. Available: http://www.oie.go.th/academic/statistics. [Accessed: 31-Jul-2015].
[m] J. B. Hunt, W. McDevitt, G. Hunt, and J. Morris, Water Efficiency Manual for Commercial, Industrial and Institucional Facilities. North Calorina: Land-of-Sky Regional Council, 1998.
[n] Department of Industrial Works, Cleaner Production Best Practice for Food Processing Industry. Bangkok: Department of Industrial Works, 2002.
[o] C. Visvanathan, S. Kumar, A. Priambodo, and S. Vigneswaran, "Energy and environmental indicators in the Thai textile industry," in Proceedings of the Third Asia-Pacific Conference on Sustainable Energy and Environmental Technologies, 2001, pp. 524–528.
[p] Rangsit University, "Executive Summary Report: Developing of Biomass Database Potential in Thailand," Bangkok, 2012.
[q] U.S. Department of Agriculture, "Agricultural Waste Characteristics," in Agricultural Waste Management Field Handbook, Natural Resources Conservation Service, United States Department of Agriculture, 2008.
[r] Based on Anon., "Lecture Document: Manures, Fertilizers and Agrochemicals," 2011 and Q. Zhu, S. Tu, Z. Chen, and Z. Wang, "Potassium balance on sloping lands as affected by farming systems," Better Crops with Plant Food, no. 2, pp. 6–7, 2007.

Table C-2: Summary of potassium flows in the Thai economy in 2012

Flows	Potassium amount (tonnes K_2O)
Inputs	
1. Ore extraction	0
2. Import	684,539
2.1 Fertilizers	524,551
2.2 Chemicals	18,721
2.3 Goods	141,266
2.3.1 Agricultural products	130,333
- Key crops	110,300
- Tree products and vegetables	3,517
- Oil plants	16,516
2.3.2 Processed foods	10,931
2.3.3 Industrial products	2
3. Reuse	618,201
3.1 Household wastes	76,374
3.2 Industrial wastes	21,053
3.3 Agricultural wastes	520,773
- Biomass	214,465
- Animal excretion	306,308
Outputs	
4. Export	117,609
4.1 Fertilizers	16,660
4.2 Chemicals	7,461

Flows	Potassium amount (tonnes K_2O)
4.3 Goods	93,488
4.3.1 Agricultural products	58,812
- Key crops	35,252
- Tree products and vegetables	21,572
- Oil plants	702
- Other animal products	1,285
4.3.2 Processed foods	34,194
4.3.3 Industrial products	482
5. Wastes	1,382,319
5.1 Mining wastes	0
5.2 Household wastes	594,080
5.3 Industrial wastes	58,798
5.3.1 Industrial wastewater	20,507
- Food processing	19,074
- Textile	1,433
5.3.2 Food processing waste	38,292
5.4 Agricultural wastes	729,441
5.4.1 Biomass	116,824
5.4.2 Animal excretion	612,617
6. Losses	152,367

Appendix D: Calculation of potash price volatility

The 10-year average annualized volatility of potash price is calculated from the monthly price statistics during years 2006 to 2015. The price data is obtained from the World Bank data in IndexMundi website[1]. The details are shown in Table D-1.

Table D-1: Calculation of 10-year average annualized volatility of potash price

Year		Month												SD	Annual volatility
		January	February	March	April	May	June	July	August	September	October	November	December		
2006	Price	170.00	170.00	173.33	180.00	180.00	172.00	173.75	175.00	175.00	175.00	175.00	175.00		
	Change	0.00%	0.00%	1.96%	3.85%	0.00%	-4.44%	1.02%	0.72%	0.00%	0.00%	0.00%	0.00%	1.89%	6.53%
2007	Price	175.00	175.00	176.88	177.50	180.00	196.88	203.13	212.50	212.50	220.00	232.50	240.00		
	Change	0.00%	0.00%	1.07%	0.35%	1.41%	9.38%	3.17%	4.62%	0.00%	3.53%	5.68%	3.23%	2.86%	9.91%
2008	Price	273.00	385.00	445.00	477.63	518.30	537.50	560.00	640.00	705.00	762.50	765.00	772.50		
	Change	13.75%	41.03%	15.58%	7.33%	8.52%	3.70%	4.19%	14.29%	10.16%	8.16%	0.33%	0.98%	10.80%	37.40%
2009	Price	853.13	872.50	870.00	745.00	717.50	717.50	655.50	432.50	432.50	435.00	435.00	399.00		
	Change	10.44%	2.27%	-0.29%	-14.37%	-3.69%	0.00%	-8.64%	-34.02%	0.00%	0.58%	0.00%	-8.28%	11.18%	38.71%
2010	Price	354.38	335.00	312.50	314.38	315.00	319.00	320.00	345.00	337.50	335.00	340.63	354.00		
	Change	-11.18%	-5.47%	-6.72%	0.60%	0.20%	1.27%	0.31%	7.81%	-2.17%	-0.74%	1.68%	3.93%	5.02%	0.00%
2011	Price	367.50	375.00	380.00	413.75	418.33	436.00	461.25	482.50	470.00	470.00	474.00	475.00		
	Change	3.81%	2.04%	1.33%	8.88%	1.11%	4.22%	5.79%	4.61%	-2.59%	0.00%	0.85%	0.21%	3.08%	0.42%
2012	Price	476.25	483.00	480.00	468.75	457.50	457.50	462.50	467.50	464.25	440.20	425.00	425.00		
	Change	0.26%	1.42%	-0.62%	-2.34%	-2.40%	0.00%	1.09%	1.08%	-0.70%	-5.18%	-3.45%	0.00%	2.03%	0.32%
2013	Price	395.00	387.50	390.00	391.50	393.00	392.50	392.50	393.25	389.50	358.70	334.00	332.00		
	Change	-7.06%	-1.90%	0.65%	0.38%	0.38%	-0.13%	0.00%	0.19%	-0.95%	-7.91%	-6.89%	-0.60%	3.28%	0.28%
2014	Price	323.00	309.50	309.50	287.00	287.00	287.00	287.00	287.00	287.00	287.00	305.50	305.63		
	Change	-2.71%	-4.18%	0.00%	-7.27%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	6.45%	0.04%	3.22%	0.14%
2015	Price	305.20	305.00	305.00	307.00	307.00	307.00	305.00	303.00	300.00	300.00	296.00	295.00		
	Change	-0.14%	-0.07%	0.00%	0.66%	0.00%	0.00%	-0.65%	-0.66%	-0.99%	0.00%	-1.33%	-0.34%	0.54%	0.05%
Average														4.39%	15.20%
SD														6.65%	
10-year average annualized volatility (2006-2015): SD of yearly SD (6.65%) x square root of trading months in a year (3.4641)														23.02%	

[1] IndexMundi, 2016. Potassium Chloride Monthly Price [WWW Document]. Commod. Prices. URL http://www.indexmundi.com/commodities/?commodity=potassium-chloride&months=180 (accessed 2.6.17).