DECISION SUPPORT FOR ENVIRONMENTAL IMPACT ASSESSMENT FOR MALAYSIAN BAUXITE MINING INDUSTRY USING ANALYTIC NETWORK PROCESS

BY

NAGENDRAN PERIAIAH

A thesis submitted in fulfilment of the requirement for the degree of Doctor of Philosophy in Business Administration

Kulliyyah of Economics and Management Sciences
International Islamic University Malaysia

MAY 2020

ABSTRACT

The mining industry plays a very important and necessary role in the development of our country. However, uncontrolled mining activities caused detrimental environmental impacts. In recent case of bauxite mining in Kuantan, Pahang, fifteen kilometres of Pahang's coastline were stained red with arsenic and heavy metal pollution washed from open-pit bauxite mines into the sea. There are potential catastrophic damages to the ecosystem off the coast of Pahang. This triggered Government of Malaysia to issue temporary ban on bauxite mining while the state government is performing an expensive clean-up works. Environmental and socio-economic protection from mining operations entirely depends on Environmental Impact Assessment (EIA) and its enforcement. However, EIA is an intrinsically complex multi-dimensional procedure. There are many dependences among environmental factors. EIA also has subjectivity issues in the decision making process. Many decisions still depend on expert opinion and justification. Due to its complexity, the implementation of EIA is often not entirely satisfactory. A systematic multiple criteria decision making (MCDM) tools is required to assist EIA panel to study interaction among decision variables and convert subjective elements objectively. This research focuses on developing a decision support framework for EIA, specific for bauxite mining operations. Through various literature surveys, this study introduces Analytic network process (ANP), the latest quantitative methodology in MCDM, into the EIA decision support framework. ANP is much more flexible in handling the MCDM problems in which the criteria are interdependent, it has attracted many scholars' attention and has been applied into many different areas. In the first stage of the research, an exploratory study through literature review and semi structured interviews with relevant subject experts (i.e., two experts – EIA Consultants and one Regulator – DOE Officer) was conducted to understand the criteria, element definition, and the influence network. Ten criteria were selected and grouped into clusters according to their common property/attribute. A decision support framework by consists air, water, soil, noise, waste, terrestrial, aquatic, economics, society, and culture were selected and grouped into three main clusters according to their common property/attribute. The second stage involved development and use of questionnaires to determine the pairwise comparisons. Survey questionnaires were pre-tested to determine content validity and the pilot test was conducted using the different group of subject experts (i.e., two experts – EIA Consultants and one Regulator – DOE Officer). The questionnaires findings were obtained from 22 respondents belonging to the six different categories (EIA consultants specialised in the general environment, EIA consultants specialised in socio-economic, EIA consultants specialised in ecology, DOE enforcement officers, academician, and public residing close to the bauxite mining sites. As ANP methodology, 22 sample size was sufficient to gather the required information accurately. The ANP was used to determine the overall weightage and rank of each criterion. During the third stage, the collected data were synthesised using the ANP-SuperDecision software. The ANP analysis ranked air pollution as the first priority at 16.6% followed by water pollution at 15.5%, soil pollution at 14.0%, economic impact at 12.0%, waste generation at 11.6%, terrestrial impact at 8.8%, cultural impact at 7.7%, aquatic impact at 7.2%, society at 3.9 %, and finally noise at 2.8%. Significant environmental impacts produced by bauxite mining operation is identified and synthesised results from ANP-SuperDecision software was used to develop the decision support framework. Further categorical analysis was conducted among six different group of respondents. Some subjectivity issues were detected during the ranking process for individual categories. Respondents from environmental background rated environmental component higher, while those with socio-economic background prioritised economic impact and those with an ecological background focused on the ecological cluster. Nevertheless, selecting representative samples from all categories provided a good model for decision making pertaining to bauxite mining. Finally, the model was tested by three relevant subject experts from first stage of research. The subject experts fill up the environmental pollution/ impact assessment form based on 2015 Bauxite mining condition and data. Results showed that the overall bauxite mining project at Kuantan scored 21.48 point out of 50, hence, representing an overall project score of 41.92%. Based on this result, the decision on bauxite mining in Kuantan should be rejected by DOE. Study concluded that an ANP network model gives a much more realistic view of complex bauxite mining issues. The study contributes to the application of MCDA tools in EIA specific for bauxite mining operations. Further recommendations to reduce the identified significant environmental impact of the bauxite mining activities have been provided.

خلاصة البحث

تلعب صناعة التعدين دورًا مهمًا وضروريًا للغاية في تنمية بلدنا. ومع ذلك، تسببت أنشطة التعدين غير المنضبط في آثار بيئية ضارة في الحالة الأخيرة لتعدين البوكسيت في كوانتان، باهانج، كانت خمسة عشر كيلومترًا من ساحل باهانج ملطخة باللون الأحمر مع تلوث الزرنيخ والمعادن الثقيلة من مناجم البوكسيت المفتوحة في البحر. هناك أضرار كارثية محتملة على النظام البيئي قبالة سواحل باهانج. لقد أدى ذلك بحكومة ماليزيا إلى إصدار حظر مؤقت على تعدين البوكسيت بينما تقوم حكومة الولاية بأعمال تنظيف باهظة الثمن. وتعتمد الحماية البيئية والاجتماعية الاقتصادية من عمليات التعدين بشكل كامل على تقييم الأثر البيئي (EIA) وإنفاذه. ومع ذلك، فإن تقييم التأثير البيئي هو إجراء متعدد الأبعاد معقد جوهريًا. هناك العديد من التبعيات بين العوامل البيئية. وكان تقييم الأثر البيئي (EIA) أيضا لديها قضايا ذاتية في عملية صنع القرار. هناك العديد من القرارات التي لا تزال تعتمد على رأي الخبراء والتبرير. نظرًا لتعقيدها، غالبًا ما يكون تنفيذ تقييم التأثير البيئي غير مرضٍ تمامًا. كانت أدوات منهجية لاتخاذ قرارات المعايير المتعددة مطلوبة (MCDM) لمساعدة لوحة تقييم التأثير البيئي على دراسة التفاعل بين متغيرات القرار وتحويل العناصر الذاتية بموضوعية. يركز هذا البحث على تطوير إطار دعم القرار لتقييم التأثير البيئي، خاص بعمليات تعدين البوكسيت. من خلال مسوحات الدراسات المختلفة، تقدم هذه الدراسة عملية شبكة تحليلية (ANP)، أحدث منهجية كمية في MCDM، في إطار دعم اتخاذ القرار لتقييم الأثر البيئي. وكان ANP أكثر مرونة في التعامل مع مشاكل MCDM التي تكون فيها المعايير مترابطة، وقد جذبت انتباه العديد من العلماء وتم تطبيقها في العديد من المجالات المختلفة. في المرحلة الأولى من البحث، تم إجراء دراسة استكشافية من خلال مراجعة الدراسات والمقابلات شبه المنظمة مع الخبراء المعنيين بالموضوع (على سبيل المثال، خبيران – ومستشارو تقييم الأثر البيئي ومنظم واحد – موظف وزارة الطاقة) لفهم المعايير وتعريف العنصر والتأثير شبكة الاتصال. لقد تم اختيار عشرة معايير وتجميعها في مجموعات وفقًا لخاصية/خاصية مشتركة. وتم اختيار إطار دعم القرار من خلال

الهواء والماء والتربة والضوضاء والنفايات والأرض والماء والاقتصاد والمجتمع والثقافة، وتم تجميعها في ثلاث مجموعات رئيسية وفقًا لخصائصها/سماتها المشتركة. قد تضمنت المرحلة الثانية تطوير واستخدام الاستبيانات لتحديد المقارنات الزوجية. وتم اختبار الاستبيان مسبقًا لتحديد صلاحية المحتوى، وأجري الاختبار التجريبي باستخدام مجموعة مختلفة من الخبراء المتخصصين (أي خبيرين – مستشاري تقييم التأثير البيئي وواحد منظم – موظف وزارة الطاقة). كما تم الحصول على نتائج الاستبيانات من 22 مستجيبًا ينتمون إلى الفئات الست المختلفة (المستشارون المتخصصون في تقييم التأثير البيئي في البيئة العامة، والمستشارون المتخصصون في تقييم الأثر البيئي في المجال الاجتماعي والاقتصادي، والمستشارون المتخصصون في تقييم الأثر البيئي في علم البيئة، وضباط تنفيذ وزارة الطاقة، والأكاديمي ، والجمهور المقيم بالقرب من مواقع التعدين للبوكسيت. كمنهجية ANP، كان حجم العينة 22 كافيًا لجمع المعلومات المطلوبة بدقة. وتم استخدام ANP لتحديد الوزن الكلي وترتيب كل معيار. خلال المرحلة الثالثة، تم تجميع البيانات التي تم جمعها باستخدام برنامج ANP-SuperDecision حيث صنف تحليل وكالة الأنباء الجزائرية تلوث الهواء على أنه الأولوية الأولى بنسبة 16.6٪، ويليه تلوث المياه بنسبة 15.5٪، وتلوث التربة بنسبة 14.0٪، والأثر الاقتصادي بنسبة 12.0٪، وتوليد النفايات بنسبة 11.6٪، والأثر الأرضي بنسبة 8.8٪، والأثر الثقافي بنسبة 7.7 ٪، والتأثير المائي عند 7.2٪، والمجتمع 3.9٪، وأخيراً الضوضاء عند 2.8٪. كانت التأثيرات البيئية الهامة الناتجة عن عملية تعدين البوكسيت تم تحليلها باستخدام النتائج المستنيرة والمركبة من برمجيات ANP-SuperDecision لتطوير إطار دعم القرار. وتم إجراء مزيد من التحليل القاطع بين ست مجموعات مختلفة من المستجيبين. كما تم الكشف عن بعض القضايا الذاتية خلال عملية الترتيب للفئات الفردية. لقد قام المجيبون من الخلفية البيئية بتقييم المكون البيئي على أنه أعلى، في حين أعطى أولئك الذين أصحاب الخلفية الاجتماعية والاقتصادية الأولوية للتأثير الاقتصادي وأولئك الذين لديهم خلفية بيئية بالتركيز على المجموعة البيئية. ومع ذلك، فإن اختيار عينات تمثيلية من جميع الفئات قدم نموذجًا جيدًا لصنع القرار المتعلق بتعدين البوكسيت. أخيرًا، تم اختبار النموذج من قبل ثلاثة خبراء متخصصين من المرحلة الأولى من البحث. ويقوم الخبراء المتخصصون بملء استمارة تقييم التلوث البيئي/التأثير بناءً على حالة

وبيانات تعدين البوكسيت لعام 2015. لقد أظهرت النتائج أن إجمالي مشروع تعدين البوكسايت في كوانتان قد سجل 21.48 نقطة من أصل 50، وبالتالي يمثل إجمالي نقاط المشروع 41.92٪. وبناءً على هذه النتيجة، يجب رفض قرار وزارة الطاقة بشأن تعدين البوكسيت في كوانتان. وخلصت الدراسة إلى أن نموذج شبكة ANP يعطي نظرة أكثر واقعية لقضايا تعدين البوكسيت المعقدة. كما تساهم الدراسة في تطبيق أدوات MCDA في تقييم التأثير البيئي.

APPROVAL PAGE

The thesis of Student’s Name has been approved by the following:

____
Rafikul Islam
Supervisor

____
Muhammad Faris Abdullah
Co-Supervisor

____
Mansor Ibrahim
Internal Examiner

____
Mohamad Nasir Hi Saludin
External Examiner

____
Latifah Abd Manaf
External Examiner

____
Mohd Adam Suhaimi
Chairman

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Nagendran Periaiah

Signature .... Date ....

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE OF UNPUBLISHED RESEARCH

DECISION SUPPORT FOR ENVIORNMENTAL IMPACT ASSESSMENT FOR MALAYSIAN BAUXITE MINING INDUSTRY USING ANALYTIC NETWORK PROCESS

I declare that the copyright holders of this dissertation are jointly owned by the student and IIUM.

By signing this form, I acknowledged that I have read and understand the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by Nagendran Periaiah

……..……………………..   ………………………..

Signature   Date

DEDICATION

This thesis is dedicated to my parents, Periaiah Vellusamy and Sayasamah Papoo for laying the foundation of what I turned out to be in life.

ACKNOWLEDGEMENTS

I would like to express my gratitude to the Almighty God for giving me an opportunity to begin this knowledge searching journey. It is with His grace; blessings and His perfect planning has allowed me to complete my doctorate dissertation successfully.

I would like to acknowledge contribution from my supervisor, Prof. Dr Rafikul Islam for his dedication in guiding me. Without his help, guidance and insights, the studies would have taken a long time, and it would have been more arduous than the already arduous task. Thanks also to my co-supervisor Dr Muhammad Faris Abdullah for his guidance and help.

I would like to express gratitude to my parents Periaiah Vellusamy and Sayasamah Papoo who has always encouraged and morally supported my pursuit. It is also important to acknowledge and thank them for their sacrifices in ensuring I get a proper education and becoming a valuable member of the society and the country.

I would like to thank my wife Khomahla Waney Sarangabani for her prayers, understanding and endurance and my children Kirrthana, Haaresh and Shasmitha for their patience while completing the thesis.

I also would like express gratefulness to my siblings, colleagues, friends, the respondents and others who I have not mentioned, who have directly or indirectly helped me in completing my doctorate successfully.

Finally, to the Almighty God, no amount of thanks would amount to the grace You have showered upon me. The only way I could pay gratitude to You is by applying the knowledge that I have learnt during the years and to serve the people for the betterment
.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

AHP	Analytic *Hierarchy Process*
AIR	Air
AMD	Acid Mine Drainage
ANP	Analytical Network Process
API	Air Pollutant Index
AQU	Aquatic
BM	Bauxite Mining
BOD	Biological Oxygen Demand
CBA	Cost-Benefit Analysis
CLT	Culture
CMO	Clean Malaysia Organization
COD	Chemical Oxygen Demand
CR	Consistency Ratio
DO	Dissolve oxygen
DOE	Department of Environment
ECL	Ecological
ECM	Economy
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
ENV	Environmental
ERA	Ecological Risk Assessment
ESA	Environmentally Sensitive Areas
EU	European Union
GDP	Gross Domestic Product
GIS	Geographic Information System
H	High
JMG	Malaysian Minerals and Geoscience Department
JMSC	Johore Mining and Stevedoring Co
L	Low
LCA	Life Cycle Assessment
M	Medium
MAUT	Multi-Attribute Utility Theory
MAVT	Multi-Attribute Value Theory
MCDA	Multi-criteria Decision Analysis
MCDM	Multi-Criteria Decision Making
N	None
NEPA	National Environmental Policy Act
NGOs	Non-Governmental Organisations
NH_3-N	Ammoniacal Nitrogen
NMC	National Mineral Council
NMP	National Mineral Policy
NOS	Noise
PDRI	Project Definition Rating Index

PROMETHEE	Preference Ranking Organisation Method for Enrichment Evaluations
RQ	Research Question
SCY	Society
SMAA	Stochastic Multi-Criteria Acceptability Analysis
SOL	Soil
SOP	Standard Operating Procedures
SS	Suspended Solid
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TRL	Terrestrial
TSP	Total Suspended Particulate
VH	Very High
VL	Very Low
WB	World Bank
WQI	Water Quality Index
WST	Waste
WTR	Water

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The bauxite mining industry plays a significant and necessary role in the development of a country. It assures an adequate and continuous supply of raw materials to construction and manufacturing sectors; both of which are the root for a nation's economic development. Over 33 different types of mineral comprising of metallic, non-metallic, and energy minerals are available in Malaysia. The metallic mineral mining subsector commonly produces minerals such as tin, gold, bauxite, iron ore, and ilmenite. Additionally, by-products such as zircon, monazite, rutile, struverite, and silver are also produced from tin and gold mining (Malaysian Mineral.com , 2009). The non-metallic, or commonly known as industrial mineral subsector produces limestone, clay, kaolin, silica, sand and gravel aggregates, feldspar, and mica. In Malaysia, coal is the only mineral produced by the energy mineral subsector (Malaysian Mineral.com , 2009).

Bauxite Mining industries contribute eminently towards the nation's economy. In the year 2017, Malaysia's economy accelerated with a 5.9% growth in the gross domestic product (GDP), at a value of RM1,352.4 billion at current prices. Mining and quarrying alone contributed RM123.2 billion, which made up 9.11% of the country's GDP (MCOM, 2017). The Malaysian Chamber of Mines reported that for the year 2015, non-metallic minerals' production valued at RM4.98 billion, followed by metallic and energy minerals at RM1.06 billion and RM0.16 billion, respectively. Overall, the total production value of major minerals in Malaysia increased by 55%; which was from RM4.00 billion in 2010 to RM6.20 billion in 2015 (MCOM, 2017). The increasing demands for minerals, especially from China and India, has opened the path for companies to explore various types of deposits, from iron ore to gold. In the 1980s, the collapse of the tin market caused a decline in the Malaysian mining industry. However, that incident did not dissuade experts from believing that there were deposits of minerals worth roughly RM336 billion, still untapped and could transform landowners into billionaires. Since 2008, Chinese companies have reportedly invested nearly RM2 billion in the extraction of iron ore from Malaysia for its steel mills. According to the Minerals and Geoscience Department, as of June 2016, a total of 34 iron ore mines, 32 tin mines, and eight gold mines operate in the Peninsular of Malaysia (JMG, 2018). Independent analysts have estimated that the iron ore reserve in the country values at RM17 billion (TMR, 2017).

1.1.1 Environmental Issues Related to Bauxite Mining Operation

Before the 1980s, Malaysia's metallic mining industries were mainly dominated by tin, iron, and gold mines. Numerous researches, including those done by Venkateswarlu et al. (2016), Thorpe et al. (2015), Jamal et al. (2015); and Irshad (2013) revealed mineral mining as one of the major causes of heavy metal contamination in the environment. Residues containing heavy metals from tin mines and metallurgical operation sites are often further dispersed into the environment by wind and/or water. In addition, soil and groundwater pollution by dissolved heavy metals have mainly been associated with Acid Mine Drainage (AMD); a serious environmental hazard often caused by the mining industry. Typically, AMD is characterised by an acidic pH and high levels of dissolved heavy metals, which often include arsenic and mercury. A study by Razo et al. (2004) showed that effluents generated by the gold mining industry contain large quantities of toxic substances, such as cyanides and heavy metals, which have severe implications on the human health and ecology. In the late 1990s, increasing technological changes resulted in reduced demand for tin, hence, resulting in many tin mines being abandoned. These deserted tin mines accumulated as waste, consisting of roaster piles, tailings ponds, waste rock piles, and acid mine drainage.

Lately, the demand for non-metal mining such as limestone, clay, kaolin, silica, sand, and gravel has increased due to the intensifying progress in the construction sector. The main environmental issue associated with the non-metal mining industry is dust emission into the environment, an unavoidable consequence of its milling and crushing operations. Bauxite is the best material for making aluminium. It is also an essential ingredient in refractory, grinding material, chemical material, and calcium aluminate cement. Bauxite is widely used in the production of paper, water purification, petroleum refining, electric power industry, aircraft industry, and machinery and civil tool-making industry. Due to its broad application, bauxite mining activities have been escalating lately. Malaysia is now the world's top producer of bauxite. However, in 2014, Malaysia barely had a bauxite mine. The advancement of Malaysia from being a zero-bauxite producer to the world's top producer comes with consequences in the form of increasing detrimental environmental impacts. Figure 1.1 shows the impact of bauxite mining on surrounding areas in Pahang state. Clean Malaysia Organization (CMO), an independent online news site reported that with the introduction of bauxite mining, the port town of Kuantan has transformed from quiet byways to heavy traffics of ore-hauling trucks (CMO, 2016). Surrounding environments, vehicles, homes, and trees have accumulated a thick layer of red dust due to emissions released from the movements of bauxite loading and unloading trucks. Locals also complained that when bauxite emissions came in contact with their skin, it caused skin irritation. Environmental experts further warned that ingestion of bauxite emissions increase the risk of developing cancer.

Figure 0.1 Impact of Bauxite Mining on the Surrounding Areas in Pahang
(Source: CMO, 2016)

Many fruit orchards and small-scale oil palm planters abandoned their agriculture business and leased their land to mining contractors for short-term cash benefits. Due to uncontrolled licensing and the presence of illegal mining contractors, the areas surrounding Kuantan port became heavily contaminated, turning it into a red coloured zone. During rainy seasons, the surface washout from these contaminated areas flow into the nearby river and turn the water red. Figure 1.2 depicts the Pahang coastline after rain. Environmental experts also warn on the occurrence of arsenic and heavy metal in water bodies washed down from the open-pit bauxite mines (CMO, 2016).