

UNIVERSITY OF MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: Lim Xin Le (I.C./Passport No:

Registration/Matric No: KGA 120036

Name of Degree: Master of Engineering Science

Title of Project Paper/Research Report/Dissertation/Thesis:

Feasibility Study on Implementation of Marine Renewable Energy in Malaysia by Considering the Project Costs and Urban Public Acceptance

Field of Study: Water Resources Engineering

I do solemnly and sincerely declare that:

- (1) I am the sole author/writer of this Work;
- (2) This Work is original;
- (3) Any use of and work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledge in this Work;
- (4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes and infringement of any copyright work;
- (5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that and reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
- (6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature:

Date:

Subscribed and solemnly declared before,

Witness's Signature:

Date:

Name:

Designation:

ABSTRACT

Energy demand due to increasing global population and the need for low carbon energy have led to the rising importance of renewable energy. Apart from the three most used renewable energy sources in Malaysia – solar energy, hydroelectric and biomass – marine renewable energy may be another potential player in the renewable energy market. Marine renewable energy, which comprises of tidal energy, wave energy, ocean thermal energy conversion (OTEC) and salinity gradient, can be harnessed in Malaysia as the country is surrounded by abundant water resources. The development of marine renewable energy, however, is currently still in its infancy and may face economical and societal challenges in its implementation. Clean Development Mechanism (CDM) and Feed-in Tariff (FiT) are believed to be the crucial driving forces for the marine renewable energy market as the mechanisms bring monetary profits to the investors. Profits earned through CDM and FiT system are expected to reduce the project cost of marine renewable energy. This study is aimed at examining the feasibility and to push forward the development of marine renewable energy in Malaysia. There are three parts in this study. First, the investigation of the implementation of renewable energy projects in Malaysia which is registered in CDM. Second, the proposal of reasonable FiTs for marine renewable energy. The third part of this study is to gauge the level of public acceptance of marine renewable energy, as it is crucial information to be known prior to the commencement of project. Data collections through literatures and interviews were done to complete the first part. The second part is achieved by proposing appropriate FiT rates for marine renewable energy based on Net Present Value approach, which are then validated by comparing with the implemented FiT in other countries. In the third part, a survey on public acceptance of marine renewable energy was conducted in *SS2, Petaling Jaya* and the data collected was analysed using SPSS. As a result, it is worth noting that 69% of the CDM projects are related to renewable energy. 102 local energy-

related projects were registered under CDM from 2006 to 2012 which bring to more than 7 million tonnes carbon dioxide equivalent (tCO_{2e}) emission reduction. For the second study, the proposed FiT for marine renewable energy in Malaysia ranged between RM 0.254 and RM 2.610 per kWh depending on the type of marine energy technology used. The proposed tariffs are exceedingly higher than the implemented FiT rates of solar power due to higher project cost. As for the final survey, 82.2% of the respondents express their support for marine renewable energy implementation in Malaysia. However, 56.8% of the respondents are reluctant to pay for green electricity. Implementation of marine renewable energy can become feasible in Malaysia once the project cost is lowered and receive supports from the government.

(462 words)

ABSTRAK

Permintaan tenaga berikutan peningkatan populasi dan keperluan untuk tenaga karbon rendah telah membawa kepada kepentingan tenaga boleh diperbaharui yang semakin meningkat. Selain daripada tiga sumber tenaga boleh diperbaharui yang terbanyak digunakan di Malaysia - tenaga solar, hidro dan biomas - tenaga boleh diperbaharui lautan boleh menjadi satu lagi pemain yang berpotensi dalam pasaran tenaga boleh diperbaharui. Tenaga boleh diperbaharui lautan, yang terdiri daripada tenaga pasang surut, tenaga ombak, penukaran tenaga terma laut dan kecerunan kemasinan, mampu memanfaatkan Malaysia yang dikelilingi oleh sumber air yang banyak. Walau bagaimanapun, pembangunan tenaga boleh diperbaharui lautan masih di peringkat awal dan mungkin menghadapi cabaran ekonomi dan masyarakat dalam pelaksanaannya. *Clean Development Mechanism (CDM)* dan *Feed-in Tariff (FiT)* memainkan peranan yang penting dalam pasaran tenaga boleh diperbaharui lautan kerana mereka membawa keuntungan kewangan kepada pelabur. Keuntungan yang diperolehi melalui *CDM* dan sistem *FiT* dijangka mengurangkan kos projek tenaga boleh diperbaharui lautan. Kajian ini adalah untuk mengetahui kemungkinan dan untuk menggerakkan pembangunan tenaga diperbaharui lautan di Malaysia. Terdapat tiga bahagian dalam kajian ini. Pertama, siasatan pelaksanaan projek-projek tenaga boleh diperbaharui di Malaysia yang didaftarkan di *CDM*. Kedua, cadangan *FiT* munasabah untuk tenaga boleh diperbaharui lautan. Bahagian ketiga kajian ini adalah untuk mengukur tahap penerimaan orang ramai terhadap tenaga boleh diperbaharui lautan, kerana ia adalah maklumat penting yang perlu diketahui sebelum permulaan projek. Keseluruhan data melalui kesusasteraan dan temuramah telah dilaksanakan untuk menyiapkan bahagian pertama. Bahagian kedua dicapai dengan mencadangkan kadar *FiT* tenaga boleh diperbaharui lautan yang munasabah berdasarkan pendekatan Nilai Bersih Semasa, yang

kemudiannya disahkan dengan membandingkan dengan FiT yang telah dilaksanakan di negara-negara lain. Dalam bahagian ketiga, satu kaji selidik telah dijalankan di SS2, Petaling Jaya dan data yang dikumpul telah dianalisis dengan menggunakan *SPSS*. Hasilnya, 69% daripada projek-projek *CDM* berkaitan dengan tenaga. 102 projek tempatan yang berkaitan dengan tenaga telah didaftarkan di bawah *CDM* dari 2006 ke 2012 dan mengurangkan pelepasan karbon melebihi 7 juta tan karbon dioksida bersamaan (tCO₂e). Bagi kajian kedua, *FiT* yang dicadangkan untuk tenaga boleh diperbaharui lautan di Malaysia adalah antara RM0.254 dan RM2.610 setiap *kWh* bergantung kepada jenis teknologi tenaga lautan yang digunakan. Tarif yang dicadangkan adalah sangat tinggi berbanding dengan kadar *FiT* yang dilaksanakan oleh kuasa solar disebabkan oleh kos projek yang lebih tinggi. Bagi kajian yang terakhir, 82.2% daripada responden menyatakan sokongan untuk pelaksanaan tenaga boleh diperbaharui lautan di Malaysia. Walau bagaimanapun, 56.8% daripada responden enggan membayar untuk tenaga elektrik hijau. Pelaksanaan tenaga boleh diperbaharui lautan boleh dilaksanakan di Malaysia dengan menurunkan kos projek dan mendapatkan sokongan daripada kerajaan.

(412 patah perkataan)

ACKNOWLEDGEMENTS

First and foremost, I am especially grateful to my supervisors, Prof. Ir. Dato' Dr. Roslan bin Hashim and Associate Professor Dr Lam Wei Haur, who have supported me throughout my thesis with their patience and knowledge whilst allowing me the room to work in my own way. Without their encouragement and guidance, this thesis would not be completed.

Besides, I wish to extend my gratitude to the Ministry of Higher Education for the financial support under the UM/MOHE High Impact Research Grant (H-1600-00-D000047) and the Graduate Research Assistantship Scheme. Without the financial support, my study would be impossible to complete on time.

My gratitude also goes to my colleagues, Ms Aalisha Bhatia, Mr Chen Long, Ms Cindy Soon Kong Seet, Mr Ng Kai Wern, Ms Yew Wan Tian, Mr Chandra Roy Bhushan, Ms Genia Nagara and Ms Farhana Arzu Mohona, for their accompaniment and helpful assistance. They also gave me mental support whenever I need it.

Last but not least, I attribute the completion of this thesis to the love of my family. Without their support throughout my study in the University of Malaya, I am unable to complete my study on time and without worries.

TABLE OF CONTENTS

TITLE	PAGE NUMBER
TITLE PAGE	i
ORIGINAL LITERARY WORK DECLARATION FORM	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	vii
TABLE OF CONTENTS	viii
LIST OF FIGURES	xii
LIST OF TABLES	xiv
LIST OF EQUATIONS	xvii
LIST OF SYMBOLS AND ABBREVIATIONS	xvii
CHAPTER 1: INTRODUCTION	
1.1 BACKGROUND OF STUDY	1
1.2 THESIS ORGANISATION	5
1.3 PROBLEM STATEMENTS	5
1.4 OBJECTIVES	6
CHAPTER 2: LITERATURE REVIEW	
2.1 INTRODUCTION	8
2.2 MARINE RENEWABLE ENERGY	8

2.3 GLOBAL MARINE RENEWABLE ENERGY DEVELOPMENT	11
2.3.1 EUROPE	12
2.3.2 AMERICA	15
2.3.3 ASIA	16
2.3.4 AUSTRALIA/OCEANIA	18
2.4 COSTS	19
2.4.1 CAPITAL COSTS	20
2.4.2 OPERATING COSTS	23
2.4.3 ENERGY CAPTURE PERFORMANCE	25
2.5 DEVELOPMENT IN MALAYSIA	25
2.5.1 PHYSICAL MARINE CONDITIONS	28
2.6 RENEWABLE ENERGY-RELATED POLICIES IN MALAYSIA	30
2.6.1 ELECTRICITY CONSUMPTION IN MALAYSIA	31
2.6.2 COST OF ELECTRICITY IN MALAYSIA	33
2.7 CLEAN DEVELOPMENT MECHANISM	35
2.7.1 INSTITUTIONAL ADMINISTRATION IN MALAYSIA	38
2.7.2 PROJECT CYCLE	41
2.8 FEED-IN TARIFF	46
2.8.1 FEED-IN TARIFF SYSTEM IN MALAYSIA	48
2.8.2 FEED-IN TARIFF OF MARINE RENEWABLE ENERGY	51
2.9 PUBLIC ACCEPTANCE OF MARINE RENEWABLE ENERGY	53
CHAPTER 3: METHODOLOGY	
3.1 INTRODUCTION	55
3.2 DATA COLLECTION	55
3.2.1 INTERVIEW	56

3.3 CALCULATION METHOD	57
3.3.1 NET PRESENT VALUE APPROACH	57
3.3.2 VALIDATION OF THE PROPOSED FEED-IN TARIFF	60
3.4 THE SURVEY	62
3.4.1 THE STUDY AREA	62
3.4.2 THE QUESTIONNAIRE	65
3.4.3 THE SAMPLES	69
3.4.4 CHI-SQUARE TEST	72
CHAPTER 4: RESULTS AND DISCUSSION	
4.1 INTRODUCTION	73
4.2 REDUCTION OF PROJECT COSTS THROUGH CARBON CREDITS	73
4.2.1 ENERGY-RELATED CLEAN DEVELOPMENT MECHANISM PROJECTS IN MALAYSIA	74
4.2.2 TIDAL ENERGY PROJECT IN CLEAN DEVELOPMENT MECHANISM	77
4.2.3 CARBON REDUCTION FROM MARINE RENEWABLE ENERGY PROJECTS	79
4.3 REDUCTION OF PROJECT COSTS THROUGH FEED-IN TARIFF	80
4.3.1 PROPOSED FEED-IN TARIFF FOR MARINE RENEWABLE ENERGY	81
4.3.2 VALIDATION OF RESULTS	85
4.4 BREAKEVEN POINT OF THE PROJECT COSTS	88
4.5 THE SURVEY	89
4.5.1 SOCIO-DEMOGRAPHIC VARIABLES	90

4.5.2 OPEN-ENDED QUESTION	91
4.5.3 CLOSE-ENDED QUESTIONS	92
4.5.3.1 POLAR QUESTIONS	93
4.5.3.2 INFLUENCE OF SOCIO-DEMOGRAPHIC DEMOGRAPHIC VARIABLES TO THE RESULTS	96
4.5.3.3 CHI-SQUARE TEST OF POLAR QUESTIONS	102
4.5.3.4 MULTIPLE-CHOICE QUESTIONS	104
CHAPTER 5: CONCLUSION AND RECOMMENDATION	
5.1 INTRODUCTION	111
5.2 CONCLUSION	111
5.3 RECOMMENDATIONS	113
REFERENCES	115
LIST OF PUBLICATIONS AND PAPERS PRESENTED	135

LIST OF FIGURES

FIGURE	TITLE	PAGE NUMBER
1.1	Framework of study	7
2.1	Types of marine renewable energy	9
2.2	SeaGen 1.2MW tidal energy convertor was installed in Strangford Lough in Northern Ireland in 2008	14
2.3	Factors affecting LCOE of marine renewable energy	20
2.4	Capital cost breakdown for wave energy device	21-22
2.5	Capital cost breakdown for tidal stream energy device installation of a particular energy device in a farm of a certain size	23
2.6	Operating cost breakdown for wave energy device	23-24
2.7	Map of Malaysia	26
2.8	Malaysia Generation Mix of Electricity for 1995, 2003, 2010 and 2011	33
2.9	The mechanism of CDM	37
2.10	The CDM Institutional Administration in Malaysia	38
2.11	National Clean Development Mechanism Project Cycle	42
3.1	The city of <i>Petaling Jaya</i> located adjacent to the capital of Malaysia, <i>Kuala Lumpur</i> . The circle indicates <i>Kuala Lumpur</i> while the equilateral triangle marks the location of <i>Petaling Jaya</i>	63
3.2	Map of <i>Petaling Jaya</i> showing the sections of <i>PJU</i> , <i>SS</i> and <i>PJS</i>	65
3.3	Pictures showing marine renewable energy devices were provided in the open-ended question	66

4.1	The Sihwa Tidal Power Plant Project is located in the Republic of Korea, 37°2'N longitude and 126°4'W latitude	78
4.2	Graph of accumulated cash flows (in <i>Ringgit Malaysia</i>) of tidal stream shallow project	89
4.3	Public acceptance of marine renewable energy implementation among different age groups	97
4.4	Public acceptance of marine renewable implementation among respondents with different monthly incomes	99
4.5	Willingness to pay for green electricity among different age groups	100
4.6	Willingness to pay for green electricity among respondents with different monthly incomes	102
4.7	This question is designed in order to know the most popular renewable energy technology in the respondents' current perspective	104
4.8	This question is designed in order to know the perspective of respondents towards the challenges in implementing marine renewable energy in Malaysia	105
4.9	This question is designed in order to know the perspective of respondents towards the main support of the Malaysian government in the implementation of marine renewable energy	107
4.10	This question is designed in order to know the perspective of respondents regarding the difficulty faced by the Malaysian government	109
4.11	This question is designed in order to know the willingness to pay of respondents for using electricity generated by renewable energy	110

LIST OF TABLES

TABLE	TITLE	PAGE NUMBER
2.1	Full scale devices installed or currently operating in UK Waters	13
2.2	Summary of marine renewable energy roadmap proposed by the National Oceanography Directorate	27
2.3	The primary energy supply, final energy demand, energy input in power stations, installed generation capacity, electricity generation and final electricity consumption in Malaysia from year 2002 to 2012	31
2.4	Domestic tariff of main electricity suppliers in Malaysia	35
2.5	List of Annex 1 countries to the UNFCCC	36
2.6	Feed-in tariff by SEDA, Malaysia, 2012	49-50
2.7	Comparison of feed-in tariff for marine energy in different countries	52
2.8	Literature review on the public acceptance of marine renewable energies and renewable energy related studies in Malaysia.	54
3.1	Information regarding various marine energies demonstration projects obtained from a report to the Scottish Government	60
3.2	Conventional electricity and feed-in tariffs in various countries	61
3.3	Polar questions in the questionnaire	67
3.4	MCQ in the questionnaire	68
3.5	Sample size table	69
3.6	Distribution of SS2 population based on ethnic groups	71

4.1	CDM projects grouped in types	75
4.2	Number of registered CDM projects in energy sectors in Malaysia	76
4.3	Annual estimated and actual emission reductions	79
4.4	CO ₂ displaced by wave and tidal sector in 2017 and 2020 under two deployment scenarios	80
4.5	Proposed feed-in tariff of different marine renewable energy technologies based on the Net Present Value Approach	85
4.6	Comparison of ratio of feed-in tariff rates of marine renewable energy to electricity tariffs and feed-in tariff of other renewable energy technologies in different countries	86
4.7	Assumption of the cash flows of the tidal stream shallow project	88
4.8	Characteristics of the respondents	90
4.9	Examples of answers of the respondents when answering the question ‘What can you relate from the pictures?’ as shown in Figure 3.3	92
4.10	Results of polar questions	93
4.11	Chi-square test of polar questions	103

LIST OF EQUATIONS

EQUATION	TITLE	PAGE NUMBER
2.1	Energy Usage	34
2.2	Electricity Cost	34
3.1	Net Present Value	58
3.2	Capacity Factor	59
3.3	Required Sample Size	70
3.4	Chi-square test	72

LIST OF SYMBOLS AND ABBREVIATIONS

ABBREVIATION OR SYMBOL	DESCRIPTION
ADB	Asian Development Bank
AIS	Additional Information Sheet
CAPEX	Capital Expenditures
CDM	Clean Development Mechanism
CDMEB	Clean Development Mechanism Executive Board
CERs	Certified Emission Reductions
CO ₂	Carbon Dioxide
DCF	Discounted Cash Flow
DLs	Distribution Licensees
DNA	Designated National Authority
DOE	Designated Operational Entity
ERPA	Emission Reduction Purchase Agreement
FIAHS	Feed-in Approval Holders
FiT	Feed-in Tariff
FRIM	Forest Research Institute Malaysia
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Gigawatts
h	hour
IEA	International Energy Agency

IET	International Emissions Trading
JI	Joint Implementation
<i>KeTTHA</i>	<i>Kementerian Tenaga, Teknologi Hijau dan Air</i>
KRW	Korean won
ktoe	kilo tonnes of oil equivalent
kW	kilowatt
kWh	kilowatt hour
LCOE	Levelised Cost of Energy
MARDI	Malaysian Agricultural Research and Development Institute
<i>MBPJ</i>	<i>Majlis Bandaraya Petaling Jaya</i>
MCQ	Multiple-Choice Questions
MCT	Marine Current Turbine
MOSTI	Ministry of Science, Technology and Innovation
Mtoe	Million tonnes of oil equivalent
MW	Megawatt
NCCDM	National Committee on Clean Development Mechanism
NIMBY	Not in My Backyard
NOD	National Oceanography Directorate
NPV	Net Present Value
NRE	Ministry of Natural Resources and Environment
NSCCC	National Steering Committee on Climate Change
O&M	Operational and Maintenance
OECD	Organisation for Economic Cooperation and Development
OPEX	Operating Expenditures
OTEC	Ocean Thermal Energy Conversion
OWC	Oscillating Water Column

PDD	Project Design Document
PIN	Project Idea Note
<i>PJS</i>	<i>Petaling Jaya Selatan</i>
<i>PJU</i>	<i>Petaling Jaya Utara</i>
<i>PTM</i>	<i>Pusat Tenaga Malaysia</i>
R&D	Research and Development
<i>RM/kWh</i>	<i>Ringgit Malaysia per kilowatt hour</i>
ROI	Return of Investment
SCORE	Special Committee on Renewable Energy
<i>SEB</i>	<i>Sarawak Energy Berhad</i>
SEDA	Sustainable Energy Development Authority
<i>SESB</i>	<i>Sabah Electricity Sdn Bhd</i>
SPSS	Statistical Package for the Social Sciences
SREP	Small Renewable Energy Program
<i>SS</i>	<i>Sungei Way-Subang</i>
TCCDM	Technical Committee on Clean Development Mechanism
TJ	Tera-joules
<i>TNB</i>	<i>Tenaga Nasional Berhad</i>
TWh	Terawatt-hours
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
W	Watt