

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iii
ABSTRACT	iv
TABLE OF CONTENTS	ix
LIST OF TABLES	xiii
LIST OF FIGURES	xv
CHAPTER 1 INTRODUCTION	1
1.1 Introduction	1
1.2 Literature Review	3
1.2.1 Bioethanol production	3
1.2.2 Overview of bioethanol production in Thailand	4
1.2.3 GHG emissions of bioethanol	6
1.2.4 Water footprint of bioethanol	13
1.3 Objective of the Study	17
1.4 Scope of the Study.	17
CHAPTER 2 THEORY	19
2.1 Life cycle assessment (LCA) methodology	19
2.2 Carbon footprint methodology	22
2.2.1 Scoping	24
2.2.2 Data collection	27
2.2.3 Calculation	28
2.2.4 Interpretation	29
2.3 Water footprint methodology	29
2.3.1 Component of a water footprint	31

2.3.2 Step in water footprint assessment	33
2.4 Scenario analysis	52
CHAPTER 3 METHODOLOGY	55
3.1 The review of harvested areas, products and yields of sugarcane and cassava	55
3.2 The study of the increase in the sugarcane and cassava harvested areas by Geographic Information System	55
3.3 Area selection and field data collection	56
3.4 Carbon footprint assessment of sugarcane-based and cassava-based Bioethanol	57
3.4.1 Goal definition	57
3.4.2 Scope definition	57
3.4.3 Data collection	60
3.4.4 Carbon footprint calculations	62
3.4.5 Interpretation	63
3.5 Water footprint assessment of bioethanol from sugarcane and cassava	64
3.5.1 Setting goals and scope of the study	64
3.5.2 Data collection	64
3.5.3 Calculation of WFs of sugarcane and cassava	66
3.5.4 Calculation of WFs of sugarcane- and cassava-based bioethanol	72
3.6 The scenario analysis of bioethanol for Thailand	73
3.6.1 Definitions and system boundaries	73
3.6.2 Scenario I: Compare gasoline 95, E10, E20 and E85	76
3.6.3 Scenario II: Increase capacity to 9 million liters of ethanol per day by 2021	77
CHAPTER 4 RESULTS AND DISCUSSION	82
4.1 The data from the literature and GIS concerning the selected areas for the field data collection	82
4.1.1 Harvested areas, products and yields of sugarcane and cassava	82

4.1.2	The study of harvested areas of sugarcane and cassava by geological information system	83
4.1.3	General survey data of sugarcane and cassava plantations in northern Thailand	84
4.2	Carbon footprint	86
4.2.1	Data collection results	86
4.2.2	Carbon footprint calculations and interpretation	95
4.3	Water footprint	102
4.3.1	The green and blue evapotranspiration of sugarcane and cassava	102
4.3.2	WFs of sugarcane and cassava	108
4.3.3	WFs of sugarcane-based bioethanol	113
4.3.4	WFs of cassava-based bioethanol	116
4.3.5	The reduction of carbon and water footprints	119
4.4	The results of scenario analysis	120
4.4.1	Scenario I: Compare gasoline 95, E10, E20 and E85	120
4.4.2	Scenario II: Increasing ethanol production to 9 million liters per day by 2021	122
CHAPTER 5 CONCLUSION AND RECOMMENDATIONS		132
5.1	Conclusion	132
5.1.1	Carbon footprint	132
5.1.2	Water footprint	133
5.1.3	Comparing the effects between gasoline 95, E10, E20 and E85	135
5.1.4	The future of bioethanol of AEDP	135
5.2	Guidelines to promote ethanol uses in Thailand	138
5.2.1	Guidelines of land uses for growing sugarcane and cassava	138
5.2.2	Guidelines to reduce greenhouse gas emissions	139
5.2.3	Guidelines for water uses	140
5.3	Recommendations	142

REFERENCES	144
APPENDICES	150
APPENDIX A THE DATA OF SOIL SERIES OF CULTIVATION AREA OF SUGARCANE AND CASSAVA IN NORTHERN THAILAND	151
APPENDIX B THE SUMMARY OF IMPORTANCE SERVEY DATA	154
APPENDIX C CARBON FOOTPRINT CALCULATIONS OF SUGARCANE-BASED AND CASSAVA-BASED BIOETHANOL	157
APPENDIX D WATER FOOTPRINT OF SUGARCANE-BASED AND CASSAVA-BASED BIOETHANOL CALCULATION	164
APPENDIX E LIST OF PUBLICATION	177
CURRICULUM VITAE	201

LIST OF TABLES

Table	Page
1.1 Emission of greenhouse in ethanol production from sugarcane	8
1.2 Possible modalities for ethanol production in Mexico	10
1.3 Land and water use for biofuels	16
2.1 Global warming potential at 100-year time horizon	26
3.1 Scope of information used to assess the carbon footprint of sugarcane-based ethanol	59
3.2 Scope of information used to assess the carbon footprint of cassava-based ethanol	60
3.3 Data collection procedure of sugarcane-based ethanol	61
3.4 Data collection procedure of cassava-based ethanol	61
3.5 Emission factor for calculation of bioethanol from sugarcane and cassava	63
3.6 Data and sources for the calculation of WFs	64
3.7 Capacity for ethanol and proportion production in each year	77
3.8 Target of increase the national average production	80
4.1 Harvested areas, products and yields of sugarcane and cassava	83
4.2 The inventory data for 1 hectare of sugarcane cultivation	87
4.3 The inventory data for 1 kilogram of molasses	90
4.4 Allocation by mass of sugar and molasses	90
4.5 The inventory data for 1 liter of sugarcane-based bioethanol	91
4.6 The inventory data for 1 hectare of cassava cultivation	94
4.7 The inventory data for 1 liter of cassava-based bioethanol	95
4.8 GHG emission of 1 kilogram of unburned sugarcane	97
4.9 GHG emission of 1 kilogram of burned sugarcane	97

4.10	Carbon footprint results for 1 liter of sugarcane-based bioethanol (Allocation by mass)	98
4.11	Carbon footprint results for 1 liter of sugarcane-based bioethanol (Allocation by economics)	98
4.12	GHG emission of 1 kilogram of cassava	101
4.13	Carbon footprint results for 1 liter of cassava-based bioethanol	101
4.14	The ET_a , ET_{green} and ET_{blue} of sugarcane and cassava	103
4.15	Evapotranspiration and forecast yield under optimal condition	107
4.16	Water footprint of sugarcane under rain-fed condition	109
4.17	Water footprint of sugarcane under optimal condition	109
4.18	Water footprint of cassava under rain-fed condition	111
4.19	Water footprint of cassava under optimal condition	112
4.20	The use of land for growing sugarcane and cassava	124
4.21	The areas plants sugarcane and cassava by AEDP with increased average yields	126
4.22	Water footprint for sugarcane and cassava production	129
4.23	Water footprint for increasing yield sugarcane and cassava plants	131

LIST OF FIGURES

Figure	Page
1.1 World production of bioethanol's	3
1.2 GHG emissions of different sugar-based ethanol configurations	11
1.3 Breakdown of GHG emissions by step for sugar-based ethanol scenarios	11
1.4 Modeling of changes in agricultural systems to satisfy increased demand of a ton of cassava in Thailand	12
2.1 Life cycle stages	20
2.2 Phase of LCA	21
2.3 Steps of carbon footprint calculation	24
2.4 Cradle-to-gate and cradle-to-grave assessments	26
2.5 Components of a water footprint	31
2.6 Chain supply in the production process of water footprint	33
2.7 Steps in the water footprint assessment	34
2.8 Reference crop evapotranspiration (ET _o), crop evapotranspiration under standard condition (ET _c) and non-standard conditions (ET _c adj)	39
2.9 Crop coefficients and crop development stages	42
2.10 Schematization of the production system to produce one output product <i>p</i>	47
2.11 Schematization of the production system to produce output product <i>p</i>	48
2.12 The five phases of general scenario process	53
3.1 Graphical depiction of the methodology of this research work	56
3.2 A process map for sugarcane-based ethanol	58
3.3 A process map for cassava-based ethanol	58
3.4 The entire system boundary of this research study	59
3.5 Climate data input to the CROPWAT model	67

3.6	Rain data input to the CROPWAT model	67
3.7	Sugarcane data input to the CROPWAT model	68
3.8	Cassava data input to the CROPWAT model	69
3.9	Soil data input to the CROPWAT model	69
3.10	The results derived from the model execution	71
3.11	Key determinants of the potential for bioethanol production from sugarcane and cassava in Thailand	74
3.12	System boundary of scenario I	76
3.13	System boundary of scenario II	77
4.1	The density of the spread of sugarcane and cassava harvested areas in northern Thailand	85
4.2	The life cycle of sugarcane-based ethanol	89
4.3	The life cycle of cassava-based ethanol	93
4.4	Mass balance of 1 liter of sugarcane-based bioethanol	96
4.5	Mass balance of 1 liter of cassava-based bioethanol	100
4.6	CF calculation results during the life cycle of cassava-based bioethanol	102
4.7	Evapotranspiration, yield, total rainfall and effective rainfall in case of sugarcane	104
4.8	Evapotranspiration, yield, total rainfall and effective rainfall in case of cassava	104
4.9	Total crop water use and sugarcane yield of each province in northern Thailand	105
4.10	Total crop water use and cassava yield of each province in northern Thailand	106
4.11	Yield of sugarcane under rain-fed and optimal condition	108
4.12	Yield of cassava under rain-fed and optimal condition	108
4.13	The WFs of sugarcane producer countries	110
4.14	The WFs of cassava producer countries	112
4.15	The water use for sugarcane-based bioethanol, showing the product fraction and value fraction per processing step	114
4.16	The WFs of sugarcane, molasses and bioethanol steps for sugarcane cultivated under rain-fed condition	115

4.17	The WFs of sugarcane, molasses and bioethanol steps for sugarcane cultivated under optimal condition	115
4.18	The WFs of country producer sugarcane-based bioethanol	116
4.19	The water use for cassava-based bioethanol, showing the product fraction and value fraction per processing step	117
4.20	The WFs of cassava, cassava chips and bioethanol steps for cassava cultivated under rain-fed condition	118
4.21	The WFs of cassava, cassava chips and bioethanol steps for cassava cultivated under optimal condition	118
4.22	Land use for different types of fuels	121
4.23	Greenhouse gas emissions of each fuel type	121
4.24	Water consumption for different types of fuel productions	122
4.25	Comparing land use for growing sugarcane and cassava	124
4.26	Carbon footprints for a constant and changed ratio of ethanol production (Allocation of molasses by mass)	127
4.27	Carbon footprints for a constant and changed ratio of ethanol production (Allocation of molasses by economics)	128
4.28	Water footprints for fixed and changed ratios of ethanol production	130

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่

Copyright© by Chiang Mai University
All rights reserved