

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**Transfer of Sustainable Energy Technology to Developing
Countries as a Means of Reducing Greenhouse Gas
Emission:
The Case of Bangladesh**

**A thesis submitted in partial fulfillment of the requirements for the
degree of**

**Doctor of Philosophy
in
Applied and International Economics
at Massey University
Palmerston North, New Zealand**

Mohammad Ershad Ali

2001

Abstract

Over the last two decades the world has been becoming increasingly concerned about greenhouse gas (GHG) emissions, global warming, unsustainable development, and poverty in the developing countries. The most acceptable way of mitigating GHG emission is the use of sustainable energy technology (SET) instead of fossil fuel. SET is available in the global market, but is outside the scope of availability for many developing countries. Due to the lack of economic and technical capabilities and wide-spread poverty, developing countries are unable to introduce SET independently, hence a need for appropriate assistance from developed countries. The case study was conducted in Bangladesh, one of the poorest countries in the world, with acute shortages of energy and largely disadvantaged rural population.

The study assessed three energy technologies—biomass, solar, and wind—to identify the most viable options of SET for the rural Bangladesh. The appropriateness of the proposed SETs is assessed on the basis of certain criteria: availability of resources, cost-effectiveness, degree of technological complexity, matching demand and supply, and contribution to reducing GHG emission. It has been found that each SET taken separately, has its limitations. The main barrier for biomass energy technology is the availability of biomass due to scarcity of land, and hence, producing food is preferable to growing trees for fuel. The major limitations for solar and wind energy technologies are high levels of capital investment and technological complexity.

The study proposes a combination of biomass, solar, and wind SETs as a long-term solution of energy crisis in the rural Bangladesh. It suggests relevant policy and types of assistance in the form of investment in education and training, machinery, spare parts, know-how etc. A brief proposal for capacity building has been prepared. It is expected that the proposed SETs will benefit sustainable development, poverty alleviation of rural Bangladesh, and the national socio-economic conditions. The study findings contribute to general knowledge, and are especially useful for developing countries.

Acknowledgments

I am grateful to almighty Allah who gave me the opportunity to complete this research amidst many difficulties. I owe a great deal to Dr. Peter Read who supervised me throughout the period of this research. His guidance, advice, and comments at every stage of this research were crucial to the success of this research project. Indeed, I feel fortunate and proud of having worked under his supervision. I also acknowledge the invaluable guidance received from my supervisors Professor John Overton and Dr. A.K.Enamul Haque.

It is a pleasure to acknowledge financial assistance provided by the Massey University without which I could not have undertaken this research. I also acknowledge the financial assistance received from the Department of Applied and International Economics. I am greatly indebted to all staff members of this Department.

I gratefully acknowledge the continuous support from my relatives, friends and well wishers in completing this study.

I acknowledge my sincere gratitude to Professor Srikanta Chatterjee, Dr. Nabiul Islam and Dr. Waresul Karim for their kind help and support in completing this study. Without their support and assistance it would have been impossible to complete this research. I also express my thanks to Abdul Wahab, Kamal Ahmed, Ainul Islam and Omar Al Farooque for their friendly co-operation and logistical support in completing my study.

Finally, I am proud of the support and co-operation provided by my wife Julekha who sacrificed a lot for the success of my research. My daughters Sumaya and Shakiya always encouraged and pushed me to step forward to the door of success.

Table of Contents

	Page
Abstract	ii
Acknowledgment	iii
Table of contents	iv
List of Tables	xi
List of Maps	xiv
List of Figures and Photographs	xv
List of Annexes	xvi
List of Acronyms and Abbreviations	xvii
Energy Conversion Factors	xx
CHAPTER ONE: INTRODUCTION	1
1.1. Introduction	1
1.2. The Bangladesh Context	5
1.3. Energy Demand and supply scenario of Bangladesh	9
1.4. Research Problem	10
1.5. Objectives of the Study	14
1.6. Sustainable Energy Technology	14
1.7. Importance of the Study	14
1.8. Scope and Limitations of the Study	16
1.8.1. Scope	16
1.8.2. Limitations	17
1.9. Structure of the Thesis	17
CHAPTER TWO: LITERATURE REVIEW	20
2.1 Introduction	20
2.2. Studies Relevant to Global Concern of environmental effects	21
2.3. Studies Relevant to Availability of SET	28
2.4. Conceptual Debate	31
2.4.1. Sustainable Development, Poverty and Environment	32
2.4.2. Alternative, Renewable and Sustainable Energy	34

2.4.3. Difference in Gross and Net Reduction of CO ₂ Emission	35
2.5. The Bangladesh Context	38
2.6. Conclusion	42
CHAPTER THREE: METHODOLOGY	44
3.1 Introduction	44
3.2 Identification of Parameters and Their Definitions	46
3.3 Nature of Demand and Supply	48
3.3.1 Demand for Energy	48
3.3.2 Supply of Energy	50
3.4 Household as an Unit	51
3.4.1 Family Size	52
3.4.2 Joint Family	52
3.5 Background Characteristics of Energy Users	53
3.5.1 Land Ownership	53
3.5.2 Household Income	53
3.5.3 Education	54
3.6 Environmental Awareness	54
3.7 Willingness of Participation in SET Transfer	55
3.8 Methods of Data Collection	55
3.8.1 Questionnaire Administration	55
3.8.2 Participant Observation	56
3.8.3 Participatory Rural Appraisal	57
3.9 Sampling Design	61
3.10 The Questionnaire	64
3.11 The Interview Team	66
3.12 Data Analysis	67
3.13 Conclusion	68
CHAPTER FOUR: BANGLADESH ENERGY SCENARIO	69
4.1 Introduction	69
4.2 General Features of Bangladesh	69

4.3	Background of the Energy Sector	71
4.4	Institutional Arrangements	72
4.5	Energy Supply Networks	75
4.6	Energy Consumption Networks	77
4.7	Major Weaknesses of Energy Infrastructure of Bangladesh	79
4.8	Non Renewable Energy Resources in Bangladesh	84
4.8.1	Natural Gas	84
4.8.1.1	Gas Resource Classification and Reserve Estimation	86
4.8.1.2	Differences in Opinions on Gas Reserve Records	88
4.8.1.3	Projection of Gas Demand	89
4.8.1.4	Projection of Gas Supply	90
4.8.1.5	Existing Gas Pipelines	91
4.8.1.6	Projection of Gas Production Capacity in Bangladesh	91
4.8.1.7	Would Natural Gas be a Sustainable Resource of Energy for Rural Bangladesh	93
4.8.2	Coal	93
4.8.2.1	Coal Use	93
4.8.2.2	Jamalganj Coal	94
4.8.2.3	Dinajpur Coal	96
4.8.2.4	Peat Reserve	96
4.8.2.5	Would Coal be a Sustainable Source of Energy for Rural Bangladesh	97
4.8.3	Electricity	98
4.8.4	Hydropower	99
4.8.5	Oil	100
4.9	Renewable Energy Resources in Bangladesh	101
4.10	Pattern of Energy Balance	102
4.11	Conclusion	104
CHAPTER FIVE: SET OPTIONS IN RURAL BANGLADESH		107
5.1	Introduction	107
5.2	Pattern of Expenditure on Energy in Rural Bangladesh	107
5.3	Pattern of Energy Supply and Demand in Rural Bangladesh	110
5.3.1	Biomass	110

5.4	Available Renewable Energy Technologies in Rural Bangladesh	113
5.4.1	Biomass Energy Technology	113
5.4.1.1	Charcoal	114
5.4.1.2	Charcoal Cake	116
5.4.1.3	Animal Dung Cake or Stick	116
5.4.1.4	Woods, Twigs, Leaves	119
5.4.1.5	Crop Residues	121
5.4.1.6	Biogas	124
5.5	Other Renewable Energy Technologies	127
5.5.1	Solar Energy	127
5.5.2	Passive Solar Systems	128
5.5.3	Solar Ponds	128
5.5.4	Solar Drying	129
5.5.5	Light Utilizing Systems	129
5.6	Wind Energy	134
5.7	Sustainable Energy Technologies (SETs) in Rural Bangladesh	136
5.8	Conclusion	138
 CHAPTER SIX: ENERGY USE IN RURAL BANGLADESH		 139
6.1	Introduction	139
6.2	Characteristics of the Sample	142
6.3	Rural Energy Situation in Bangladesh	147
6.3.1	Sources of Existing Energy Supply	147
6.3.1.1	Energy from Own Animals	148
6.3.1.2	Energy from Own Forest/Land	149
6.3.1.3	Energy from Market Based Sources	149
6.3.1.4	Electricity	150
6.3.2	Usage of Energy by Rural Households	150
6.3.3	Usage of Energy for Commercial Activities	151
6.3.4	Reasons for Using the Existing Sources of Energy	152
6.3.5	Energy from Home Sources	153
6.4	Potential for SET in Rural Bangladesh	154
6.5	Perception on Producing Energy with SETs	158

6.6	Rural Energy Demand	160
6.7	Leaders'p Opinions on SETs	164
6.8	Conclusion	165

CHAPTER SEVEN: ANALYSIS OF RESPONDENTS' BACKGROUND CHARACTERISTICS

		167
7.1	Introduction	167
7.2	Energy users' Characteristics	169
7.2.1	Dung Users' Characteristics	169
7.2.2	Firewood Users' Characteristics	173
7.2.3	Leaf Users' Characteristics	176
7.2.4	Kerosene Users' Characteristics	178
7.2.5	Diesel Users' Characteristics	181
7.2.6	Environmental Awareness	183
7.2.7	Willingness to Participate in SET Transfer Process	185
7.2.8	Energy Needs for Cooking	187
7.2.9	Energy Needs for Lighting	189
7.2.10	Energy Uses for Entertainment	191
7.3	Correlation Analysis	194
7.4	Regression Test	195
7.5	Conclusion	198

CHAPTER EIGHT: CHOICE OF SET FOR RURAL BANGLADESH

		201
8.1	Introduction	201
8.2	Criteria of Justifying SET	202
8.3	Nature of Energy Needs in Rural Bangladesh	203
8.3.1	Energy for Households	207
8.3.1.1	Cooking in Rural Households	208
8.3.1.2	Household Lighting	211
8.3.2	Energy for Commercial Activities	213
8.3.3	Energy Demand in Agriculture	215
8.3.3.1	Human Labor	216

8.3.3.2	Animal Power	218
8.3.3.3	Energy for Irrigation	219
8.3.4	Energy for Rural Industries	221
8.3.5	Summary	221
8.3.6	Justification of SET	222
8.4	Feasibility of Biomass Technology	222
8.4.1	Availability of Biomass for Energy	222
8.4.2	Technological Complexity of Biomass Use	231
8.4.3	Cost Effectiveness of Biomass Technology	231
8.4.4	Matching with Demand and Supply	232
8.4.5	Contribution to GHG Reduction	232
8.4.6	Major Constraints of Biomass Technology	233
8.5	Feasibility of Solar Energy	234
8.5.1	Availability of Solar radiation for Energy	234
8.5.2	Technological Complexity of Solar Energy	234
8.5.3	Cost Effectiveness of Solar Energy	235
8.5.4	Matching with Demand and Supply	237
8.5.5	Contribution to GHG Reduction	237
8.5.6	Major Constraints of Solar Energy Technology	237
8.6	Feasibility of Wind Power	237
8.6.1	Availability of Wind for Energy	238
8.6.2	Technological Complexity of Wind Power	239
8.6.3	Cost Effectiveness of Wind Power	240
8.6.4	Matching with Demand and Supply	241
8.6.5	Contribution to GHG Reduction	242
8.6.6	Major Constraints of Wind Power Technology	242
8.7	Summary of Feasibility of SET in Matrix Format	242
8.8	Energy Supply and Demand Linkage Model	244
8.9	Conclusion	247
CHAPTER NINE: CONCLUSION AND POLICY IMPLICATIONS		248
9.1	Introduction	248
9.2	Summary of Previous Chapters	248

9.2.1	Background of the Study	248
9.2.2	Literature Review	249
9.2.3	Methodology of the Study	250
9.2.4	Bangladesh Energy Scenario	251
9.2.5	SET Options in Rural Bangladesh	253
9.2.6	Energy Use in Rural Bangladesh	254
9.2.7	Analysis of Respondents' Background Characteristics	256
9.2.8	Choice of SET in Rural Bangladesh	257
9.3	Achievement of Objectives	259
9.4	Policy Implications	260
9.5	Directions for Further Research	263
9.6	Conclusion	263
	REFERENCES AND BIBLIOGRAPHY	265

LIST OF TABLES

Table 1.1	Percentage of Export Earnings Spent for Fuel Import of Bangladesh	8
Table 1.2	Energy Demand and Supply Scenario of Bangladesh	10
Table 3.1	Major Topographical Features of Sampled Villages	56
Table 3.2	Number of Sampled Respondents by Sex, Land Ownership, and Divisions	62
Table 4.2.1	Comparison of Per Capita Energy Consumption of Bangladesh and Some Neighbouring Countries	71
Table 4.4.1	Organisations Involved in Energy Management, and Their Responsibilities	74
Table 4.5.1	Energy Supply Networks in Bangladesh	76
Table 4.6.1	Energy Consumption Networks in Bangladesh	78
Table 4.8.1	Information on Discovered Gas Fields	87
Table 4.8.1.2	Announced Gas Reserves in Bangladesh	89
Table 4.8.1.4	Gas Production Capacity of Bangladesh as of 2000	91
Table 4.8.1.6	Production Forecast Till 2005 of Gas Fields	92
Table 4.8.2.1	Summary of Typical Seam Sections of Jamalgonj Coal Reserve	95
Table 4.8.3.1	Installed, Production and Distribution Capacity of Electricity in Bangladesh	98
Table 4.8.5.1	Volume of Oil Import (in Thousand Tons)	100
Table 4.10.1	Bangladesh Overall Energy Balance (1994/95)	103
Table 5.2.1	Energy Expenditure Pattern in Rural Bangladesh	108
Table 5.3.1	Major Sources of Biomass in Rural Bangladesh	111
Table 5.4.1.5	Alternative Use of Crop Residues	121
Table 5.5.1.1	Solar-Based Power Plants in Rural Bangladesh	128
Table 5.6.1	Wind Power Generation in Bangladesh	134
Table 6.1.1	Sampled Household survey by Division	140
Table 6.2.1	Educational Qualification of Respondents	142
Table 6.2.2	Respondents by Occupation	144
Table 6.2.3	Annual Income of Rural Households	145

Table 6.2.4	Homestead Land Area	145
Table 6.2.5	Arable Land Area	147
Table 6.3.1	Sources of Energy Supply in Rural Bangladesh	148
Table 6.3.2	Animals Owned by Rural Households	149
Table 6.3.2.1	Use of Energy by Rural Households	151
Table 6.3.3.1	Use of Energy by Rural Commercial Enterprises	152
Table 6.3.4.1	Reasons for Using the Existing Energy Sources	153
Table 6.3.5.1	Energy from Home Sources by Rural Households	154
Table 6.4.1	Awareness about Environmental Pollution from Energy Use	155
Table 6.4.2	Knowledge of Environmental Consequences of Energy Use	155
Table 6.4.3	Knowledge of SET	156
Table 6.4.4	Knowledge of Wind Energy and Its Use	156
Table 6.4.5	Knowledge of Biogas and Its Use	157
Table 6.4.6	Knowledge of Solar Energy and Its Use	158
Table 6.5.1	Will You Participate in Producing SET?	158
Table 6.5.2	What Do You Need to Participate in Producing Energy Using SET?	159
Table 6.5.3	Assistance Available from the Rural Population in Building SET Plants	160
Table 6.6.1	Activities Suffering Due to Energy Shortages	161
Table 6.6.2	What Will You Do if You Have More Energy?	162
Table 6.6.3	More Energy Means	163
Table 6.6.4	Potential Future Benefits from More Energy in Rural Bangladesh	163
Table 6.7.1	Number of Respondents According to Sampled Villages	164
Table 7.2.1	Dung Users' Characteristics	172
Table 7.2.2	Firewood Users' Characteristics	175
Table 7.2.3	Leaf Users' Characteristics	177
Table 7.2.4	Kerosene Users' Characteristics	180
Table 7.2.5	Diesel Users' Characteristics	182
Table 7.2.6	Characteristics of Respondents' Environmental Awareness	184
Table 7.2.7	Characteristics of Respondents' Willingness to SET	186
Table 7.2.8	Characteristics of Respondents' Who Used Energy for Cooking	188
Table 7.2.9	Characteristics of Respondents' Who Used Energy for Lighting	190

Table 7.2.10	Characteristics of Respondents' Who Used Energy for Entertainment	193
Table 7.3.1	Correlation Output	194
	Regression Equation 7.1	197
	Regression Equation 7.2	197
Table 8.3.1.1	Per Capita Biomass Fuel Consumption for Cooking as Estimated by Some Studies	209
Table 8.3.2.1	Estimated Energy Consumption in Major Areas of Rural Households of Bangladesh	214
Table 8.3.3.3	Area Covered by Using Different Devices in 1998 in Rural Bangladesh	220
Table 8.4.1	Projection of Biomass Fuel Supply in Usual Business Scenario	223
Table 8.7.1	Feasibility of Introducing SET in Rural Bangladesh, in Matrix Format	243

LIST OF MAPS

Map 4.7.1:	Category-Related Location of Power Plants in Bangladesh	83
Map 4.8.1:	Location of Gaswells, Existing and Proposed Gas Transmission Pipelines in Bangladesh	85
Map 5.1:	Forestland of Bangladesh	122
Map 5.2:	Types of Land in Bangladesh	123
Map 5.3:	Location of PV System Used in Bangladesh	132
Map 5.4:	Location of Wind Power Generators in Bangladesh	135
Map 6.1	Sample Location for Household Survey in Bangladesh	141
Map 8.1	Characteristics of Arable Land in Bangladesh	229

LIST OF FIGURES AND PHOTOGRAPHS

Figure 4.8.1.1	Production Shares of Natural Gas by Operators	92
Figure 4.9.1	The Use of Ill Health Cows for Preparing Land	102
Figure 5.3.1	A Woman Carrying Firewood	112
Figure 5.3.1.2	Children Carrying Collected Biomass	112
Figure 5.4.1.1	Charcoal Production System in Rural Community	115
Figure 5.4.1.3.c	A Woman Making Dung Cakes with Cow Dung	117
Figure 5.4.1.3a	A Woman Collecting Cow Dung	118
Figure 5.4.1.3b	A Woman Making Dung Sticks with Cow Dung and Jute Straws	118
Figure 5.4.1.6a	Biogas Plant under Construction	126
Figure 5.4.1.6b	A Woman Cooking with Biogas	126
Figure 5.5.4.1a	A Woman Cooking with Solar Cooker	133
Figure 5.5.4.1b	A Woman Drying Chili with Solar Dryer	133
Figure 8.8.1	Energy Supply and Demand Linkage Model for Rural Bangladesh (Household Purposes)	245
Figure 8.8.2	Energy Supply and Demand Linkage Model for Rural Bangladesh (Commercial Purposes)	246

LIST OF ANNEXES

Annex 1	Sea Level Rise at Low Growth Rate	293
Annex 2	Sea Level Rise at Medium Growth Rate	294
Annex 3	Air Pollution: Photograph taken from Dhaka City	295
Annex 4	Focus Group Interview: Some of the Female Participants of Kutubdia Village	296
Annex 5	Focus Group Interview (PRA Survey) Female Participants Drawing Map of the Area to Suitable Location for Windmill at Loxmikola Village	297
Annex 6	Focus Group Interview (PRA Survey) Male Participants Drawing Map of the Area to Suitable Location for Windmill at Kutubdia Village	298
Annex 7	Living Condition of Focus Group in Kutubdia Village	299
Annex 8	Location of Windmill Site Proposed by Focus Group of Loxmikola Village	300
Annex 9	Location of Windmill Site Proposed by Focus Group of Kutubdia Village	301
Annex 10	Questionnaire for Household Survey	302
Annex 11	Questionnaire of Leadership Opinion Survey	309
Annex 12	Map of Bangladesh	312
Annex 13	Width of Banks of Major Rivers in Bangladesh	313
Annex 14	Intensity and Duration of Sunshine in Bangladesh	317
Annex 15	Wind Speed Data of Bangladesh	322
Annex 16	Concept/ Guideline for Preparing Project Proposal of Capacity Building on Sustainable Energy Technology Transfer	327
Annex 17	Concept of Mann-Whitney Test	348
Annex 18a	Regression Output (Table 7.4.1 a)	351
Annex 18b	Regression Output (Table 7.4.1b)	352

List of Acronyms and Abbreviations

AC	Alternating current
ACRE	Unit of land (1 acre=100 decimals)
ADB	Asian Development Bank
ADP	Annual Development Programme
BBS	Bangladesh Bureau of Statistics
BCIC	Bangladesh Chemical Industries Corporation
BCSIR	Bangladesh Council for Scientific and Industrial Research
BFIDC	Bangladesh Forest Industries Development Corporation
BIDS	Bangladesh Institute of Development
BPC	Bangladesh Petroleum Corporation
BPDB	Bangladesh Power development Board
BRAC	Bangladesh Rural Advancement Committee (NGO)
BRDB	Bangladesh Rural Development Board
BREB	Bangladesh Rural Electrification Board
BSCIC	Bangladesh Small and Cottage Industries Corporation
BTC	British Tobacco Company
btc/year	Billion tons per year
BTV	Bangladesh Television
BUET	Bangladesh University of Engineering and Technology
BUP	Bangladesh Unnayan Parishad
BWDB	Bangladesh Water Development Board
CMI	Census of Manufacturing Industries
CO ₂	Carbon dioxide
DC	Direct current
DE	Department of Environment
DESA	Dhaka Electric Supply Authority
DESCO	Dhaka Electric Supply Company
FCCC	Framework Convention for Climate Change
FFYP	Fourth Five-Year Plan
FFYP	Fifth Five-Year Plan
SFYP	Sixth Five-Year Plan

GHG	Greenhouse gas
GIIP	Gas Initially In Place
GJ	Gigajoule, Energy unit of 10*10
GOB	Government of Bangladesh
GTCL	Gas Transmission Company Limited
Ha	Unit of land measurement
IFAD	International Fund for Agricultural Development
IOC	International Oil Company
IPCC	Inter-Governmental Panel on Climate Change
Kg	Kilogram
LGED	Local Government Engineering Department
LPG	Liquid Petroleum Gas
ME&F	Ministry of Environment and Forestry
MEMR	Ministry of Energy and Mineral Resources
MLR	Multiple Linear Regression
NEP	National Energy Policy
NGO	Non-Government Organisation
OECD	Overseas Economic Cooperation and Development
PC	Planning Commission of the Government of Bangladesh
PJ	Peta Joule, energy unit of 10*15 joules
PRA	Participatory Rural Appraisal
PSC	Production Sharing Contract
PSMP	Power Sector Master Plan
PV	Photovoltaic
REDB	Rural Electrification Development Board
RES	Rio Earth Summit
RISP	Rural Industries Study Project
SET	Sustainable Energy Technology
SFYP	Second Five-Year Plan
SPSS	Statistical Package for Social Science
sq.km.	Square kilometre
tcf	Trillion cubic foot
TFYP	Third Five-Year Plan
TGL	Titas Gas Limited

TOE	Ton of Oil Equivalent
UNDP	United Nations Development Programmes
WAPDA	Water and Power Development Authority
WB	World Bank

Energy Conversion Factors

1000 cft of gas	=	6.4 gallon of crude oil
1000 cft of gas	=	6.5 gallon of furnace oil
1000 cft of gas	=	6.1 gallon of kerosene
1000 cft of gas	=	6.1 gallon of diesel oil
1000 cft of gas	=	6.1 gallon of gasoline oil
1 ton crude oil	=	40 MCF of gas
1 gallon of kerosene oil	=	164 cft of gas
1 gallon of diesel oil	=	164 cft gas
1 mound firewood	=	572 cft gas
1 ton firewood	=	15.5 MCF gas
1 ton coal	=	28.00 MCF gas
1 hectare	=	2.471 acres
1 acre	=	4,046 sq.m
1 acre	=	100 decimals
1 bigha (10cal unit)	=	33 decimals
1 BTU	=	1055 J
1 calorie	=	4.184 J
1 foot	=	0.3048 m
1 sft.	=	0.092903 sq.m
1 yard	=	0.9144 m
1 toe	=	42.7 GJ
1 PJ	=	10 E15 J