

Contents

List of Figures	xv
List of Tables	xxi
List of Abbreviations	xxiv
1 Introduction	1
1.1 Motivation and problem context	1
1.2 Research Questions	3
1.3 Research Methodology and boundary	4
2 Sustainability performance measurement in a product life cycle	7
2.1 Sustainable development context	7
2.1.1 Weak and Strong Sustainability	8
2.1.2 Economic dimension	12
2.1.3 Social dimension	13
2.1.4 Environmental dimension	14
2.2 Sustainability conceptual framework	15
2.3 Scope and focus of sustainability performance measurement	26
2.3.1 Product life cycle and product life cycle management	26
2.3.2 Corporate sustainability vs corporate social responsibility	28

2.4	Introduction to sustainability performance measurement	31
2.5	Sustainability performance measurement terminology	33
2.6	Sustainability performance measurement system: systematic literature review	34
2.6.1	Result of the systematic literature review	35
2.6.2	Global Reporting Initiative (GRI)	38
2.6.3	Life cycle approaches	41
2.6.4	Multiple criteria decision making	46
2.6.5	Statistical methods	47
2.6.6	Discussion on the result of SLR	49
2.6.7	Conclusion	51
3	Sustainability performance measurement conceptual framework	53
3.1	Propose framework of sustainability performance measurement	53
3.2	Defining goals and scope of the measurement	55
3.2.1	The wind turbine industry	55
3.2.2	An overview of the wind turbine's product life cycle	57
3.2.3	Sustainable development in the wind turbine industry	61
3.2.4	Goals and scope definition in the context of the wind turbine industry	65
3.3	Development of the endpoint impact criteria	66
3.3.1	Initial endpoint impact criteria development	67
3.3.2	Delphi methodology	73
3.3.3	Theory of Fuzzy Analytical Hierarchy Process (FAHP)	75
3.3.4	Pair-wise comparison result: consistency test	84
3.3.5	Fuzzy pairwise comparison matrix	85

3.3.6	Calculation of weight vectors: the extent analysis method . . .	87
3.3.7	Calculation of weight vectors: extent analysis modified approach	89
3.3.8	Summary result of FAHP	89
3.4	Development of the midpoint impact criteria	94
3.5	Conclusion	103
4	Design of a scorecard system: a sustainability scorecard	105
4.1	Structure of the sustainability scorecard	105
4.1.1	Concept of the sustainability scorecard	106
4.2	Defining measurement indicators	107
4.2.1	Midpoint impact criteria: Revenue and profit	115
4.2.2	Midpoint impact criteria: Capital investment	117
4.2.3	Midpoint impact criteria: Production process development . . .	118
4.2.4	Midpoint impact criteria: Operating and maintenance cost . . .	119
4.2.5	Midpoint impact criteria: Fair salary	121
4.2.6	Midpoint impact criteria: Freedom of association and collective bargaining	122
4.2.7	Midpoint impact criteria: Discrimination and equal opportunity .	123
4.2.8	Midpoint impact criteria: Health and safety of workers	125
4.2.9	Midpoint impact criteria: Child labor and forced labor	127
4.2.10	Midpoint impact criteria: Working hour	129
4.2.11	Midpoint impact criteria: Training and education of employee .	130
4.2.12	Midpoint impact criteria: Social benefits and social security . .	131
4.2.13	Midpoint impact criteria: Local employment	133
4.2.14	Midpoint impact criteria: Local community acceptability	134

4.2.15 Midpoint impact criteria: Contribution to economic development	135
4.2.16 Midpoint impact criteria: Public commitment to sustainability issue	136
4.2.17 Midpoint impact criteria: Corruption	137
4.2.18 Midpoint impact criteria: Consumer health and safety	138
4.2.19 Midpoint impact criteria: Pollution production	138
4.2.20 Midpoint impact criteria: Environmental management system	140
4.2.21 Midpoint impact criteria: Eco-design	142
4.2.22 Midpoint impact criteria: Resource consumption	144
4.2.23 Midpoint impact criteria: Reverse logistics	145
4.2.24 Summary and conclusion of the measurement indicator development	146
4.3 Sustainability impact score calculation	147
4.4 Integrative Sustainability Triangle (IST)	150
4.5 Conclusion	154
5 Sustainability performance measurement in the product life cycle of wind turbines	155
5.1 Inventory data collection	155
5.2 Sustainability performance result interpretation	184
5.2.1 Overall sustainability performance	184
5.2.2 Endpoint and midpoint impact criteria performance	186
5.2.3 Result analysis	189
5.3 Sustainability scorecard validation	195
5.3.1 Validation of the sustainability scorecard	195
5.4 Conclusion	201

6 Conclusion and research perspectives	203
6.1 Research conclusion	204
6.2 Research discussion	206
6.3 Research limitations and opportunities for future research	208
A Systematic Literature review	211
A.1 Literature review of sustainability performance measurements	211
B Questionnaire for the endpoint impact criteria development	225
B.1 Example of the questionnaire	225
C Fuzzy Analytical Hierarchy Process	233
C.1 Results of pair-wise comparisons and consistency test	233
C.1.1 Pairwise comparison result: expert 1	234
C.1.2 Pairwise comparison result: expert 2	238
C.1.3 Pairwise comparison result: expert 3	242
C.1.4 Pairwise comparison result: expert 4	244
C.1.5 Pairwise comparison result: expert 5	248
C.1.6 Pairwise comparison result: expert 6	252
C.2 Weight vector calculation	256
C.2.1 Weight vector calculation: main criteria	256
C.2.2 Weight vector calculation: economic	260
C.2.3 Weight vector calculation: social	267
C.2.4 Weight vector calculation: environment	274
D Sustainability Scorecard evaluation score	281
D.1 Summary of the sustainability scorecard evaluation result	281

E Sustainability scorecard	291
E.1 Sustainability scorecard interface	291
F Assessment data references	297
F.1 List of references	297
Bibliography	301