Contents

Abstract ..... **iii**

Zusammenfassung ..... **iv**

List of Figures ..... **ix**

List of Tables ..... **xi**

List of Abbreviations ..... **xii**

1 Introduction **1**

1.1 The increasing importance of variable renewable energy sources 1

1.2 Development of spot and balancing markets 4

1.3 Literary focus on intraday markets and the balancing systems 7

1.4 Research questions 8

1.5 Data and methodology 10

1.6 Outline of the thesis 11

2 Short-term electricity trading for system balancing **13**

2.1 Introduction 13

2.2 Background 15

2.2.1 The balancing system 15

2.2.2 Recent developments in balancing 17

2.3 Data and market development 20

2.3.1 Quarter-hourly trading 21

2.3.2 24/7 trading 22

2.4 Methodology 24

2.5 Results 27

2.5.1 Quarter-hourly trading 27

2.5.2 24/7 trading 30

2.5.3 Biased balancing incentives 31

2.6 Conclusions 35

2.7 Appendix 37

3 Passive balancing through intraday trading **39**

3.1 Introduction 39

3.2 Background 41

3.2.1 The balancing system 41

3.2.2 The concept of passive balancing 42

3.3 Materials and methodology 43
3.4 Influence of system balance on intraday prices 47
3.4.1 Correlation analysis 48
3.4.2 Quantile regression model 50
3.5 Impact of passive balancing on system balance 53
3.5.1 Approximation of passive balancing volumes 53
3.5.2 Comparison of system stability indicators 54
3.5.3 Overshooting of system balance 55
3.5.4 Effect of stronger reactions to the system balance 57
3.6 Discussion 58
3.7 Conclusion 59
4 Intraday imbalance optimization 61
4.1 Introduction 61
4.2 Background 62
4.2.1 The balancing system 63
4.2.2 Price incentives for intraday imbalance optimization 64
4.3 Materials and methodology 65
4.4 Results and discussion 70
4.4.1 Model results 70
4.4.2 Trading strategy 73
4.4.3 Impact on system balance 75
4.4.4 Stricter intraday constraint 77
4.5 Conclusion 80
5 Findings and outlook 83
References 87
Statement of contribution 102