

# Table of contents

|          |                                                              |           |
|----------|--------------------------------------------------------------|-----------|
| <b>1</b> | <b>Introduction.....</b>                                     | <b>1</b>  |
| 1.1      | Background.....                                              | 1         |
| 1.2      | Objectives.....                                              | 3         |
| <b>2</b> | <b>Biogas production: State of the art.....</b>              | <b>5</b>  |
| 2.1      | Biogas plants .....                                          | 5         |
| 2.2      | Theory of anaerobic digestion.....                           | 9         |
| 2.2.1    | Disintegration and hydrolysis.....                           | 10        |
| 2.2.2    | Acidogenesis .....                                           | 11        |
| 2.2.3    | Acetogenesis.....                                            | 13        |
| 2.2.4    | Methanogenesis .....                                         | 15        |
| 2.3      | Models for anaerobic digestion.....                          | 16        |
| 2.3.1    | Stationary models .....                                      | 16        |
| 2.3.2    | Dynamic models.....                                          | 18        |
| 2.4      | Conversion processes and their kinetics .....                | 20        |
| 2.4.1    | Disintegration, hydrolysis and decay of microorganisms ..... | 23        |
| 2.4.2    | Substrate and microorganisms growth rate .....               | 24        |
| 2.4.3    | Inhibition of processes.....                                 | 27        |
| 2.5      | Biological process engineering .....                         | 30        |
| 2.5.1    | Reactor types .....                                          | 30        |
| 2.5.2    | Solid retention time and organic loading rate .....          | 32        |
| 2.5.3    | Temperature.....                                             | 35        |
| 2.5.4    | pH and buffer system .....                                   | 36        |
| <b>3</b> | <b>Materials and methods .....</b>                           | <b>38</b> |
| 3.1      | Experiment description .....                                 | 38        |
| 3.1.1    | Lab scale batch biogas plant.....                            | 38        |
| 3.1.2    | Lab scale quasi-continuous reactor .....                     | 39        |

|          |                                                                                        |            |
|----------|----------------------------------------------------------------------------------------|------------|
| 3.2      | Laboratory analysis and calculation .....                                              | 41         |
| <b>4</b> | <b>Mathematical modelling and simulation.....</b>                                      | <b>47</b>  |
| 4.1      | Model implementation .....                                                             | 47         |
| 4.2      | Input characteristics .....                                                            | 62         |
| 4.3      | Simulation procedure .....                                                             | 63         |
| 4.4      | Model calibration and validation .....                                                 | 64         |
| 4.5      | Sensitivity analysis.....                                                              | 66         |
| <b>5</b> | <b>Results and discussion .....</b>                                                    | <b>67</b>  |
| 5.1      | Batch experiments and results.....                                                     | 67         |
| 5.2      | Quasi-continuous experiments and results for maize silage anaerobic<br>digestion ..... | 70         |
| 5.3      | Quasi-continuous experiments and results for sugar beet silage .....                   | 81         |
| 5.4      | Model parameters sensitivity .....                                                     | 97         |
| <b>6</b> | <b>Conclusion and future work.....</b>                                                 | <b>99</b>  |
| <b>7</b> | <b>List of abbreviations and symbols .....</b>                                         | <b>102</b> |
| <b>8</b> | <b>Bibliography .....</b>                                                              | <b>106</b> |
| <b>9</b> | <b>Appendices .....</b>                                                                | <b>112</b> |