

Sebastian Rainer Awiszus

**Environmental impact of a  
biogas plant with digestate  
processing and lactic acid  
extraction from silages**



UNIVERSITY OF  
HOHENHEIM

INSTITUTE OF AGRICULTURAL ENGINEERING  
Tropics and Subtropics Group  
PROF. DR. JOACHIM MÜLLER

**Environmental impact of a biogas plant with digestate  
processing and lactic acid extraction from silages**

Dissertation

Submitted in fulfillment of the requirements for the degree of  
*“Doktor der Agrarwissenschaften”*  
(Dr.sc.agr.)

to the  
Faculty of Agricultural Sciences

presented by

Sebastian Rainer Awiszus  
Born in Radolfzell am Bodensee

2019

This thesis was accepted as a doctoral dissertation in fulfillment of the requirements for the degree “Doktor der Agrarwissenschaften” by the Faculty of Agricultural Sciences at Universität Hohenheim on 04.09.2019.

Date of oral examination: 24.10.2019

**Examination Committee**

Prof. Dr. Joachim Müller	(Supervisor and Reviewer)
Prof. Dr. –Ing. Artur Mennerich	(Co-Reviewer)
apl. Prof. Dr. Eva Gallmann	(Additional examiner)
Prof. Dr. Jörn Bennewitz	(Deputy of the Dean)

Schriftenreihe des Lehrstuhls für Agrartechnik in den Tropen und  
Subtropen der Universität Hohenheim  
herausgegeben von Prof. Dr. Joachim Müller

Band 2019/17

**Sebastian Rainer Awiszus**

**Environmental impact of a biogas plant  
with digestate processing and lactic acid extraction  
from silages**

D 100 (Diss. Universität Hohenheim)

Shaker Verlag  
Düren 2019

**Bibliographic information published by the Deutsche Nationalbibliothek**

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at <http://dnb.d-nb.de>.

Zugl.: Hohenheim, Univ., Diss., 2019

Copyright Shaker Verlag 2019

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the publishers.

Printed in Germany.

ISBN 978-3-8440-7054-5

ISSN 1867-4631

Shaker Verlag GmbH • Am Langen Graben 15a • 52353 Düren

Phone: 0049/2421/99011-0 • Telefax: 0049/2421/99011-9

Internet: [www.shaker.de](http://www.shaker.de) • e-mail: [info@shaker.de](mailto:info@shaker.de)

## Acknowledgements

I would like to express my gratitude to all those who supported me in completing this dissertation. The work of this dissertation was carried out within the framework of the project *GOBi-Ganzheitliche Optimierung der Biogasprozesskette*, financed by the Federal Ministry of Education and Research (BMBF), represented by the project management Jülich (PTJ) under the grant number 03EK3525A from 01.06.2013 – 31.05.2016.

First of all, I would like to express my sincere thanks to Prof. Dr. Joachim Müller for supervising my work. His scientific guidance and his empathy were the cornerstones of my journey as a doctoral student at all times. Furthermore, I would like to express my great gratitude to my daily supervisor Dr. Klaus Meissner for always keeping me on the right track and supporting all of my work faithfully. Many thanks goes to Prof. Dr. Artur Mennerich for his willingness and his effort for providing the second assessment.

Since it is not possible to work purposefully without a supporting atmosphere, my special appreciation goes to my office mates and friends Sebastian Reyer, Ziba Barati, Alice Reineke and Bastian Stürmer-Stephan. I would like to thank them for their input and feedback to my work, for the numerous scientific discussions and the great joyful time in room 0024/4.

My special thanks goes to our administrative staff, Sabine Nugent and Ute Kayser for helping me through the bureaucratic-jungle and correcting my manuscripts. Further thanks go to our lab team, Sarah Fleischmann, Olga Gotra, Ute Waldeck, Dorothea Hirschbach-Müller, for analysing my odorous digestate samples with highest accuracy. Thank you for always supporting me and my experiments in an amicable atmosphere with your expertise and effort. I also would like to thank the team of the wood-, metal- and electronics workshop for their assistance and efforts to convert my ideas into viable devices and constructions.

I am very grateful to my parents, my stepmother, my parents-in-law and my family for their great and unconditional support during my long educational journey, always providing advice and assistance.

My special gratitude goes to my wife Maryna. Words can't describe the value of your unwavering love and great support during all the ups and downs during my life and all phases of my work as a doctoral student and while completing this dissertation.

Hohenheim, April 2019

Sebastian Awiszus

## Table of contents

<b>1</b>	<b>General introduction .....</b>	<b>1</b>
1.1	The biogas production sector in Germany .....	1
1.2	Drying of biogas digestate.....	3
1.3	Nutrient recovery from digestate.....	4
1.4	Extraction of lactic acid from silages .....	4
1.5	Bio-refinery concepts .....	5
1.6	Problem statement - Challenges of biogas production systems .....	5
1.7	Objectives and structure of research .....	6
1.8	References .....	8
<b>2</b>	<b>Part I: Utilization of digestate in a convective hot air dryer with integrated nitrogen recovery.....</b>	<b>11</b>
2.1	Abstract .....	11
2.2	Introduction .....	11
2.3	Material and methods .....	12
2.3.1	Material.....	12
2.3.2	Two belt dryer and ammonia recovery.....	13
2.3.3	Measuring of the air composition .....	14
2.3.4	Experimental design .....	15
2.4	Results and discussion.....	16
2.4.1	Air flow .....	16
2.4.2	Energy consumption .....	17
2.4.3	Impact of the drying on the nutrient content of the solid fraction digestate .....	18
2.4.4	Ammonia emissions and ammonia scrubber .....	18
2.5	Conclusion.....	20
2.6	References .....	21

<b>3</b>	<b>Part II: Ammonia and methane emissions during drying of dewatered biogas digestate in a two-belt conveyor dryer.....</b>	<b>23</b>
3.1	Abstract .....	23
3.2	Introduction .....	23
3.3	Material and methods .....	26
3.3.1	Two-belt conveyor dryer .....	27
3.3.2	Measurement of air condition .....	30
3.3.3	Experimental design .....	30
3.4	Results and Discussion .....	31
3.4.1	Effect of digestate drying on the nutrient composition.....	31
3.4.2	Emissions during digestate drying.....	32
3.4.3	Ammonia scrubber .....	34
3.5	Conclusion.....	35
3.6	Acknowledgements .....	35
3.7	References .....	36
<b>4</b>	<b>Part III: Gas releasing potential of biogas digestate .....</b>	<b>39</b>
4.1	Abstract .....	39
4.2	Introduction .....	41
4.3	Material and methods .....	42
4.3.1	Types of biogas digestate.....	42
4.3.2	Experimental design .....	44
4.3.3	Analysis .....	45
4.4	Results and discussion.....	45
4.4.1	Ammonia .....	45
4.4.2	Methane .....	47
4.4.3	Carbon dioxide .....	49
4.5	Conclusion.....	52
4.6	Acknowledgements .....	52
4.7	Declaration of interest .....	52
4.8	Funding.....	52



4.9	References .....	53
<b>5</b>	<b>Part IV: Environmental assessment of a bio-refinery concept comprising biogas production, lactic acid extraction and plant nutrient recovery .....</b>	<b>56</b>
5.1	Abstract .....	56
5.2	Introduction .....	56
5.3	Materials and Methods .....	59
5.3.1	Scope and goal definition .....	59
5.3.2	Life Cycle Inventory.....	61
5.3.3	Life Cycle Impact Assessment .....	73
5.4	Results .....	73
5.4.1	Reference scenario.....	73
5.4.2	Nutrient recovery.....	76
5.4.3	Lactic acid extraction.....	77
5.4.4	Comparison of scenarios.....	78
5.5	Discussion .....	80
5.6	Conclusions .....	83
5.7	Funding.....	84
5.8	Acknowledgments .....	84
5.9	Conflicts of Interest .....	84
5.10	References .....	85
<b>6</b>	<b>General discussion.....</b>	<b>89</b>
6.1	Energy demand of digestate drying.....	89
6.2	Gas releasing potential during the drying of biogas digestate.....	89
6.3	Benefits of digestate drying.....	91
6.4	Environmental impacts of nutrient recovery from biogas digestate and generation of lactic acid from silages.....	92
6.5	Outlook.....	94
6.6	References .....	96

<b>7</b>	<b>Summary .....</b>	<b>99</b>
<b>8</b>	<b>Zusammenfassung .....</b>	<b>103</b>
<b>9</b>	<b>Curriculum Vitae.....</b>	<b>107</b>
<b>10</b>	<b>Publications .....</b>	<b>109</b>