BIOENERGY
DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY

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18TH/19TH SEPTEMBER, 2023

UNIVERSITY OF APPLIED SCIENCES AND ARTS
HILDESHEIM/HOLZMINDEN/GÖTTINGEN

TAGUNGSREADER
28

#DOC2023
WWW.DOC-BIOENERGY.DE

IMPRINT

Published by:
DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH
Torgauer Straße 116
04347 Leipzig
Phone: +49 (0)341 2434 - 112
E-Mail: info@dbfz.de

Funded by:
Federal Ministry of Food and Agriculture
on the basis of a resolution of the German Bundestag

With support from
Federal Ministry of Food and Agriculture
by decision of the German Bundestag

General management:
Prof. Dr. mont. Michael Nelles (Scientific Managing Director)
Dr. Christoph Krukenkamp (Administrative Managing Director)

DBFZ Tagungsreader, Nr. 28
6th Doctoral Colloquium BIOENERGY
18th/19th September, 2023, Goettingen
ISSN: 2199-9856 (online)
ISBN: 978-3-949807-10-7
DOI: 10.48480/dvmt-q267

Date of publication: 09/04/2024

Pictures: © DBFZ/HAWK

Design: Beate Kämpf / **DTP:** Paul Trainer

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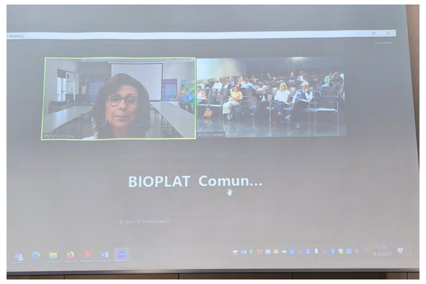
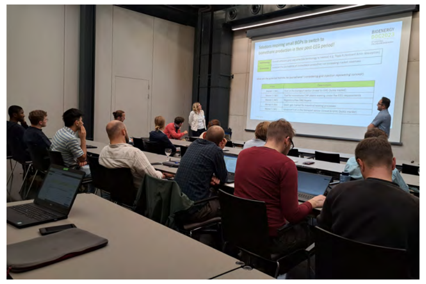
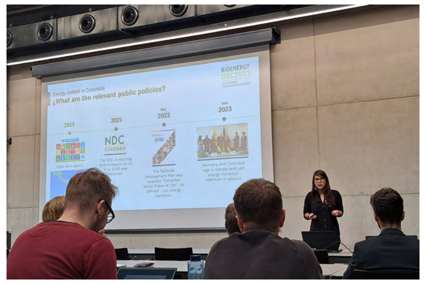
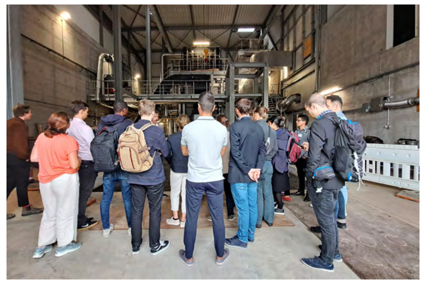
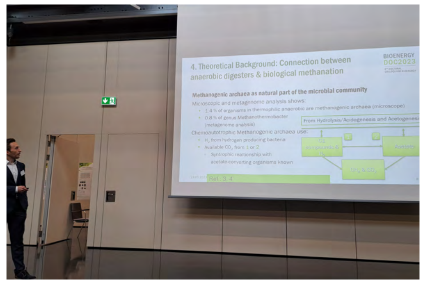







Pictures: Prof. Dr. Achim Loewen (HAWK)

6TH DOCTORAL COLLOQUIUM BIOENERGY

GREETINGS

Greetings from our host, Prof. Dr. Achim Loewen

Dear Participants of the 6th Doctoral Colloquium BIOENERGY,

energy supply is an essential basic need of humankind. However, climate change and other environmental impacts are endangering ecosystems worldwide and thus important foundations of life. In addition, also crises such as the war in Ukraine enforce a re-thinking about energy sources, energy generation and distribution technologies as well as energy consumption in all different sectors. Wind and solar energy will play an increasingly important role, but are fluctuating strongly and still cannot cover the rising global demand. Therefore, bioenergy can provide an important contribution for electricity, heat and fuel production. Nevertheless, as also biomass availability is limited, it is important to apply only sustainable resources in most efficient conversion paths, e.g. in biorefineries with integral production of energy, fuels, platform chemicals or other products.

Especially the use of biogenic residual and waste materials for energy generation can at the same time replace fossil fuels and reduce treatment costs. The co- and cascade use of biogenic resources is a central element of a climate-neutral bioeconomy. Carbon and nutrient cycles are to be closed, whereby the smart use of biomass in interaction with the other renewable energy sources should take place where the greatest system benefit is achieved in an increasingly digitalized society. Therefore, a comprehensive consideration and optimization of entire process chains in terms of sustainability is necessary and life cycle analyses need to be performed not only from cradle to grave, but from cradle to cradle.

The 6th Doctoral Colloquium Bioenergy held 2023 at the HAWK University of Applied Science and Arts in Göttingen has once again shown that numerous engaged and ambitious young scientist worldwide are working on developing and optimizing biomass-based approaches and technologies for a more sustainable future. We do not have much time left for the transition of our economies, but based on the presentations given in the conference I am still optimistic that solutions for the challenges mentioned above can be available and applied within the next years.

Prof. Dr. Achim Loewen (HAWK)

Finally yet importantly, I would like to thank all participants for their interesting contributions, the organizing team in Göttingen and Leipzig for their tireless commitment and the programme committee for evaluating the abstracts and moderating the sessions. All of you together made it possible to carry out the conference successfully, and I am looking forward to seeing many of you again next year at the 7th Doc BIOENERGY in Leipzig.

With kind regards,

Prof. Dr. Achim Loewen
(University of Applied Sciences and Arts Hildesheim/Holzminden/Göttingen)

Greetings from our patron, Prof. Dr. Daniela Thrän

Dear Participants of the 6th Doctoral Colloquium BIOENERGY,

we recall on two incredibly productive days of the 6th Doctoral Colloquium BIOENERGY (DOC2023), which were filled with inspiring lectures and discussions, intense scientific debates, and a vibrant conversation with Myrsini Christou, the Joint Programme Coordinator of EERA Bioenergy.

This year in Göttingen (Germany), 42 participants from ten countries (Austria, China, Columbia, Germany, Great Britain, India, Iran, Italy, Norway and Pakistan) presented and discussed their new results and findings in over 30 lectures, scientific posters and one engaging „get-in-touch session".

And you all, dear participants, made this event a success. Through your high-level oral and poster presentations, we all were able to learn more about your current PhD projects in the area of bioenergy and bioeconomy in Europe and some cases worldwide. We discussed your latest results and findings, and networked along interactive group activities like our scientific Talk Show on "Climate protests that make a difference". We really enjoyed DOC2023 event with you!

One thing has become clear, that it is not only the bioenergy technology but more and more the social, legal, and institutional context, which pave the road to a sustainable bioenergy in resilient net-zero bio-economy and renewable energy systems. We also learned, that with better use of data driven approaches, new research approaches came into the game and enable us for better and faster management of the bioeconomy value chains - from process optimisation to holistic assessment concepts.

With the valuable support of the Program Committee members, we successfully arranged an engaging and captivating program for the sixth time in a row. The program consisted of five oral sessions, one core poster session & exhibition. The conference programme was rounded off by a tour of the HTWK NEUTEC - Sustainable Energy and Environmental Technology department and the BioWärme-Zentrum Stadtwerke Göttingen.

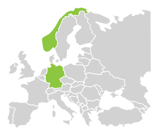
Prof. Dr. Daniela Thrän (DBFZ/UFZ/Uni Leipzig)

Finally yet importantly, we would like to congratulate the winner of the Best Scientific Poster >> Mr Matthis Kurth from the DBFZ for his convincing poster presentation, the scientific content of his PhD project (Topic "Binary mass transport through a nano porous carbon membrane layer. Usage of Maxwell-Stefan surface diffusion and experimental verification") and of course appealing layout of his poster. As a follow-up to our successful event in Göttingen, I am pleased to present the Conference Reader of the 6th Doctoral Colloquium BIOENERGY to you all. In this conference reader, you will find all the abstracts, presentation slides and posters.

I wish you an informative read and hope to see you all again next year at the 7th Doctoral Colloquium BIOENERGY (DOC2024) on 24./25. September 2024 at DBFZ in Leipzig!

Prof. Dr. Daniela Thrän
DBFZ / UFZ / University of Leipzig

The recent history of the Doctoral Colloquium BIOENERGY

1st Doctoral Colloquium BIOENERGY 2018	2nd Doctoral Colloquium BIOENERGY 2019	3rd Doctoral Colloquium BIOENERGY 2020	4th Doctoral Colloquium BIOENERGY 2021
Initiator and host: DBFZ, Leipzig	Host: FAU, Nuremberg	Host: DBFZ, Leipzig	Host: KIT, Karlsruhe
71 Participants	51 Participants	185 Participants	70 Participants
 Participants from Germany	 Participants from Germany and Norway	Participants from Algeria, Austria, Brazil, France, Germany, India, Indonesia, Ireland, Mexico, Netherlands, Nigeria, Norway, Poland, Sweden, Switzerland, Turkey and USA	Participants from Austria, Brazil, Canada, China, Germany, Ghana, Greece, Iran, Nigeria, Poland, Russia, Syria, Thailand and Zambia
Scientific Advisory Board 9 Members representing 11 Institutions	Scientific Advisory Board 34 Members representing 27 Institutions	Scientific Advisory Board 46 Members representing 37 Institutions	Scientific Advisory Board 46 Members representing 37 Institutions

5st Doctoral Colloquium BIOENERGY 2022	6nd Doctoral Colloquium BIOENERGY 2023	7nd Doctoral Colloquium BIOENERGY 2024
Host: DBFZ, Leipzig	Host: HAWK, Goettingen	Host: DBFZ, Leipzig
75 Participants	42 Participants	
Participants from Austria, Belgium, China, Columbia, Denmark, France, Germany, Ghana, Greece, India, Indonesia, Iran, Iraq, Italy, Norway, Pakistan, Phillipines, Republic of Cameroon, South Africa, Spain, Sweden and Switzerland	Participants from Austria, China, Columbia, Germany, Great Britain, India, Iran, Italy, Norway and Pakistan	
Scientific Advisory Board 46 Members representing 37 Institutions	Scientific Advisory Board 46 Members representing 37 Institutions	

POSTERSESSION /
POSTER SPEED PRESENTATION

6TH DOCTORAL COLLOQUIUM BIOENERGY

Sebastian Foth, University of Rostock

Options for the material and energy recovery of water care material (WCM) from the maintenance of water bodies

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In Germany, the federal states are responsible for the categorization and maintenance of the surface water bodies. The legal regulations for this are contained in the Federal Water Act (WHG) and in the corresponding state water laws. In Mecklenburg-Western Pomerania, 27 independent water and soil associations (WBV) are responsible for the maintenance of second order water bodies. These are medium-sized streams that are important in terms of their characteristics from the perspective of water management. Through the development and maintenance of more than 18,000 km of surface water (e.g. ditches and cannels), the WBV contribute to securing flood runoff in the public interest. In the last decades, the WBV are increasingly required to focus their work on the needs of nature conservation and environmental protection. Often the WBV are not able to follow the recommendations and regulations of nature conservation because of economic reasons. For example, the removal and disposal of WCM from the water system after maintenance poses major logistical and financial strains for the WBV.

In a current study, drone technology was used to determine the biomass potential of WCM in terms of utilization and the amount of nutrients accumulated by waterbody-associated vegetation. Preliminary results show that an estimated 36,000 tons of DM are potentially available for material and energy recovery each year throughout Mecklenburg-Western Pomerania.

The harvested material is usually left in the slope area without further utilization. When the biomass rots, the nutrients bound in it return to the profile, which has negative effects on the trophic conditions in the water body. In addition, berms form over time in the slope area, which restrict the surface runoff of surrounding areas. Against the background that the harmlessness of the harvested biomass can be assumed in principle, there are many valuable utilization options in the field of material and energy recovery. To illustrate this, various investigated recycling paths (Composting, Anaerobic digestion, Carbonization, Soil improver) are presented in this study from an economic as well as an ecological point of view.

The long-term goal is to develop an utilization perspective for the usable resource WCM. There are ecological and economic interests in the development of new biomass sources and innovative utilization and recycling concepts. In accordance with the principles of the circular economy, there is a demand not to concentrate material loads in the system, but to decompose them by means of innovative treatment, refinement and utilization processes.

In the context of current status or ecological potential of our water bodies, which do not meet the requirements and objectives of the Water Framework Directive, ecologically oriented water body management is the basic prerequisite for improving water body quality. The approach to harvest and utilize highly productive free available biomass from water maintenance for recovery may therefore serve as a model for an economically and environmentally sustainable water body management.

BIOENERGY DOC2023 | 6TH DOCTORAL COLLOQUIUM BIOENERGY

18-19 SEPTEMBER 2023, GÖTTINGEN

Options for the material and energy recovery of water care material (WCM) from the maintenance of water bodies

Sebastian Foth, Department of Waste and Resource Management, University of Rostock

Background

In Mecklenburg-Western Pomerania, the water and soil associations organizing the maintenance of second order water bodies. More than 18,000 km of surface water (e.g. ditches and canals) every year will be freed from water vegetation to avoid hydraulic damage. The method and extent of water maintenance are largely determined by the type of water body and the uses in the catchment area [1].
Preliminary results show that an estimated 36,000 tons of DM are potentially available for material and energy recovery each year throughout Mecklenburg-Western Pomerania. Depending on the method of cutting the vegetation, the WCM consist of mainly macrophytes of the water body profile. In addition, it can contain of wood, soil substrate, water and other impurities. Challenging substrate handling, additional costs for water maintenance as well as increasing disposal costs have so far restricted the stakeholders from politics, municipalities and industry from launching state-wide initiatives for the implementation of a value chain for the resource WCM.

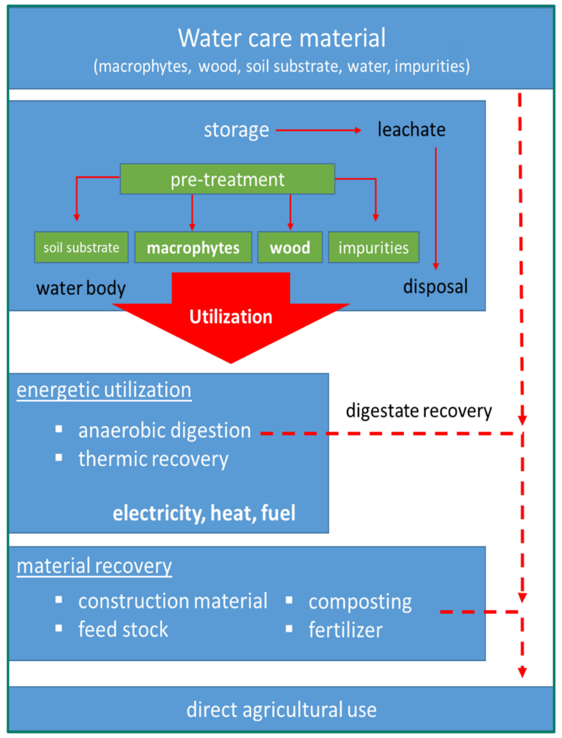

Figure 1: Schematic illustration of the composition, treatment and potential use of WCM

Energetic utilization

Anaerobic digestion

The Ministry of Economics, Labor and Tourism of Mecklenburg-Western Pomerania states already in 2009 that an energy recovery of WCM in biogas plants can be ecologically and economically valuable [2].
The material produced during the annual water maintenance differs in terms of properties, acquisition and handling from most of the conventionally used substrates for the production of biogas. It is therefore recommended to utilize the material in a mixture with conventional substrates. Preliminary studies confirm that WCM can be used in biogas production and is able to at least partially replace conventional substrates such as corn silage [3].

Thermic recovery

The energy recovery of water-associated biomass, such as *Phragmits australis*, *Carex sp.*, *Phalaris arundinacea* or *Typha sp.* provides high energy yields, e.g. in solid fuel combustion plants. Challenges in yield balancing in this context are the heterogeneity of the harvested biomass and the associated non-standardized substrate properties [4].

Hydrothermal carbonization

This thermochemical process, that simulates the natural process of charring, transform the biomass into a material with a higher calorific value similar to lignite. This conversion requires a lot of energy and water. In addition, complex pre-treatment, such as intensive shredding, is necessary. However, studies determines the suitability of water care material (WCM) for a utilization in hydrothermal carbonization (HTC). The end product can be utilized in thermic recovery or used as a soil improver due to its high particle surface and material composition.

Material recovery

Due to its composition and properties, WCM is also suitable for various material recycling paths, such **construction material** production, **composting**, **feed stock** or as **fertilizer**. In this way, the accumulated nutrients can be distributed in the system or permanently bound. To achieve a high and consistent quality of the product, the harvest method as well as pretreatment is particularly important. An already practiced alternative, is the direct distribution of the biomass on agricultural land.

Conclusion

There are ecological and economic interests in the acquisition of new biomass sources and development of innovative utilization and recycling concepts. In accordance with the principles of the circular bioeconomy, there is a demand not to concentrate material loads in the system, but to decompose them. In the context of energy crisis, land use competition and current status or ecological potential of our water bodies, economically and ecologically oriented water body management is the basic prerequisite. The approach to harvest and utilize highly productive free available biomass from water maintenance for recovery may therefore serve as a model for an sustainable water body management.

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Christoph Siol, Deutsches Biomasseforschungszentrum

Environmental and economic life-cycle assessments of residual biomasses in agricultural and forestry – a review

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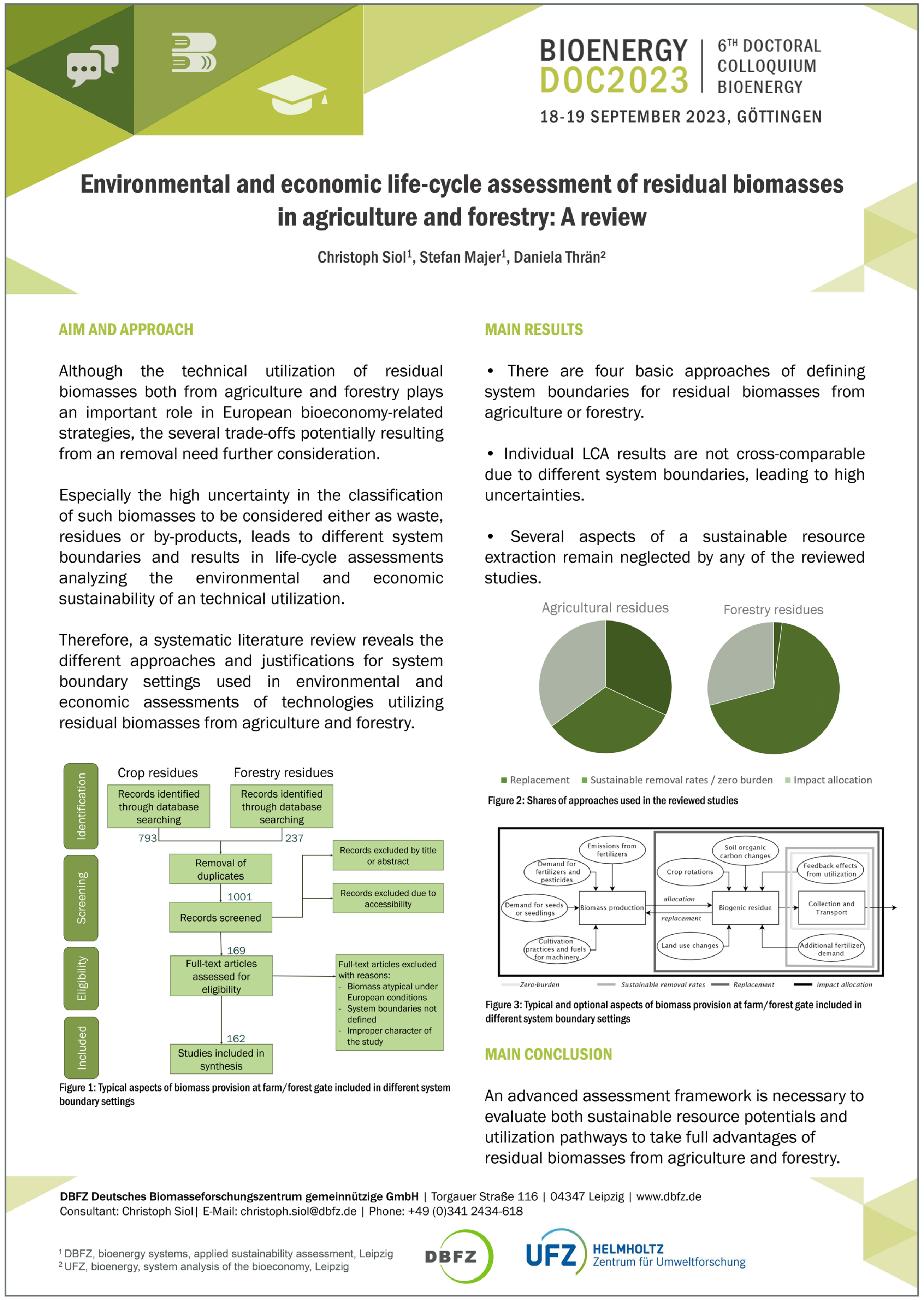
Increasing utilization of residual biomasses from agriculture and forestry raises the question of limits and trade-offs regarding sustainable extraction and utilization. There is a controversial debate on this topic, not at least because of vague requirements for farmers and operators to monitor the complex effects on soil health and fertility resulting from an extraction of such biomasses. To ensure a sustainable resource provision it is necessary to address the various trade-offs by appropriate assessment methods.

A systematic literature review of 162 studies has revealed how environmental and economic Life-Cycle Assessments (LCA) handle the multi-functionality of agricultural and forest production systems. The review identified basic approaches of system boundary settings as well as capabilities and limitations regarding sustainable resource extraction. It showed that individual LCA results are not cross-comparable, leading to high uncertainties regarding the actual life-cycle impacts of a technical utilization. Several aspects of sustainable resource extraction remain neglected by any of the reviewed studies, e.g. effects of soil organic carbon build-up on soil fertility, soil biodiversity, and crop yields or replacement effects when residual biomasses are already used for other purposes.

Furthermore, the review indicates that there is a need for an advanced assessment framework capable of addressing various impacts from a life-cycle sustainability perspective, focusing on assets and drawbacks of different management practices and utilization strategies. The development of an advanced assessment framework will base on a set of appropriate indicators and methods and will contribute to the ongoing debate about benefits and trade-offs of sustainable extraction and utilization of residual biomasses from agriculture and forestry.



Muhammad Sadr, Helmholtz Centre for Environmental Research

Modeling the integration of BECCS into the German bioenergy system

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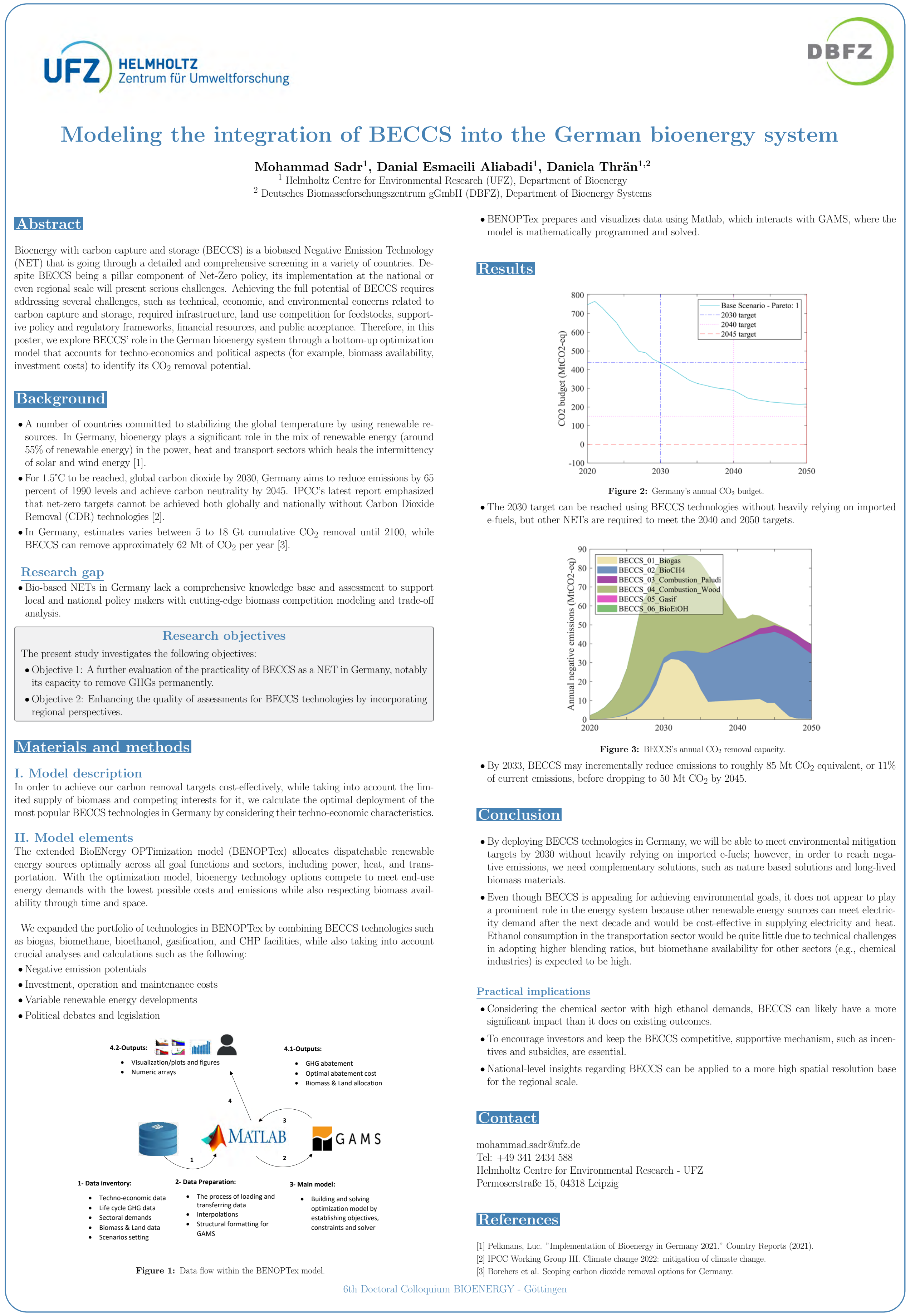
Bioenergy with carbon capture and storage (BECCS) is a biobased Negative Emission Technology (NET) that is going through a detailed and comprehensive screening in a variety of countries. IPCC's latest report emphasized that net-zero targets cannot be achieved both globally and nationally without Carbon Dioxide Removal (CDR) technologies. Germany aims to achieve carbon neutrality by 2045 and from 2050 onwards, it plans to have a negative emissions balance. This means removing more greenhouse gases (GHG) than it emits. In Germany, estimates range from 5 to 18 Gt cumulative CO_2 removal until 2100 while BECCS has a potential of 0.5 to 29.6 Mt CO_2 per year. Despite BECCS being a pillar component of Net-Zero policies, its implementation on a national or even regional scale will present serious challenges.

The technical, economic and environmental concerns in carbon capture and storage, required infrastructure, land use competition for feedstock, supportive policy and regulatory frameworks, financial resources, and public acceptance are among the obstacles BECCS must overcome to reach its full potential. Therefore, we analyze the role of BECCS in the German bioenergy system with a bottom-up optimization model, which accounts for techno-economics and political aspects of BECCS (e.g., availability of biomass, investment costs). The analysis is based on today's bioenergy provision being very decentralized which contributes to the reduction of fossil fuel usage by using locally sourced feedstocks. Our findings will provide a better understanding of BECCS feasibility and viability in Germany within the bioenergy context, and its potential to meet the targets by removing GHG. In addition, using insights from a national standpoint can allow BECCS to expand to a more high spatial resolution basis in Germany. The results as a computational decision support will also assist policymakers in creating development roadmaps for BECCS.



Sören Richter, Deutsches Biomasseforschungszentrum

Explorative scenarios for system integration of biorefineries in cascaded material flows within a future circular bioeconomy in Germany up to 2045

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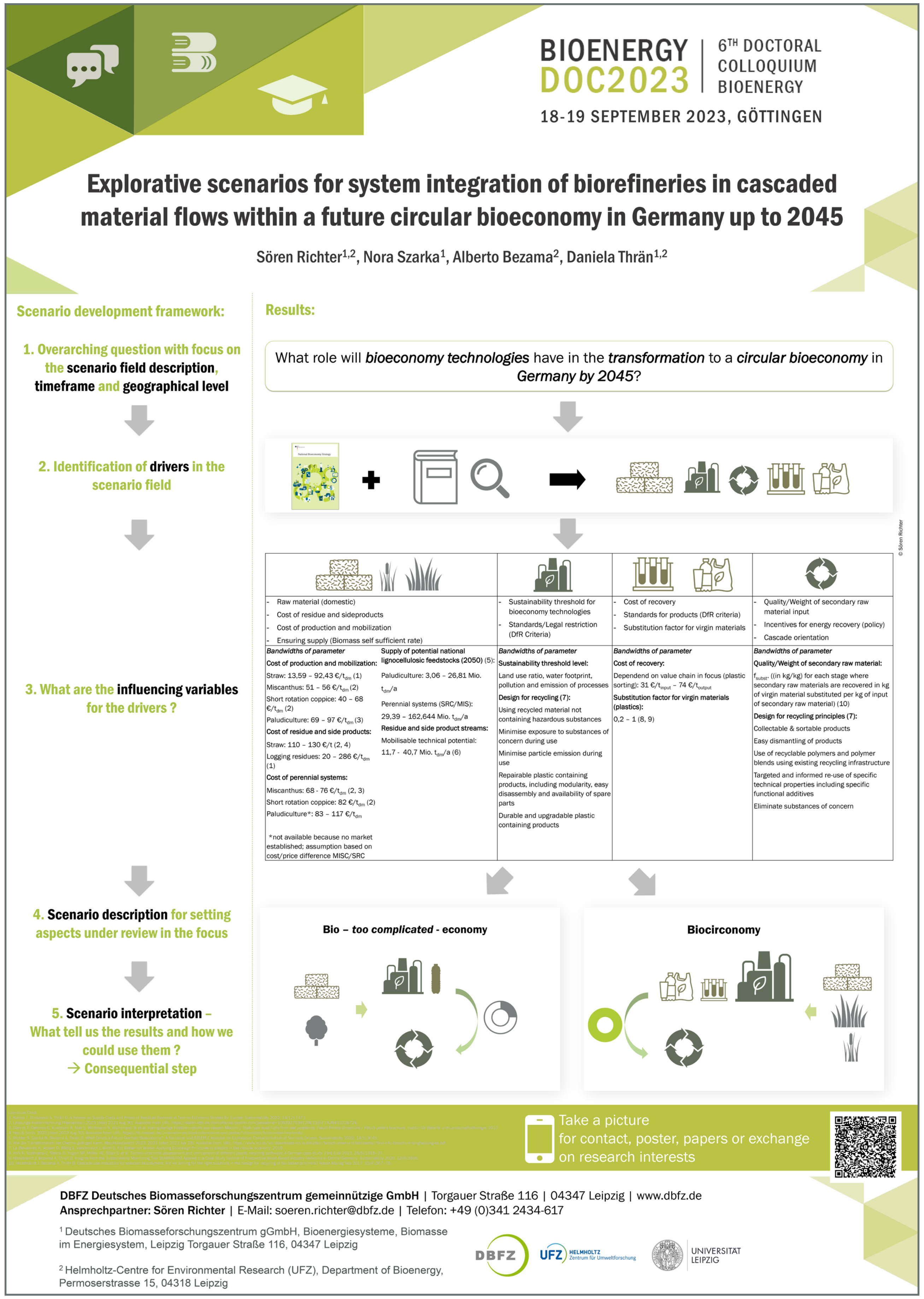
A future bioeconomy will be central to the reduction of the environmental impact of fossil-based energy and material flows [1 - 10.2777/792130]. Various documents such as the German National Bioeconomy Strategy 2020 (GNBS 2020) indicate that there will be not one bioeconomy in the future but several different ones based on country specifications in biomass availability, industries and regional value chains. To elaborate these characteristics, in our previous work we identified 19 drivers for a future German bioeconomy based on this national strategy paper [2 - 10.3390/su14053045]. Among these drivers' biogenic residues and side product streams; production plants of bioeconomy products; cascade principle; fully recyclable biopolymers and environmentally-friendly chemicals are considered particular important. Additional they follow the observed technology-oriented perspective of the strategy. In the work presented, the analysis examined the interface between production plants of bioeconomy products, here biorefineries, and the cascade principle as a first step towards a circular economy. Therefore, explorative scenarios for distinct biorefineries through to 2045 will be developed, that illustrate their future role in a more circular oriented German bioeconomy.

The identified drivers are used in connection to literature based specific barriers and drivers for biorefineries and the circular (bio)economy to define impact categories that are analysed in the scenarios. Following, an overview of biorefineries in Germany is given and, on the basis of interviews with stakeholders, the status quo and future perspectives of material biomass flows in a circular economy is elaborated. The data collected is used to develop explorative scenarios. The focus is on increasing the circularity of material flows and identifying the enabling and disabling policy environment.

Obtained biorefinery overview is concentrated on biorefinery plants that are built for the specific purpose of material and chemical production of products based on biomass in Germany. The elaborated drivers and barriers from the literature review and stakeholder interview illustrating opportunities for circular oriented bio-based material flows. The developed scenarios demonstrate the influence of increasing biorefinery plant implementation onto circular material flows and identify policies that are enabling or disabling for a higher shares of circular material flows.

Based on the developed scenarios, integration opportunities and barriers of biorefineries within a future German circular bioeconomy could be specified and sequential step for a transparent scenario development within the field of bioeconomy could be presented.



Martin Dotzauer, Deutsches Biomasseforschungszentrum/University of Leipzig

Simulating the future development of bioenergy plants in the german power sector using object-oriented programming

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Bioenergy is one major renewable energy sources in the German power sector. It accounts for about 18 % of total renewable power generation in 2022. Limited biomass potentials and increasing installations of wind- and solar power plants will shrink the relative share in the coming years. Nevertheless, flexible bioenergy plants could play an important role for balancing residual load fluctuations, even more important after the prices for natural gas rise and security of supply dropped last year. Federal government set a goal of 8.4 GW installed capacity in 2030 which is very close to the recent portfolio capacity. But it is not clear if a sufficient number of plant operators can manage the increasing challenges of rising prices for input materials, competing market opportunities for biomethane and increasing number of regulations, to reach the goal.

The current tendering scheme of the EEG is the dominating regulation to control the installation of new as well as the consecutive operation of existing bioenergy plants. Since the tendering scheme is very complex and the results for the coming rounds cannot be simply extrapolated it is unclear if the regulation is suitable for reaching the defined goals. To tackle this blind spot for assessing the current regulation framework an agent-based modelling (ABM) approach can be used to simulate the tendering mechanism in detail. Using object-oriented programming (OOP) the simplified behaviour of all bioenergy plants can be mimicked to capture all relevant aspects of the current tendering scheme. The high granularity, OOP is operating at individual plant level, is later aggregated to major groups of bioenergy plants in the power sector to achieve results for the whole plant fleet. Beside technical key numbers (installed capacity and generated electricity) the OOP-approach allow also be to include even more aspects, such as the used amounts of biomass, generated heat or spatial analytics for smaller regions like the German federal states. Since most energy system models are following a fundamental approach to model the future development, ABM in contrast can better represent the effects and interaction of and between individual entities. Thus, this work can complement other research approaches and support decision making for the future role of biomass in the energy system.

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Simulating the future development of bioenergy plants in the German power sector using object-oriented programming

M.Sc. Martin Dotzauer[1]

Background

Bioenergy is one major renewable energy sources in the German power sector. It accounts for about 18 % of total renewable power generation in 2022. Limited biomass potentials and increasing installations of wind- and solar power plants will shrink the relative share in the coming years. Nevertheless, flexible bioenergy plants could play an important role for balancing residual load fluctuations, especially after prices for natural gas rise and security of supply dropped last year. Federal government set a goal of 8.4 GW installed capacity in 2030 which is very close to the recent portfolio capacity (Fig. 1). But it is unclear if a sufficient number of plant operators can manage the increasing challenges of rising prices for input materials, competing market opportunities for biomethane and new regulations, to reach the goal.

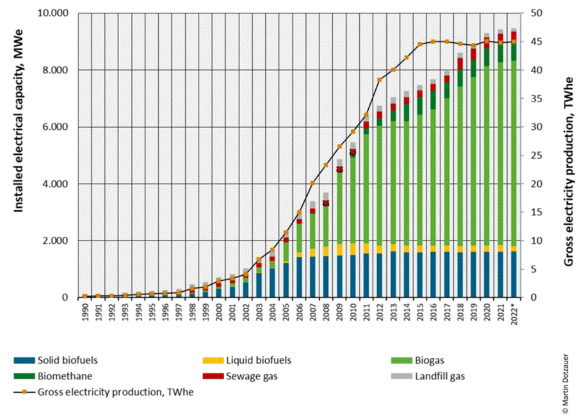

Figure 1: Fleet development of bioenergy plants in the German power sector, Own illustration, DBFZ 2022. Database: time series of the AGEE-Stat from 1990 -2021 (BMWK 2022).

Method

Tendering scheme of the EEG control the installation of new as well as consecutive operation of existing plants (Fig. 2). To tackle the complexity of the tendering mechanism an agent-based modelling (ABM) approach is used. Bioenergy plants were simulated using object-oriented programming (OOP).

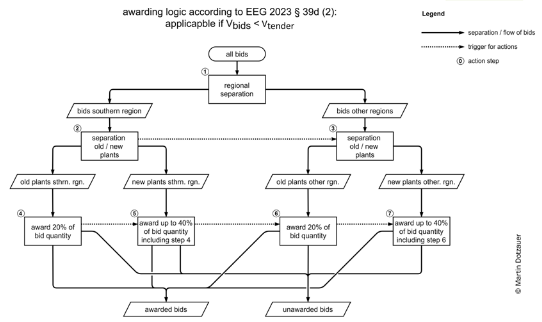

Figure 2: Awarding logic for subscribed tenders (less bidding volume than the given tender volume) for an individual year according to the EEG 2023

Results

OOP is operating at individual plant level and later aggregate groups of the plant fleet (see Figure 3). The "realistic scenario" is based on assumptions for moderate shares of existing plants, which extend their operation, beyond the first remuneration period. Beside installed capacity, generated electricity the OOP-approach also allow to include even more aspects, such as biomass turnover, heat generation or spatial analytics on small scales. Since most energy system models are following a fundamental approach to model the future development, ABM in contrast can better represent the effects and interaction of and between individual entities. Thus, this work can complement other research approaches and support decision making for the future role of biomass in the energy system.

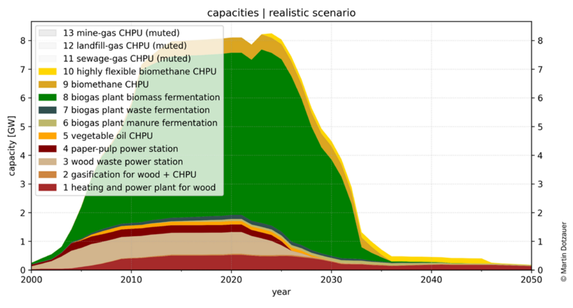

Figure 3: Simulated future fleet development of bioenergy plants in the German power sector until 2050, 'realistic scenario', Own illustration, DBFZ 2022.

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Deutsches Biomasseforschungszentrum gemeinnützige GmbH DBFZ

Krishna P. Sangam, University of Hohenheim

Case study of a combined digestate and distillers wash biorefinery

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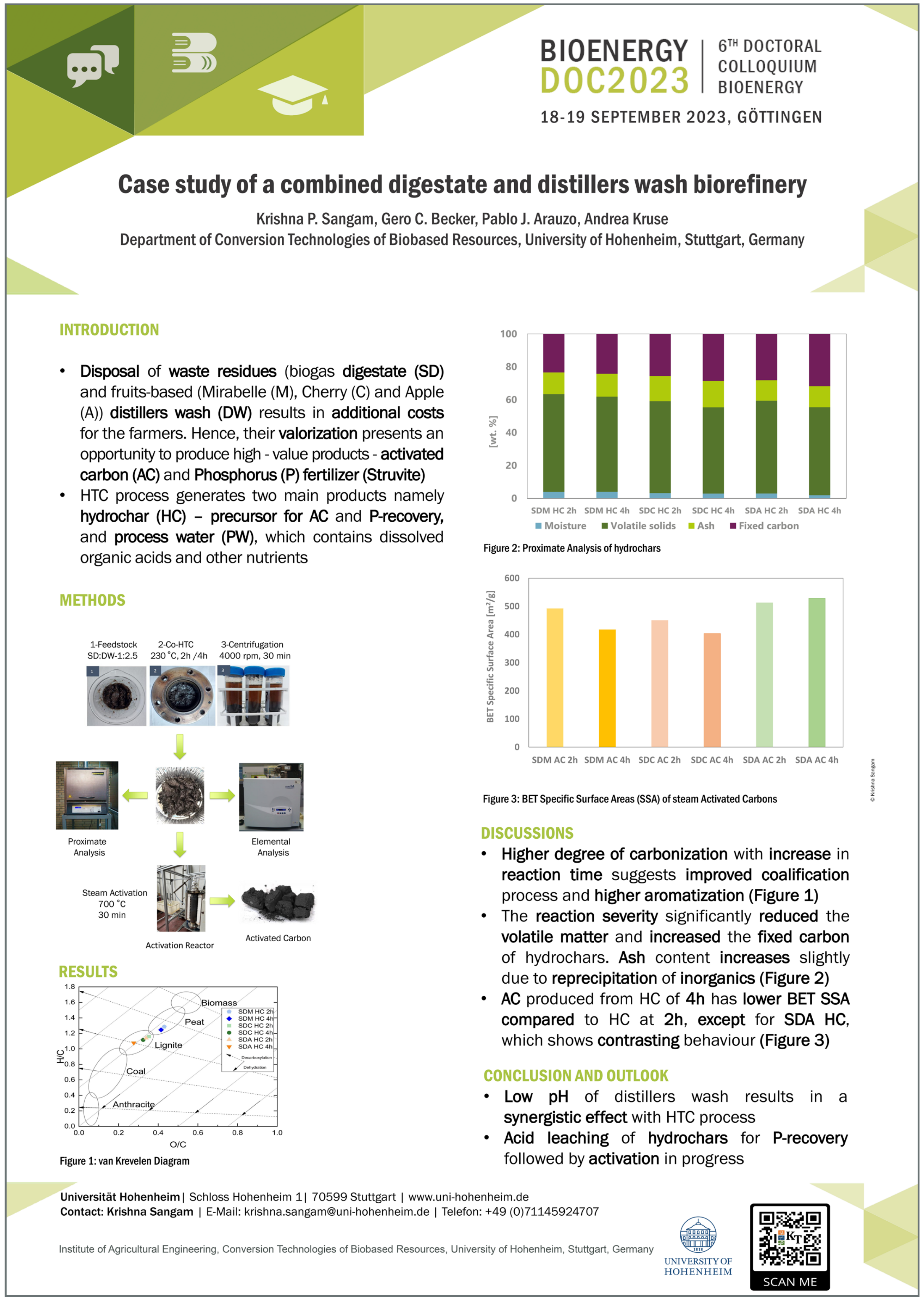
Dependency of the global economy on fossil resources like coal, oil and natural gas has gained new relevance during the Covid-19 crisis and ongoing conflict in Europe. Increasing energy costs have affected global phosphate prices to levels last seen during the 2009 fertilizer crisis. The necessity for local supply of energy and fertilizers, independent of global availability and markets, is currently more vital than ever.

Decentralised biorefinery concepts currently play an important role in the local supply. This trend is reflected in comprehensive coverage of biomass treating biogas plants across Europe, and especially in Germany. These facilities reduce the need for natural gas supply and additionally produce a residue, usable as fertilizer.

Several German biogas plants are agricultural-based, operated by entrepreneurs constantly seeking optimization of operations. With the transition towards green economy, a high demand for innovation adaptable to the rapid change in the legislative framework has become requisite.

An innovative concept for waste management was evaluated in this case study as the first step to a pilot operation envisioned in southern Germany. Thermochemical processing was employed to valorise potential agricultural biomass occurring on-farm, namely digestate produced from the local biogas plant and waste residues from fruits distillation of hard liquor.

Biogas digestates are a source of fertilizer largely but the stillage from the hard liquor production treated as waste presents a challenge to dispose. Hydrothermal Carbonization (HTC) process was employed to treat this mixture of wet feedstocks, showing synergistic effects at set operating conditions (230 °C, reaction times of 2 hand 4 h). Steam activation of received hydrochars at 700 °C produces activated carbon, which subsequently can be applied for micropollutant removal, biogas upgrading amongst others. Process water as a source for the production of organo/mineral fertilizers presents value addition to the biorefinery concept and sustainable bioeconomy.



Simon Hellmann, Deutsches Biomasseforschungszentrum

Extended and Unscented Kalman Filter Design for Mass-Based ADM1 Simplification

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Introduction

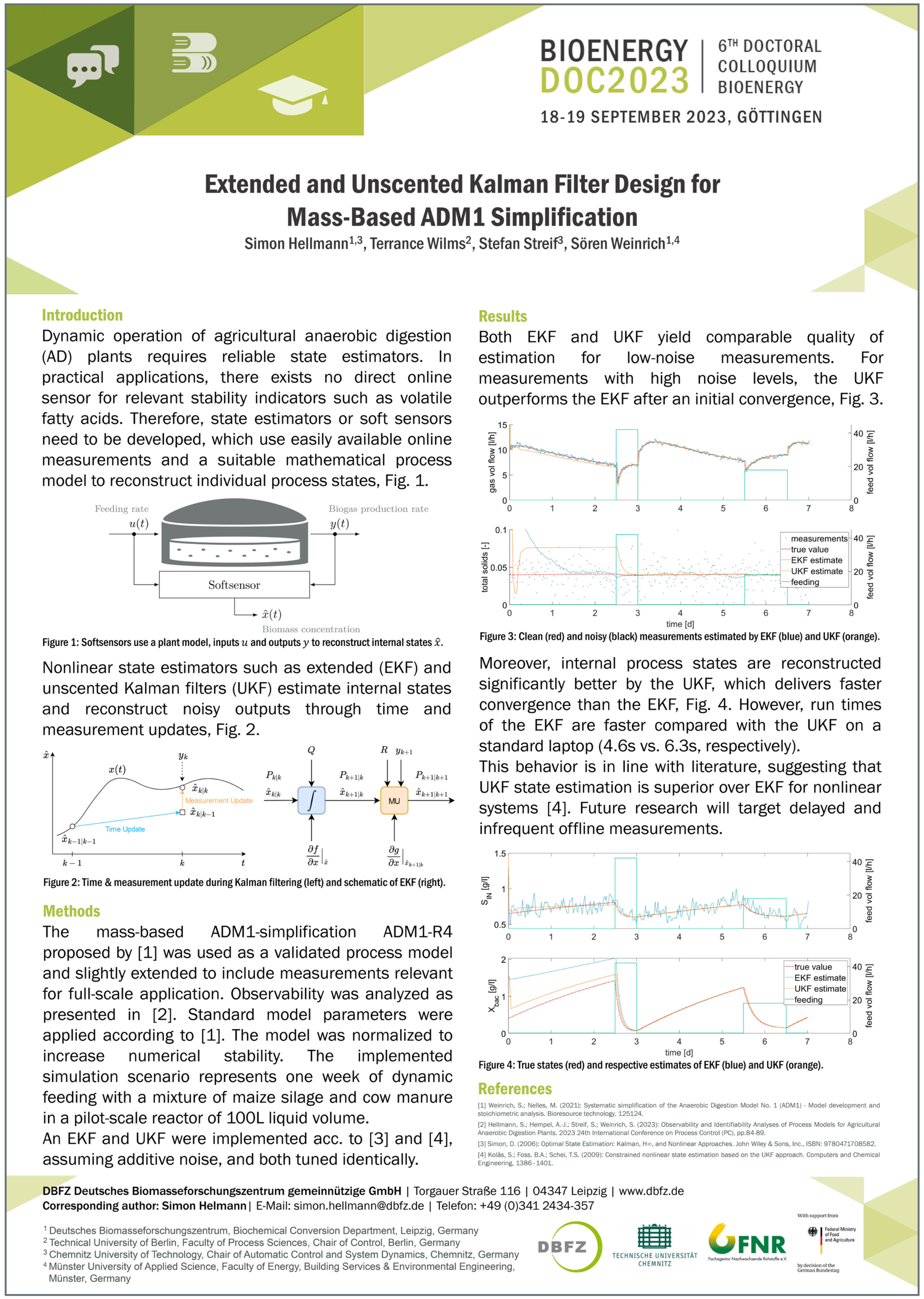
Dynamic operation of agricultural anaerobic digestion (AD) plants requires reliable state estimators. In practical applications, there exists no direct online sensor for relevant stability indicators such as volatile fatty acids. Therefore, state estimators or soft sensors need to be developed, which use easily available online measurements and a suitable mathematical process model to reconstruct individual process states. This study presents the design of extended and unscented Kalman filters (EKF/UKF) which rely on a mass-based simplification of the original Anaerobic Digestion Model No. 1 (ADM1). As a prerequisite, observability of the underlying model is analyzed following a differential algebraic approach.

Methods

Weinrich and Nelles (2021) recently proposed mass-based simplifications of the ADM1 [1 - 10.1016/j.biortech.2021.125124]. In the present study, the model class ADM1-R4 was slightly modified to improve practical application. Modification included a second carbohydrate fraction to better model gas production as well as measurement equations of total and volatile solids (TS, VS). The modified ADM1-R4 was analyzed for observability following a differential algebraic approach as described in Hellmann et al. (2023) [2 - 10.48550/arXiv.2301.05068]. For this purpose, we assumed online measurements of the gas composition, and slowly time-varying offline measurements of TS, VS, and inorganic nitrogen. For the offline measurements, we assumed a sample-and-hold behavior in between measurements. Moreover, a synthetic simulation scenario was developed, which models one week of dynamic feeding with a common agricultural substrate in a pilot-scale reactor. Standard model parameters were applied according to Weinrich and Nelles (2021) [1 - 10.1016/j.biortech.2021.125124]. Measurement noise was considered according to data sheets of established sensor equipment. Finally, both EKF and UKF were designed based on the modified and normalized ADM1-R4. Tuning matrices were chosen in accordance with best practice [3 - 10.1021/ie300415d]. Both Kalman filters was implemented in Matlab and tested for the synthetic simulation scenario.

Results and Outlook

Global observability could be shown for the modified ADM1-R4 applying the differential algebraic approach. State estimates of the Kalman filters allowed to reconstruct the original, undisturbed model outputs and showed a good agreement with noisy synthetic measurements. Moreover, the Kalman filters allowed to estimate internal process states such as microbial biomass. The Kalman filters could therefore be used as soft sensors for uncertain measurements such as biogas volume flow. Further research will be focused on implementing larger model classes such as the ADM1-R3 to consider stability indicators such as acetic acid. Further, real measurement data, offline measurement latency and joint state and parameter estimation will be addressed.



Julius Frontzek, Deutsches Biomasseforschungszentrum/Technical University Berlin

Model Predicitive Control of Agricultural Biogas Plants with Uncertain Substrate Characterization

Julius Frontzek, Simon Hellmann, Terrance Wilms, Steffi Knorn, Stefan Streif, Sören Weinrich
DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH
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Biogas plants have the potential to produce renewable electricity on demand. Thus, they are indispensible for balancing demand and supply in an electricity grid increasingly dominated by fluctuating renewable sources such as wind and solar. How-ever, the majority of German biogas plants are still operated in quasi steady state applying static feeding schedules [1]. Flexible feeding for demand-oriented biogas production could drastically increase revenues for operators but incurs the risk of process inhibition due to the instable nature of the anaerobic digestion process. This study presents a model predictive control (MPC) scheme which optimizes the revenue from electricity produced in the combined heat and power (CHP) unit of the biogas plant. Process stability is maintained by adjusting the feeding amounts and substrate composition.

We investigated the standard configuration of agricultural biogas plants in Germany consisting of the anaerobic digstion process in a continuous stirred-tank reactor (CSTR), gas storage and CHP unit. Therefore, we extended the mass-based simplification of the Anaerobic Digestion Model No. 1 (ADM1) presented by Weinrich and Nelles (2021) to incorporate feeding of multiple substrates. Further, we included measurements of total and volatile solids, a second carbohydrate fraction for improved accuracy of predicted biogas production, as well as a simplified gas storage model based on volumetric balancing. A representative electricity prize curve of one week was assumed in order to derive an appropriate operating schedule of the CHP unit. The optimization problem was defined using a quadratic cost function subject to linear constraints on the input.

Optimizing the feeding amounts and substrate composition resulted in drastically increased revenues from electricity production when compared with conventional, static feeding schedules. Enhanced flexiblility in response to varying process conditions was achieved by combining multiple agricultural substrates with different degradation characteristics. This increased process stability despite significantly higher averaged organic loading rates.

The results of this study contribute to sketch future operating pathways for agricultural biogas plants in Germany. Moreover, the presented optimization allows for stabilizing process control even in less dynamic operating scenarios. Nevertheless, future research needs to be directed at coupling MPC with state estimation and experimental demonstration in full-scale.

BIOENERGY DOC2023 | 6TH DOCTORAL COLLOQUIUM BIOENERGY
18-19 SEPTEMBER 2023, GÖTTINGEN

Model Predictive Control of Agricultural Biogas Plants with Uncertain Substrate Characterization

Julius Frontzek[1,2], Simon Hellmann[1,3], Terrance Wilms[2], Steffi Knorn[2], Stefan Streif[3], Sören Weinrich[1,4]

INTRODUCTION

A mass-based simplification of the Anaerobic Digestion Model No. 1, called ADM1-R3, proposed by [1] allows for the embedding in a model predictive control (MPC) loop. The basic principle of MPC is illustrated in Fig. 1. The goal is to optimize the trajectory of substrates fed into the biogas plant such that a maximum amount of biogas is produced while avoiding process inhibition.

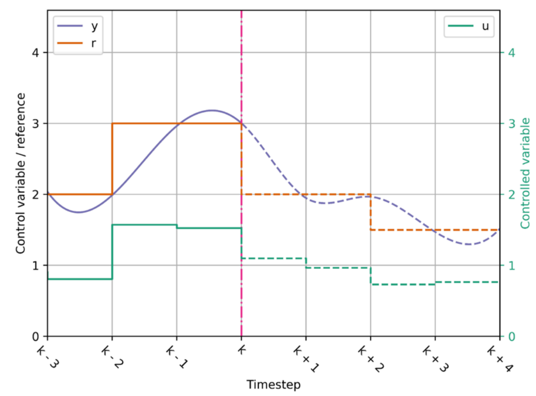

Fig. 1: Exemplary illustration of a model predictive control algorithm. Control variable (y), reference (r), and controlled variable (u) depicted. Solid lines: Actual past values; dashed lines: Computed future values; dash-dotted line: Current time

METHODS

The MPC algorithm was implemented using the Python-based open source library 'do-mpc' [2].
The system of ordinary differential equations was discretized by using orthogonal collocation on finite elements and solved using CVODES [3]. The ADM1-R3 was extended by a gas storage model which comprises a mixture of methane (CH_4), carbon dioxide (CO_2) and water vapor (H_2O) as illustrated in Fig. 2. Disturbances such as random uniform errors for the feeding volumes were introduced.

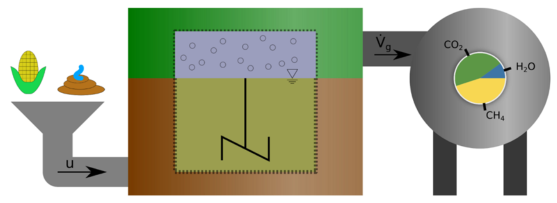

Fig. 2: Modeled biogas process extended by gas storage. Left: Agricultural substrate feed; center: fermenter with liquid (bottom) and gaseous phase (top); right: gas storage

RESULTS AND OUTLOOK

Biogas outflow setpoint changes were successfully met within three hours while allowing for random uniform feeding errors of up to 5% as shown in Fig. 3.
As a next step, a multi-stage approach will be used to account for uncertainties in input feed concentrations. Further, different load cases will be examined.

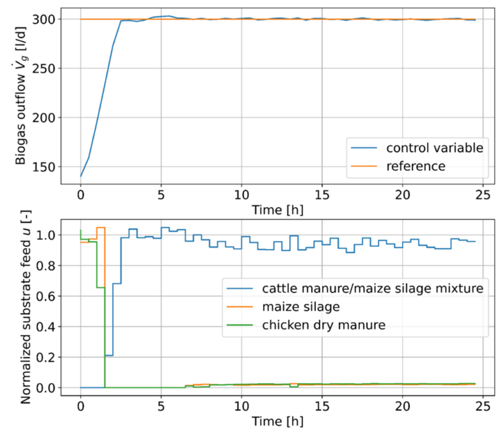

Fig. 3: Step response of Biogas outflow in the presence of a random uniform feeding volume error of +/- 5%

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[3] Chemnitz University of Technology, Chair of Automatic Control and System Dynamics, Chemnitz, Germany
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Matthis Kurth, Deutsches Biomasseforschungszentrum

Maxwell-Stefan Surface Diffusion Modeling on Nano-Porous Carbon Membranes

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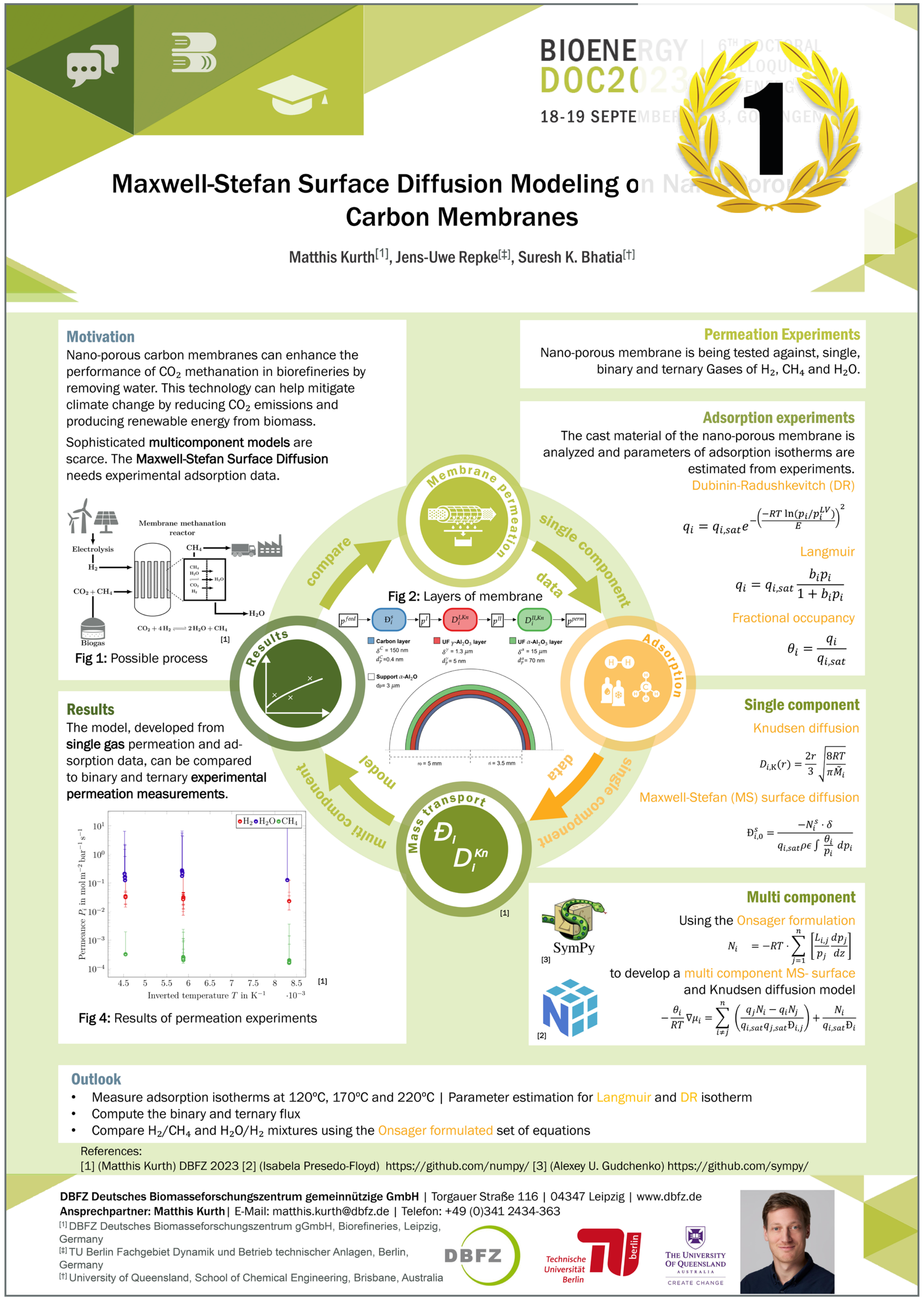
The prediction of binary fluxes is of significant importance in the design and optimization of gas separation membranes. A critical element of these models is the accurate representation of adsorption behavior by developing isotherm models that reflect the sorbate-sorbent interactions. Several isotherm models, such as the Langmuir isotherm, BET isotherm, and Dubinin-Radushkevich isotherm, have been proposed to describe the sorption behavior of gases on porous carbon materials. (Cavenati et al., 2004; Dubinin, 1960; Radushkevich & Dobrokhotov, 1962; Zhang et al., 2015)

The present study focuses on predicting binary fluxes of hydrogen and methane in a porous carbon material with a pore size of 0.4 nm. The primary aim is to investigate the performance of a model based on the Maxwell-Stefan equations and the Dubinin-Radushkevich equation approach in predicting the binary fluxes in this specific system. Previous research has shown that the Maxwell-Stefan equations can be successfully used to model binary diffusion in various chemical systems, and the Dubinin-Radushkevich equation has been proven to be a reliable method of predicting the adsorption behavior of gas sorption on porous materials. (Barker, 2017; Cavenati et al., 2004)

While the modeling of binary diffusion is well-established, predicting binary fluxes in real-world systems remains a significant scientific challenge due to the complexities of the interactions. By comparing the predicted binary fluxes to previously published experimental data, we aim to assess the accuracy of the model in real-world scenarios. Additionally, we will evaluate the performance of the model using binary mixtures of gases and compare the predictions to published data. (Barker, 2017)

This research has the potential to contribute towards the development of more accurate models for predicting binary fluxes, which could have important implications for the design and optimization of gas separation membranes and ultimaPhoney lead to the development of more efficient and sustainable gas separation processes.



SESSION
THERMOCHEMICAL PROCESSES

Prof. Dr. Jürgen Karl
Dr. Kathrin Weber

6TH DOCTORAL COLLOQUIUM BIOENERGY

Ask Lysne, Norwegian University of Science and Technology

Steam Reforming of Bio-Syngas Hydrocarbon Impurities with Ni-Co/Mg(Al)0 Catalysts – Operating Parameter Effects

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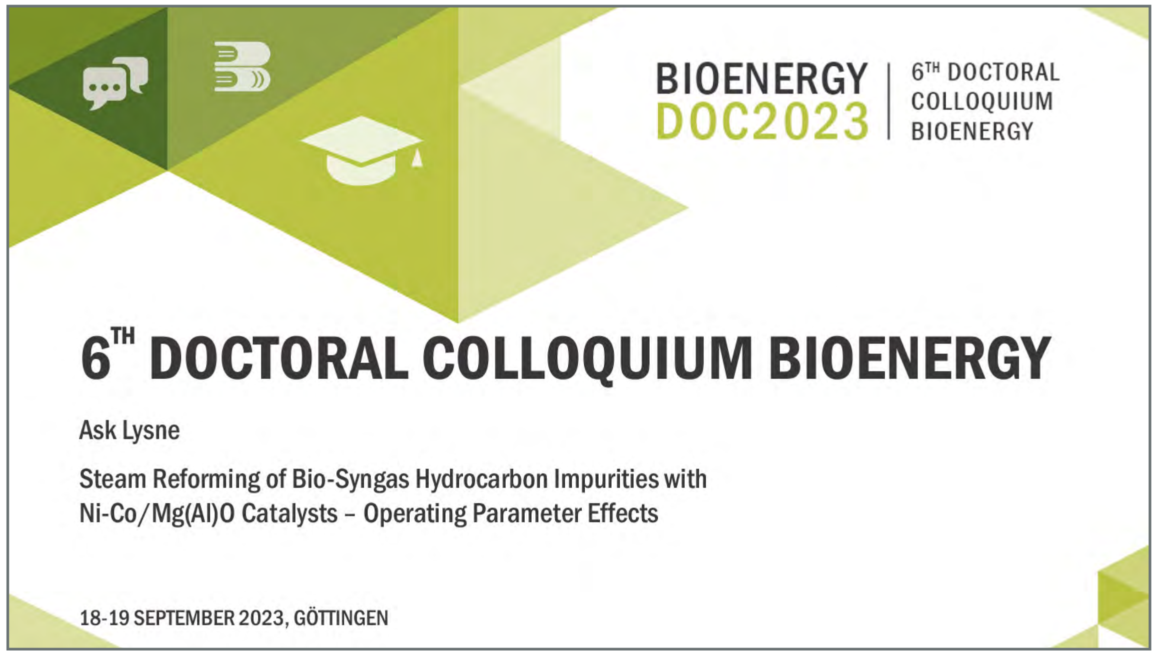
Biomass gasification can provide low CO_2 emission bio-syngas for application in renewable chemical and fuel production. The gasification product typically contains hydrocarbon impurities, including condensable aromatic hydrocarbons (tars), causing downstream condensation and coking issues. Such impurities can be removed by catalytic steam reforming, avoiding cost-intensive high temperature cracking and physical separation strategies. Recent reviews call upon further development of bi-metallic Ni-Co systems for such applications, targeting high-stability, low-coking reforming catalysts. Ni-Co/Mg(Al)O catalysts were synthesized via calcination of hydrotalcite precursors, following the protocol reported by He et al. Fresh samples were characterized by XRD, XRF, ICP-MS, TPR, N2-physisorption and H2-chemisorption. Activity and deactivation experiments were performed in model bio-syngas ($CH_4/H_2/CO/CO_2$ ratio = 10/35/25/25, molar) with and without model tar addition.

The catalyst performance was tested (8 hours on stream) at different operating temperatures (650-800 °C), steam-to-carbon (S/C) ratios (2-5), tar loading (10-30 g/Nm³, toluene) and model tar compositions (Tar-1 = 100/0/0, Tar-2 = 75/25/0, Tar-3 = 70/25/5 wt% toluene/1-methylenaphthalene/phenol). Coke formation effects were evaluated by characterization of spent catalyst samples with TGA-TPO, Raman spectroscopy and STEM/EDS

Fresh catalyst characterization results and effects of Ni-Co ratio have been reported elsewhere. Complete model tar removal at the expense of catalyst deactivation by coke formation was found at all tested conditions. The added tar was well accounted for as $CH_4/CO/CO_2$ in the effluent flow. The results indicate optimum temperature and S/C ratio conditions, minimizing overall coke formation and sintering effects. Simultaneous adjustment of the bio-syngas $H_2/CO/CO_2$ composition by WGS reaction equilibration (preparing for downstream Fischer-Tropsch applications) was demonstrated throughout the range of tested conditions.

The project is funded by the Norwegian Research Council (no. 257622) through the Centre for Environment-friendly Energy Research (FME) Bio-4Fuels. The Norwegian Research Council is also acknowledged for the support to the Norwegian Micro- and Nano-Fabrication Facility, NorFab (no. 295864).



Short introduction

Title of the Doctoral Project:	Steam Reforming of Hydrocarbon Impurities from Biomass Gasification
Doctoral Student:	Ask Lysne
DBFZ Supervisor:	N.A.
Cooperating University:	Norwegian University of Science and Technology
University Supervisor:	Prof. Edd A. Blekkan
Funding / Scholarship provider:	Norwegian Research Council Centre for Environment-friendly Research, Bio4Fuels [grant 257622] Norwegian Micro- and Nano-Fabrication Facility, NorFab [grant 295864]
Logo:	BIO4 FUELS; Forskningssenter for miljøvennlig energi
Duration:	08/2019 – 03/2024

Liquid Biofuels in NZE 2050 Scenario

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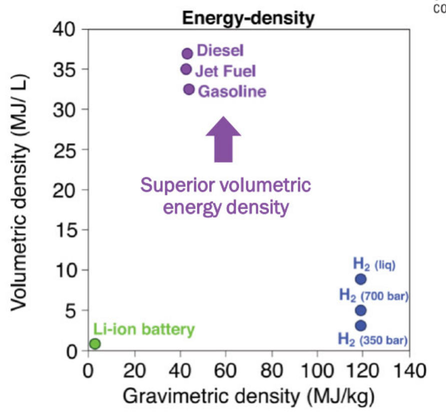
- Long-distance aviation will depend on green liquid fuels due to superior energy density
- IEA NZE 2050 scenario relies heavily on advanced biofuels from bio-FT technology
- Commercialization of bio-FT technology depends on bio-syngas conditioning step



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Bio-Syngas Conditioning

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BIOMASS GASIFICATION

Gas products:
20-40% H_2
25-40% CO
20-35% CO_2

Gas impurities:
5-10% CH_4
0-0.4% C_2H_6
0-4.4% C_2H_4
0-0.5% C_2H_2

Solid inorganics (ash):
Na_2O, K_2O, MgO, CaO, SiO_2, P_2O_5, SO_3, Al_2O_3 and Fe_2O_3

Volatile inorganics:
NH_3, HCN, H_2S and HCl

Tars: ca 10 g/Nm³
65% One-ring aromatics
22% Two-ring aromatics
13% Other compounds

1. **Remove inorganics and particulates**
2. **Remove hydrocarbon impurities**
3. **Adjust H_2/CO ratio**

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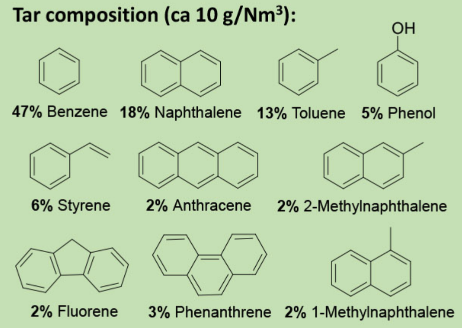
The Tar Problem

BIOENERGY DOC2023 6TH DOCTORAL COLLOQUIUM BIOENERGY

- Mainly one-ring (66%) and two-ring (22%) condensable aromatic hydrocarbons
- Downstream condensation and coking
- Possible solution: Catalytic steam reforming following biomass gasification
- Increasing process efficiency compared to physical separation and thermal cracking
- Catalyst with high reforming activity without deactivation by coke formation

Tar composition (ca 10 g/Nm³):



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Catalyst System

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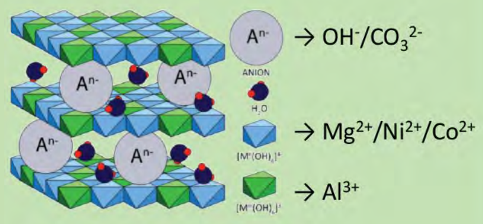
- Hydrotalcite-like precursors through coprecipitation
- Ni-Co/Mg(Al)O catalysts by calcination and reduction
- Stable high-surface-area and high-dispersion catalysts
- Promising performance reported in other steam reforming systems



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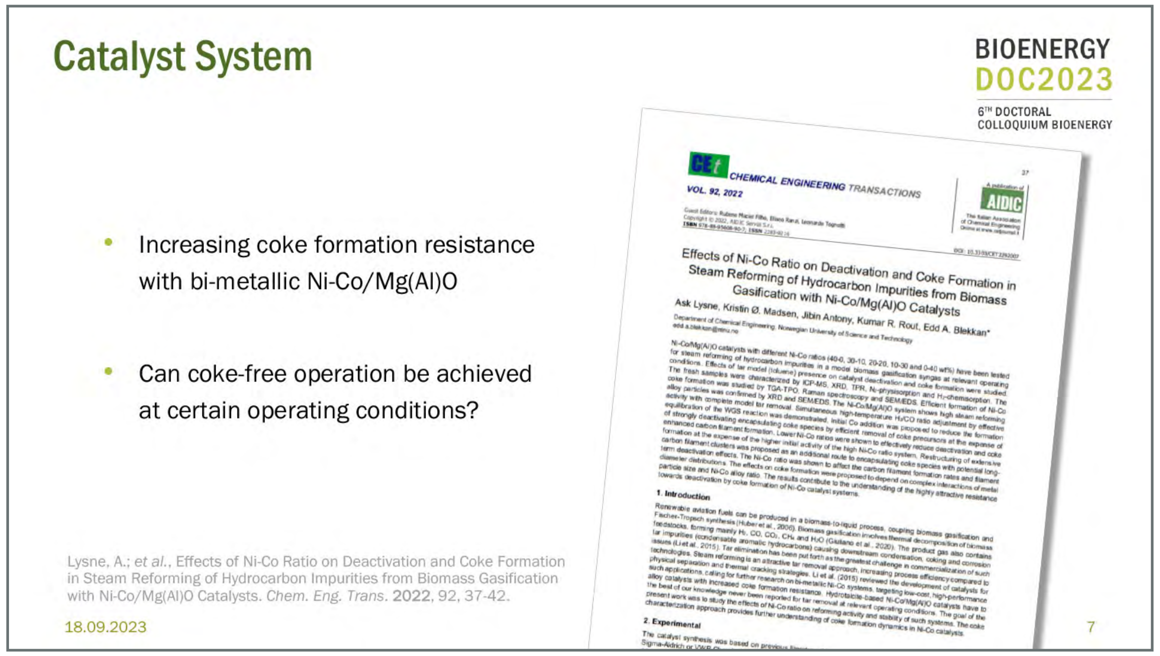
Catalyst System
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Increasing coke formation resistance with bi-metallic Ni-Co/Mg(Al)O
Can coke-free operation be achieved at certain operating conditions?
CHEMICAL ENGINEERING TRANSACTIONS
VOL. 92, 2022
AIDIC
Effects of Ni-Co Ratio on Deactivation and Coke Formation in Steam Reforming of Hydrocarbon Impurities from Biomass Gasification with Ni-Co/Mg(Al)O Catalysts
Lysne, A.; et al., Effects of Ni-Co Ratio on Deactivation and Coke Formation in Steam Reforming of Hydrocarbon Impurities from Biomass Gasification with Ni-Co/Mg(Al)O Catalysts. Chem. Eng. Trans. 2022, 92, 37-42.
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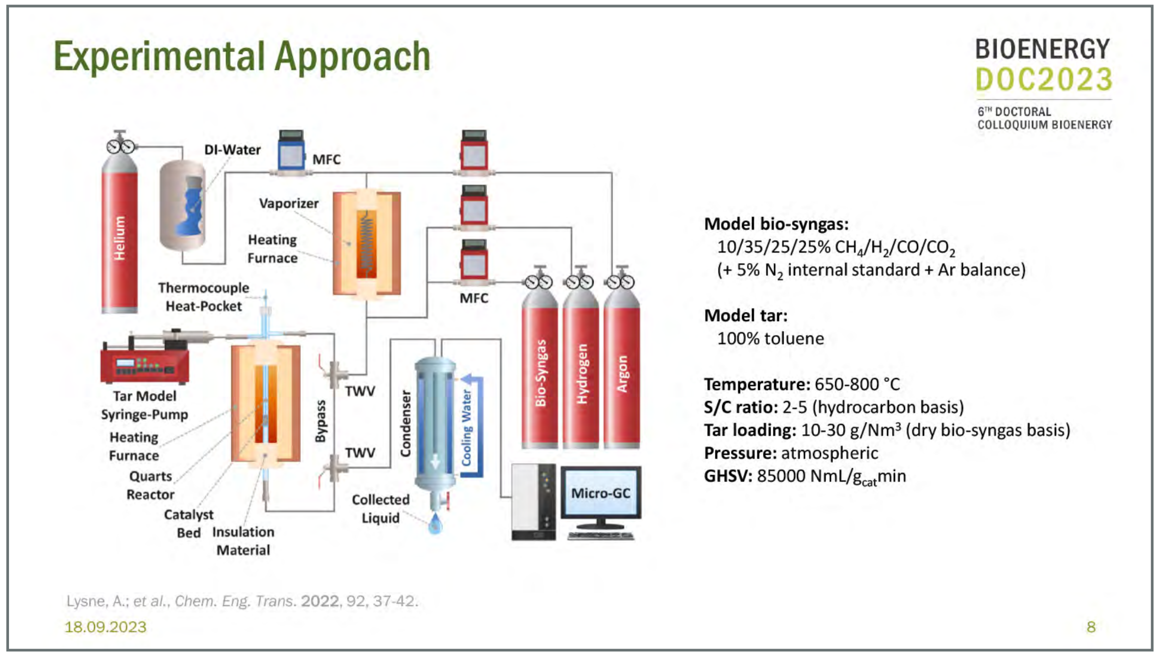
Experimental Approach
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Helium
DI-Water
MFC
Vaporizer
Heating Furnace
Thermocouple Heat-Pocket
MFC
Tar Model Syringe-Pump
Heating Furnace
Quarts Reactor
Catalyst Bed
Insulation Material
Bypass
TWV
TWV
Condenser
Cooling Water
Collected Liquid
Bio-Syngas
Hydrogen
Argon
Micro-GC
Model bio-syngas:
10/35/25/25% CH4/H2/CO/CO2
(+ 5% N2 internal standard + Ar balance)
Model tar:
100% toluene
Temperature: 650-800 °C
S/C ratio: 2-5 (hydrocarbon basis)
Tar loading: 10-30 g/Nm³ (dry bio-syngas basis)
Pressure: atmospheric
GHSV: 85000 NmL/gcatmin
Lysne, A.; et al., Chem. Eng. Trans. 2022, 92, 37-42.
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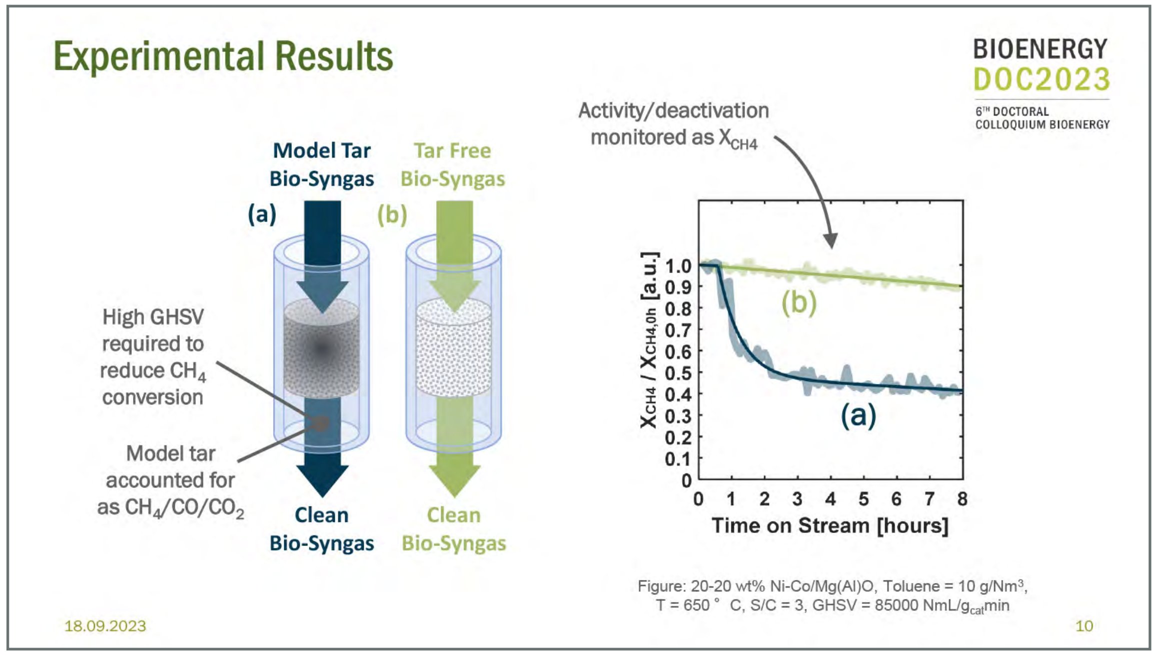
Experimental Results
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6TH DOCTORAL COLLOQUIUM BIOENERGY
Model Tar Bio-Syngas
Tar Free Bio-Syngas
(a)
(b)
High GHSV required to reduce CH4 conversion
Model tar accounted for as CH4/CO/CO2
Clean Bio-Syngas
Clean Bio-Syngas
Activity/deactivation monitored as XCH4
XCH4 / XCH4,0h [a.u.]
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
(b)
(a)
0 1 2 3 4 5 6 7 8
Time on Stream [hours]
Figure: 20-20 wt% Ni-Co/Mg(Al)O, Toluene = 10 g/Nm³, T = 650 °C, S/C = 3, GHSV = 85000 NmL/gcatmin
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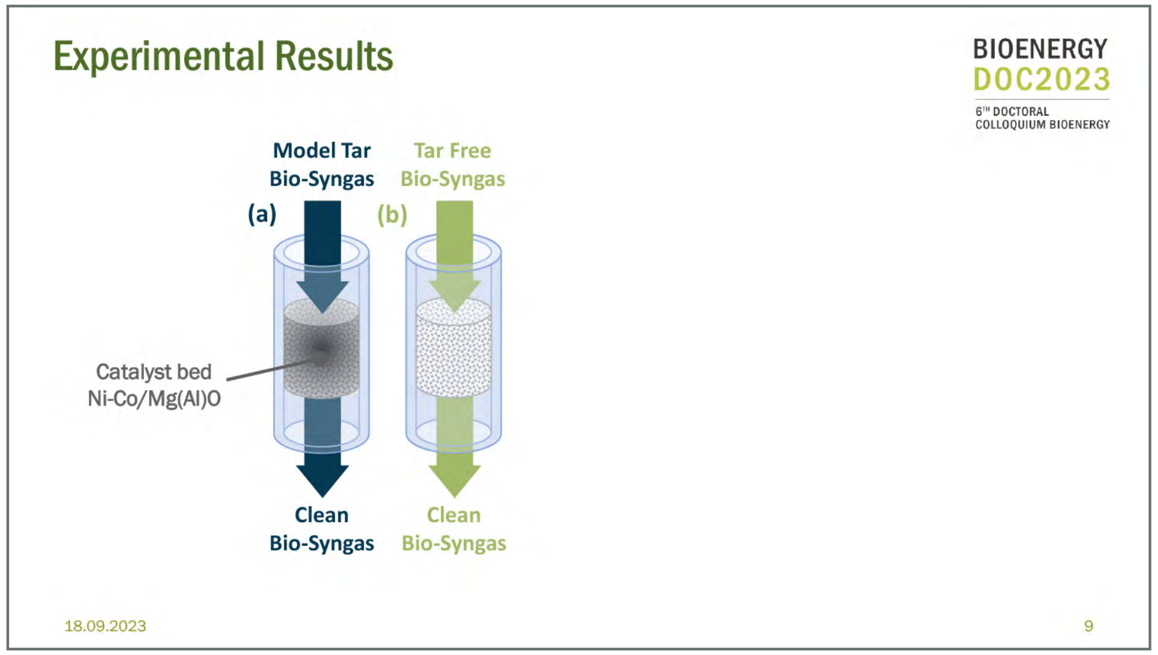
Experimental Results
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Model Tar Bio-Syngas
Tar Free Bio-Syngas
(a)
(b)
Catalyst bed Ni-Co/Mg(Al)O
Clean Bio-Syngas
Clean Bio-Syngas
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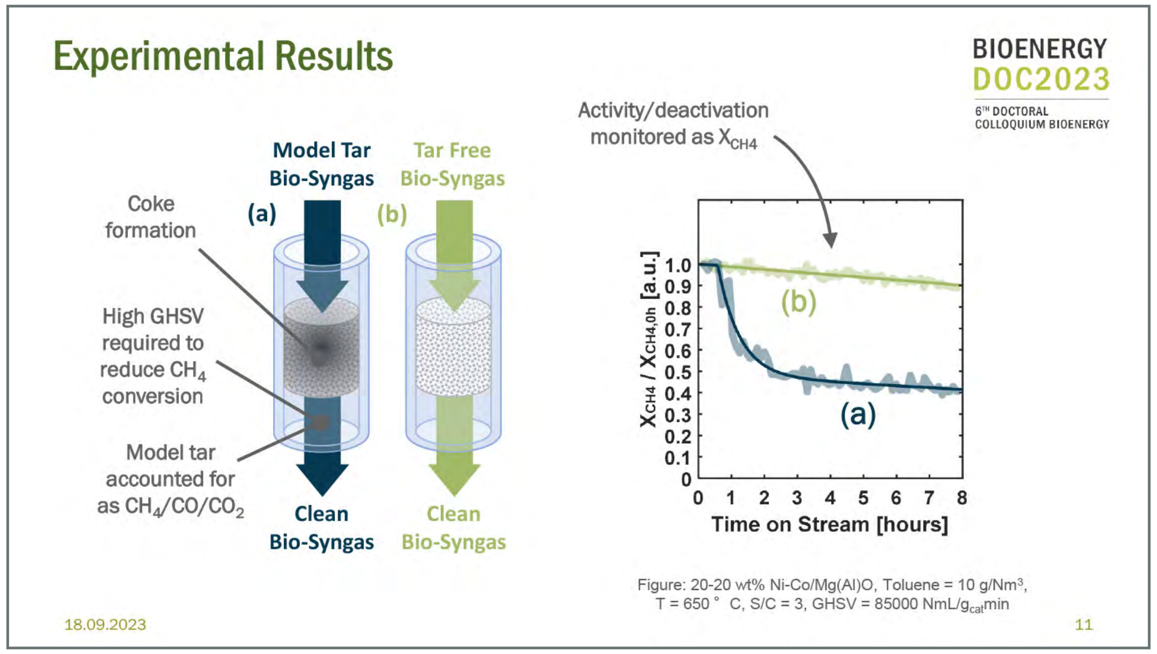

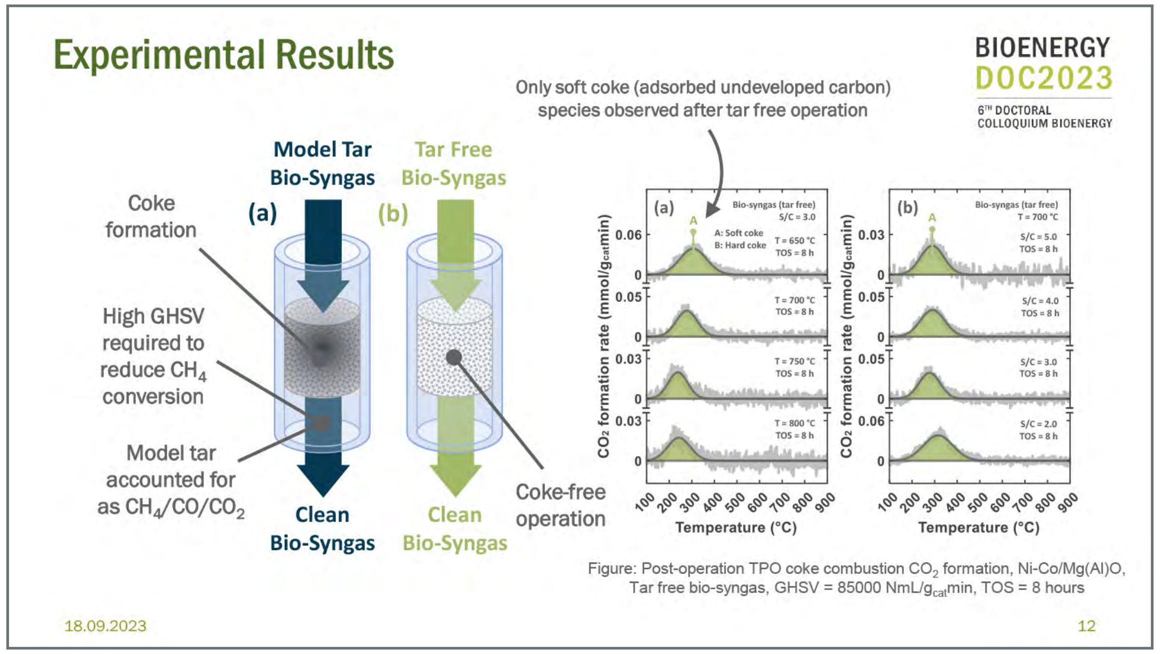

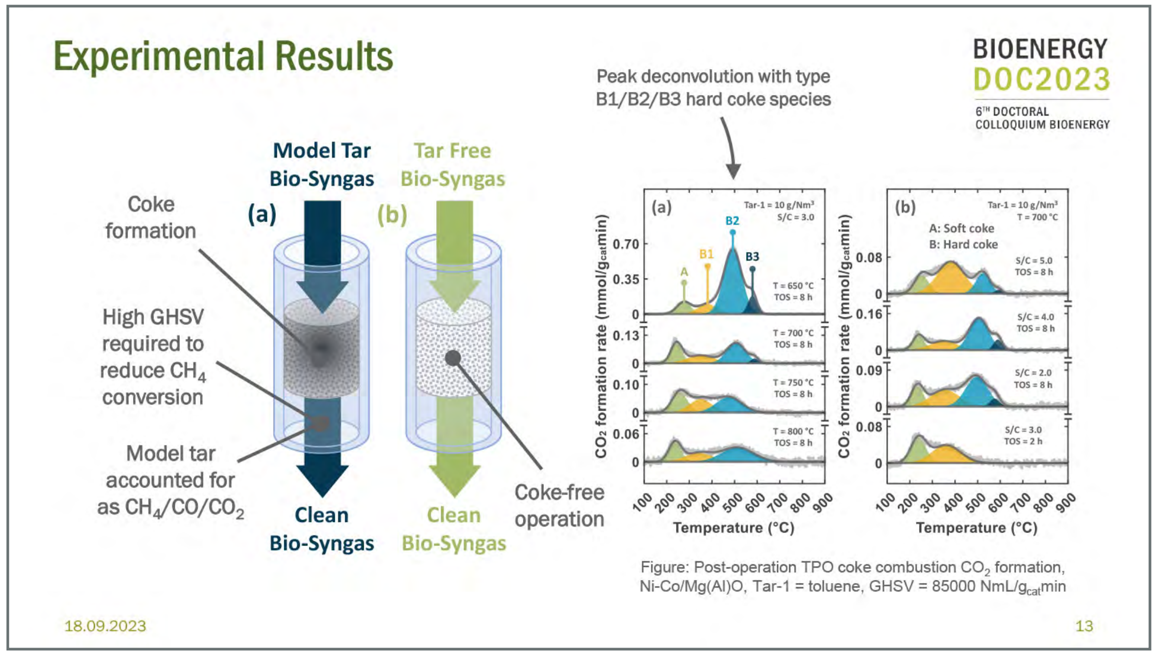

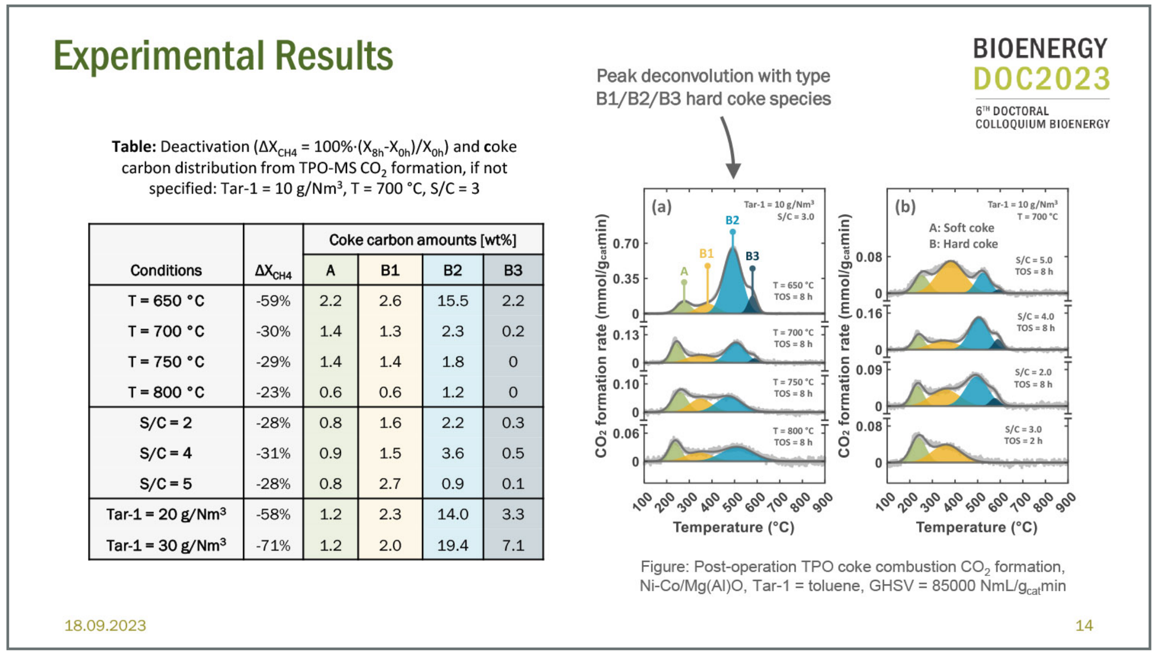

Table: Deactivation ($\Delta X_{CH4} = 100\% \cdot (X_{8h}-X_{0h})/X_{0h}$) and coke carbon distribution from TPO-MS CO_2 formation, if not specified: Tar-1 = 10 g/Nm³, T = 700 °C, S/C = 3

Conditions	ΔX_{CH4}	Coke carbon amounts [wt%]			
		A	B1	B2	B3
T = 650 °C	-59%	2.2	2.6	15.5	2.2
T = 700 °C	-30%	1.4	1.3	2.3	0.2
T = 750 °C	-29%	1.4	1.4	1.8	0
T = 800 °C	-23%	0.6	0.6	1.2	0
S/C = 2	-28%	0.8	1.6	2.2	0.3
S/C = 4	-31%	0.9	1.5	3.6	0.5
S/C = 5	-28%	0.8	2.7	0.9	0.1
Tar-1 = 20 g/Nm³	-58%	1.2	2.3	14.0	3.3
Tar-1 = 30 g/Nm³	-71%	1.2	2.0	19.4	7.1

Experimental Results

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Deactivation accompanied by enhanced B2/B3 formation (+ lower Raman D/G ratios)

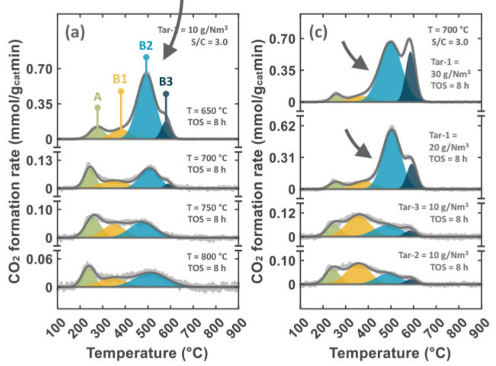

Figure: Post-operation TPO coke combustion CO_2 formation, Ni-Co/Mg(Al)O, Tar-1 = toluene, GHSV = 85000 NmL/g_{cat}min

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Experimental Results

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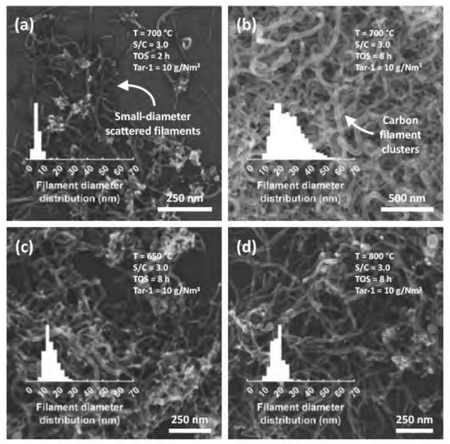

Figure: STEM images, Tar-1 = toluene

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Experimental Results

BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY

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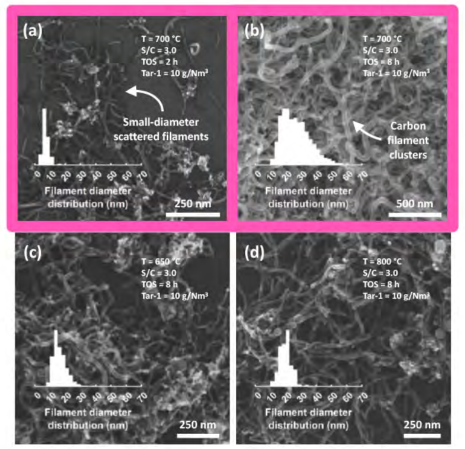

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Type B1 : Initial growth of small-diameter scattered filaments

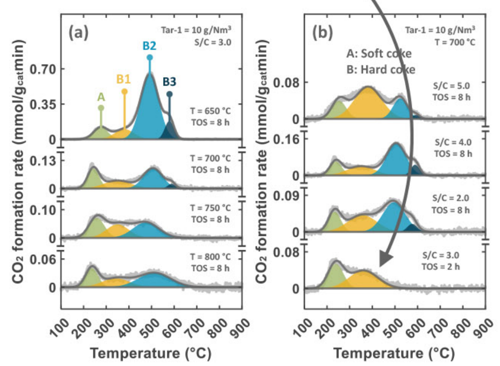

Figure: Post-operation TPO coke combustion CO_2 formation, Ni-Co/Mg(Al)O, Tar-1 = toluene, GHSV = 85000 NmL/g_{cat}min

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Experimental Results

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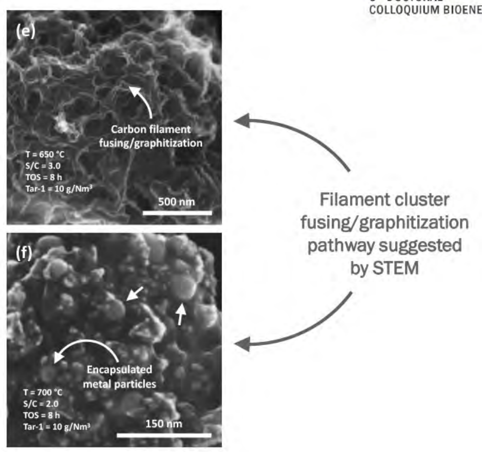

Figure: STEM images, Tar-1 = toluene

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Coke Formation/Classification

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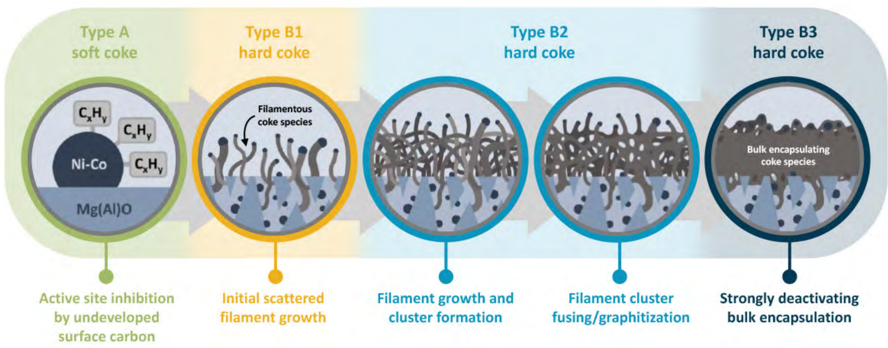

18.09.2023 Figure: Proposed coke formation/classification scheme 20

Concluding Remarks

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1. Ni-Co/Mg(Al)O catalyst effectively removes model tar at all tested conditions, at the expense of coke formation
2. Deactivation by coke accumulation could not be completely avoided at any of the tested conditions
3. Critical low-temperature and tar loading limits were identified
4. Coke formation/classification scheme proposed

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Dr. Fabian Gievers, University of Applied Sciences and Arts

Life cycle assessment of sewage sludge pyrolysis and HTC – Energetic or material use of hydrochar and biochar

Fabian Gievers, Achim Loewen, Michael Nelles
University of Applied Sciences and Arts Hildesheim/Holzminden/Göttingen,
Faculty of ressource management
Rudolf-Diesel-Straße 12
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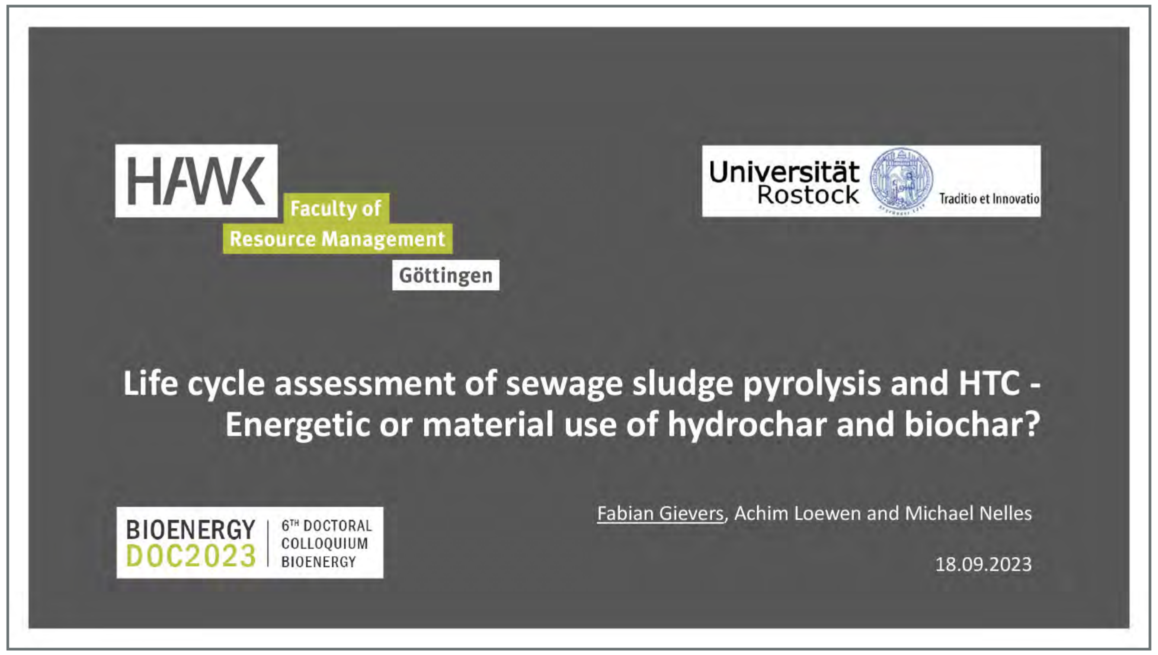
Phone: +49 (0)551/5032-184
E-Mail: fabian.gievers@hawk.de

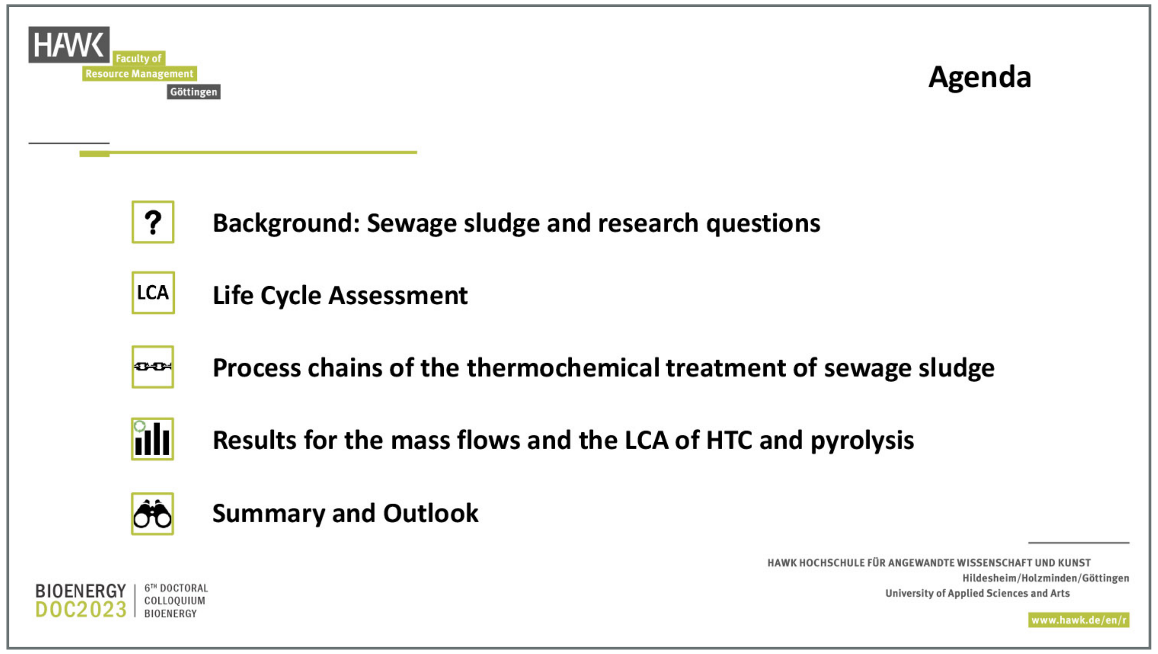
In view of current developments in sewage sludge treatment away from material recycling in agriculture and towards mono-incineration, a life cycle assessment (LCA) was conducted to investigate whether the thermochemical conversion processes of hydrothermal carbonization (HTC) and pyrolysis, as well as the material and energy applications of the resulting biochars and hydrochars, represent a more sustainable form of sewage sludge treatment. The study was based on material and energy modeling of HTC, pyrolysis, and subsequent utilization pathways of the biochar and hydrochar.

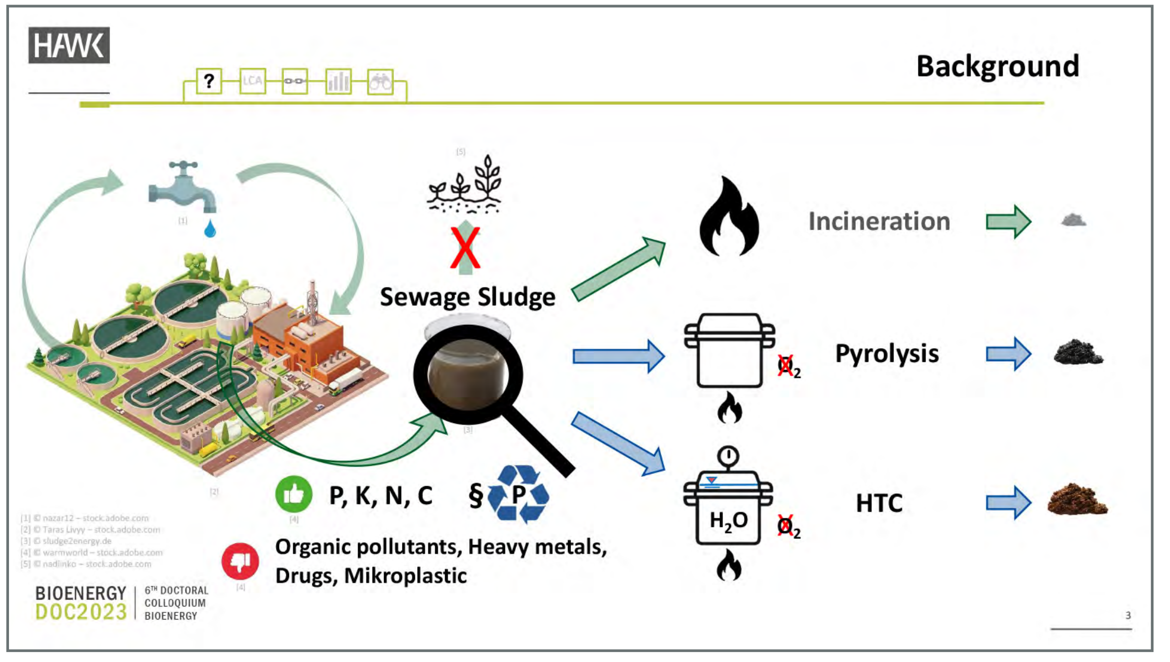
The LCA generally focused on the process chains for HTC and pyrolysis of the anaerobically pre-treated sewage sludge compared to the process chain of mono-incineration and ash disposal. In addition, different application pathways for the produced carbonisates were investigated: Firstly, material use as a soil conditioner in agriculture and as a peat substitute in horticulture. On the other hand, the energetic application in mono-incineration and co-incineration was evaluated.

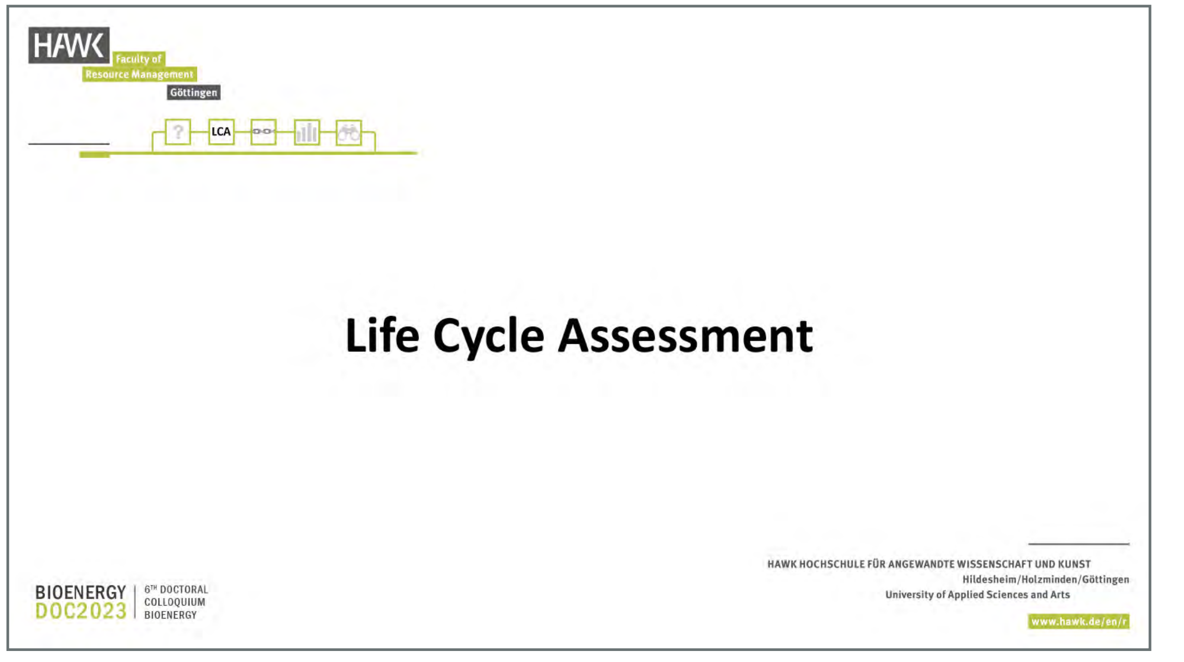
In addition to energetic aspects, the concentration and accumulation of organic pollutants (such as PCDD/F and PCB) and heavy metals, among others, were considered in order to quantify the overall environmental impact and to identify possible uses of the carbonisates. The LCA was performed using GaBi Professional software, ecoinvent and GaBi databases, while the environmental impacts were determined using the ReCiPe midpoint method.

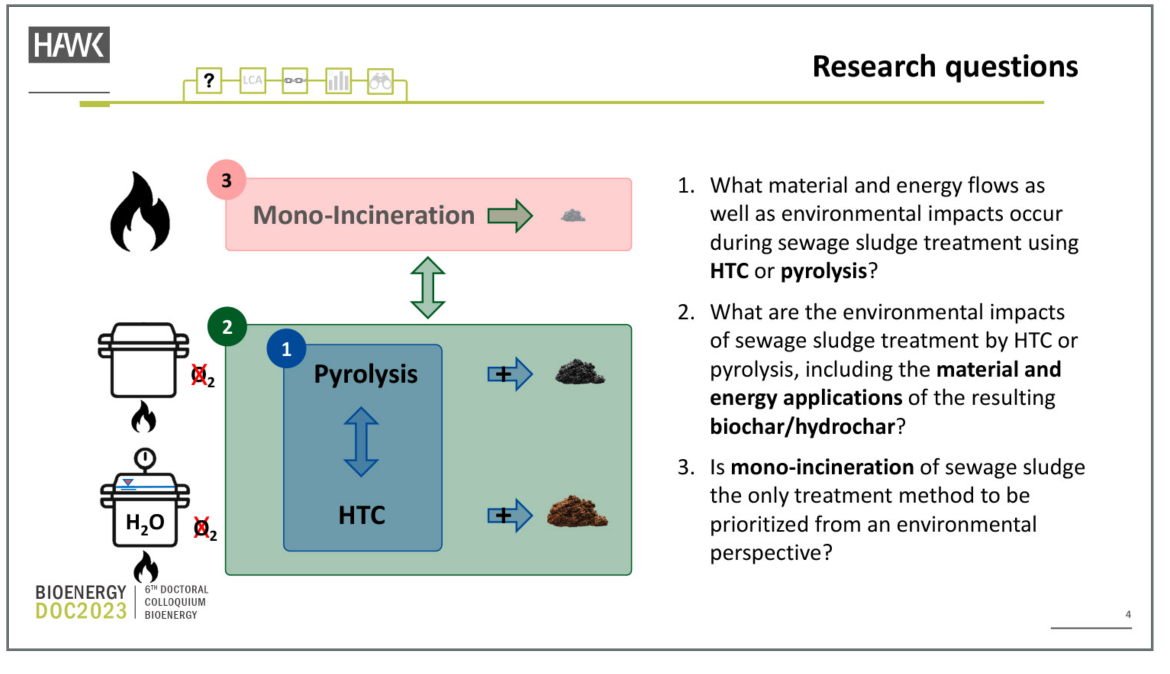
The LCA results show a positive overall balance for both HTC and pyrolysis compared to mono-incineration of sewage sludge, although increased emissions were found in some impact categories for different application pathways. In addition, energy and material advantages over direct incineration of sewage sludge were identified for both thermochemical conversion processes, depending on the processes used, and further potential improvements to the thermochemical conversion chains were identified. The LCA therefore contributes to developing a basis and decision support for the selection of the most ecologically sound sewage sludge utilization technology in the context of a sustainable bioeconomy.

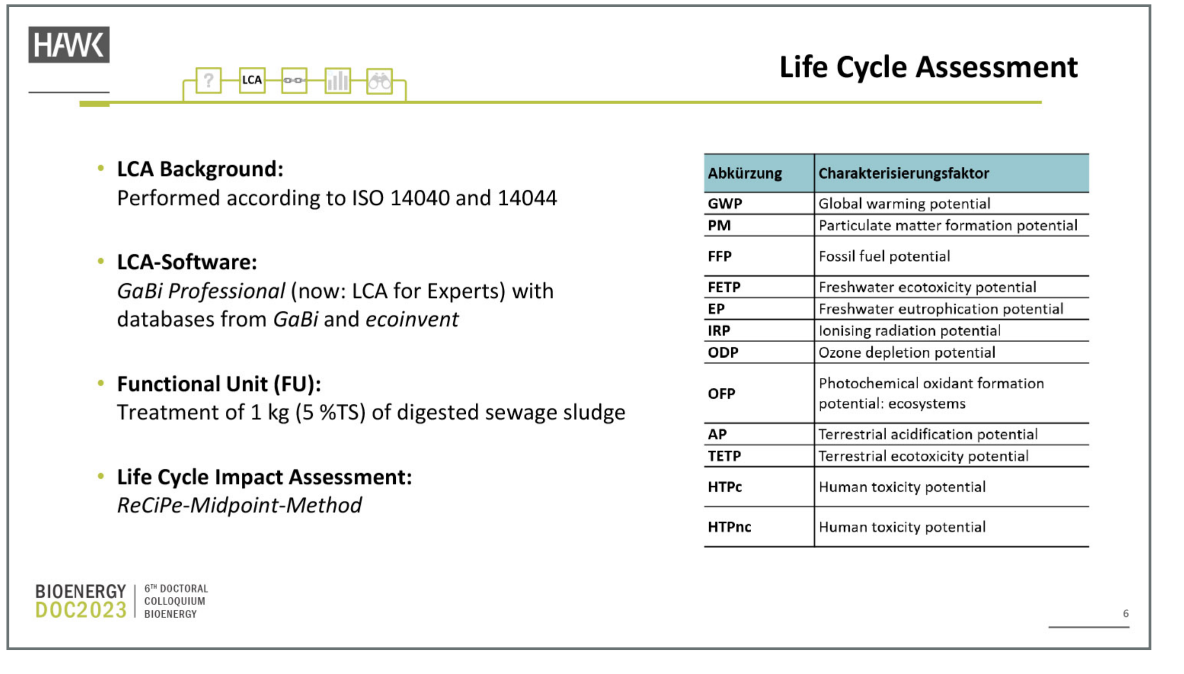






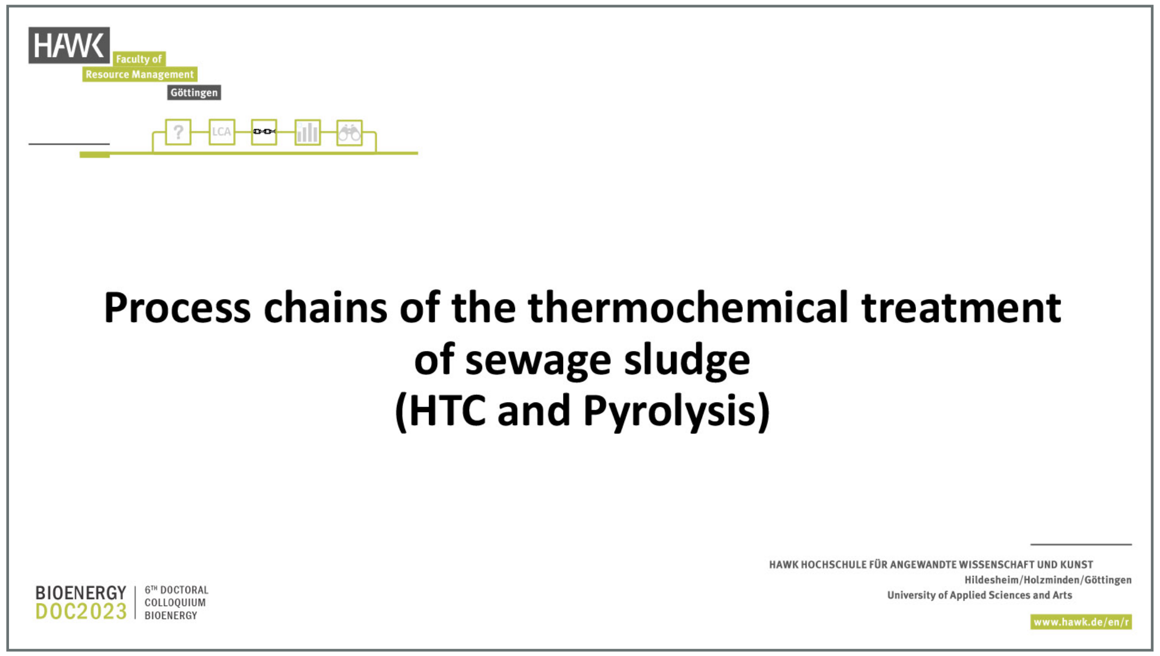






- **LCA Background:** Performed according to ISO 14040 and 14044
- **LCA-Software:** *GaBi Professional* (now: LCA for Experts) with databases from *GaBi* and *ecoinvent*
- **Functional Unit (FU):** Treatment of 1 kg (5 %TS) of digested sewage sludge
- **Life Cycle Impact Assessment:** *ReCiPe-Midpoint-Method*

Abkürzung	Charakterisierungsfaktor
GWP	Global warming potential
PM	Particulate matter formation potential
FFP	Fossil fuel potential
FETP	Freshwater ecotoxicity potential
EP	Freshwater eutrophication potential
IRP	Ionising radiation potential
ODP	Ozone depletion potential
OFP	Photochemical oxidant formation potential: ecosystems
AP	Terrestrial acidification potential
TETP	Terrestrial ecotoxicity potential
HTPc	Human toxicity potential
HTPnc	Human toxicity potential


HAWK
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Resource Management
Göttingen
Process chains of the thermochemical treatment
of sewage sludge
(HTC and Pyrolysis)
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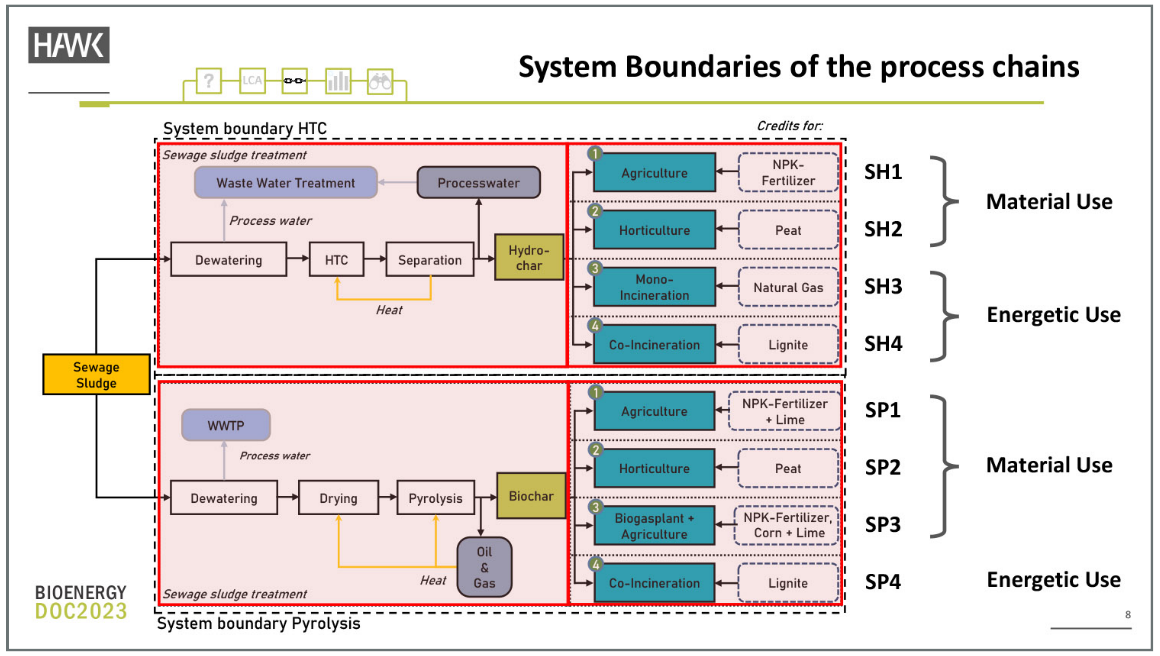
HAWK HOCHSCHULE FÜR ANGEWANDTE WISSENSCHAFT UND KUNST
Hildesheim/Holzminden/Göttingen
University of Applied Sciences and Arts
www.hawk.de/en/r


HAWK
System Boundaries of the process chains
System boundary HTC
Credits for:
Sewage sludge treatment
Waste Water Treatment
Processwater
Process water
Dewatering
HTC
Separation
Hydro-char
Heat
Agriculture
NPK-Fertilizer
Horticulture
Peat
Mono-Incineration
Natural Gas
Co-Incineration
Lignite
SH1
SH2
SH3
SH4
Material Use
Energetic Use
Sewage Sludge
WWTP
Process water
Dewatering
Drying
Pyrolysis
Biochar
Oil & Gas
Heat
Sewage sludge treatment
Agriculture
NPK-Fertilizer + Lime
Horticulture
Peat
Biogasplant + Agriculture
NPK-Fertilizer, Corn + Lime
Co-Incineration
Lignite
SP1
SP2
SP3
SP4
Material Use
Energetic Use
System boundary Pyrolysis
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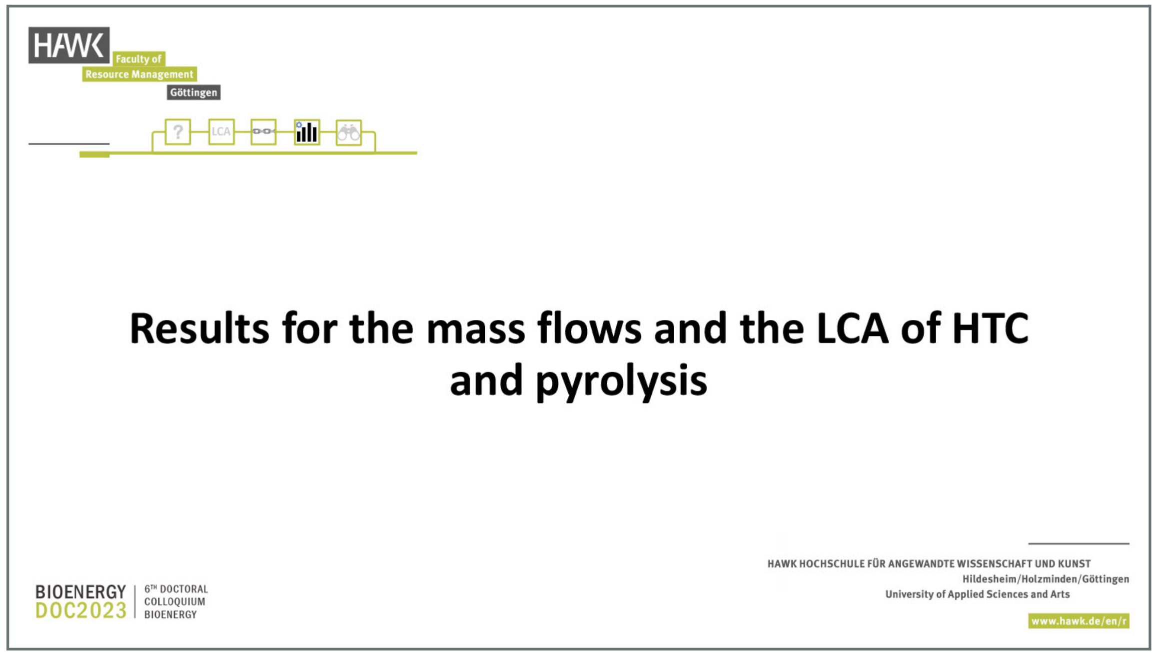
HAWK
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Göttingen
Results for the mass flows and the LCA of HTC
and pyrolysis
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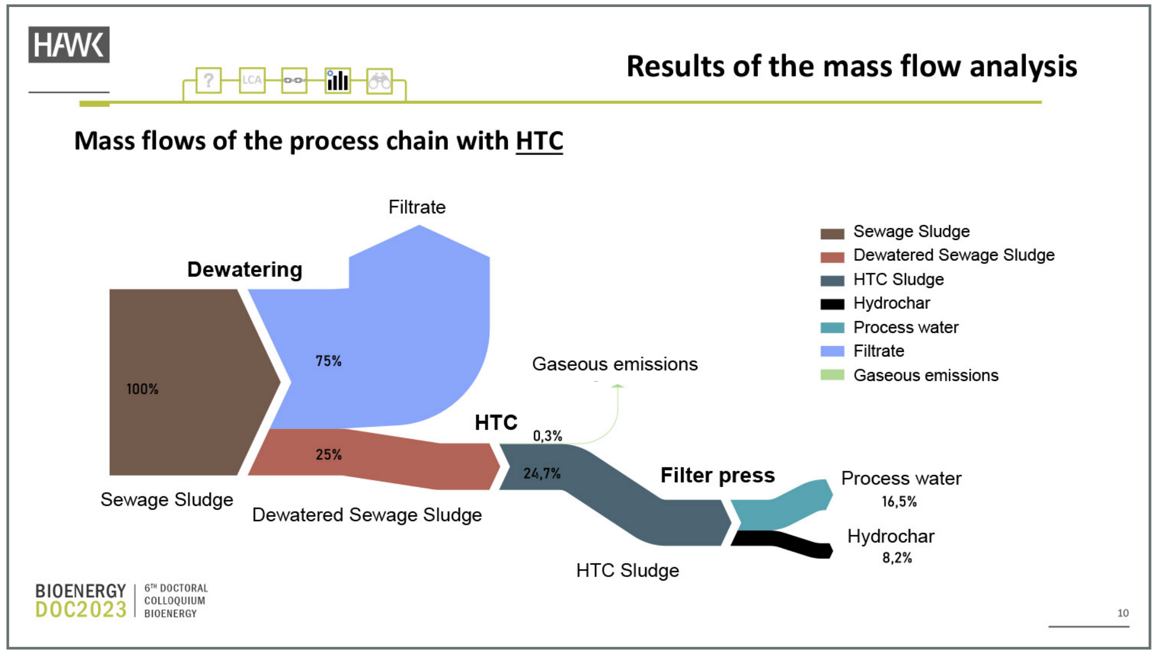
HAWK
Results of the mass flow analysis
Mass flows of the process chain with HTC
Filtrate
Dewatering
100%
75%
25%
Sewage Sludge
Dewatered Sewage Sludge
HTC
0,3%
Gaseous emissions
24,7%
HTC Sludge
Filter press
Process water
16,5%
Hydrochar
8,2%
Sewage Sludge
Dewatered Sewage Sludge
HTC Sludge
Hydrochar
Process water
Filtrate
Gaseous emissions
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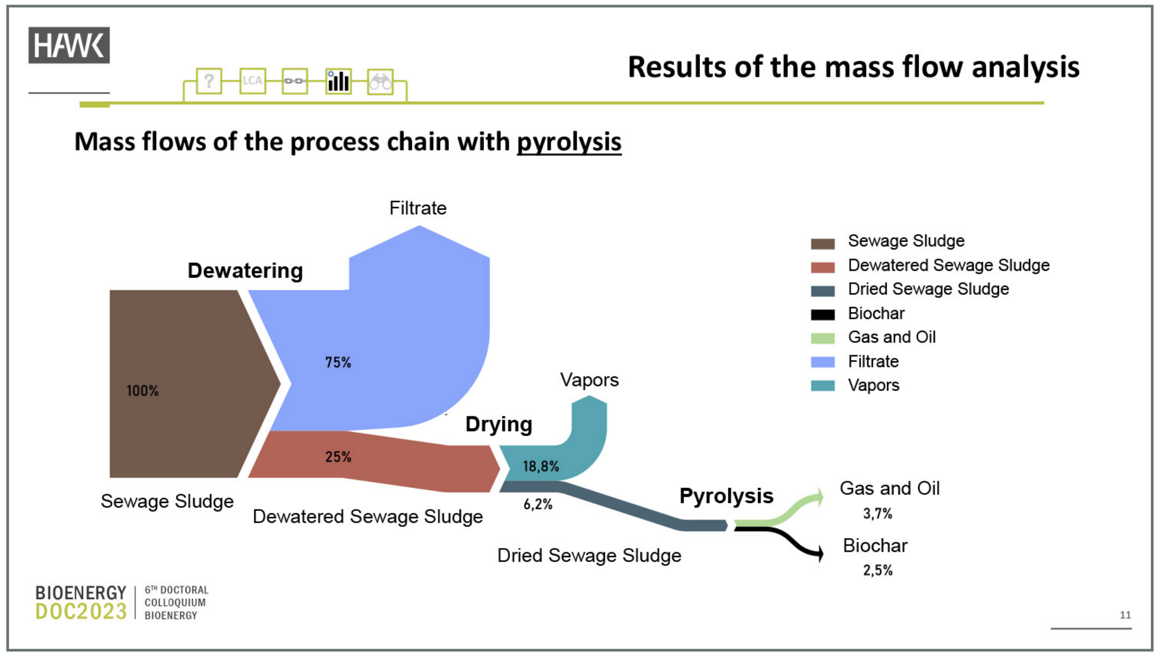
HAWK
Results of the mass flow analysis
Mass flows of the process chain with pyrolysis
Filtrate
Dewatering
Vapors
Drying
Pyrolysis
100%
75%
25%
18,8%
6,2%
Sewage Sludge
Dewatered Sewage Sludge
Dried Sewage Sludge
Gas and Oil
3,7%
Biochar
2,5%
Sewage Sludge
Dewatered Sewage Sludge
Dried Sewage Sludge
Biochar
Gas and Oil
Filtrate
Vapors
BIOENERGY DOC2023
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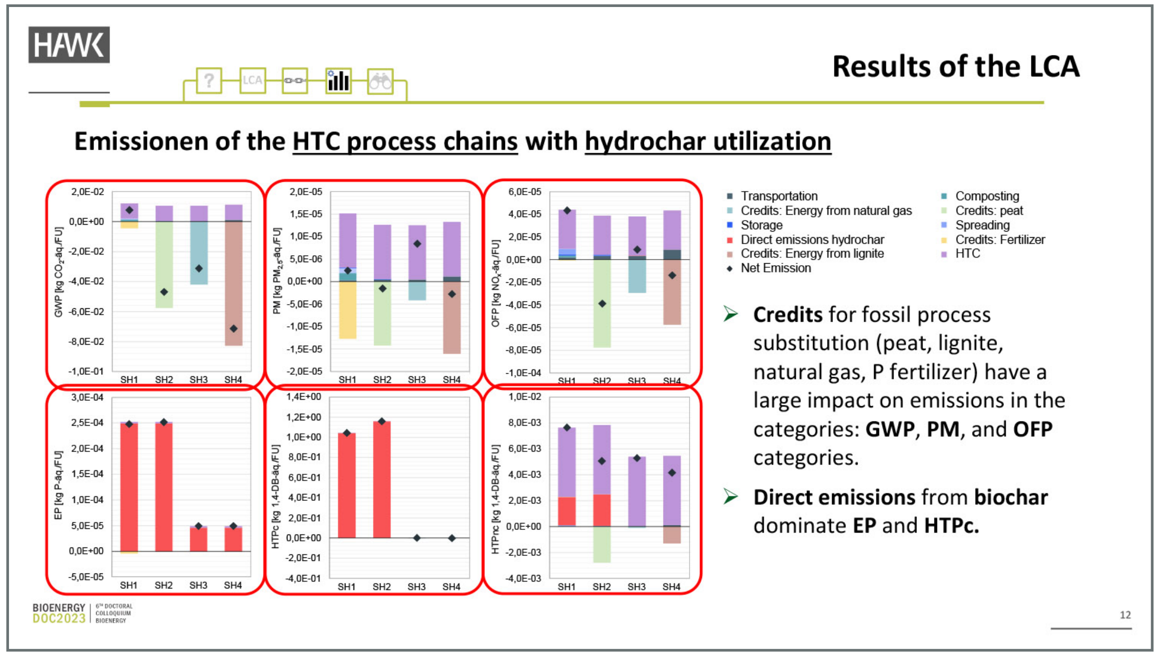
HAWK
Results of the LCA
Emissionen of the HTC process chains with hydrochar utilization
Transportation
Credits: Energy from natural gas
Storage
Direct emissions hydrochar
Credits: Energy from lignite
Net Emission
Composting
Credits: peat
Spreading
Credits: Fertilizer
HTC
Credits for fossil process substitution (peat, lignite, natural gas, P fertilizer) have a large impact on emissions in the categories: GWP, PM, and OFP categories.
Direct emissions from biochar dominate EP and HTPc.
SH1 SH2 SH3 SH4
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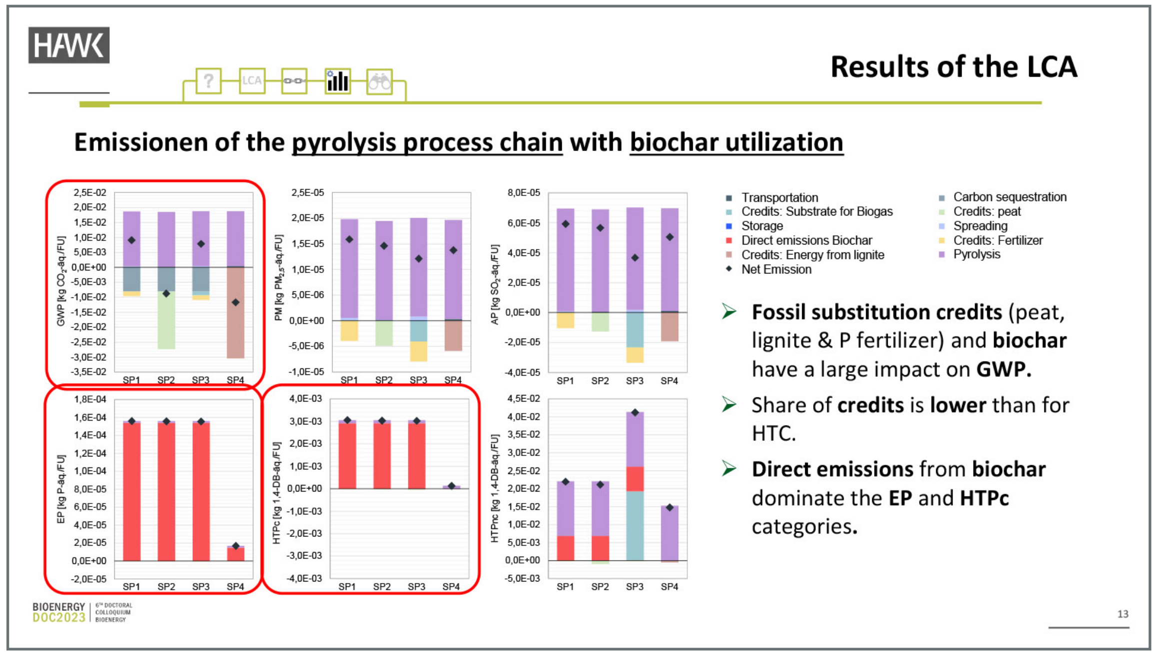
HAWK
Results of the LCA
Emissionen of the pyrolysis process chain with biochar utilization
Transportation
Credits: Substrate for Biogas
Storage
Direct emissions Biochar
Credits: Energy from lignite
Net Emission
Carbon sequestration
Credits: peat
Spreading
Credits: Fertilizer
Pyrolysis
Fossil substitution credits (peat, lignite & P fertilizer) and biochar have a large impact on GWP.
Share of credits is lower than for HTC.
Direct emissions from biochar dominate the EP and HTPc categories.
SP1 SP2 SP3 SP4
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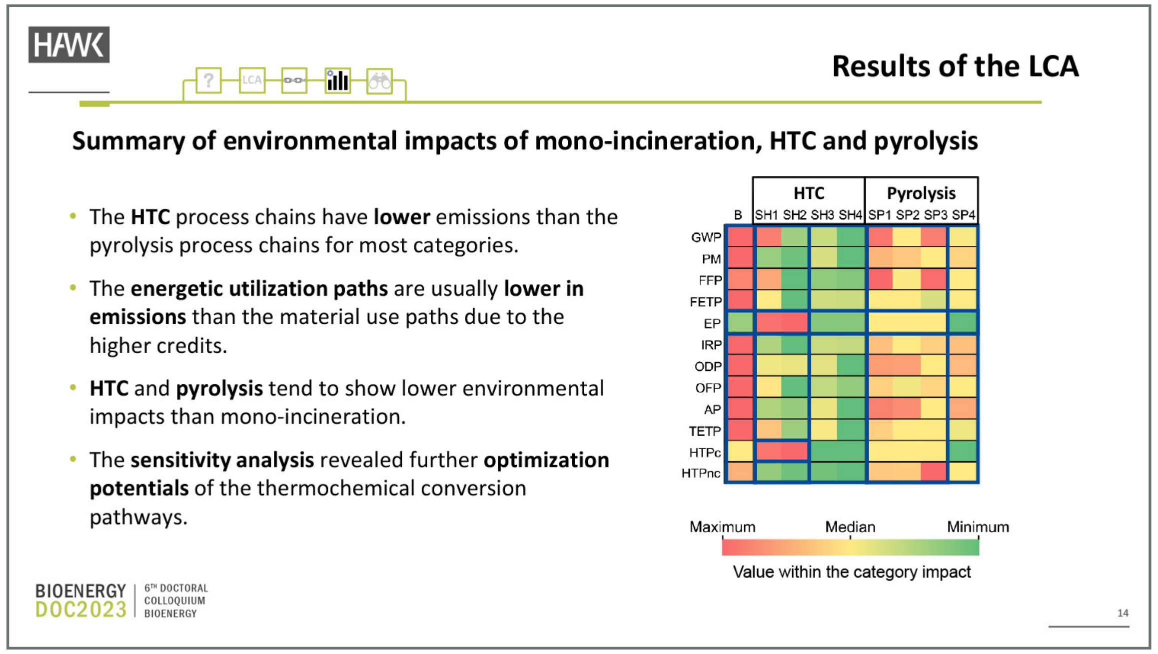
HAWK
Results of the LCA
Summary of environmental impacts of mono-incineration, HTC and pyrolysis
The HTC process chains have lower emissions than the pyrolysis process chains for most categories.
The energetic utilization paths are usually lower in emissions than the material use paths due to the higher credits.
HTC and pyrolysis tend to show lower environmental impacts than mono-incineration.
The sensitivity analysis revealed further optimization potentials of the thermochemical conversion pathways.
HTC
Pyrolysis
B SH1 SH2 SH3 SH4 SP1 SP2 SP3 SP4
GWP
PM
FFP
FETP
EP
IRP
ODP
OFP
AP
TETP
HTPc
HTPnc
Maximum
Median
Minimum
Value within the category impact
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Summary and Outlook

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Hildesheim/Holzminden/Göttingen
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Summary and Outlook

1
- **HTC** offers **energy advantages** over pyrolysis, which requires drying.
- **Synergies** can be exploited (e.g.: biogas, process water, pyrolysis gas and oil).

2
- The **energetic use of biochar/hydrochar** generates high emission **credits.**
  -> Net emissions are reduced and fossil resources are replaced.
- High toxicity potentials can occur with **HTC** due to **organic contaminants**.
- The material use of biochar/hydrochar allows **nutrient recycling** for both processes and **sequestration** of **carbon** via **pyrolysis**.

3
- The process chains with **HTC** and the process chains with **pyrolysis** tend to show lower environmental impacts than **mono-incineration**.

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Summary and Outlook

- **Economic considerations** of the balanced process chains must be made.
- A comprehensive **implementation** of the modeled process chains in practice **is missing** so far.
- In order to use biochar/hydrochar, it is necessary to adjust the **legislative framework.**
- Direct closing of (nutrient) **material cycles** is made possible.
- In the future, the material use of biochar could be used for **carbon sequestration**.

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HAWK Faculty of Resource Management Göttingen

Universität Rostock Traditio et Innovatio

Thank you for your attention

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René Bindig, Deutsches Biomasseforschungszentrum

Catalyst development procedure for exhaust gas aftertreatment of small-scale combustion plants

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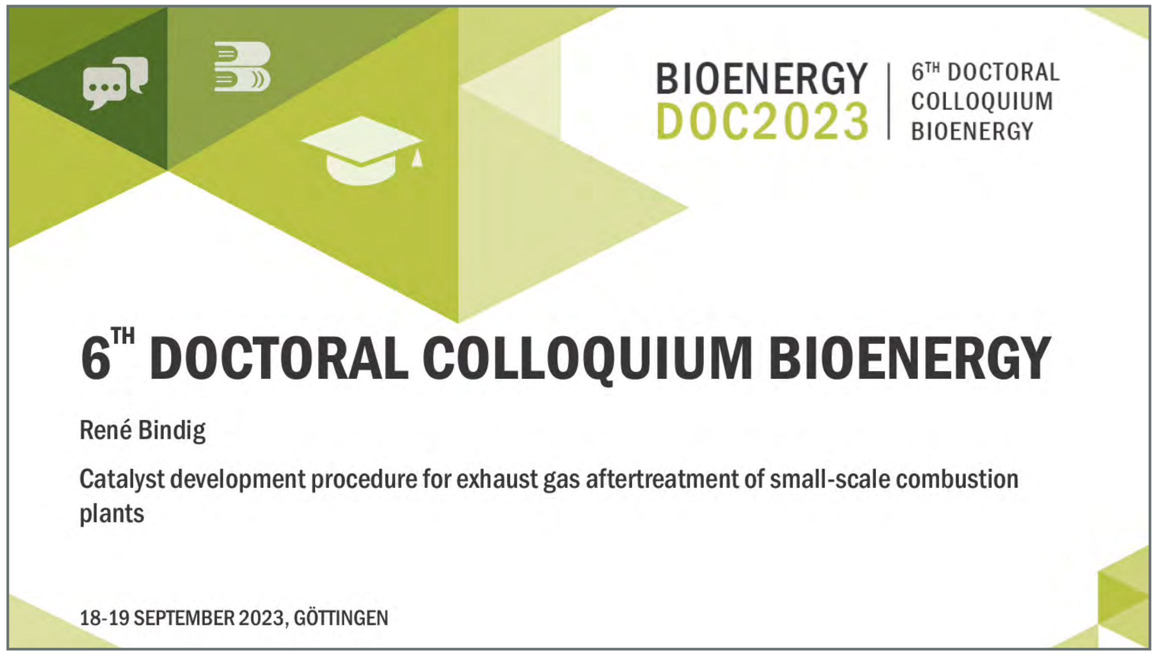
Catalyst development is a topic of constant high relevance, because process optimizations and adaptations to changed boundary conditions, for, e.g. industrial processes or flue gas aftertreatment require new and further developed catalysts.
Great difficulties encountered in catalyst development arise during the transition from one stage of development to the next. Reliable estimation of the behaviour of newly developed catalyst in real applications based on laboratory results could minimize the risk of having to repeat especially the final, very cost-intensive development step several times. This could significantly reduce the overall development costs.

Furthermore, on a laboratory scale under conditions similar to those in a real plant a more accurate temperature setting and recording of the temperature distribution over a catalyst sample is possible. This allows a more accurate investigation of the various factors affecting the observed effective kinetics of a catalyst sample. The aim of the thesis is to develop a multistage method that can be used to reliably estimate the full-scale behavior of a new catalyst under development.

For this purpose, special test rigs have been developed to obtain the necessary experimental data from laboratory-scale samples. These data are to be incorporated into a mathematical model. This model is to be used to describe the turnover-temperature behavior of the catalyst at full scale under the conditions of a real combustion plant.
The range of applicability of the process is initially limited to the development of catalysts for the exhaust gas aftertreatment of combustion plants in the small power range (i.e. combined heat and power plants and small combustion plants).

The necessary test rigs have been designed and set up. A commercially available catalyst was used to determine the suitability of the test rigs for this procedure and a mathematical model was developed. The test rigs, the experimental data obtained with these test rigs, and the mathematical model developed are presented and discussed.



Short introduction

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Title of the Doctoral Project:	Procedure for the development of catalysts for the reduction of emissions from small-scale combustion plants
Doctoral Student:	René Bindig
DBFZ Supervisor:	Prof. Dr. Ingo Hartmann
Cooperating University:	Martin-Luther-University Halle-Wittenberg
University Supervisor:	Prof. Dr. Thomas Hahn
Funding / Scholarship provider:	/
Logo:	
Duration:	07/2018 – ...

Scientific Background

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Catalyst development *

- Defining a **development goal** (e.g. oxidation catalyst for methane abatement)
- Synthesis of **powder samples**
- Application of active phase on a carrier: **monolithic samples**
- Scale-up
- **Scale-Up,** production of a **real scale monolith**

In practice:
- often empirical procedures
- based on experience, not science-based
- use of simple mathematical models

Determination of **intrinsic kinetics** ("Mikrokinetik")
- Scale: laboratory
- Use of **synthetic test gas**

Determination of **effective kinetics** („Makrokinetik")
- Scale: laboratory, bench, pilot
- Use of **synthetic test gas**
- Influenced by **mass and heat transfer effects**

Determination of **behavior** in the **real application**
- Scale: real application
- Use of **real flue gas**

29.09.2023 * **monolithic catalysts** for **catalytic post-combustion** of flue gases from combustion units 3

Aim

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- **Development of a procedure** with which the **behavior of a full-scale catalyst*** in real application can be reliably estimated **on the basis of catalyst samples on a laboratory scale**
- **Development** and **construction** of the required **test rigs**
- **Proof of the suitability** of the test rigs
- Derivation and **Validation** of a **mathematical model** for a real scale monolith

* **monolithic catalysts** for **catalytic post-combustion** of flue gases from combustion units

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Approach

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Development of the procedure and proof of suitability of the test benches by means of a catalyst* for wood log stoves

- Carried out in reverse order to "catalyst development"
  1) Tests with the catalyst in a stove
  2) Monolithic samples in MoKatTA
  3) Monolithic samples in VGA
  4) Powder samples in KDA

29.09.2023 * **Commercially available** 5

Approach

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Catalyst development
- Defining a **development goal** (e.g. oxidation catalyst for methane abatement)
- Synthesis of **powder samples**
- Application of active phase on a carrier: **monolithic samples**
- **Scale-Up,** production of a **real scale monolith**

Development of the procedure

Determination of activity of **powder samples**	3. Test rig: **KDA** • Synthentic test gas • **Active phase/material**
	3. Test rig: **KDA** • Synthentic test gas • **Powdered monolith**
Determination of activity of **monolithic samples** in **laboratory/ bench scale**	2. Test rig: **VGA** • **Synthentic test gas** • **adiabatic operation**
	1. Test rig: **MoKatTA** • **Real flue gas** • **Nonadiabatic operation**
Test run with **real scale monolith** in **real-life operation (RLO)**	

29.09.2023 **RLO** = real-life operation; **MoKatTA** = Mobile Katalysatortestapparatur; **VGA** = Vergleichsapparatur; **KDA** = Katalytische Durchflussapparatur 6

Experimantal Set-Up
MoKatTA

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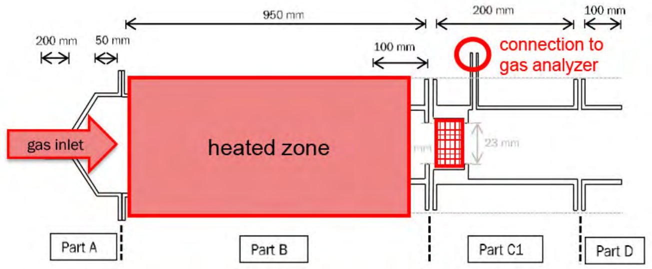
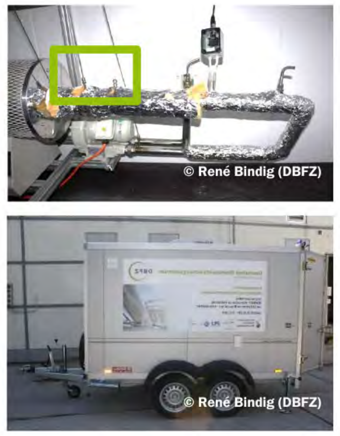
1. Test rig: **MoKatTA**
- **Real flue gas**
- **Nonadiabatic operation**

Sample size:
Diameter: 25 mm
Length: 20 mm





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Experimantal Set-Up
VGA

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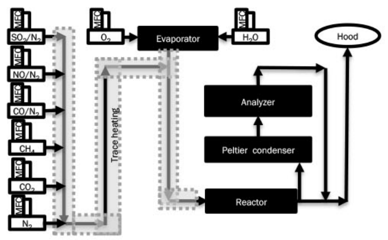
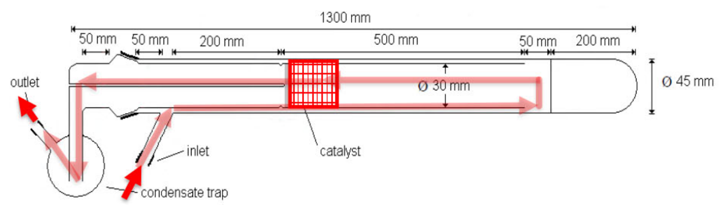
2. Test rig: **VGA**
- **Synthentic test gas**
- **adiabatic operation**

Sample size:
Diameter: 25 mm
Length: 20 mm





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Experimantal Set-Up
KDA

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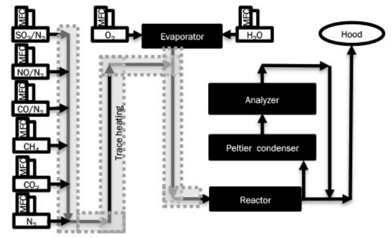
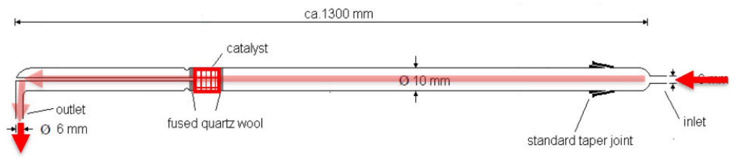
3. Test rig: **KDA**
- Synthentic test gas
- **Powdered monolith**
- **Active phase/material**

Typical filling size (powder):
Diameter: 10 mm
Length: 10 mm





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Experimantal results
Tests with the catalyst in a stove (real-life operation = RLO)

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- **Determination** of **conversions of different pollutants**, which can be achieved with the catalyst
- **Derivation** of the **test gas composition** for **KDA/VGA** by calculation of **average concentrations** of pollutants over complete burning cycles

		Averages in Vol.-%			Averages in mg/m³ (i.N.) at 13 Vol.-% O_2, dry basis		
		O_2	H_2O	CO_2	CO	Org. C	NO_x
Dummy	1. burn cycle	14,0	6,4	6,5	2170	36	129
	2. burn cycle	14,0	5,6	6,5	2705	15	123
	3. burn cycle	13,3	6,7	6,9	3632	56	122
	4. burn cycle	14,2	6,1	6,0	3414	98	120
		13,9	**6,2**	**6,5**	**2980**	**51**	**124**

		Averages in [Vol.-%]			Averages in mg/m³ (i.N.) at 13 Vol.-% O_2, dry basis		
		O_2	H_2O	CO_2	CO	Org. C	NOx
Catalyst	1. burn cycle	14,0	6,1	6,6	743	18	139
	2. burn cycle	13,8	6,3	6,7	684	16	131
	3. burn cycle	13,7	6,3	6,8	1058	41	126
	4. burn cycle	13,5	6,2	7,0	818	7	129
		13,8	**6,2**	**6,8**	**826**	**21**	**131**
Conversions in %					72,3	59,8	-6,3

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Experimantal results
Tests with MoKatTA, VGA, KDA

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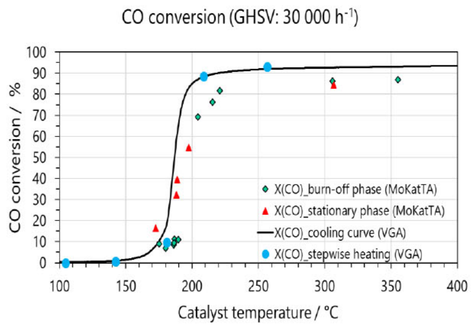

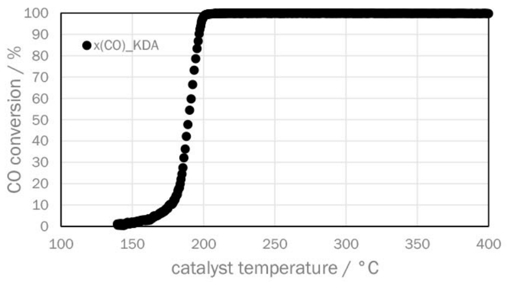

MoKatTA: Conversion in real flue gas at non-adiabatic operation
VGA: Conversion in synthetic flue gas at adiabatic operation

KDA: Conversion in synthetic flue gas at isothermic operation;
→ Arrhenius-Plot → $\mathbf{E_A}$, $\mathbf{k_0}$: to be used for modelling

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Derivation and Validation of a mathematical model for a real scale monolith

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- Assumptions for the calculation of the **Arrhenius plot**:
  1. Consideration as a quasi-homogeneous reaction is justified.
  2. It is an irreversible reaction of the **type A → B** .
  3. The reaction (partial) order with respect to the CO concentration **n = 1**.
  4. Due to the high excess of O_2, the partial order of the reaction with respect to the O_2 concentration is 0.
  5. This means that the CO oxidation proceeds according to **quasi-1st order**.
  6. The reaction rate can be formally described by **r = kcⁿ**.
  7. The volume changes of the reaction mixture are negligible.
  8. The pressure in the entire reactor is constant.

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Derivation and Validation of a mathematical model for a real scale monolith

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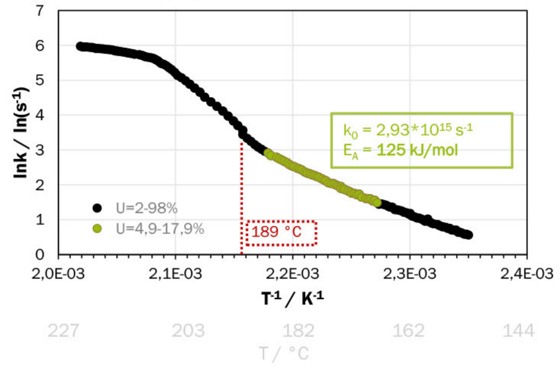
Arrhenius diagram from cooling curve (KDA, powder sample):



- **The evaluation was carried out in the range from 4.5 to 10.0% CO conversion**

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Derivation and Validation of a mathematical model for a real scale monolith

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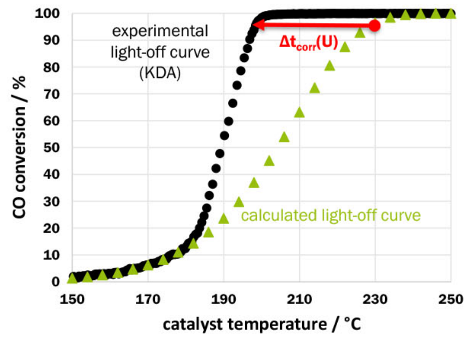

- With same assumption as for Arrhenius plot: simple model (isothermic) for KDA reactor created (Solver: Excell)
  → **significant deviation** at high conversions; →→ **overheating?**
- **First approach:**
  introduction of an conversion-dependend correction term for the catalyst temperature
  → $\Delta t_{corr}(U)$

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Derivation and Validation of a mathematical model for a real scale monolith

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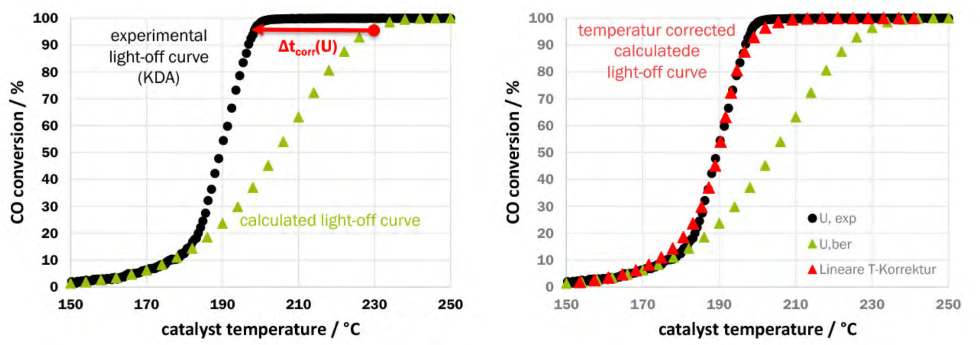

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Derivation and Validation of a mathematical model for a real scale monolith

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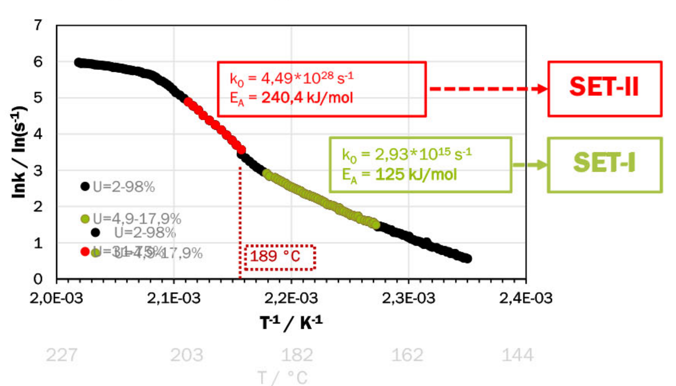
Arrhenius diagram from cooling curve:



- **Buckling to be observed**
- **Change of mechanism on the surface?**
- **Second approach:** Use of **different parameter sets** for two different conversion ranges

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Derivation and Validation of a mathematical model for a real scale monolith

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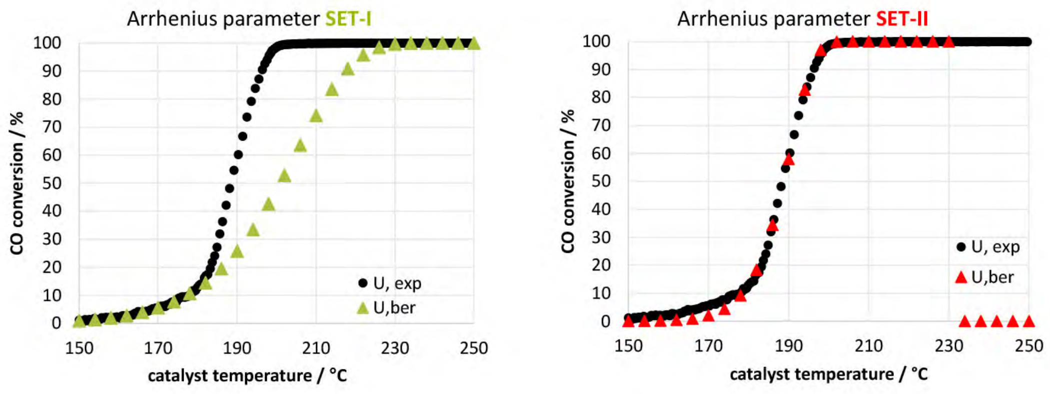

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Derivation and Validation of a mathematical model for a real scale monolith

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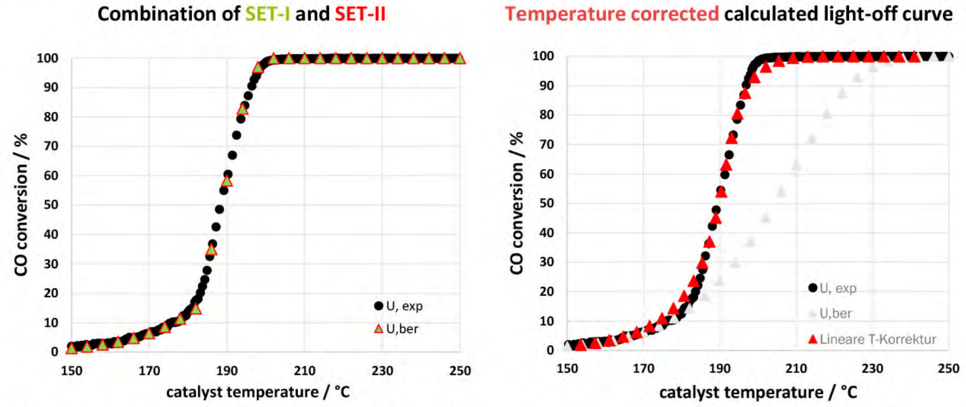

→ Moderately closer match for "combination of SET-I and SET-II"

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Derivation and Validation of a mathematical model for a real scale monolith

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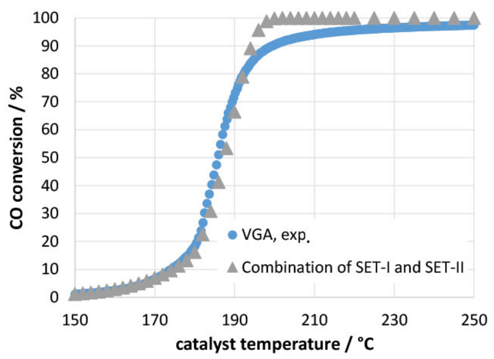

For VGA data:

- Use of **SET-I and SET-II** (**KDA data**) to calculate the CO conversions in different regions
  - ➢ Much better fit than calculation (isotherm or adiabatic) with only one parameter set
  - ➢ Take into account **transport influences** (mass and heat?) or **change of mechanism** on the surface
  - ➢ A kind of **pseudo-isothermic reactor model**
- Significant **deviations** at CO conversions **>80%**

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Conclusions

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Calculation of **VGA light-off curve** with **two parameter sets** from **KDA Arrhenius plot**:

- Transfer of the powder data to the monolithic sample was possible with the test equipment under these conditions.
- Deviations occurred at CO conversions >80%.

Calculation of **VGA light-off curve** with **one parameter set** from **KDA Arrhenius plot**:

- Not possible/high deviations.

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Outlook

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Calculation of **VGA light-off curve** with **3 parameter sets** from **VGA Arrhenius plot**:

- Minimization of the deviation occurring at CO conversions >80%.
- Take into account (further) transport influences (mass and heat)

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SESSION

BIOENERGY SYSTEMS ANALYSIS

Prof. Dr. Daniela Thrän
Dr. Ludger Eltrop
Dr. Fabian Schipfer

Milad Rousta, Institute of Energy Economics and Rational Energy Use

Descision making for post-EEG concepts for biogas plants under uncertainty in energy markets

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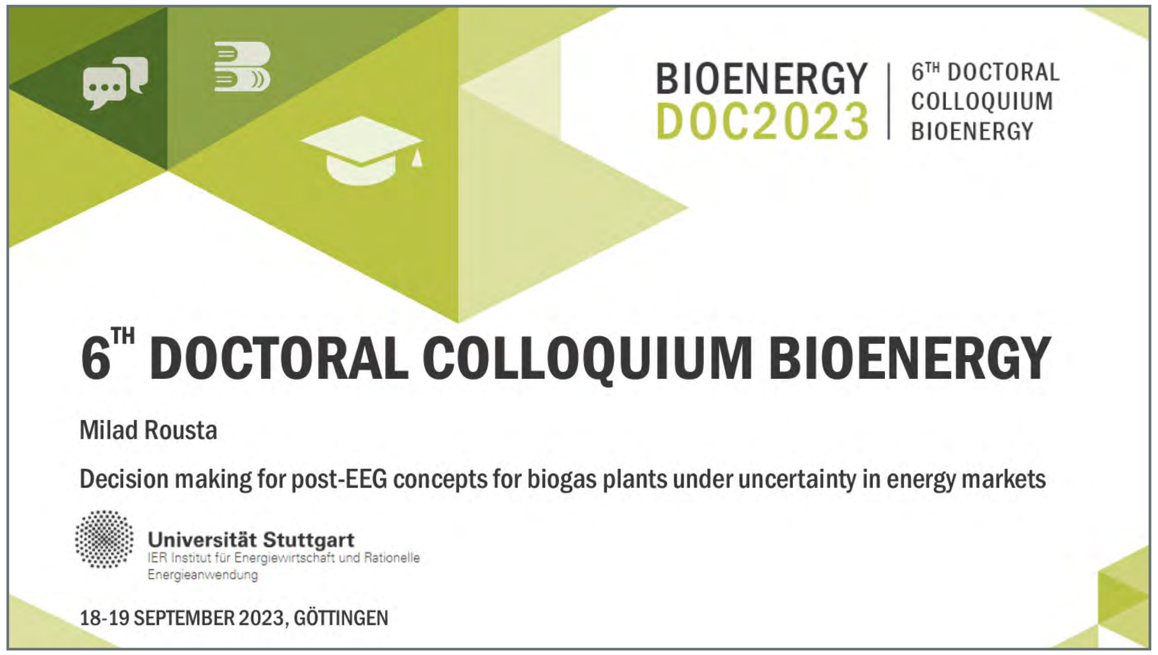
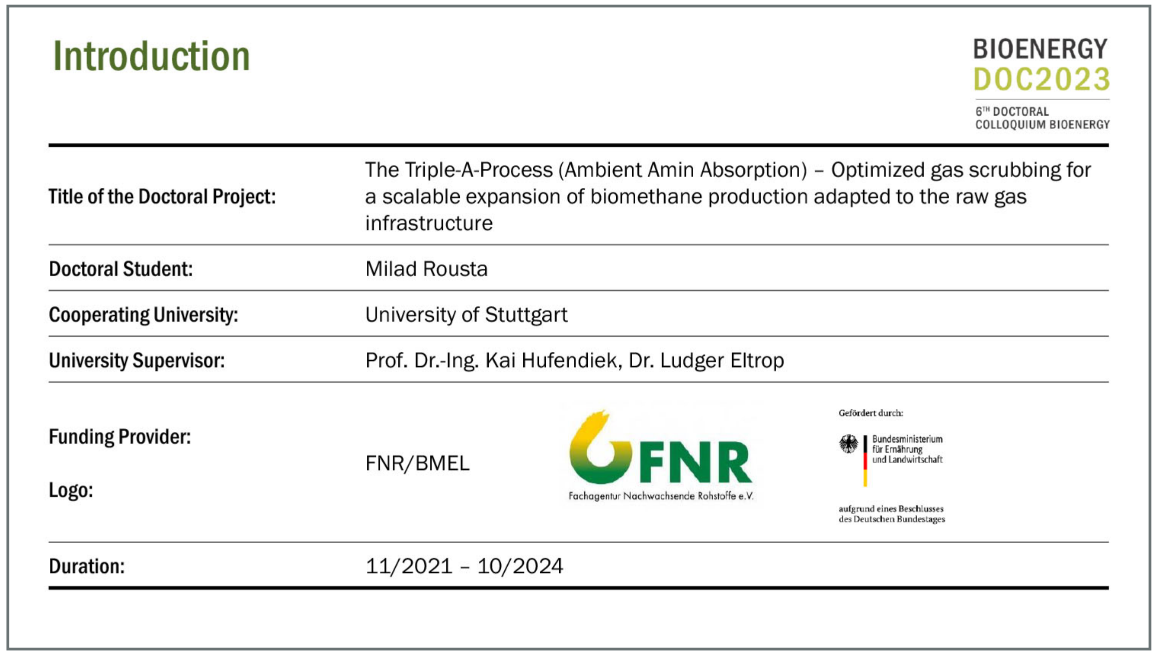
Various sources of uncertainty such as renewable energy production, weather forecast, regulatory environment, economic development and the current geopolitical tensions cause energy markets to be highly volatile. Consequently, there is a great deal of risk about market revenues, compelling market participants to put considerable effort into making a profitable decision. Biogas plants (BGPs), compared to solar panels and wind turbines, would be much more influenced by the uncertain energy market revenues, most notably because of producing diverse products including power, heat, and gas. In literature [1] various repowering concepts have been recommended to BGPs' operators to extend the operations profitably in the post-EEG period. But most suggested repowering concepts are based on risk-free energy market prices posing a potential overestimation of the available revenues. Thus, the aim of my research is to analyze different energy market risks and price volatilities in order to reduce the errors prevailing in the current profitability assessment of BGPs. To support the operator's decision making and operation of BGPs, suitable risk management strategies concerning the allocation of biogas or biomethane volume to different available markets will be investigated.

First, a suitable method for the forecast of the future market price volatility and the generation of, for example, electricity price time series is selected and employed. Second, the potential revenues, entailing market price volatility, and the relevant costs are entered into the substrate mix optimization linear programming (LP) model, which is responsible for the formation of gas allocation portfolio. As a result, the optimal substrate mixture, minimizing the gross margin of the biogas production while complying with regulations of different markets as well as technical process restrictions, is achieved. The new results will be compared with the literature results (not including market price volatility) [1] in order to see the extent to which the inclusion of risk and uncertainty would make a difference. Moreover, in order to minimize the potential risk of revenue losses while confronting the portfolio of gas allocation, an appropriate risk assessment technique, e.g. value at risk (VaR), will be adopted.

It is expected that the reduction of errors regarding the market revenues through conducting market risk and volatility analysis and also hedging risk strategies could help to acquire much more robust solutions for optimal repowering concepts of BGPs in their Post-EEG period.





Title of the Doctoral Project:	The Triple-A-Process (Ambient Amin Absorption) – Optimized gas scrubbing for a scalable expansion of biomethane production adapted to the raw gas infrastructure
Doctoral Student:	Milad Rousta
Cooperating University:	University of Stuttgart
University Supervisor:	Prof. Dr.-Ing. Kai Hufendiek, Dr. Ludger Eltrop
Funding Provider: Logo:	FNR/BMEL
Duration:	11/2021 – 10/2024

Project Goal

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Development of a novel biogas upgrading process suitable for small biogas plants (production capacity < 250 Nm³/h)

- Process engineering developments & experimental investigation (IFK)
- Practical testing of the pilot plant at a biogas plant (Energiehof Weitenau, Winfried Vees)
- Determination of potentials for implementation at existing biogas plants (IER)

What are the promising business models for biomethane production units?

Future energy markets analysis

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Outline

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- **Background (including our under review paper)**
  - The status quo & outlook on biomethane production
  - Uncaptured capacity of biomethane production & corresponding challenges
  - Solutions inspiring small BGPs to switch to biomethane production in their post-EEG period
  - Substrate mix optimization LP model
  - Portfolio of biomethane allocation between different potential markets
- **Research Questions**
- **Methodology & Challenges**
- **Conclusions & Future Research**

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The status quo & outlook on biomethane production

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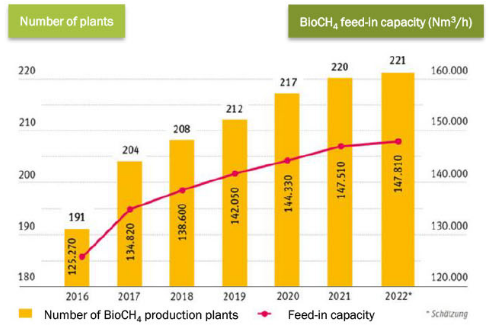
What are the reasons driving biomethane demand?

- Need for carbon neutral fuels in high-temperature industrial heating processes and the transport sector [1].
- Need for economically competitive fuels while confronting geopolitical challenges e.g. supply disruption and the resultant increase in the natural gas price.
- Current discussion on climate-neutral fuels for heating in residential areas (GEG – Gebäudeenergie-, resp. Heizungsgesetz).



Development of biomethane production

Ref= FNR nach dena (2022)

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How the biomethane production could be increased? Where the uncaptured capacity lies?

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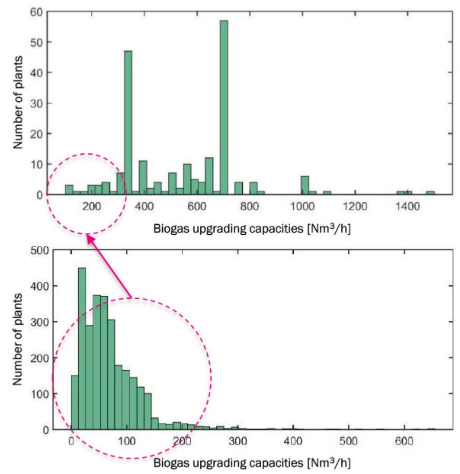
Small BGPs (with the capacity of below 250 Nm³ biogas/h) account for the majority of the BGPs with on-site CHP utilization currently in operation in Germany [2].

Challenges regarding biomethane production in small BGPs [3]:

- Due to economies of scale, smaller biomethane production capacities are accompanied with higher production costs.
- Technology related costs



Distribution of biomethane production plants with respect to biogas upgrading capacities in Germany (capacities below 2000 Nm³/h, n=207, source data: dena 2019b)

Distribution of the agricultural BGPs with respect to the potential biogas upgrading capacities in BW, NI, SN & TH (n=2819, own evaluation based on project results NxtGenBGA & Aurasa-Biogas)

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Solutions inspiring small BGPs to switch to biomethane production in their post-EEG period!

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Technology	A more efficient and cost-effective technology is needed, e.g. Triple A (Ambient Amin Absorption)
Economic	Increase the profitability of biomethane production via increasing market revenues

What are the potential markets for biomethane? (*considering grid injection repowering concept*)

Index	Description
Market 1 (M1)	Fuel in the transport sector (*linked to GHG Quota market*)
Market 2 (M2)	Fuel for biomethane CHP plants working under the EEG requirements
Market 3 (M3)	Regulatory-free SNG buyers
Market 4 (M4)	Green gas market for industrial heating processes
Market 5 (M5)	Advanced fuel in the transport sector (*linked to GHG Quota market*)

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Optimization problem

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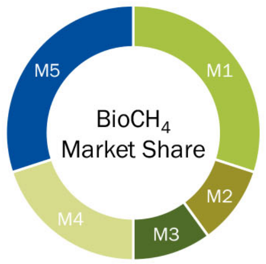

In order to maximize the profitability of biomethane production:
How much biomethane should be allocated to each market while the produced biomethane complies with the regulations of each market? [4]

Substrate mix optimization LP model

$$Max\ contribution\ margin\ of\ gas\ production = \sum_{m=1}^{M}\sum_{t=1}^{T} c_{tm} \times x_{tm}$$

output → Optimized substrate mixture yielding the maximum contribution margin → Portfolio of BioCH$_4$ allocation between the five Markets

$t = substrate\ type$
$m = market\ type$
$c = revenue - cost\ (\frac{€}{ton})$
$x_{tm} = yearly\ mass\ of\ each\ substrate\ in\ each\ market\ (\frac{ton}{year})$

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Simplified assumptions

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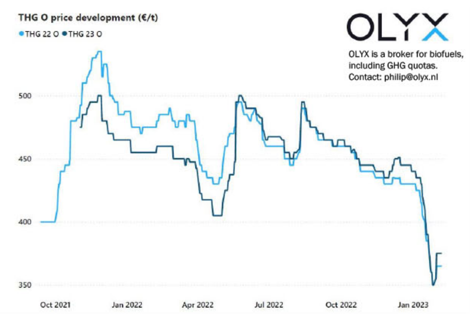
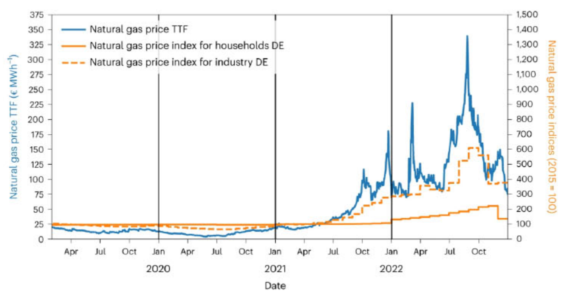
- **For each market, the average value of a normative price time series over 10 years was assumed.**
- **The Quota price time series was normatively assumed.**
- **No risk measures and preferences were considered.**



Prices of natural gas at the European wholesale and at the German retail market [5].



There is a great deal of **uncertainty** and thus our estimation of market revenues is not error free and the calculated portfolios are **highly risky.**

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Generic Research Questions

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6TH DOCTORAL COLLOQUIUM BIOENERGY

What are the viable options (business models) incentivizing small BGPs to contribute to biomethane production in their post-EEG period?

- Considering the uncertainty, which strategy could not only increase biomethane production profitability but also prevent BGPs from shouldering significant financial losses in the future (hedging future risks)?
- Which price formation model could provide BGPs with a more realistic estimation of future market prices?

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Methodology & Approach

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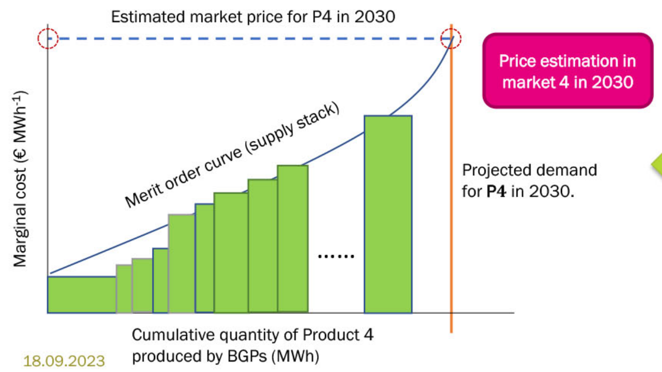
Proposed solution: futures contracts	
Advantages	• Function as a risk management strategy • Address the liquidity risk
Challenge	• Which price estimation model should be used?

Merit order model

- Creation of a supply stack called **merit order curve**
- Given the respective demand curve, the price is determined based on the market clearing assumption: $supply = demand$



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Issue of interconnected markets

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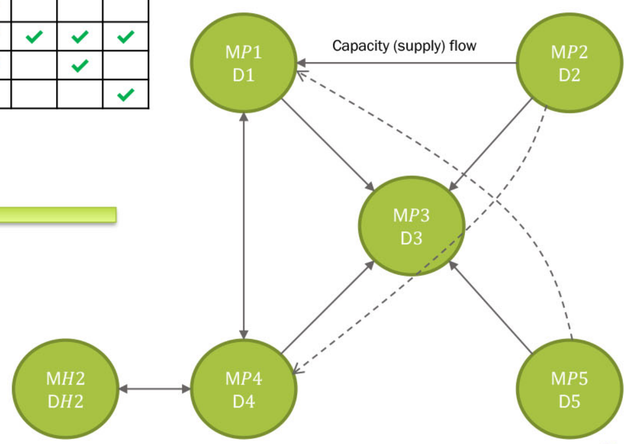
Markets	P1	P2	P3	P4	P5
Fuel in the transport sector (M1)	✓	✓		✓	✓
Biomethane CHP units (M2)		✓			
Regulatory-free SNG buyers (M3)	✓	✓	✓	✓	✓
Industrial heating processes (M4)	✓	✓		✓	
Advanced fuel in the transport sector (M5)					✓

Market Coupling Approach



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Conclusions & Future Research

BIOENERGY DOC2023 6TH DOCTORAL COLLOQUIUM BIOENERGY

- Small BGPs show great potential to contribute to biomethane production in their post-EEG periods. But given the high level of uncertainty, **they are in need of more concrete business models.**
- **Futures contracts** would be a viable option by which BGPs could hedge the future market price risks.
- The **merit order model** could form a more realistic estimation of the future market prices.
- The **market coupling method** could resolve the challenge of interconnected markets and make a better forecast of the future market prices.
- The role of **GHG Quota market** and its probable effects on biomethane price estimation need to be analyzed.
- The scenario-based parameters such as the products' demand should be investigated.
- A suitable risk measure should be recognized and the risk exposure of portfolios ought to be quantified.

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References

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2. Based on project results NxtGenBGA & Aurasa-Biogas
3. Beyrich et al. (2019) Verbundvorhaben: Effiziente Mikro- Biogasaufbereitungsanlagen (eMikroBGAA). Schlussbericht. Edited by Fachagentur Nachwachsende Rohstoffe e.V. (FNR). Fraunhofer-Institut für Energiewirtschaft und Energiesystemtechnik (Fraunhofer IEE); Deutsches Biomasseforschungszentrum (DBFZ); Gas- und Umwelttechnik GmbH (DBI); Deutsche Energie-Agentur GmbH (dena).
4. Güsewell J, Rousta M, Eltrop L (2023) Trade-offs in the substrate mix optimization of biogas plants considering biomethane market conditions. In Journal of Energy, Sustainability and Society. DOI: 10.21203/rs.3.rs-3112150/v1. (*under review*)
5. Ruhnau O, Stiewe C, Muessel J, Hirth L (2023) Natural gas savings in Germany during the 2022 energy crisis. In Nat Energy 8 (6), pp. 621–628. DOI: 10.1038/s41560-023-01260-5.

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Email:
www.hawk.de

Dan Taylor, Aston University

Can sustainable biomass help us achieve net zero? The politics of people and the planet

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UK - Birmingham, B4 7ET
E-Mail: 210139279@aston.ac.uk

Biomass is unique amongst other sources of energy in its position as a renewable source of carbon, and its interlinkages with our natural ecosystems. Against a backdrop of climate, ecological and energy emergencies, the increasingly polarised debates around biomass use mean that developing policy to incentivise sustainable biomass use is complex. Despite research demonstrating that modern biomass conversion technologies can reduce greenhouse gas emissions, as well as deliver social, environmental, and economic benefits, non-technical barriers to sustainable deployment still exist within policy. By interrogating existing economic and political forces via a political economy approach, this research seeks to influence the design of policy that incentivises biomass use that delivers maximum benefits for climate, nature, and people.

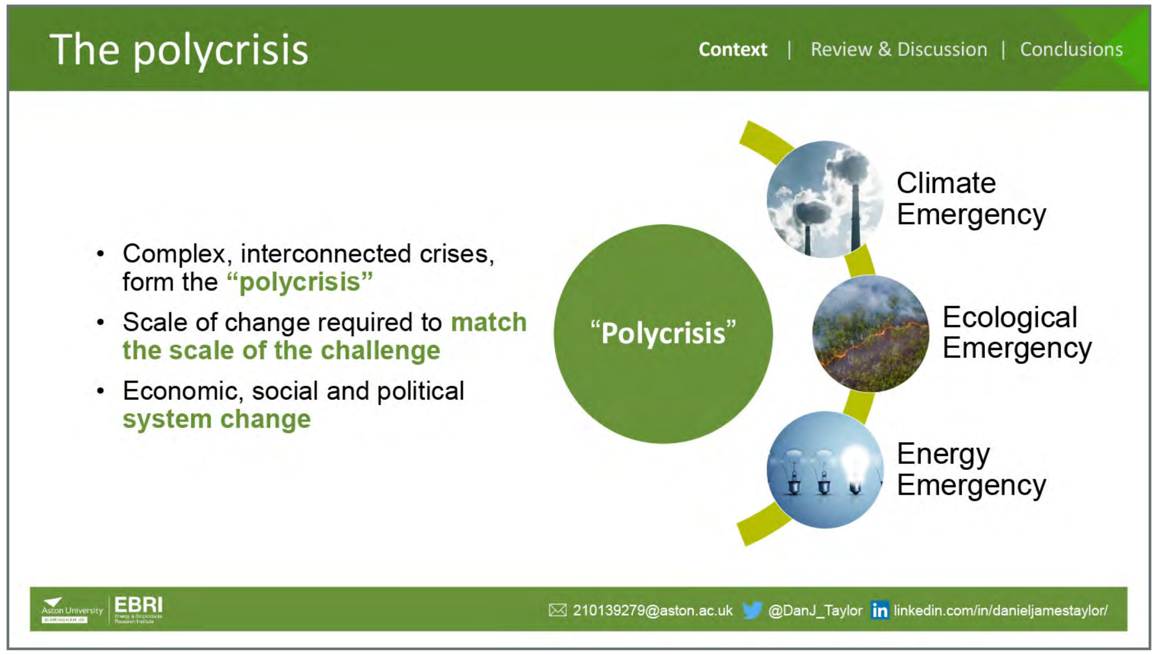
A review of existing literature on political economy and renewable energy transitions reveals a significant knowledge gap in the research around the use of biomass resources for energy and products, and a lack of focus on the concept of net zero and the associated impacts on biomass policy. Furthermore, several important themes emerged from existing research which should be considered when making policy decisions:

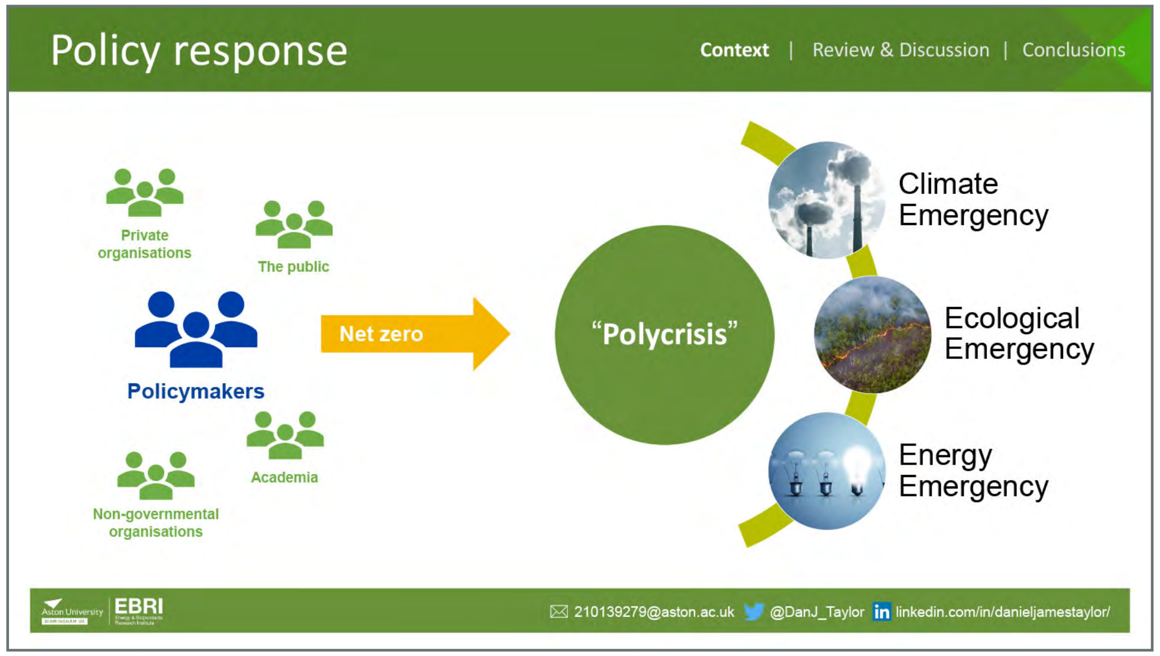
The social contract (Why): An expectation that elected policymakers ensure a secure supply of energy, on a national scale, at an affordable rate. This is threatened by powerful private interests who seek to maximise their financial gains.

The energy decarbonisation challenge (What): What technologies should we invest in now, locking in path-dependency for years to come, that will ensure we drastically reduce our carbon emissions? And how will policymakers do this without breaking the social contract and maintain the support of powerful private interests?

The approach we take (How): Top-down approaches often maintain the status quo, whereas decentralised, co-designed, local approaches to renewable energy innovation are more likely to mobilise people and garner political support; this makes them more politically sustainable.

This presentation will draw on experiences engaging with stakeholders from across UK bioenergy supply-chains, including those from policy, academia, industry, and society at large. Via a political economy approach, through qualitative analysis and stakeholder engagement, this research aims to address the identified gap in existing literature. It will do so by highlighting and outlining opportunities for socio-economic benefits associated with sustainable biomass use, promoting opportunities to incentivise best practice via policy design, and ensure that outputs are accessible to non-expert audiences.




Policy response
Context | Review & Discussion | Conclusions
Private organisations
The public
Policymakers
Academia
Non-governmental organisations
Net zero
"Polycrisis"
Climate Emergency
Ecological Emergency
Energy Emergency
EBRI
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Biomass is promoted as a carbon neutral fuel. But is burning wood a step in the wrong direction?
Biomass cofiring loopholes put coal on open-ended life support in Asia
Green groups dispute power station claim that biomass is carbon-neutral
'Carbon-neutrality is a fairy tale': how the race for renewables is burning Europe's forests
Why the next PM should take a long, hard look at biomass
Kwasi Kwarteng says biomass wood imports are "not sustainable"
Burning Biomass is NOT Carbon Neutral
The backslide on renewables Europe can't afford
Controversial biomass power station scheme 'to be greenlit by Government'
Wood pellets are sold as a clean alternative to coal. But is the subsidised bioenergy boom accelerating the climate crisis?
Why is the UK still in thrall to dirty energy?
Converting coal plants to biomass could fuel climate crisis, scientists warn
'Enough with the burning': EU executive accused of sacrificing forests
Markinch biomass plant under investigation as thick dust appears on house and car windows


Can biomass help?
Context | Review & Discussion | Conclusions
"Polycrisis"
Climate Emergency
Ecological Emergency
Energy Emergency
Renewable carbon
Links to nature
Low carbon energy
Biomass
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The biomass debate
Context | Review & Discussion | Conclusions
Public perception is not clear on biomass
Debates and discussions are increasingly polarised
Actors are able to make authoritative claims to further their own interests
Biomass is easily framed as negative
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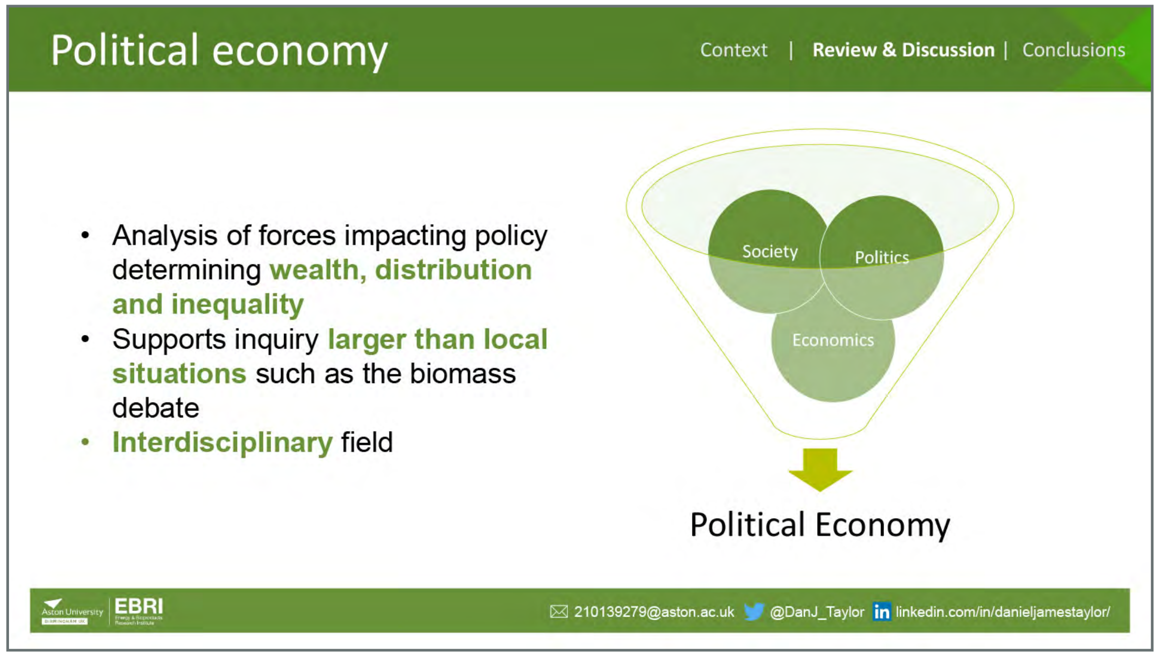
Political economy
Context | Review & Discussion | Conclusions
• Analysis of forces impacting policy determining wealth, distribution and inequality
• Supports inquiry larger than local situations such as the biomass debate
• Interdisciplinary field
Society
Politics
Economics
Political Economy
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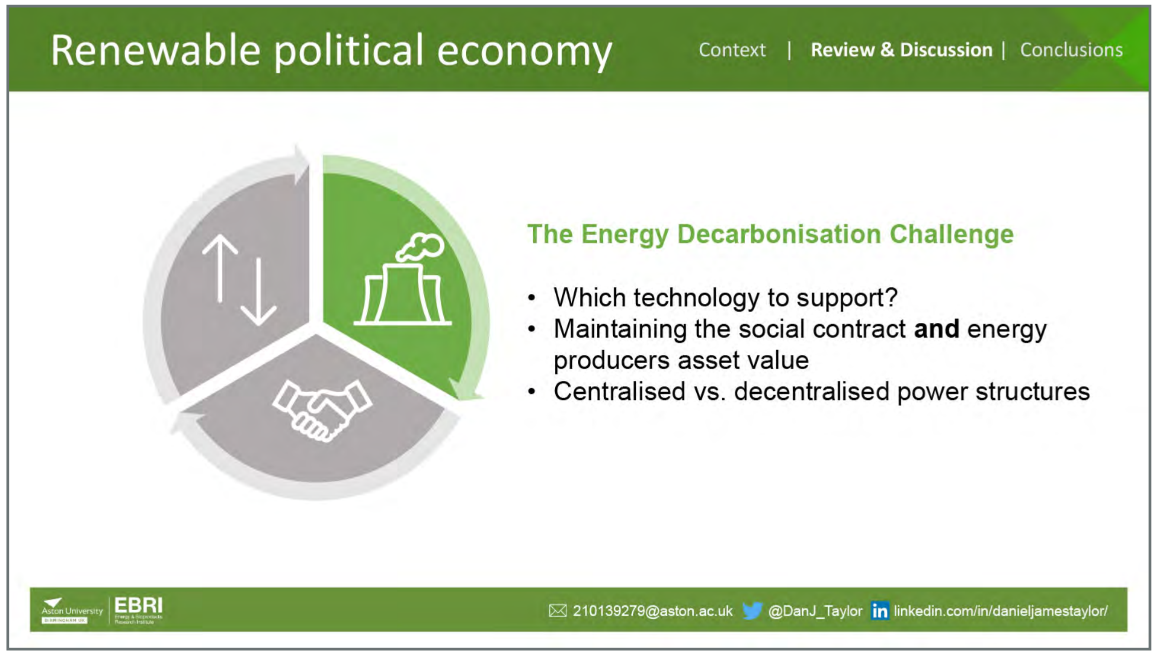
Renewable political economy
Context | Review & Discussion | Conclusions
The Energy Decarbonisation Challenge
• Which technology to support?
• Maintaining the social contract and energy producers asset value
• Centralised vs. decentralised power structures
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Renewable political economy
Context | Review & Discussion | Conclusions
The Social Contract
• Between elected policymakers and the people
• Secure, national, affordable energy
• Threatened by private interests
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Renewable political economy
Context | Review & Discussion | Conclusions
The Design Approach
• Local approaches more likely to garner political support
• Decentralised approaches build buy-in
• Top-down retains existing status quo
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Renewable political economy
Context | Review & Discussion | Conclusions
The Social Contract
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• Top-down retains existing status quo
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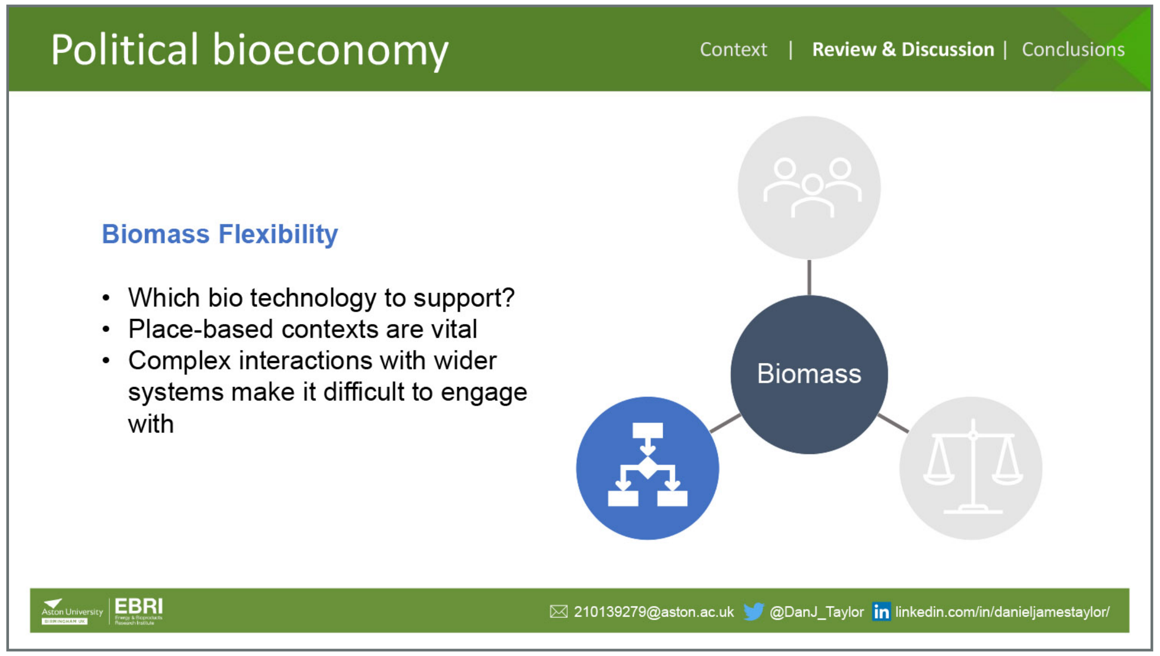
Political bioeconomy
Context | Review & Discussion | Conclusions
Biomass Flexibility
• Which bio technology to support?
• Place-based contexts are vital
• Complex interactions with wider systems make it difficult to engage with
Biomass
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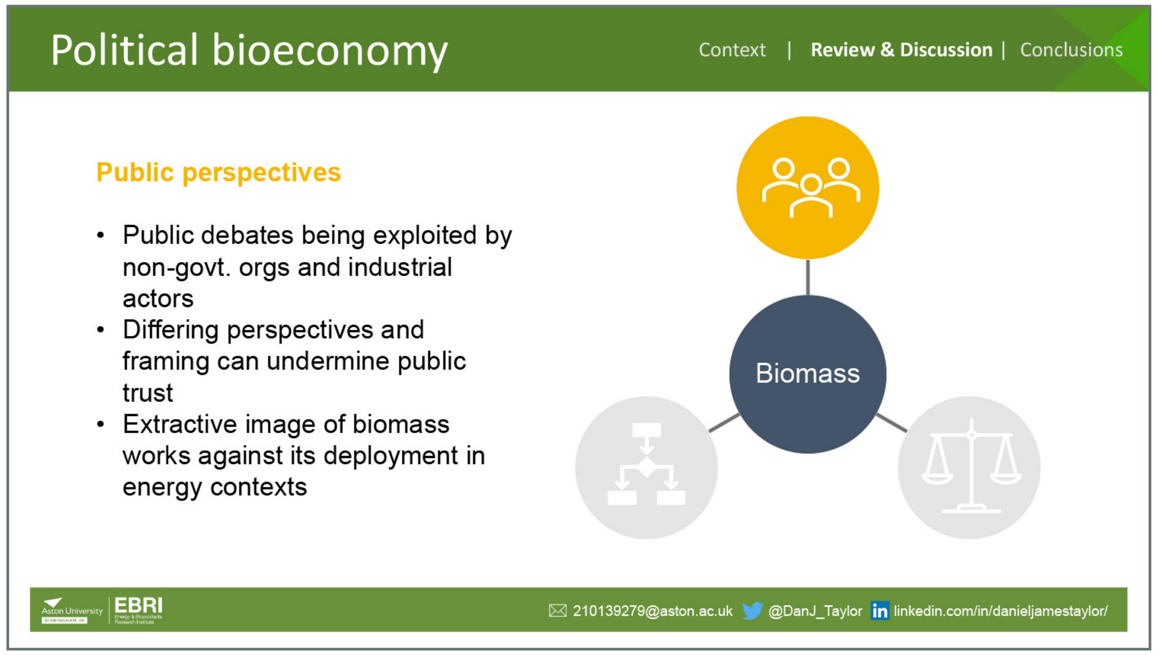
Political bioeconomy
Context | Review & Discussion | Conclusions
Public perspectives
• Public debates being exploited by non-govt. orgs and industrial actors
• Differing perspectives and framing can undermine public trust
• Extractive image of biomass works against its deployment in energy contexts
Biomass
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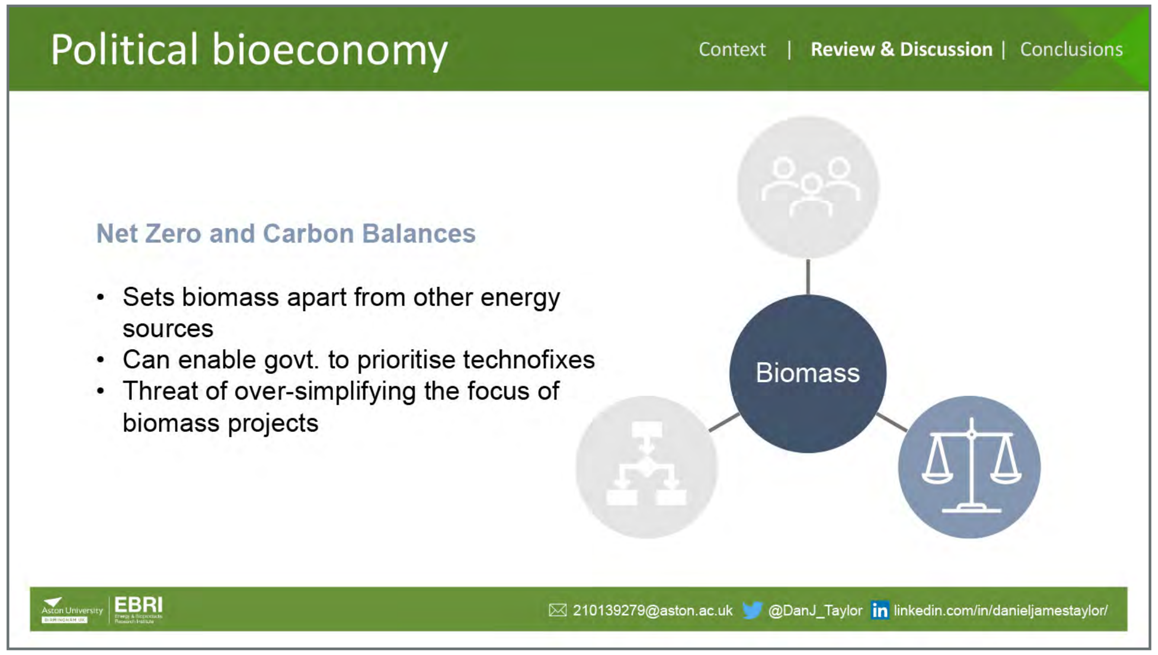
Political bioeconomy
Context | Review & Discussion | Conclusions
Net Zero and Carbon Balances
• Sets biomass apart from other energy sources
• Can enable govt. to prioritise technofixes
• Threat of over-simplifying the focus of biomass projects
Biomass
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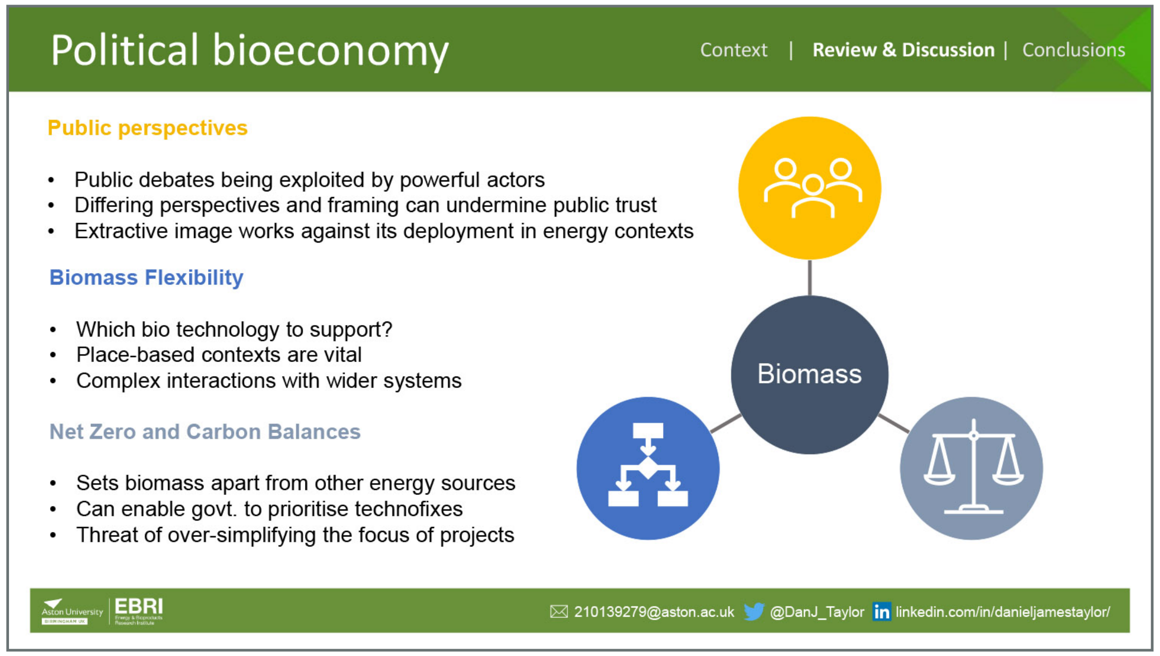

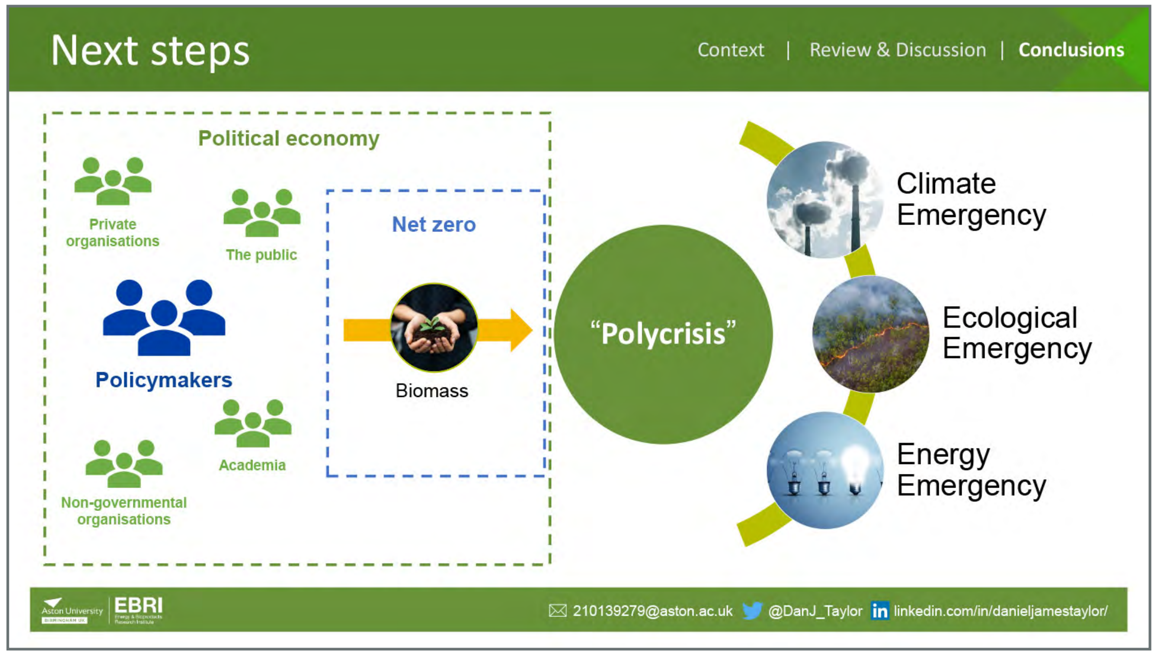

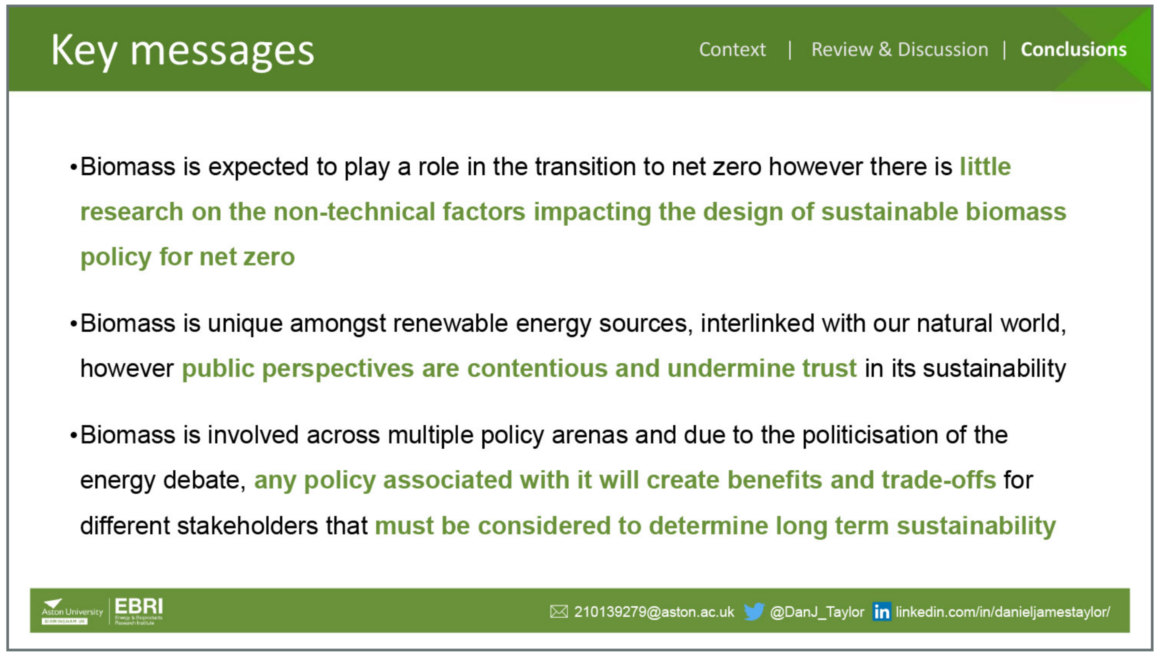

6TH DOCTORAL COLLOQUIUM BIOENERGY

Dr. Walther Zeug, Helmholtz Centre for Environmental Research

Holistic and Integrated Life Cycle Sustainability Assessment: Background, Methods and Results from Two Case Studies

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E-Mail: walther.zeug@ufz.de

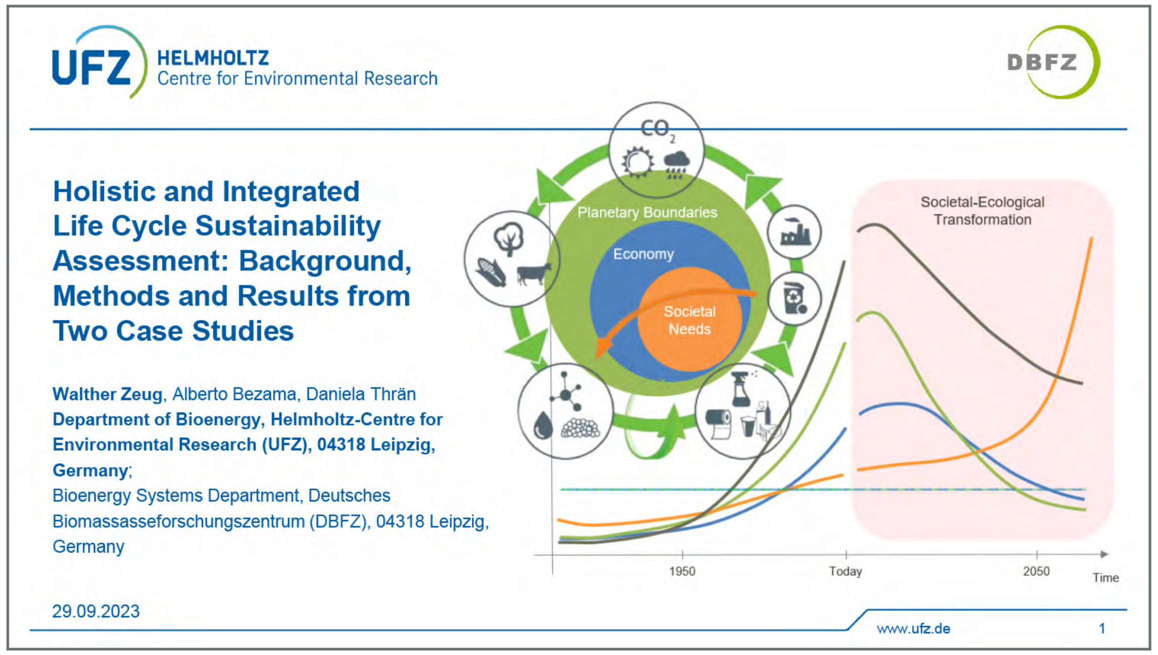
The social, economic and ecological relations have condensed into a socio-ecological crisis, since the unequal satisfaction of societal needs seems to be directly linked to a massive transgression of planetary boundaries. We introduce the double decoupling and societal-ecological transformation approach to this fundamental problem: in addition to a necessary technical decoupling, there is a need for a societal decoupling of the satisfaction of societal needs from an increasing production of goods (sufficiency).

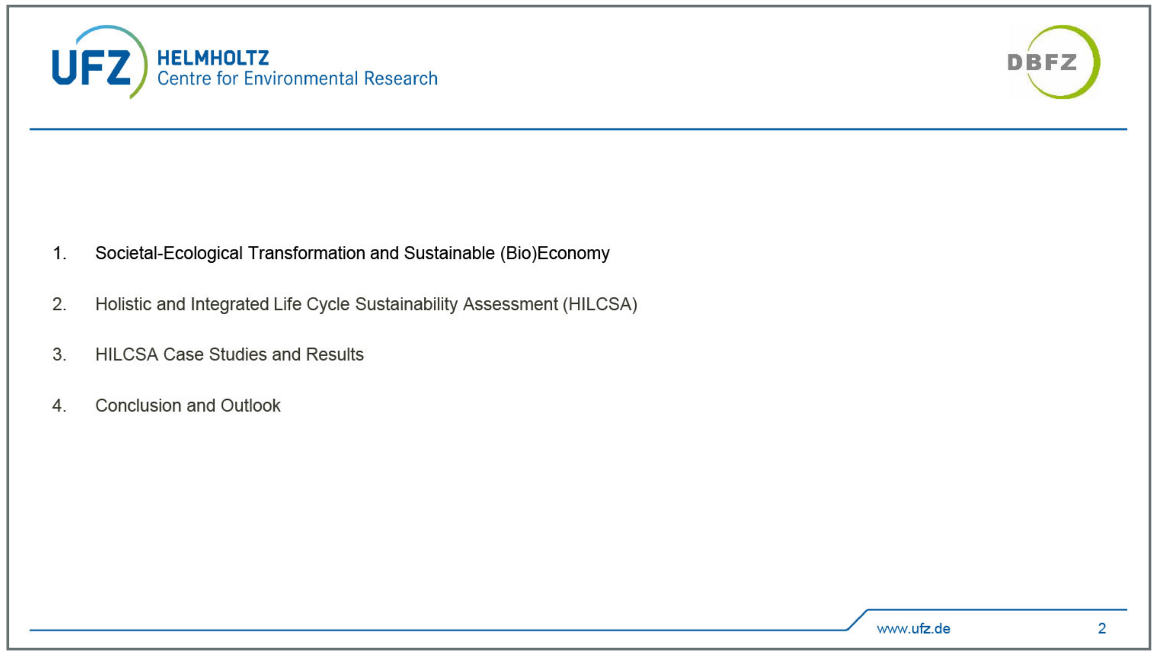
In this context, we developed an integrated sustainability framework with clear and applicable definitions of social, ecological and economic sustainability for sustainability assessment. In order to assess and analyze integrated sustainability, we developed, implemented and validated the innovative method of Holistic and Integrated Life Cycle Sustainability Assessment (HILCSA). HILCSA allows an integrative (ecological, economic, social in one method) and holistic (transdisciplinary and critical) sustainability assessment based on about 100 social, ecological and economic qualitative and quantitative indicators addressing 14 out of 17 SDGs, in order to analyze synergies, trade-offs and hotspots of production and consumption systems in the bioeconomy and beyond. This method is fully software implemented in openLCA and using the Ecoinvent/SoCa database.

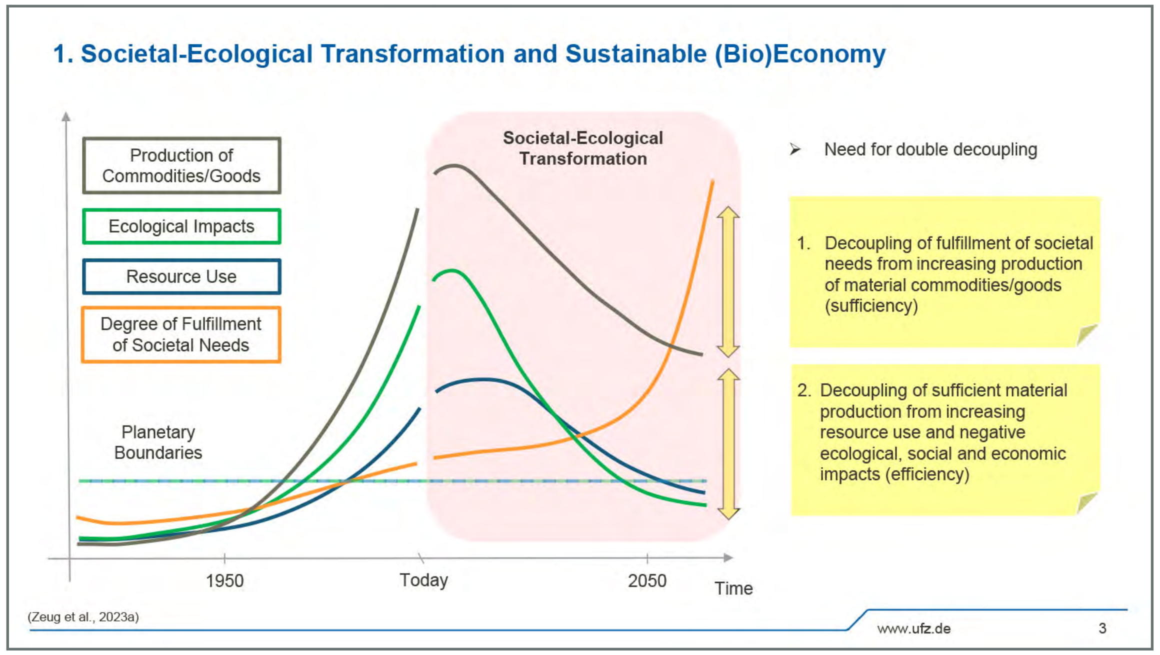
We applied HILCSA in two case studies in context of bioeconomy. In the first case, a comparison of wood building products with conventional steel beams showed that renewable bio-based construction materials can have a better holistic sustainability than fossil-based products for nearly all indicators, by less stressing the environment, having a less negative impact on society and being economically more efficient. However, fossil-based components of such as phenolic resin are main contributors of negative impacts and should be reduced and replaced. In the second case, we compare liquid biofuels as a drop-in alternative to substitute fossil fuels in the transport sector, showing some contributions to the SDG but significant sustainability risks of such biofuels in terms of land and water use, energy efficiency, working conditions and maintaining problematic global supply chains.

Through this quantitative and qualitative sustainability assessments we identify synergies, trade-offs and hot-spots of bioeconomy production systems on a detailed and aggregated level. Common problems are the very hard planetary boundary of land and water availability limiting renewable resource and goods production, as well as maintained global socio-economic problems in supply chains when bioeconomy does not go in hand with a societal-ecological transformation. It can also be concluded that renewable resources should be used primarily for material use and only energetically at the end of a cascading life cycle.

Eventually, the idea of a bioeconomy and systemic sustainability assessments is related to normative societal and political questions.






1. Societal-Ecological Transformation and Sustainable (Bio)Economy
Production of Commodities/Goods
Ecological Impacts
Resource Use
Degree of Fulfillment of Societal Needs
Planetary Boundaries
Societal-Ecological Transformation
1950
Today
2050
Time
Need for double decoupling
1. Decoupling of fulfillment of societal needs from increasing production of material commodities/goods (sufficiency)
2. Decoupling of sufficient material production from increasing resource use and negative ecological, social and economic impacts (efficiency)
(Zeug et al., 2023a)
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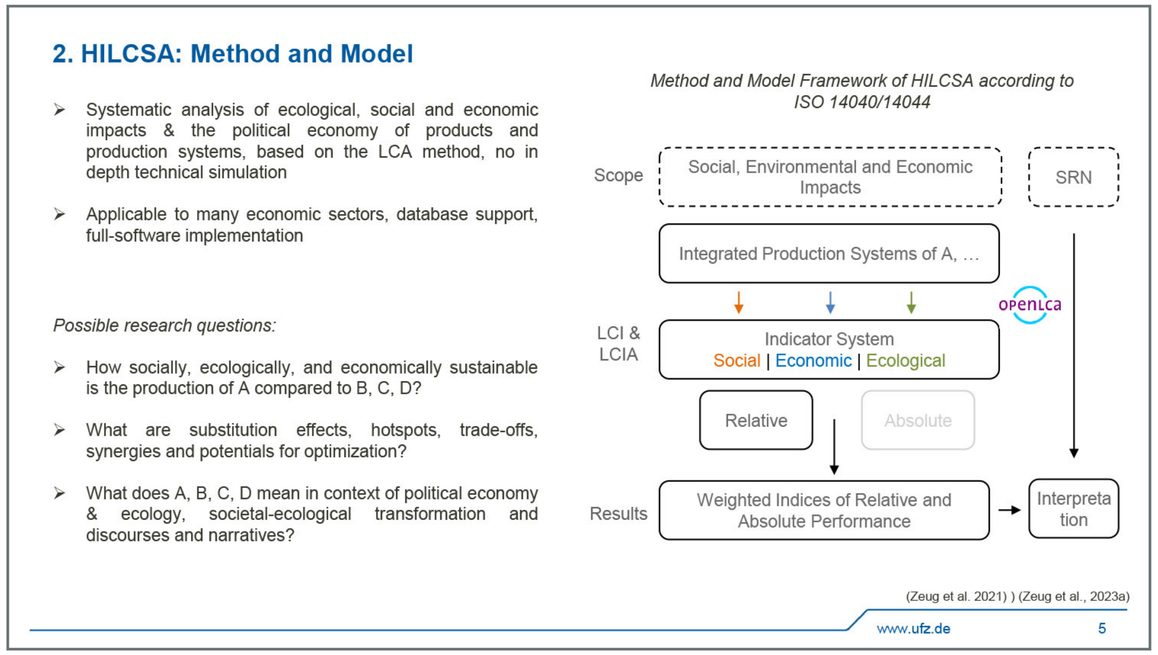
3


2. HILCSA: Method and Model
Systematic analysis of ecological, social and economic impacts & the political economy of products and production systems, based on the LCA method, no in depth technical simulation
Applicable to many economic sectors, database support, full-software implementation
Possible research questions:
How socially, ecologically, and economically sustainable is the production of A compared to B, C, D?
What are substitution effects, hotspots, trade-offs, synergies and potentials for optimization?
What does A, B, C, D mean in context of political economy & ecology, societal-ecological transformation and discourses and narratives?
Method and Model Framework of HILCSA according to ISO 14040/14044
Scope
Social, Environmental and Economic Impacts
SRN
Integrated Production Systems of A, …
LCI & LCIA
openLCA
Indicator System
Social | Economic | Ecological
Relative
Absolute
Results
Weighted Indices of Relative and Absolute Performance
Interpreta tion
(Zeug et al. 2021)) (Zeug et al., 2023a)
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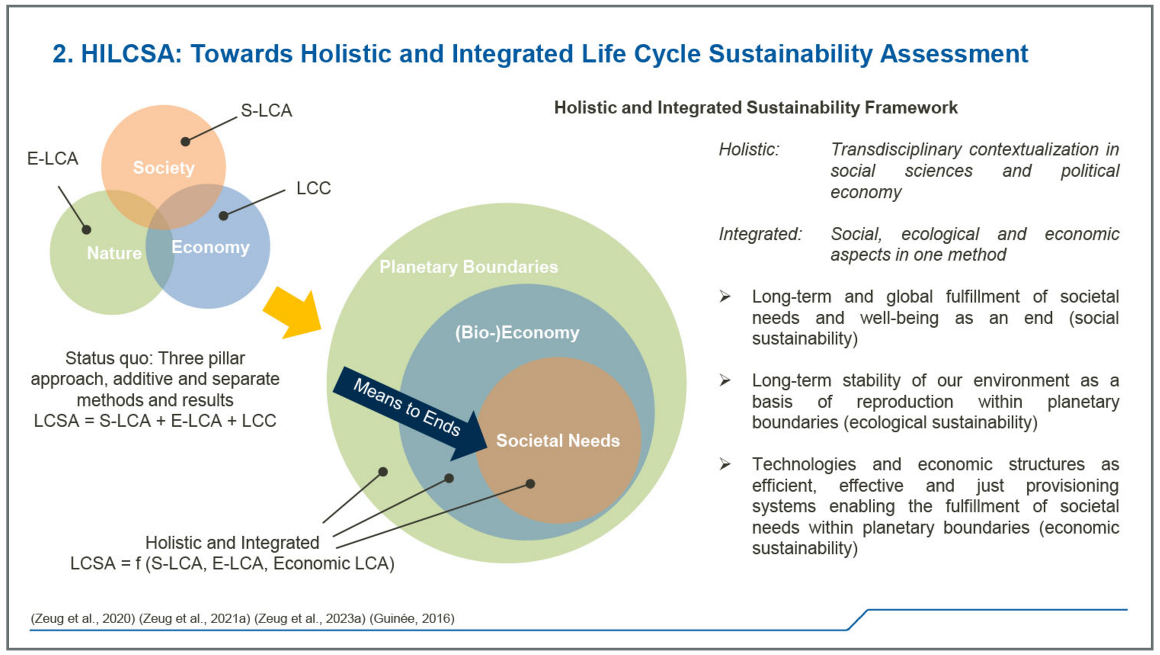
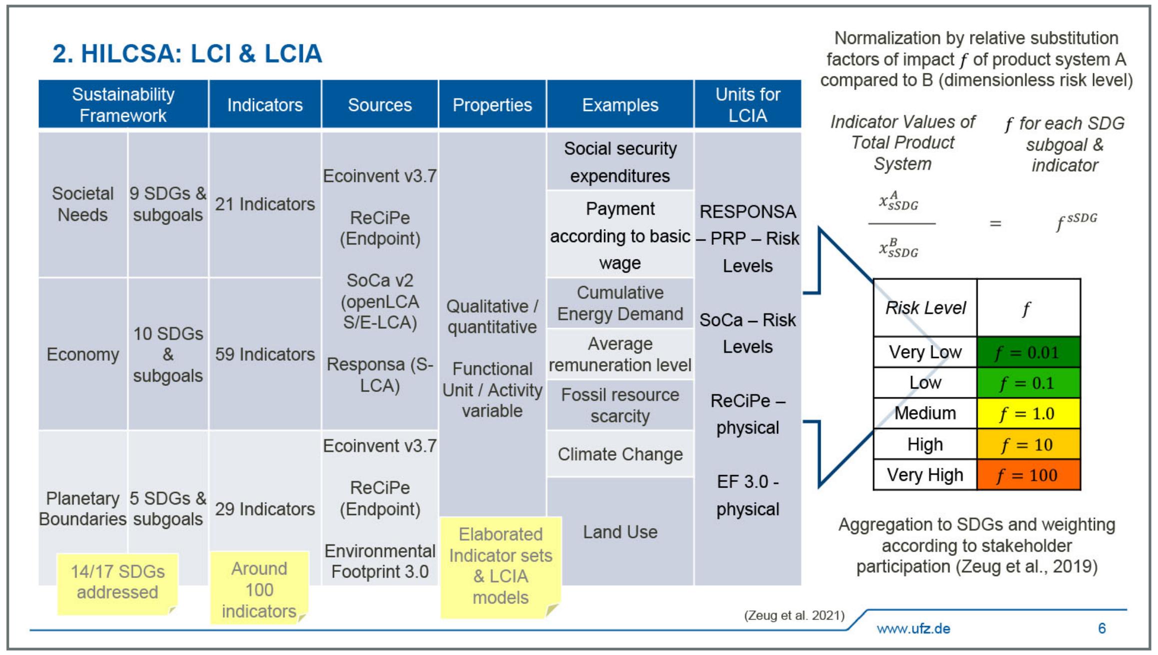
5


2. HILCSA: Towards Holistic and Integrated Life Cycle Sustainability Assessment
S-LCA
E-LCA
LCC
Society
Nature
Economy
Status quo: Three pillar approach, additive and separate methods and results
LCSA = S-LCA + E-LCA + LCC
Planetary Boundaries
(Bio-)Economy
Means to Ends
Societal Needs
Holistic and Integrated
LCSA = f (S-LCA, E-LCA, Economic LCA)
Holistic and Integrated Sustainability Framework
Holistic: Transdisciplinary contextualization in social sciences and political economy
Integrated: Social, ecological and economic aspects in one method
Long-term and global fulfillment of societal needs and well-being as an end (social sustainability)
Long-term stability of our environment as a basis of reproduction within planetary boundaries (ecological sustainability)
Technologies and economic structures as efficient, effective and just provisioning systems enabling the fulfillment of societal needs within planetary boundaries (economic sustainability)
(Zeug et al., 2020) (Zeug et al., 2021a) (Zeug et al., 2023a) (Guinée, 2016)


2. HILCSA: LCI & LCIA
Sustainability Framework
Indicators
Sources
Properties
Examples
Units for LCIA
Societal Needs
9 SDGs & subgoals
21 Indicators
Economy
10 SDGs & subgoals
59 Indicators
Planetary Boundaries
5 SDGs & subgoals
29 Indicators
14/17 SDGs addressed
Around 100 indicators
Ecoinvent v3.7
ReCiPe (Endpoint)
SoCa v2 (openLCA S/E-LCA)
Responsa (S-LCA)
Ecoinvent v3.7
ReCiPe (Endpoint)
Environmental Footprint 3.0
Qualitative / quantitative
Functional Unit / Activity variable
Elaborated Indicator sets & LCIA models
Social security expenditures
Payment according to basic wage
Cumulative Energy Demand
Average remuneration level
Fossil resource scarcity
Climate Change
Land Use
RESPONSA – PRP – Risk Levels
SoCa – Risk Levels
ReCiPe – physical
EF 3.0 - physical
Normalization by relative substitution factors of impact f of product system A compared to B (dimensionless risk level)
Indicator Values of Total Product System
f for each SDG subgoal & indicator
Risk Level
f
Very Low
f = 0.01
Low
f = 0.1
Medium
f = 1.0
High
f = 10
Very High
f = 100
Aggregation to SDGs and weighting according to stakeholder participation (Zeug et al., 2019)
(Zeug et al. 2021)
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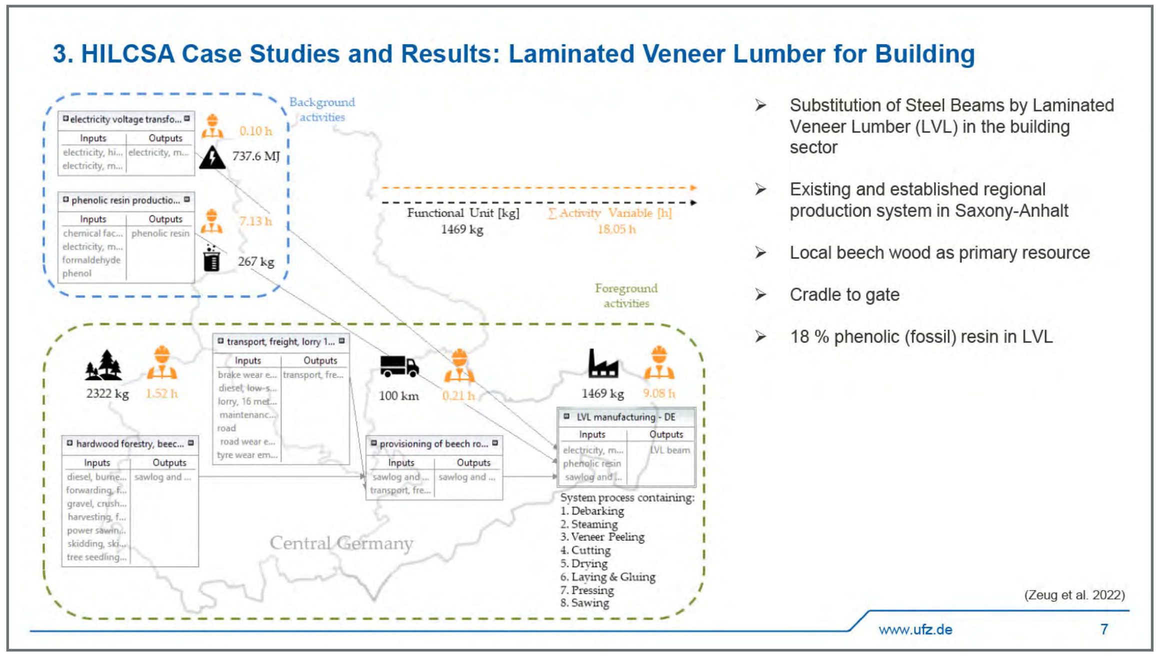
3. HILCSA Case Studies and Results: Laminated Veneer Lumber for Building
Background activities
Foreground activities
Functional Unit [kg] 1469 kg
∑ Activity Variable [h] 18.05 h
737.6 MJ
267 kg
2322 kg
100 km
1469 kg
Central Germany
System process containing:
1. Debarking
2. Steaming
3. Veneer Peeling
4. Cutting
5. Drying
6. Laying & Gluing
7. Pressing
8. Sawing
Substitution of Steel Beams by Laminated Veneer Lumber (LVL) in the building sector
Existing and established regional production system in Saxony-Anhalt
Local beech wood as primary resource
Cradle to gate
18 % phenolic (fossil) resin in LVL
(Zeug et al. 2022)
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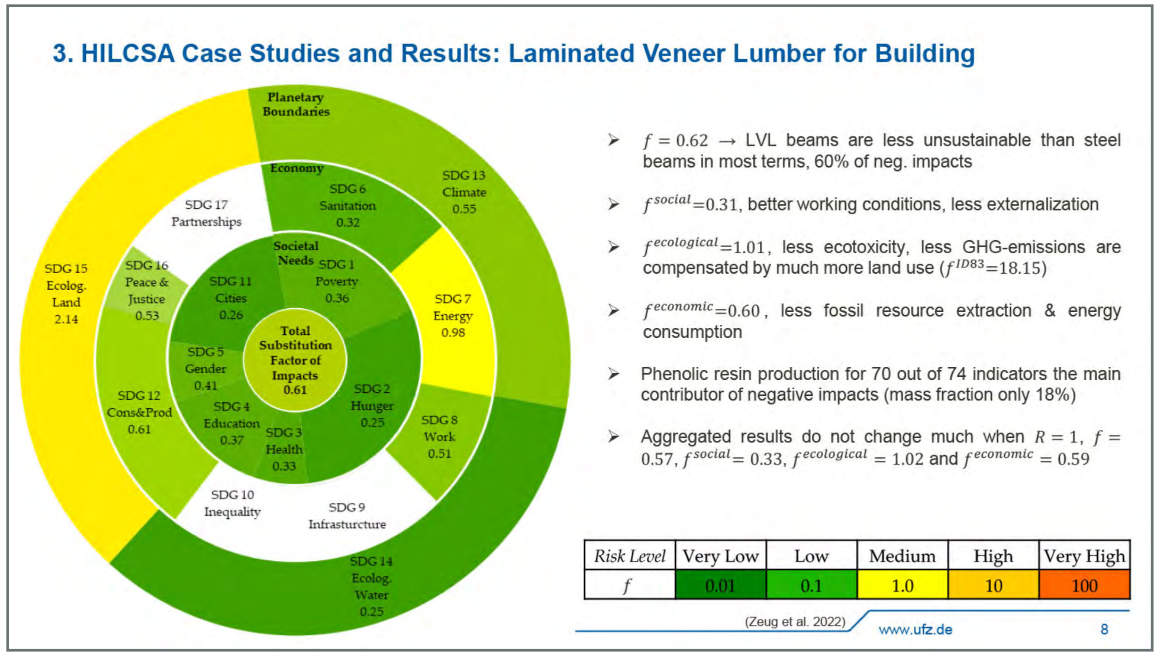
3. HILCSA Case Studies and Results: Laminated Veneer Lumber for Building
Planetary Boundaries
Economy
Societal Needs
Total Substitution Factor of Impacts 0.61
SDG 13 Climate 0.55
SDG 6 Sanitation 0.32
SDG 17 Partnerships
SDG 15 Ecolog. Land 2.14
SDG 16 Peace & Justice 0.53
SDG 11 Cities 0.26
SDG 1 Poverty 0.36
SDG 7 Energy 0.98
SDG 5 Gender 0.41
SDG 2 Hunger 0.25
SDG 12 Cons&Prod 0.61
SDG 4 Education 0.37
SDG 3 Health 0.33
SDG 8 Work 0.51
SDG 10 Inequality
SDG 9 Infrastructure
SDG 14 Ecolog. Water 0.25
$f = 0.62$ → LVL beams are less unsustainable than steel beams in most terms, 60% of neg. impacts
$f^{social}=0.31$, better working conditions, less externalization
$f^{ecological}=1.01$, less ecotoxicity, less GHG-emissions are compensated by much more land use ($f^{ID83}=18.15$)
$f^{economic}=0.60$, less fossil resource extraction & energy consumption
Phenolic resin production for 70 out of 74 indicators the main contributor of negative impacts (mass fraction only 18%)
Aggregated results do not change much when $R = 1$, $f = 0.57$, $f^{social} = 0.33$, $f^{ecological} = 1.02$ and $f^{economic} = 0.59$
Risk Level | Very Low | Low | Medium | High | Very High
f | 0.01 | 0.1 | 1.0 | 10 | 100
(Zeug et al. 2022)
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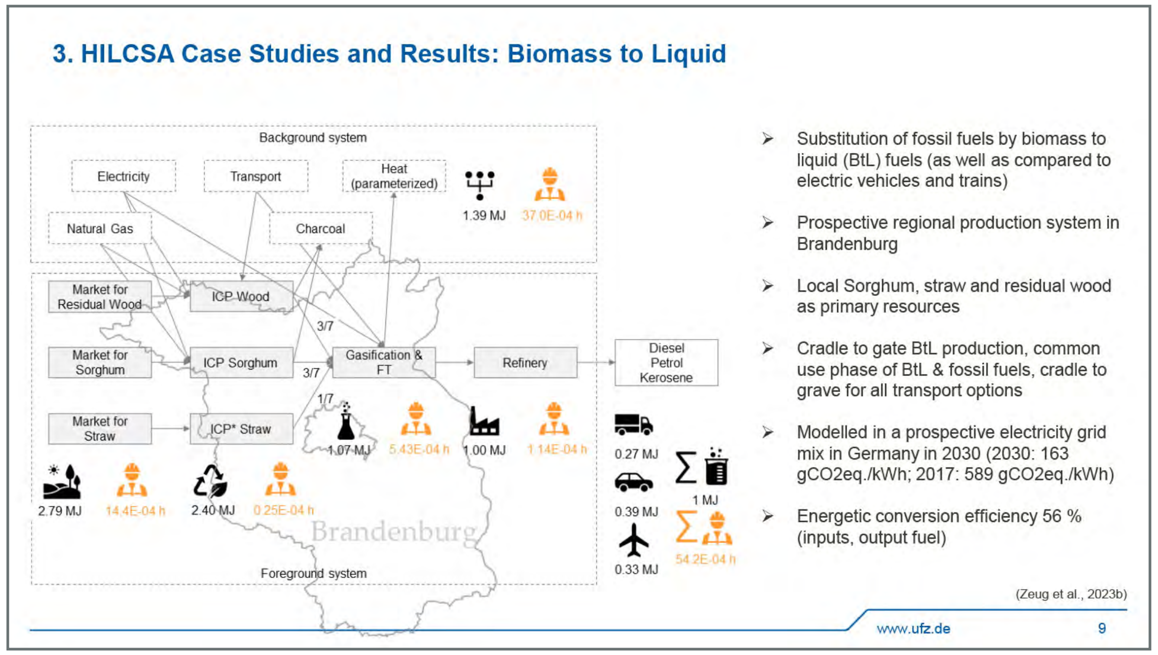
3. HILCSA Case Studies and Results: Biomass to Liquid
Background system
Electricity
Transport
Heat (parameterized)
Natural Gas
Charcoal
Market for Residual Wood
ICP Wood
Market for Sorghum
ICP Sorghum
Gasification & FT
Refinery
Diesel Petrol Kerosene
Market for Straw
ICP* Straw
Brandenburg
Foreground system
Substitution of fossil fuels by biomass to liquid (BtL) fuels (as well as compared to electric vehicles and trains)
Prospective regional production system in Brandenburg
Local Sorghum, straw and residual wood as primary resources
Cradle to gate BtL production, common use phase of BtL & fossil fuels, cradle to grave for all transport options
Modelled in a prospective electricity grid mix in Germany in 2030 (2030: 163 gCO2eq./kWh; 2017: 589 gCO2eq./kWh)
Energetic conversion efficiency 56 % (inputs, output fuel)
(Zeug et al., 2023b)
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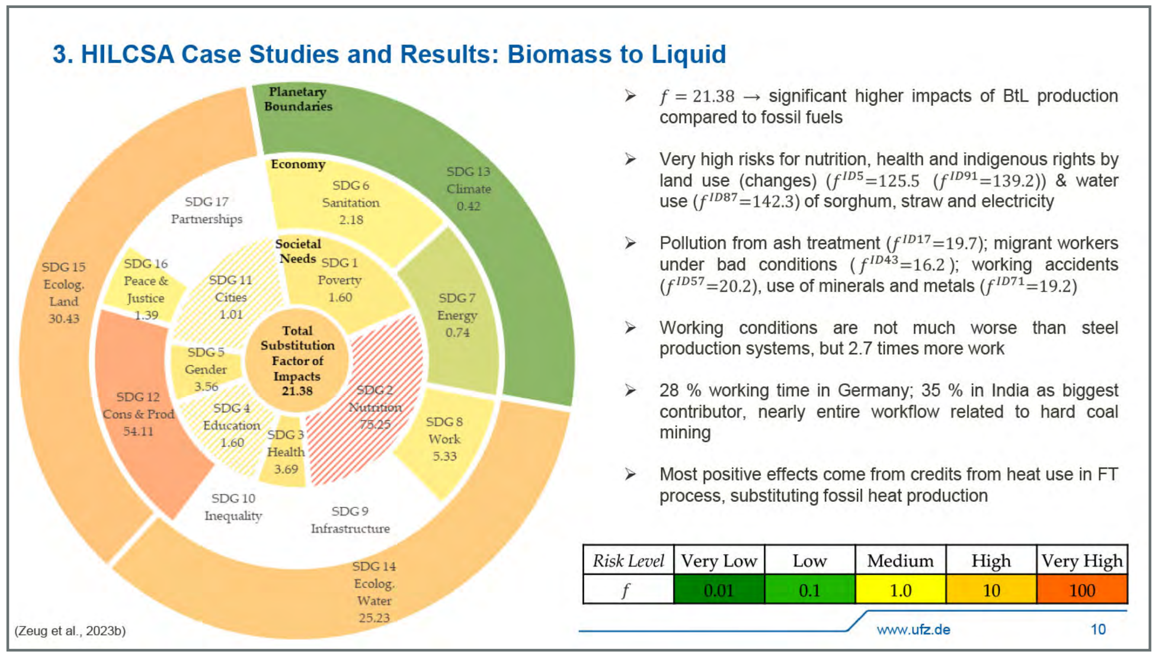
3. HILCSA Case Studies and Results: Biomass to Liquid
Planetary Boundaries
Economy
Societal Needs
Total Substitution Factor of Impacts 21.38
SDG 13 Climate 0.42
SDG 6 Sanitation 2.18
SDG 17 Partnerships
SDG 15 Ecolog. Land 30.43
SDG 16 Peace & Justice 1.39
SDG 11 Cities 1.01
SDG 1 Poverty 1.60
SDG 7 Energy 0.74
SDG 5 Gender 3.56
SDG 2 Nutrition 75.25
SDG 12 Cons & Prod 54.11
SDG 4 Education 1.60
SDG 3 Health 3.69
SDG 8 Work 5.33
SDG 10 Inequality
SDG 9 Infrastructure
SDG 14 Ecolog. Water 25.23
$f = 21.38$ → significant higher impacts of BtL production compared to fossil fuels
Very high risks for nutrition, health and indigenous rights by land use (changes) ($f^{ID5}=125.5$ ($f^{ID91}=139.2$)) & water use ($f^{ID87}=142.3$) of sorghum, straw and electricity
Pollution from ash treatment ($f^{ID17}=19.7$); migrant workers under bad conditions ($f^{ID43}=16.2$); working accidents ($f^{ID57}=20.2$), use of minerals and metals ($f^{ID71}=19.2$)
Working conditions are not much worse than steel production systems, but 2.7 times more work
28 % working time in Germany; 35 % in India as biggest contributor, nearly entire workflow related to hard coal mining
Most positive effects come from credits from heat use in FT process, substituting fossil heat production
Risk Level | Very Low | Low | Medium | High | Very High
f | 0.01 | 0.1 | 1.0 | 10 | 100
(Zeug et al., 2023b)
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4. Conclusion and Outlook: Bioeconomy & HILCSA

Bioeconomy can be more sustainable, but there are contradictions if it is only intended to be substitution, land use is very hard planetary boundary for bioeconomy (cf. Bringezu et al. 2020)

- 1. Food, 2. Materials, 3. Energy, I. Reduce, II. Reuse, III. Recycle, use in general as far as planetary boundaries are not transgressed
- Social, ecological and economic effects are intertwined in synergies and trade-offs; GHG savings can be overcompensated by ecological, social and economic risks; solely focus on GHG has high risk for mis-regulation and mis-management
- When the German BE relies on increasing biomass imports, global inequalities and externalizations are maintained (extractivism cf. Backhouse et al. 2021)
- Innovations and technology are necessary but by no means sufficient for socio-ecological transformation, biggest challenges are not technological ones but societally overcoming structural mindsets of political economy and growth oriented capitalism
- There are progressive impulses of BE technology & resource substitution, but general transformation of working conditions and global political economy is nowhere in sight (Fritz, 2022)

HILCSA as integrative and holistic sustainability analysis with qual/quan indicators and discussion, retrospective and prospective

- Consistent and comparable data and results on social, ecological, and economic indicators; identifies synergies and trade-offs
- Traces down impacts to regions in the fore-and background systems; allocates and aggregates them to the SDGs
- Future development: addressing 1st decoupling-dimension (sufficiency); implementation of absolute sustainability assessment against PB (sustainable production volume) using MRIO (hybrid LCSA); integration of more indicators on circularity

(Zeug et al., 2023a) (Zeug et al., 2023b)

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6TH DOCTORAL COLLOQUIUM BIOENERGY

SESSION
SUSTAINABLE RESOURCE BASE

Dr. Omar Hijazi
PD Dr. Kurt Möller
Prof. Andrea Parenti

6TH DOCTORAL COLLOQUIUM BIOENERGY

Andres Vargas, Leibniz Institute for Agricultural Engineering and Bioecoconomy

The potential of urban autumn tree leaves for energy generation and carbon saving at scenarios level - a case study from the city of Berlin

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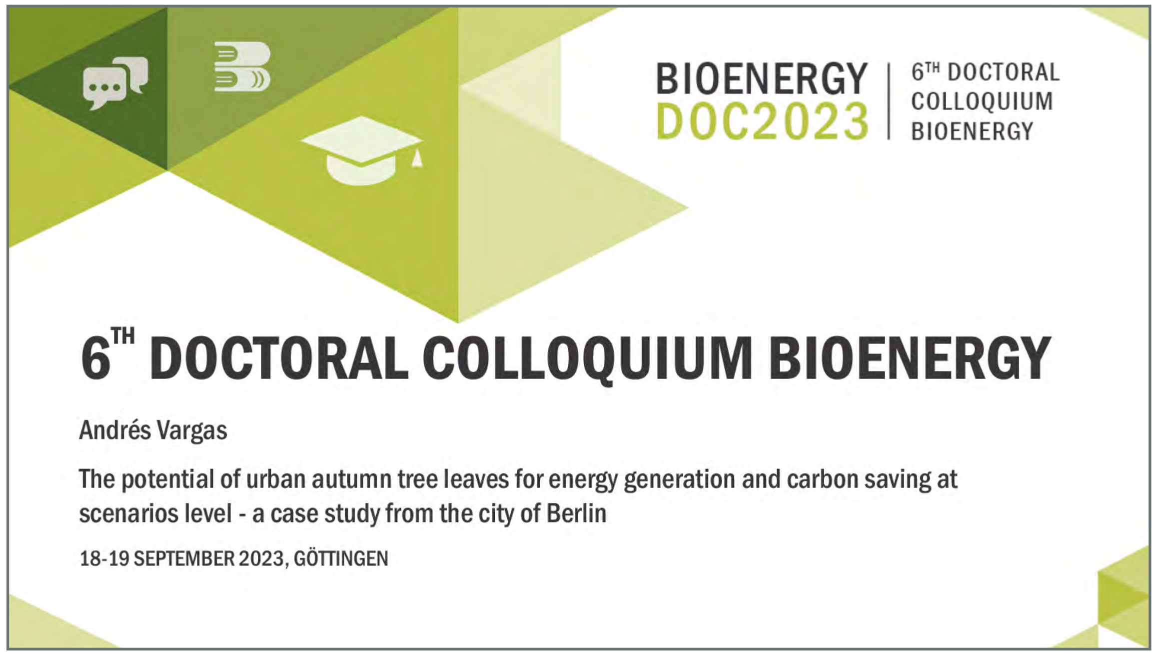
Autumn tree leaves are residues that are generated annually and usually composted, but can also be used as a feedstock for biogas production. In this study, life cycle assessment (LCA) principles were adopted to establish three scenarios to evaluate the utilization of tree leaves from the city of Berlin in Germany: a) composting (business-as-usual scenario); b) biogas production; and c) the pre-treatment of leaves before biogas production. For these scenarios, greenhouse gas emissions and energy production potential were calculated using the biological resource utilization impacts (BIORIM) model and considering the location and capacity of existing agricultural biogas plants. A special focus was set on the decay of leaves before their entry into the biogas plant. The overall comparison showed that the biogas-related scenarios had a better performance in terms of greenhouse gas emissions (-140.1 kg of CO_2eq per tonne of leaves for biogas and -167.4 kg of CO_2eq for pretreatment before biogas) than the business-as-usual scenario (49.0 kg of CO_2eq for composting).

The pretreated leaves resulted in the lowest net emissions and highest energy production per tonne of feedstock. Measures to reduce the decay of leaves, such as increasing the loading to the biogas plant or ensiling, resulted in lower net emissions and higher energy output. Net greenhouse gas emissions in the scenarios are sensitive to the type of leaves. Leaf types with lower dry matter content (i.e. lime tree leaves) resulted in lower organic carbon on a fresh matter basis, leading to lower biogenic emissions, while fossil emissions remained the same in all scenarios. Net emissions are also sensitive to the daily loads of tree leaves to the biogas plant in the biogas production scenario, such that lower loads led to more emissions from leaf decay, and less biomass available for energy production. Further research regarding costs and logistical feasibility for proper implementation is needed. Using tree leaves for biogas production would represent an alternative energy source, which could reduce the share of fossil fuels and electricity imports for the city of Berlin, where about 7.5 metric tonnes of pretreated leaves would meet the average electrical energy consumption of one person in one year.



Short introduction

BIOENERGY DOC2023 6TH DOCTORAL COLLOQUIUM BIOENERGY

Doctoral Student:	Andrés de Jesús Vargas Soplín
Institute of Research:	Leibniz Institute for Agricultural Engineering and Bioeconomy
Institute Supervisor:	Dr. Ulrich Kreidenweis
Cooperating University:	Humboldt University of Berlin
University Supervisor:	Prof. Dr. Annette Prochnow
Duration:	09/2020 – 02/2024

Introduction and motivation (1/2)

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- Autumn tree leaves are yearly residues.
- Risk in urban areas:
  - water drainages clog,
  - slippery roads and paths,
  - sign covering (accident risk),
  - fuel accumulation (fire risk),
  - rodent nest (plagues), and
  - increase of nutrient on stormwater (eutrophication)
- Berlin: 36 000 tonnes of street leaves / year (BSR, 2020, 2019, 2018)
- Final treatment: composting facilities → positive net GHG emission

Source: https://thewash.org/2020/12/01/leaf-collection-accessibility/

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Introduction and motivation (2/2)

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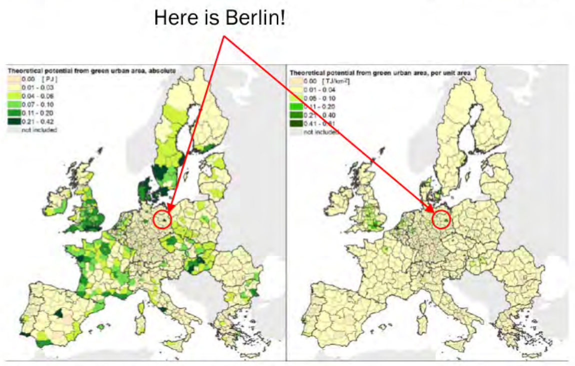
- Urban tree residues: underutilized. They could be used to energetic purposes (Sajdak et al., 2014; Sajdak and Velazquez-Marti, 2012).
- Berlin as an area with the highest potential of green urban area (Hamelin et al., 2019)
- Laboratory results on the potential use of autumn tree leaves for biogas production.
- Little investigation on autumn tree leaves at a scenario level.



Source: Hamelin et al., 2019

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Objectives

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- To assess the environmental performance, focused on GHG emissions, of autumn tree leaves for energy production in scenarios, taking Berlin as a case study.
- Identify the main sources of GHG emissions
- Identify the gas composition within the GHG emissions

Source: Davidgn/Dreamstime.com

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Methods (1/3)

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- Use of the partial Life Cycle Assessment (LCA) approach: „from cradle to grave"
- Scenario development: common source + scenarios variants
- Common source: generation of autumn tree leaves, collection and transport to temporal storage
- Scenarios variants:
  - 1. Business-as-usual (composting): transport to composting facilities, compost process, compost use for gardening
  - 2. Biogas: transport to biogas plant, biogas production, biodigestate use in agriculture
  - 3. Pretreatment and biogas: all process of "biogas" scenario, but including ensiling and pretreatment (NaOH) prior to biogas production.

Source: https://docklinemagazine.com/2021/11/composting-leaves/

Source: https://zorg-biogas.com/

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Methods (2/3)

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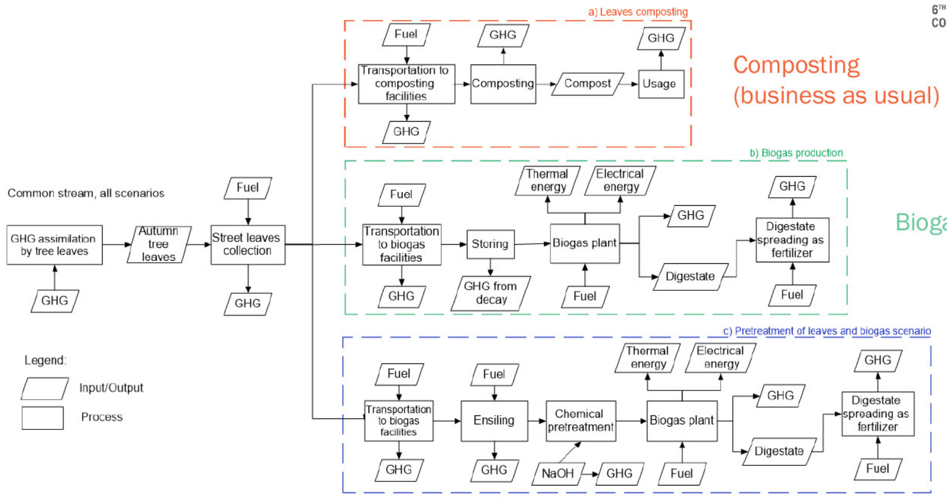

Composting (business as usual)

Biogas

Pretreatment & Biogas

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Methods (3/3)

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BIORIM - Description and advantages

- Process modelling through BIORIM (**Bio**logical **R**esource Utilization **Im**pact)
- Developed at ATB, built in Python 3.7 (updated)
- Automatize mass flow and GHG emissions calculation in individual processes
- Modularity: concatenate several processes in an scenario display
- Flexibility: open to couple with new modules

BIORIM - Limitation and challenges

- Number of environmental impacts are still limited (e.g. GHG emissions)
- Based on literature review and databases:
  - Some factors considered may vary due to the uncertainties of previous studies.
  - Few specific literature (e.g. emission factor of autumn tree leaves composting)

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Results and discussions (1/3)

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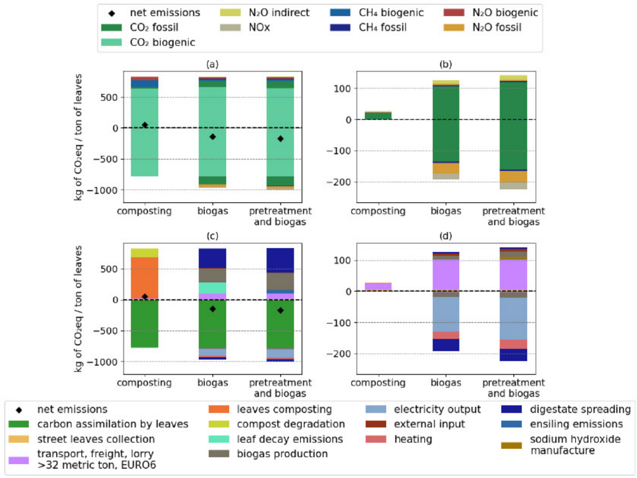

- Net GHG emissions in scenarios (kg CO2eq/tonne of leaves):
  - Pretreatment and biogas: -167.4
  - Biogas: -140.1
  - Composting: 49.0
- Fossil fuels savings from electricity output
- Interest in leaf decay process
- Methane release during composting

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Results and discussions (2/3)

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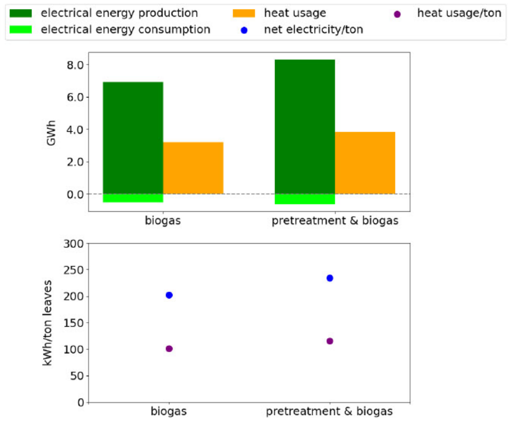

- Energy in biogas scenario
  - Electricity → 234 kWh/tonne of leaves
  - Available heat (heat usage) → 115.6 kWh/tonne of leaves
- Pretreatment: 13% more energy
- Total energy can meet the need of around 5400 people in one year

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Results and discussions (3/3)

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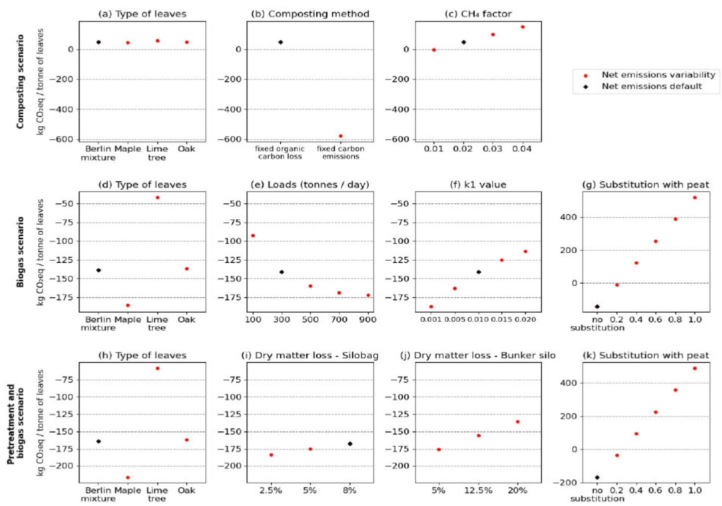
- Sensitivity analysis:
  - type of leaves
  - load of leaves per day to the digesters
  - compost substitution with peat (worst case scenario)



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Conclusions

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- Pretreatment of leaves and biogas production → lowest net GHG emissions (-167.4 kg CO2eq) and the highest energy output (234.1 kWh) per tonne of leaves
- Net GHG emission in the biogas scenarios are sensible to tree leaf types due to the amount of organic carbon content.
- Leaf decay plays and important role in the overall net GHG emissions.
- Unlocking autumn tree leaves as a feedstock for biogas production represent an opportunity to reduce the demand of fossil fuels
- More information in: https://doi.org/10.1016/j.resconrec.2022.106598

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What is next?
Topic for the second publication

BIOENERGY DOC2023
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- Energy crisis raised on 2022, alternatives sources of energy were discussed
- Media attention of (un)utilized residual biomass
- Costs analysis of the scenarios' implementation
- Composting, biogas (with and without NaOH variants), gasification (with and without pelletization variants), co-firing (with and without pelletization variants)
- Combination of partial LCA and Net Present Value (NPV) methods (extension of BIORIM)
- NPV based on Capital Expenditure (CAPEX) and Operational Expenditure (OPEX)

Source: https://www.bioenergyconsult.com/gasification-systems/

Source: https://processbarron.com/biomass-co-firing-and-chp-to-become-larger-part-of-market/

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Preliminary results of the second publication

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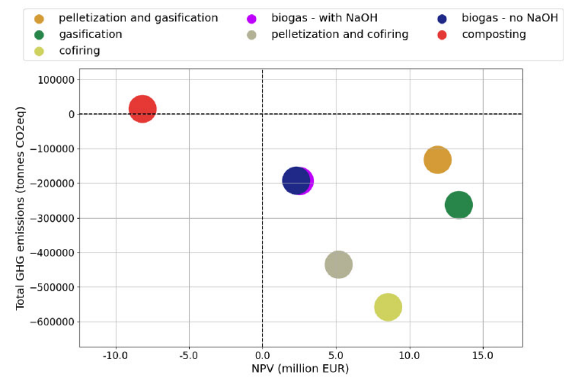
- Assumptions: new infrastructure and land purchase
- Gasification scenarios with the highest NPV
- Co-firing scenarios with the lowest net GHG emissions
- Biogas production with lower NPV but similar net GHG emission as gasification
- All scenarios presented lower net GHG emissions than composting



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Thank you for you attention!
Questions? Comments? Recommendations?

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Tom Karras, Deutsches Biomasseforschungszentrum

Straw supply costs over time: A German supply cost model for straw supply cost from 2010 - 2020

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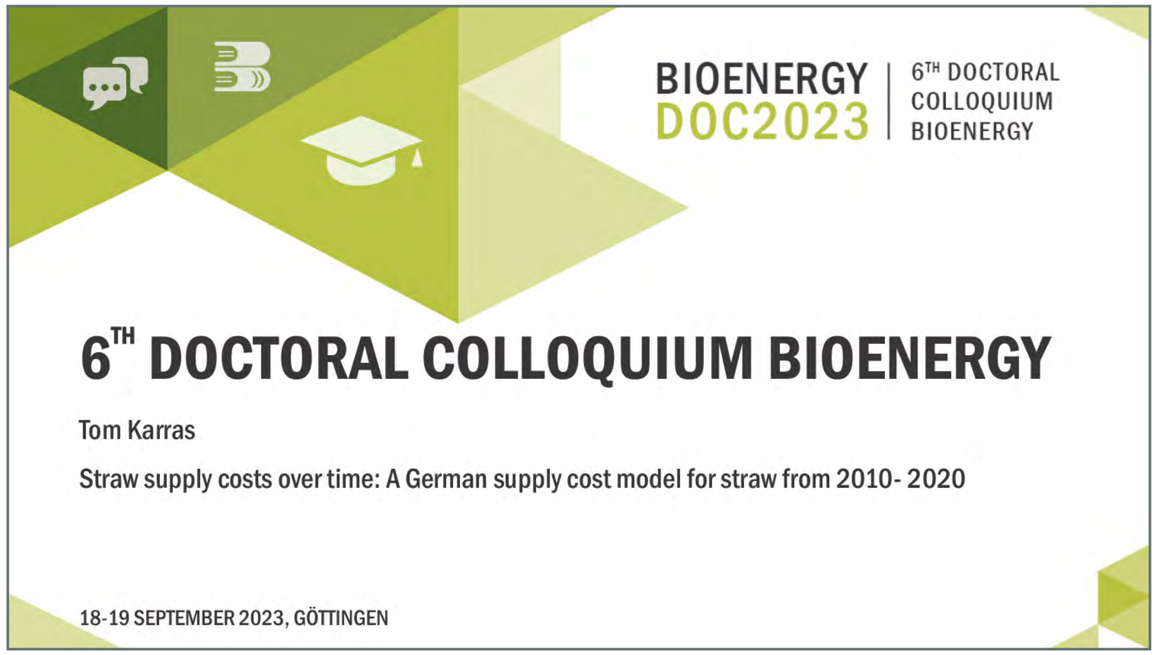
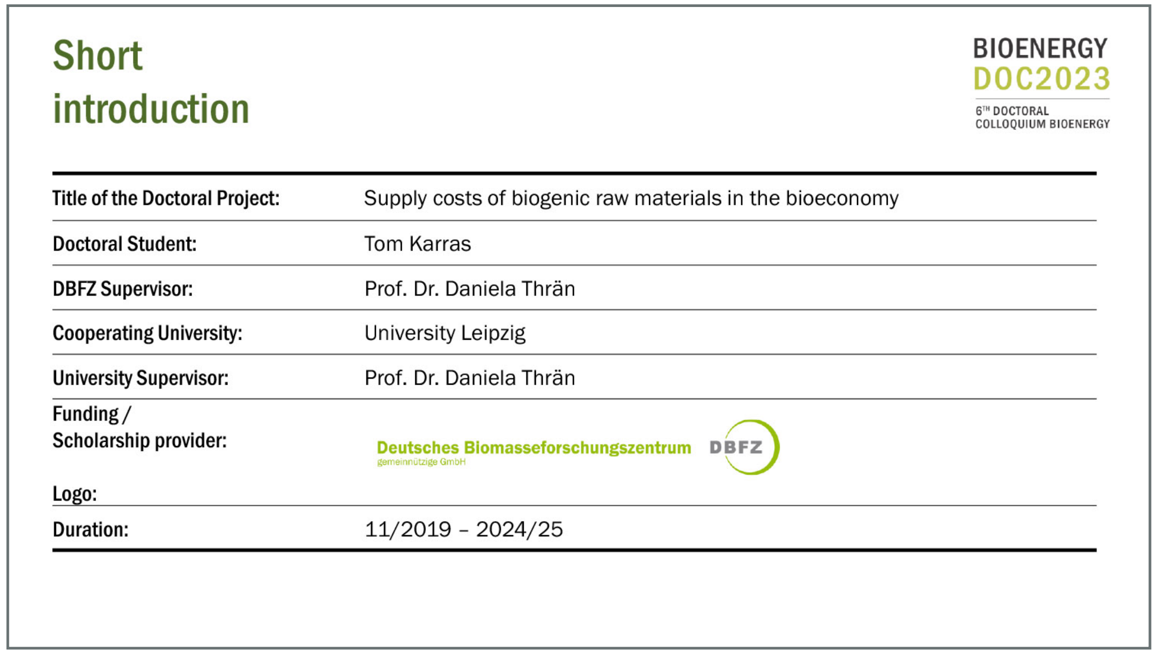
Bioenergy depends on the supply of biomass. In this context, biogenic by-products, residues and waste (BRW) are particularly important because they do not compete with food. However, these residues and waste materials are rarely traded on standardised markets, so the determination of supply costs is not consistent. For example, straw prices available from chambers of agriculture refer to bilateral and individual straw sales. This makes it difficult to monitor supply costs. One approach is to use the activity-based costing method to quantify and monetise the effort of biomass supply. The calculated supply cost is then understood as the minimum price at which the owner of the biomass is willing to sell it.

As part of my PhD, I developed a model that calculates the supply costs based on these expenses. Straw was used as a use case because it is the BRW with the highest theoretical potential in Germany. The model can show the development over time from 2010-2020 as well as the regional differences at county level (NUTS-3). Within the straw supply chain, it takes into account collection costs, transport costs from the field to the farm, storage costs at the farm and opportunity costs based on nutrient losses due to straw removal.

The DOC2023 contribution will focus on the development of straw costs over time. It could be shown that the national average straw cost from 2010 to 2020 varies between 57,19 and 61,97 EUR/t fresh matter (FM). The relative proportions of the different cost components along the supply chain remain constant over time. The sensitivity analysis showed that the assumed storage period and storage costs, the straw yield per hectare and the wage level have the greatest influence on the costs. Fuel costs for straw machinery have a minor impact on total costs.

The results of the model can be used as input data for techno-economic analyses via a data repository. The modular structure of the model allows the input data to be varied. This allows the cost of supply to be calculated under pre-defined scenario assumptions.





Short introduction

Title of the Doctoral Project:	Supply costs of biogenic raw materials in the bioeconomy
Doctoral Student:	Tom Karras
DBFZ Supervisor:	Prof. Dr. Daniela Thrän
Cooperating University:	University Leipzig
University Supervisor:	Prof. Dr. Daniela Thrän
Funding / Scholarship provider: Logo:	Deutsches Biomasseforschungszentrum DBFZ
Duration:	11/2019 – 2024/25

Why is it interesting to look at supply costs of straw?

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Supply Costs are import ...

- for calculating the profitability of bio based products
- because feedstock costs are a significant cost component within techno-economic analyses of bio based products. [1,2]

Current supply costs of straw ...

- Price information by bilateral regional trades between farmers [3]
  ➡ lack of standartized price information for straw
- Modelled supply costs available for single reference years [4,5]
  ➡ lack of supply costs over time

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Approach – How to monetize the straw supply?
Activity Based Costing of straw supply

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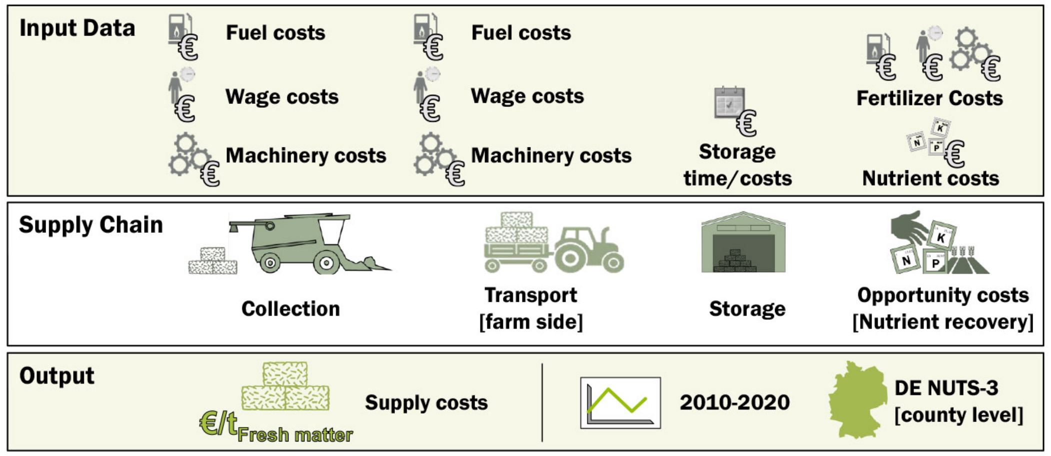

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How develop the supply costs over time?
National average per year

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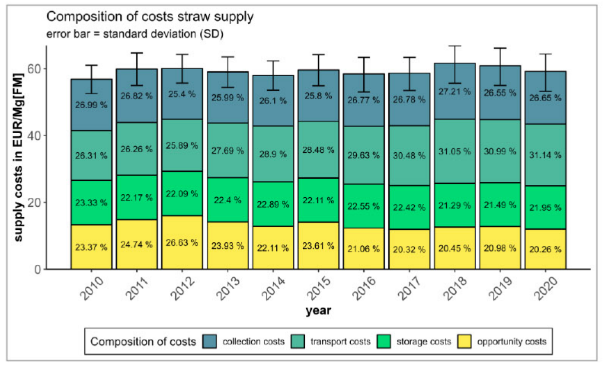

Illustration from Karras & Thrän, (2023/24) [6]

Year	Min Cost [€/Mg_{FM}]	Ave Cost [€/Mg_{FM}]	Max Cost [€/Mg_{FM}]
2010	45,72	56,77	70,68
2011	49,36	59,77	92,92
2012	50,58	59,96	73,52
2013	49,27	58,90	82,61
2014	48,10	57,88	67,02
2015	49,12	59,55	71,62
2016	47,94	58,19	72,93
2017	47,74	58,40	70,61
2018	49,25	61,23	81,97
2019	49,88	60,50	79,85
2020	48,55	58,78	82,63

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What is the relationship between costs and prices?

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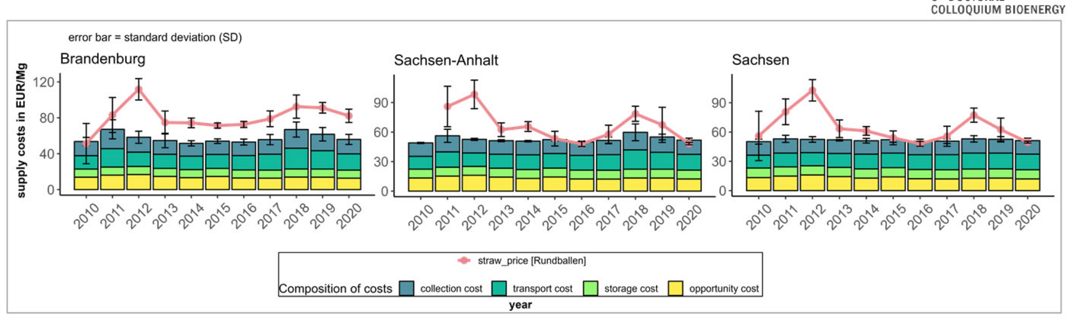

Illustration from Karras & Thrän, (2023/24) [6]

On average 75% of straw prices are explained by straw cost. From a min. of 50% to a max. of 123%.

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Sum up – Key features of the model

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- Activity based costing approach to estimate the supply costs of straw from a farmers perspective
- Supply costs over time (2010-2020)
- Modular approach to apply input parameters to individual assumptions -> assumption-based supply costs

Further model content

- Regional supply costs for Germany on county level [NUTS-3]
- Analysis of the costs drivers and most influential input parameters
- Data quality Assessment to assess the data quality of input parameters

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Outlook – How to continue?

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Publications

- **Research paper** comming soon…
  Karras & Thrän, (2023/24), The costs of straw in Germany: Development of regional straw supply costs between 2010 and 2020, Waste and Biomass Valorization, (**submitted**) [6]
- According **Data publication** will be available in combination with the paper.
  Karras, 2023, Straw supply costs for Germany – NUTS3 | 2010-2020 | farm-side, Zenodo Repository

Further steps in the PhD project

- Combination with regional potentials of straw and transport costs -> **Cost-Supply Costs**

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References

BIOENERGY DOC2023 6TH DOCTORAL COLLOQUIUM BIOENERGY

[1] Schubert, T.: Production routes of advanced renewable C1 to C4 alcohols as biofuel components – a review. Biofuels, Bioprod. Bioref. (2020). https://doi.org/10.1002/bbb.2109

[2] Lepage, T., Kammoun, M., Schmetz, Q., Richel, A.: Biomass-to-hydrogen. A review of main routes production, processes evaluation and techno-economical assessment. Biomass and Bioenergy (2021). https://doi.org/10.1016/j.biombioe.2020.105920

[3] Pfeiffer, A., Mertens, A., Brosowski, A., Thrän, D.: Der Strohmarkt in Deutschland. Marktschreier 4.0. (The straw market in Germany). Deutsches Biomasseforschungszentrum (DBFZ), Leipzig (2019)

[4] S2BIOM-Project: S2BIOM cost supply. https://s2biom.wenr.wur.nl/web/guest/data-downloads (2016)

[5] Harms, R.: Strohpreis-Rechner. Mindestpreisberechnung nach Nährstoffkosten. (Straw price calculator - Straw price calculator Minimum price calculation according to nutrient costs). https://www.lwk-niedersachsen.de/lwk/news/39294_Strohpreis-Rechner (2022)

[6] Karras & Thrän, (2023/24), The costs of straw in Germany: Development of regional straw supply costs between 2010 and 2020, Waste and Biomass Valorization, (submitted)

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BIOENERGY DOC2023 | 6TH DOCTORAL COLLOQUIUM BIOENERGY

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Pietro Peroni, DISTAL-University of Bologna

A three-level study to evaluate the use of biological inputs to improve biomass production and phytoremediation capacities in *Miscanthus x giganteus*

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I - 40127 Bologna, Italy
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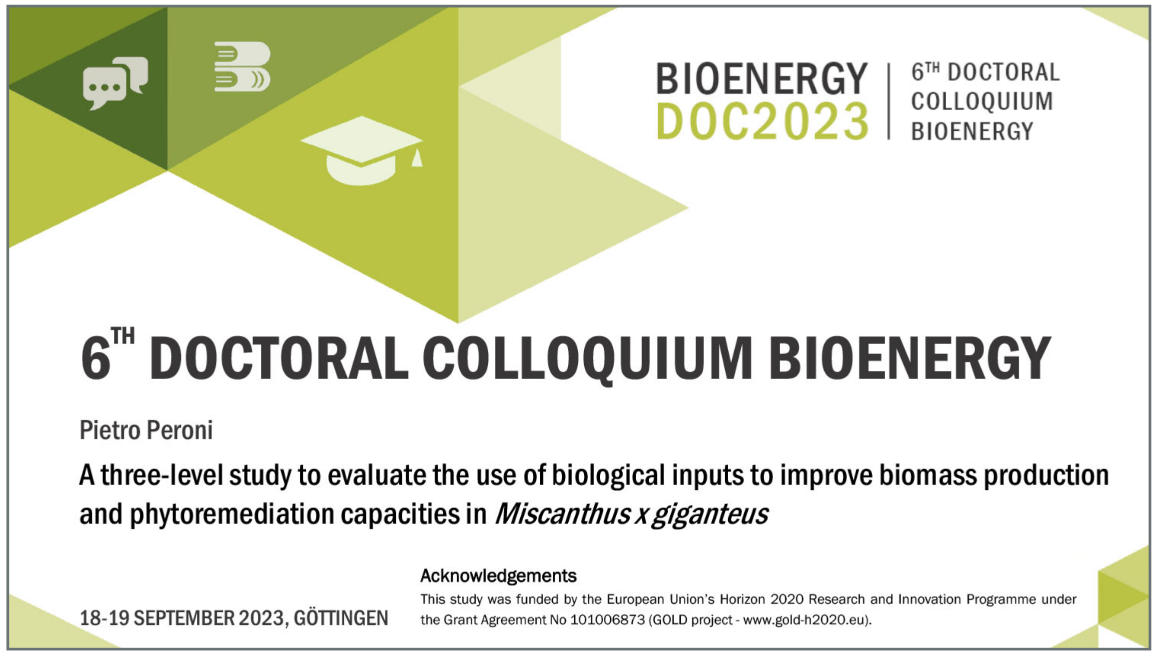
Miscanthus x giganteus is one of the most promising lignocellulosic crops to pursue the dual purpose of biomass production and phytoremediation of heavy metals in contaminated areas, not suitable for food species. Despite not being hyperaccumulator plant, several studies show how it can both accumulate good quantities of heavy metals in the aerial biomass carrying out phytoextraction action and play an important role in the phytostabilization towards those metals that cannot translocate to the aerial parts. Today, to improve these features, research focuses on the use of biostimulants and other biological inputs. As part of my PhD project, carried out in the framework of the GOLD H2020 project, I try to respond to the need to elucidate which kind of biostimulants can effectively improve miscanthus productivity and its phytoremediation capacity. To concrePhoney achieve this result is necessary to use real contaminated soil where the metals have undergone a series of chemical reactions that make them less bioavailable to root absorption over time. Indeed, the soil used belong from a landfill in the outskirt of Bologna (IT). According to Italian law 5 heavy metals concentrations exceed the contamination threshold: Zn, Cu, Ni, Pb and Sn.

The study is divided into 3 levels:
1) A greenhouse pot experiment in which 5 possible biological agents were tested for 13 weeks on miscanthus micropropagated plants in pots (12L) to understand which was the best to increase dry biomass productivity (g/plant DM). Two have been selected: root biostimulant based on humic and fulvic acids (T3, which double the untreated control C) and the combination of this treatments with mycorrhizae (T1xT3, which resulted in an increase of more than 60 % than C).
2) A field trial to test the root biostimulants, alone and in combination with mycorrhizae, and the untreated control in real conditions, through 3 replicates per treatment (plots of 10 m2) in a randomized-block design. The biomass production optimum, as heavy metals phytoextraction estimation, is expected in the second/third year as well as the major differences between the treatments. At the time of writing this abstract, the second growth season has begun, which will end in autumn 2023 with the determination of the yield both in terms of dry biomass and metals phytoextracted. However, during the season, morphological and biometric data will be periodically collected to give preliminary indications on plants growth and productivity, that is my purpose to present at the conference.
3) A further greenhouse trial with 12 transparent tubes (66L) to investigate the role of the treatment selected as most interesting (T1xT3) versus the control C, especially the interaction on the root system proliferation at 2 different layers: 0-30 cm and 30-90 cm deep and the relative effects on phytostabilization and phytoextraction capacities, as well as the plant development and metal bioavailability (each belowground measure is repeated for the 2 layers). At the time of writing this abstract the trial is in the 8^{th} week out of a total of 20. It would be my intention to present the main results obtained at the conference.



Short introduction

BIOENERGY DOC2023 6TH DOCTORAL COLLOQUIUM BIOENERGY

Title of the Doctoral Project:	BRIDGE THE GAP BETWEEN PHYTOREMEDIATION AND CLEAN BIOFUELS PRODUCTION
Doctoral Student:	Pietro Peroni
Cooperating University:	University of Bologna (UNIBO)
University Supervisor:	Professor Andrea Monti, Professor Walter Zegada-Lizarazu
Scholarship provider:	UNIBO Departement of Agricultural and Food Sciences GOLD H2020 Project
Logo	
Duration:	11/2021 – 10/2024

Scientific Background

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Why lignocellulosic crops?

To produce biomass to support EU sustainability targets

- Reduction in the use of first-generation biofuels and their replacement with advanced biofuels
- Possible cultivation on contaminated areas making phytoremediation systems productive

Why contaminated lands?

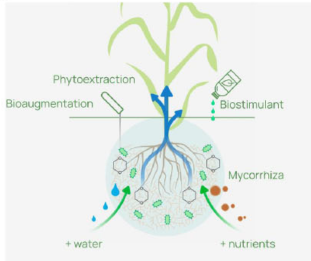
Avoiding ILUC effect and increase ecosystem services

- 2.5 million contaminated sites (650,000 ha) are estimated in Europe.
- 37% of sites contaminated primarily by heavy metals

Why biological inputs ?

Improve biomass crops growth and phytoremediation capacities

- No risk of secondary pollution phenomena
- Economical and sustainable



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Framework

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Crops

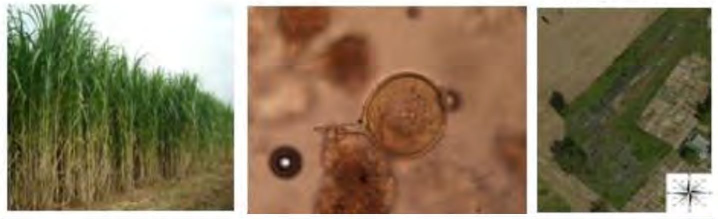
Miscanthus x giganteus
Sorghum bicolor
Cannabis sativa

Biological agents

B1: Protein hydrolisates
B2: Humic and fulvic acids
M: mychorrizae
M*B1
M*B2

Site

Ex llegal landifill «Chiarini»



Metal	Legal tresholds for green areas (mg/ kg di SS)	Legal tresholds for agricultural areas (mg/ kg di SS)	Total concentration (mg/kg ss)	Bioavailbale fraction (mg/kg ss)
Cu	120	200	137,0	45,154
Ni	120	120	209,0	9,920
Pb	100	100	159,0	32,500
Zn	150	300	455,0	62,422
Sn	1	Not defined	8,8	N A

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Aim

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Identify a crop x treatment combination suitable to be grown in a truly combined area and correctly evaluate its growth performances over time

Following the indications provided by the latest research developments

- Investigate how contaminants are translocated into plants by roots and how they affect plants growth
- Carry out trials in conditions of real contamination and not artificially induced
- Collect field data to perform productivity assessments and simulations

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Approach / Methods

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1st Level (2021-2022)

Preliminary Assesements of 18 potential combinations in a greenhouse trial

- 6 treatments x 3 crops
- Selection of two best treatments per crop

2nd Level (2022 – in progress)

Crops agronomic assessment for the area and field trials to verify the result obtained

- 3 treatment x 3 crops x 3 replicates = 27 plots (10 m^2) in a randomized block design
- Identification of the best combination
- Validation of a crop growth model under the tested conditions

3rd Level (2023)

Morpho-physiological study of the selected combination especially for root growth and metal absorption

- 2 treatments x 1 crop in a dedicated structure in controlled environment

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1st Level: main results

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Dry Biomass production

- Treatments main effect was an **incrase in biomass production**
- **Phytoxtraction** in aboveground biomass was limiteted to **Zn and Cu**
- **Phytostabilisation** capacities have been noted for **Zn, Cu, Ni, Pb**
- **No differences in metal concentrations** in aboveground tissues
- **Greater biomass production implies greater metal uptake**

Species	2 Selected treatments
Hemp	M*B2, B1
Sorghum	M*B2, M*B1
Miscanthus	M*B2, B2

M*B2 is common to all the species

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2nd Level: Agronomic characterization

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- Strong marginality conditions: stoniness (> 15%) and machine inacessability
  => Low workability
- No differences in the type of metal acquired by plants
  => No phytoremdiation advantages in using annuals
- The context require to preserve the low metal availability and to prevent their migration in the surrounding environment
  => Permanent vegetation cover

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2nd Level: field managment

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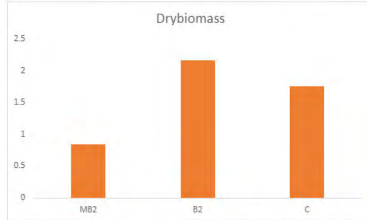
1st year

- Rhizome transplanting 18/05/2023
- Spring tratments application
- First harvest 31/1//2023
- No biomass differences in the first year

2nd year

- Emergence 23/03/2023
- Spring tratments application
- Cultivation still in progress (autmun harvest)
- Application of a miscanthus growth model



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2nd Level: Arungro model

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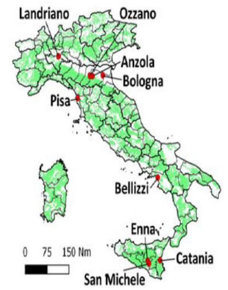
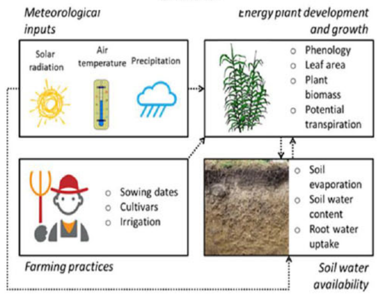
- Developed by the Italian Centre of Agricultural Research and Economics (CREA)
- 3th generation of the model: born for sugar cane, then giant reed and now miscanthus
- Calibrated using 19 multi-year datasets from 1992 across the entire Italian territory
- Accurate ABG production simulation: 73% of observed varaibility





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2nd Level: main results

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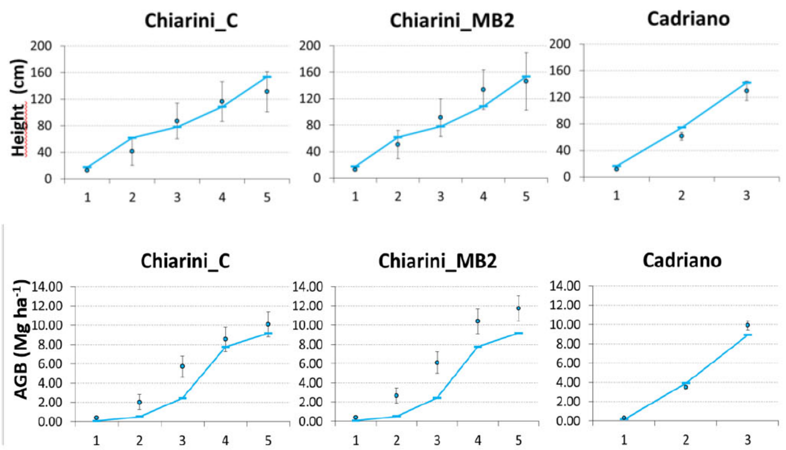
Collection of climatic and biometric data in the contaminated area «Chiarini» and in a reference field «Cadriano»



- Accurate height estimantion both in Chiarini and Cadriano. In Chiarini no distinctions for the treatment.
- Accurate AGB estimantion in Cadriano and in Chiarini C.
- Constant underestimate for Chiarini MB2.

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3rd Level: Link with the previous

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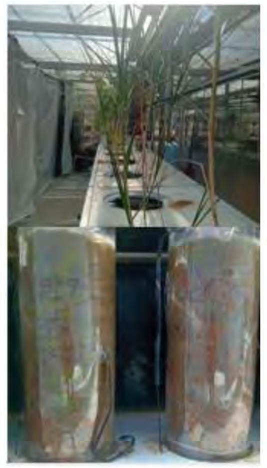
Through an **in-depth study of the differences in root growth and development** we believe it is possible to **adjust the model** to simulate the effect of the M*B2 treatment providing a first **preliminary validation in the next growing season**



Water is the key:

- Water Retention Capacity
- Water Use Capacity
- Metal assobiton by water

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3rd Level: The structure

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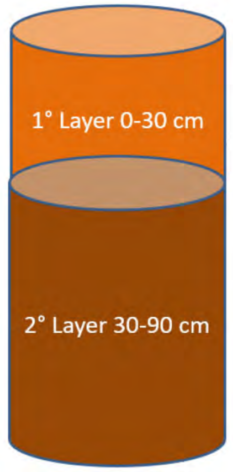

Experimental design:
- M*B2 vs Control plants
- 6 replicates per thesis totally randomized
- Each plant growth in a tube filled by contaminated soil
- Each tube has a volume of 66L

In each tube we detect separately for the two layers:
- Soil humidity by probes
- Root system estension
- Root fresh and dry biomass
- Metal Translocation Ideces (TFs)

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3rd Level: preliminary indications

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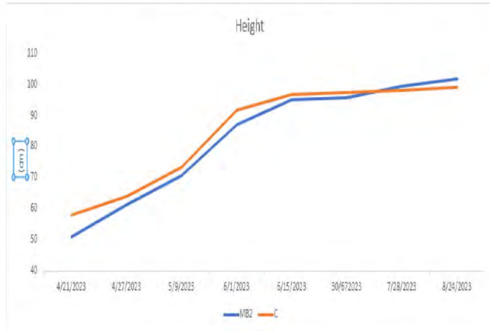
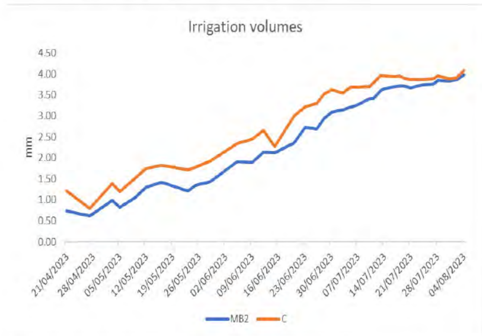
Final results will be ready by the end of october

However, something already seems to be clear…looking at irrigation demands





Water is the key!

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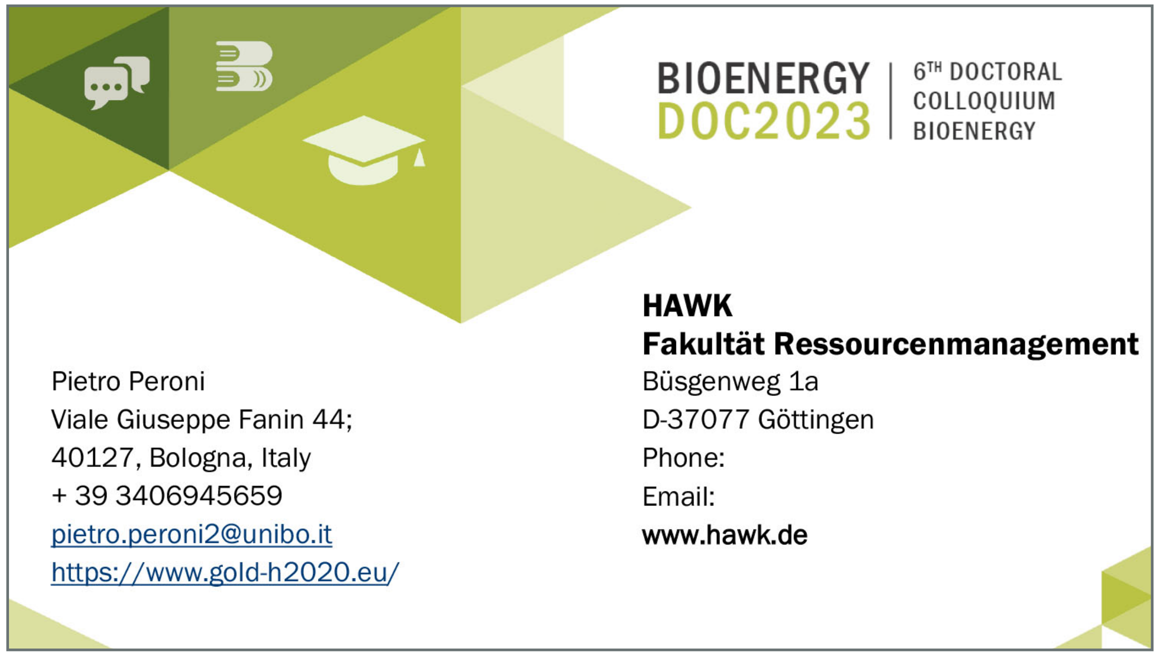
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Beike Sumfleht, Deutsches Biomasseforschungszentrum/University of Leipzig

Descision-Making Tool for the Assessment of Trade-offs in Low iLUC Risk Certification

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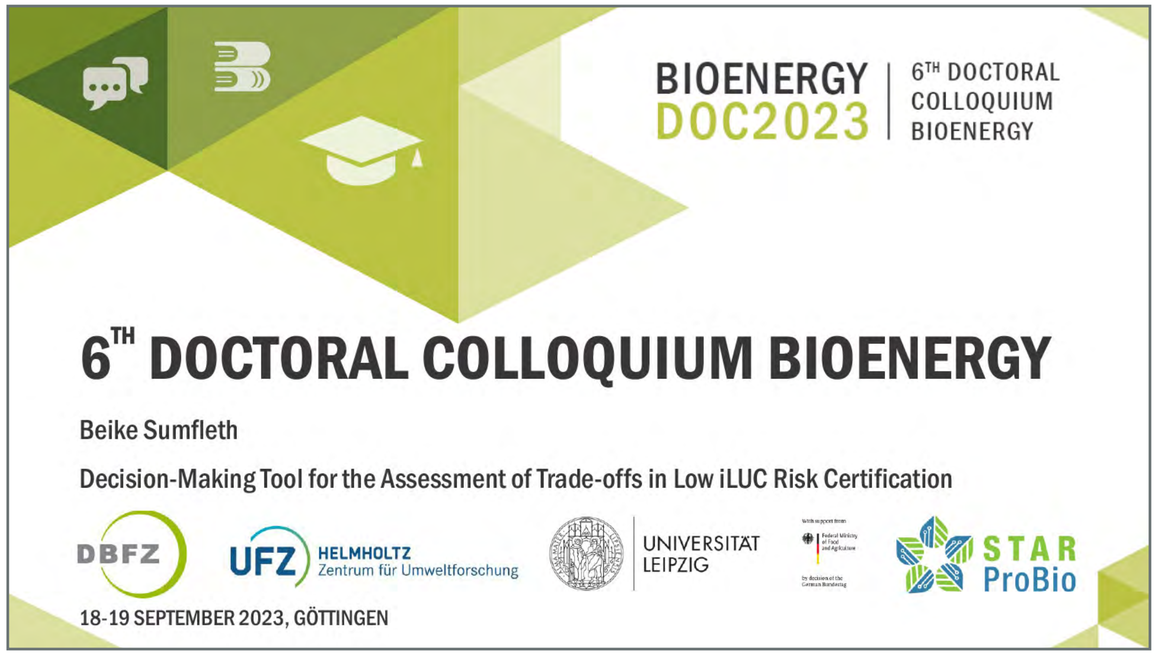
Indirect land use change (iLUC) is considered a significant challenge associated with an increasing demand for biomass and bioenergy. Sustainability certification is discussed as one instrument to manage this risk. However, expanding biofuel certification schemes towards a credible and reliable approach to account for iLUC risks is still an open question. As recently reviewed, low iLUC risk biomass production could be based on the use of additionality practices that an individual producer can adopt to provide an amount of biomass in addition to a reference case. To support the sustainable use of such practices, there is a need to determine whether existing certification instruments address trade-offs that could arise from the use of these practices and whether these instruments are based on scientific evidence, and to develop assessment approaches for the trade-offs that are not currently considered in sustainability certification.

The aim of the study is to develop a knowledge-based guidance primarily aimed at voluntary certification schemes, providing decision support for the assessment of specific trade-offs. We will present the methodological approach, results and conclusions, and recommendations for improvements in certification schemes to assess these trade-offs.

To achieve this aim, in a first step, potential trade-offs are reviewed and compared whether certification schemes take them into account or not. Based on these findings, potential assessment approaches for a selection of trade-offs are reviewed and evaluated to determine which approach is suitable and a good practice for certification. In a further step, these approaches will be compared with the instruments of biofuel certification schemes. Based on this comparison, a decision support tool for the implementation of suitable assessment approaches is developed.

We can determine trade-offs that are considered by a majority, e.g., biodiversity loss, by about half, e.g., hazardous work, and by a minority, e.g., resource depletion of schemes. From the perspective of addressing trade-offs, biomass cultivation on unused land is the most promising additionality practice. We have identified suitable assessment approaches for biodiversity loss, human disease, increased economic expenses, resource depletion, and water depletion. In addition, we can identify certification instruments currently used to assess trade-offs that are not consistent with the assessment approaches evaluated as suitable and good practice. On the other hand, we can determine approaches for those trade-offs that are only considered by a minority of schemes.

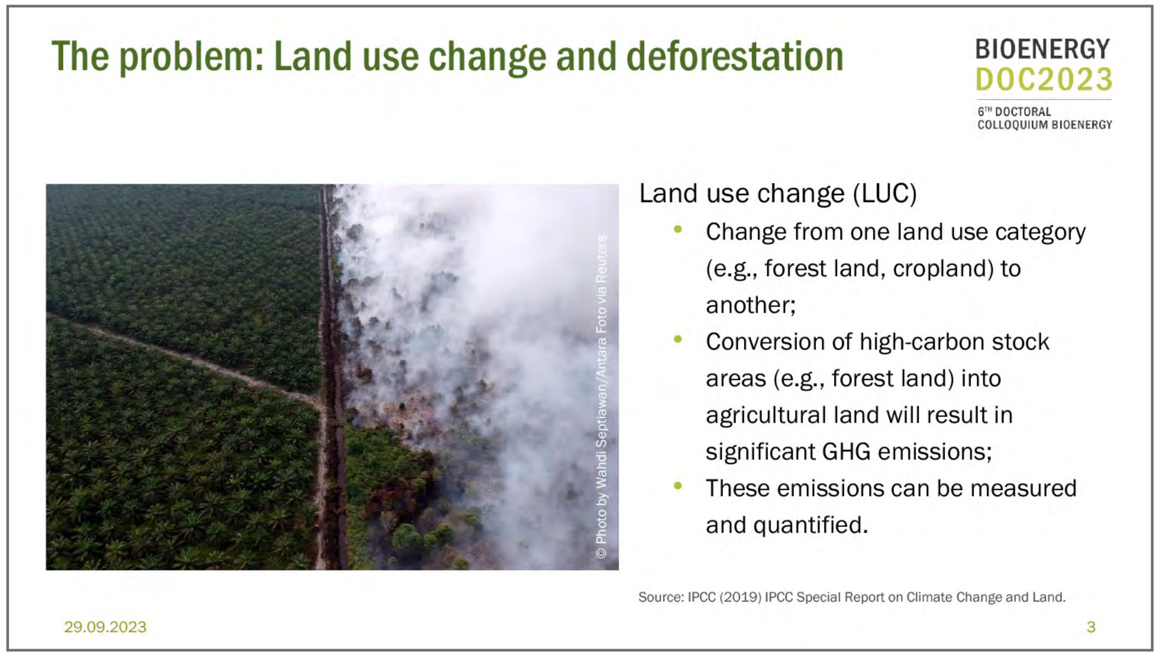
There are instruments currently used in sustainability certification of biofuels that are based on scientifically sound methods. In contrast, there are instruments that cannot be considered scientifically sound. The latter need to be improved to support effective sustainability certification of biofuels.



Short introduction

BIOENERGY DOC2023 6TH DOCTORAL COLLOQUIUM BIOENERGY

Title of the Doctoral Project:	Integrated Assessment Framework for Sustainability Certification of Low Indirect Land Use Change Risk Biofuels
Doctoral Student:	Beike Sumfleth
DBFZ Supervisor:	Stefan Majer
Cooperating University:	Leipzig University
University Supervisor:	Prof. Dr.-Ing. Daniela Thrän
Funding / Scholarship provider: Logo:	STAR-ProBio funded by by the European Union's Horizon 2020 Research and innovation action under grant agreement No 727740 Bundesministerium für Ernährung und Landwirtschaft (BMEL)
Duration:	07/2018 – 07/2024


The problem: Land use change and deforestation
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© Photo by Wahdi Septiawan/Antara Foto via Reuters
Land use change (LUC)
Change from one land use category (e.g., forest land, cropland) to another;
Conversion of high-carbon stock areas (e.g., forest land) into agricultural land will result in significant GHG emissions;
These emissions can be measured and quantified.
Source: IPCC (2019) IPCC Special Report on Climate Change and Land.
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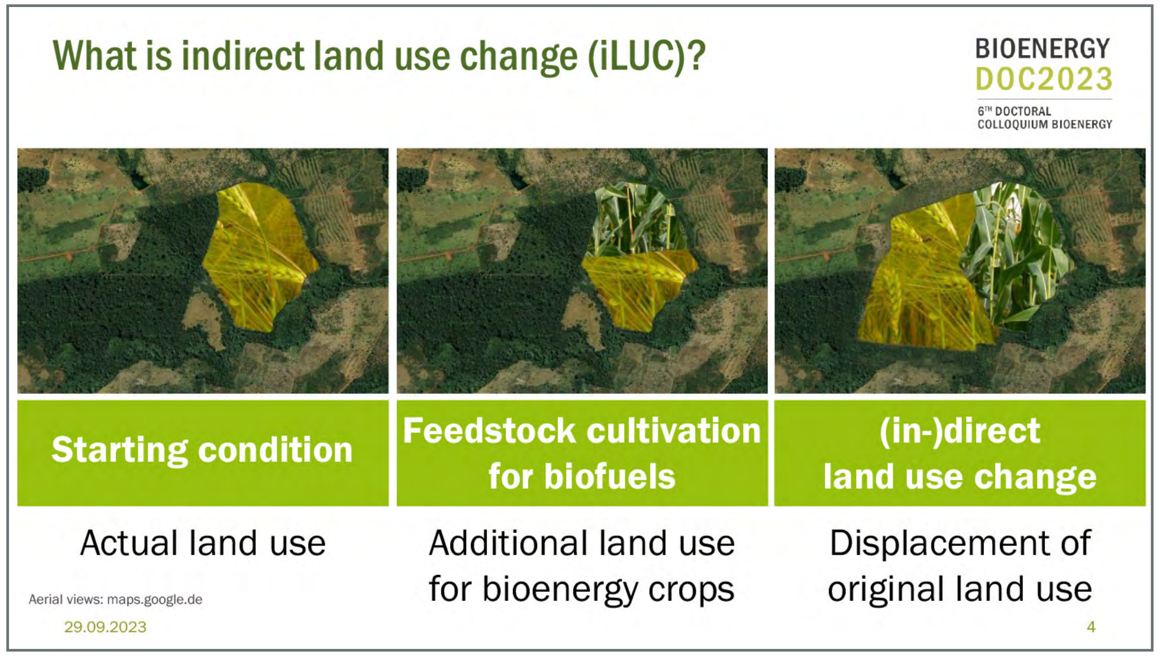
What is indirect land use change (iLUC)?
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Starting condition
Feedstock cultivation for biofuels
(in-)direct land use change
Actual land use
Additional land use for bioenergy crops
Displacement of original land use
Aerial views: maps.google.de
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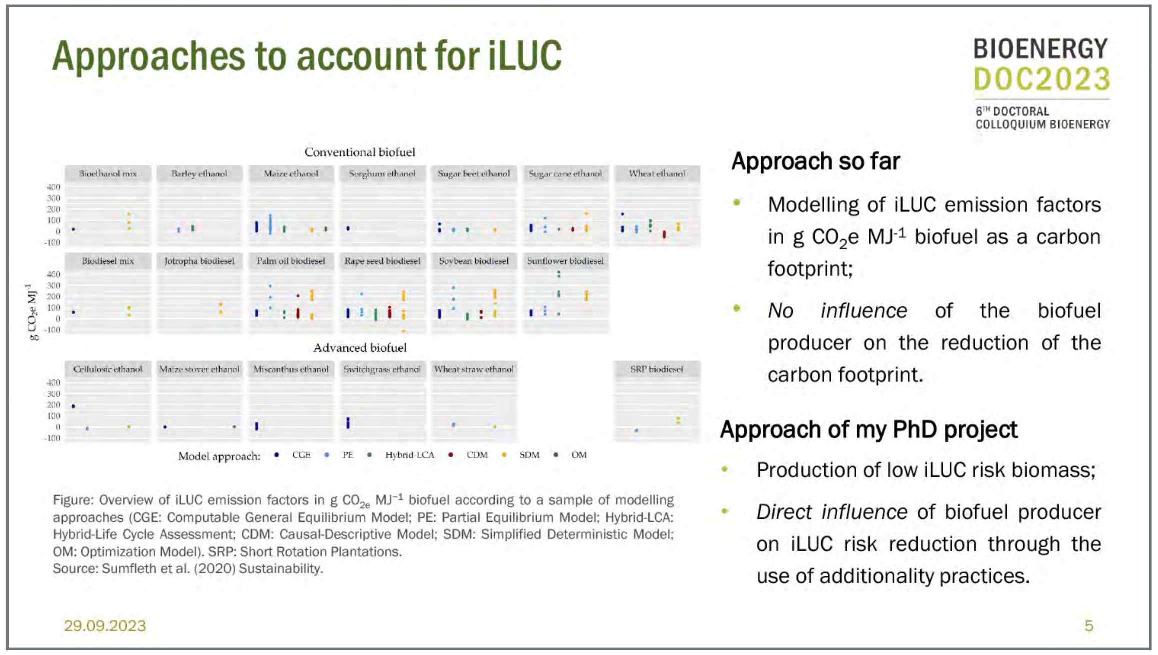
Approaches to account for iLUC
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Conventional biofuel
Advanced biofuel
Model approach: CGE PE Hybrid-LCA CDM SDM OM
Figure: Overview of iLUC emission factors in g CO2e MJ-1 biofuel according to a sample of modelling approaches (CGE: Computable General Equilibrium Model; PE: Partial Equilibrium Model; Hybrid-LCA: Hybrid-Life Cycle Assessment; CDM: Causal-Descriptive Model; SDM: Simplified Deterministic Model; OM: Optimization Model). SRP: Short Rotation Plantations.
Source: Sumfleth et al. (2020) Sustainability.
Approach so far
Modelling of iLUC emission factors in g CO2e MJ-1 biofuel as a carbon footprint;
No influence of the biofuel producer on the reduction of the carbon footprint.
Approach of my PhD project
Production of low iLUC risk biomass;
Direct influence of biofuel producer on iLUC risk reduction through the use of additionality practices.
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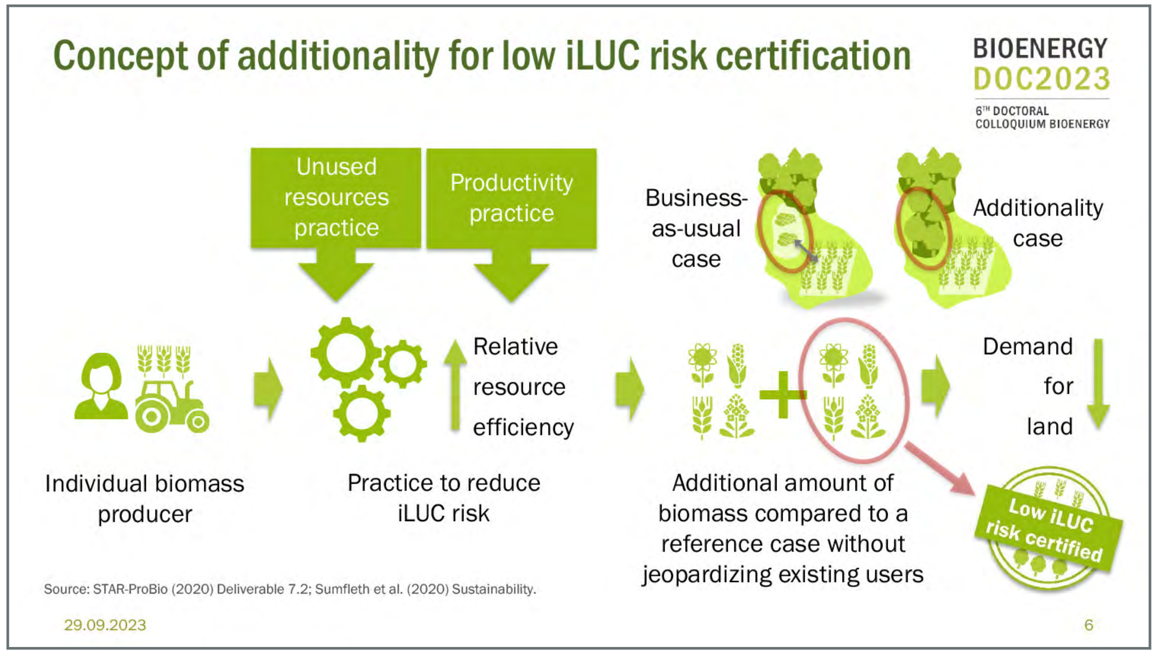
Concept of additionality for low iLUC risk certification
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6TH DOCTORAL COLLOQUIUM BIOENERGY
Unused resources practice
Productivity practice
Business-as-usual case
Additionality case
Relative resource efficiency
Demand for land
Individual biomass producer
Practice to reduce iLUC risk
Additional amount of biomass compared to a reference case without jeopardizing existing users
Low iLUC risk certified
Source: STAR-ProBio (2020) Deliverable 7.2; Sumfleth et al. (2020) Sustainability.
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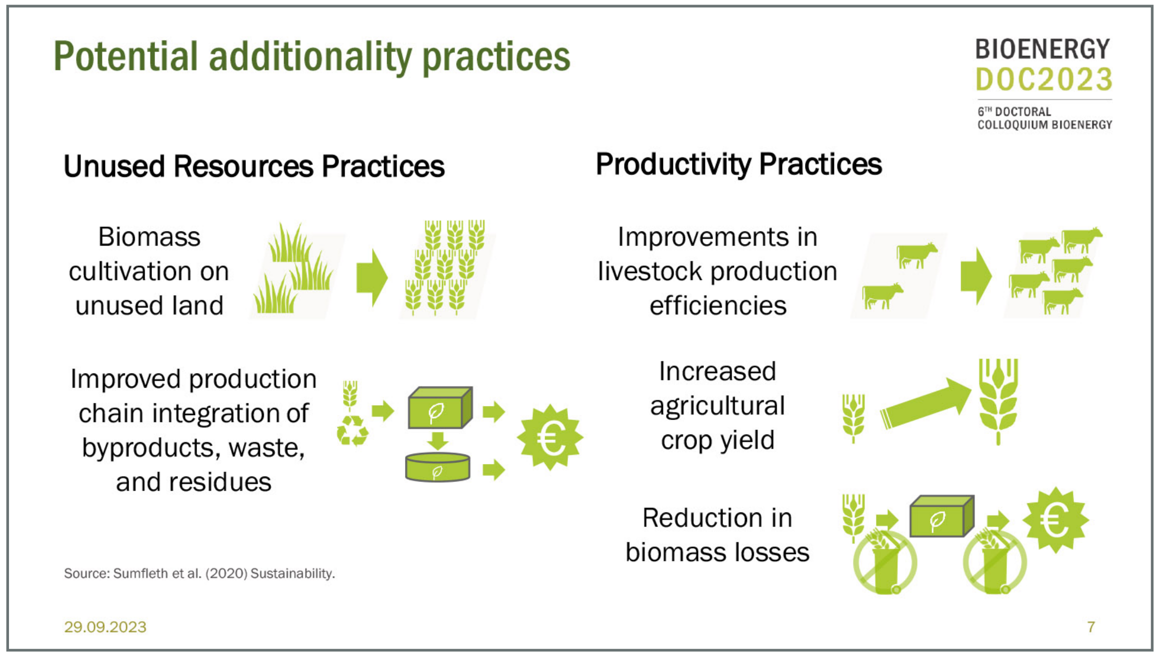
Potential additionality practices
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Unused Resources Practices
Biomass cultivation on unused land
Improved production chain integration of byproducts, waste, and residues
Productivity Practices
Improvements in livestock production efficiencies
Increased agricultural crop yield
Reduction in biomass losses
Source: Sumfleth et al. (2020) Sustainability.
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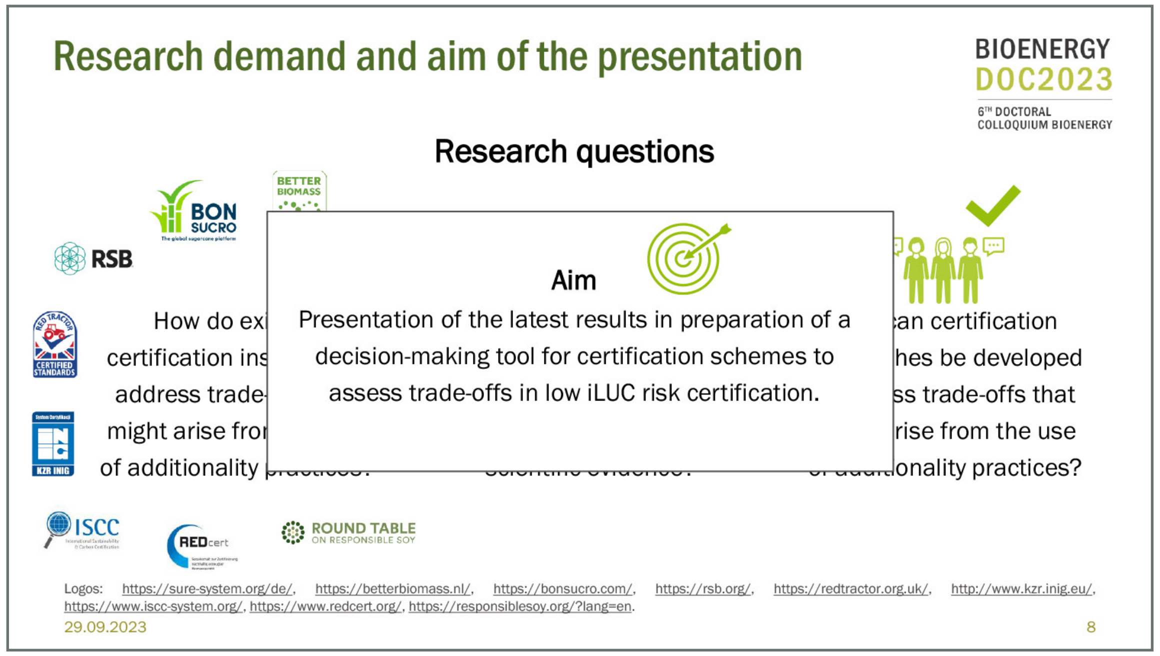
Research demand and aim of the presentation
BIOENERGY
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Research questions
BON SUCRO
BETTER BIOMASS
RSB
How do exi
certification ins
address trade-
might arise fro
of additionality
Aim
Presentation of the latest results in preparation of a decision-making tool for certification schemes to assess trade-offs in low iLUC risk certification.
an certification
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rise from the use
onality practices?
ISCC
REDcert
ROUND TABLE ON RESPONSIBLE SOY
Logos: https://sure-system.org/de/, https://betterbiomass.nl/, https://bonsucro.com/, https://rsb.org/, https://redtractor.org.uk/, http://www.kzr.inig.eu/, https://www.iscc-system.org/, https://www.redcert.org/, https://responsiblesoy.org/?lang=en.
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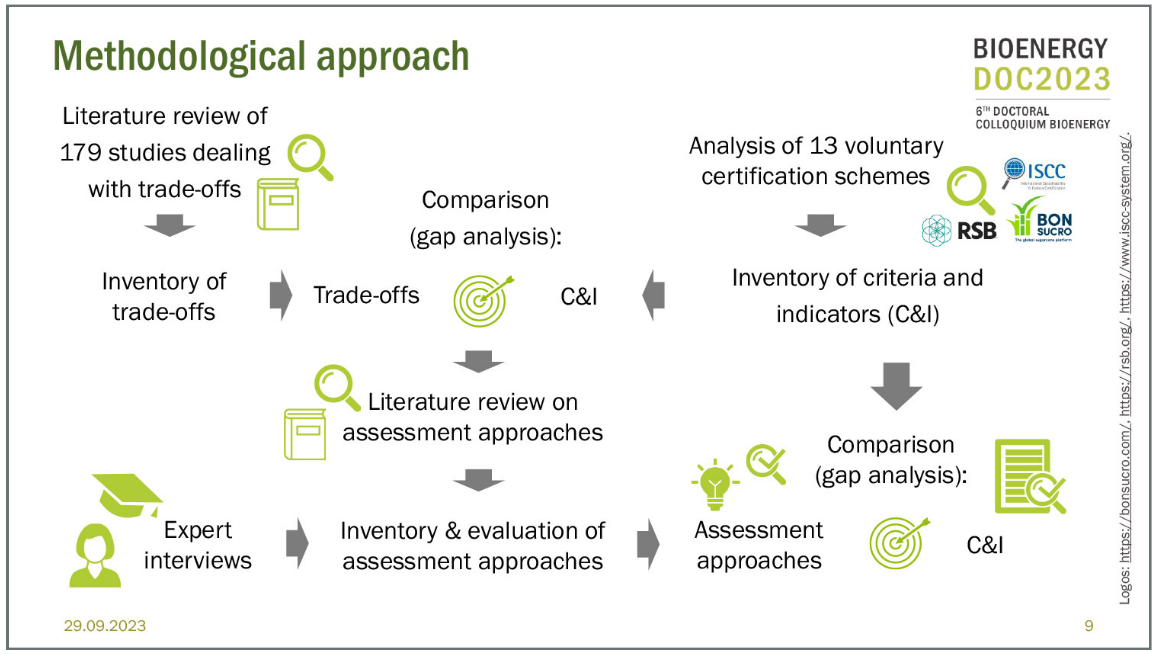
Methodological approach
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Literature review of 179 studies dealing with trade-offs
Inventory of trade-offs
Comparison (gap analysis):
Trade-offs
C&I
Analysis of 13 voluntary certification schemes
ISCC
RSB
BON SUCRO
Inventory of criteria and indicators (C&I)
Literature review on assessment approaches
Expert interviews
Inventory & evaluation of assessment approaches
Assessment approaches
Comparison (gap analysis):
C&I
Logos: https://bonsucro.com/, https://rsb.org/, https://www.iscc-system.org/
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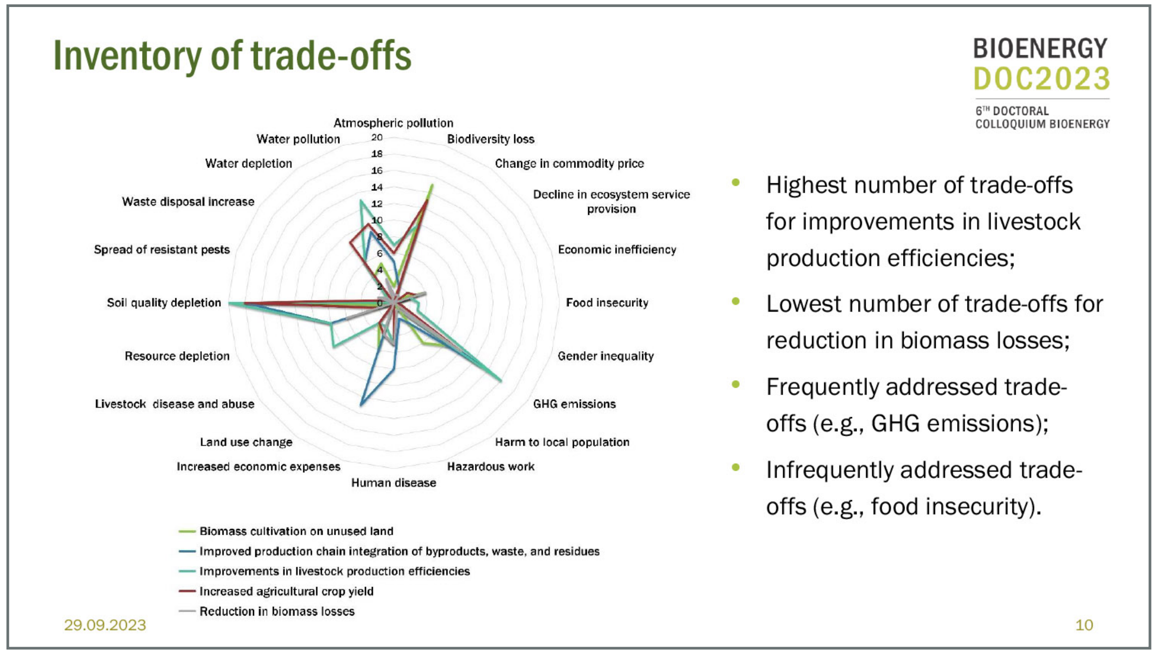
Inventory of trade-offs
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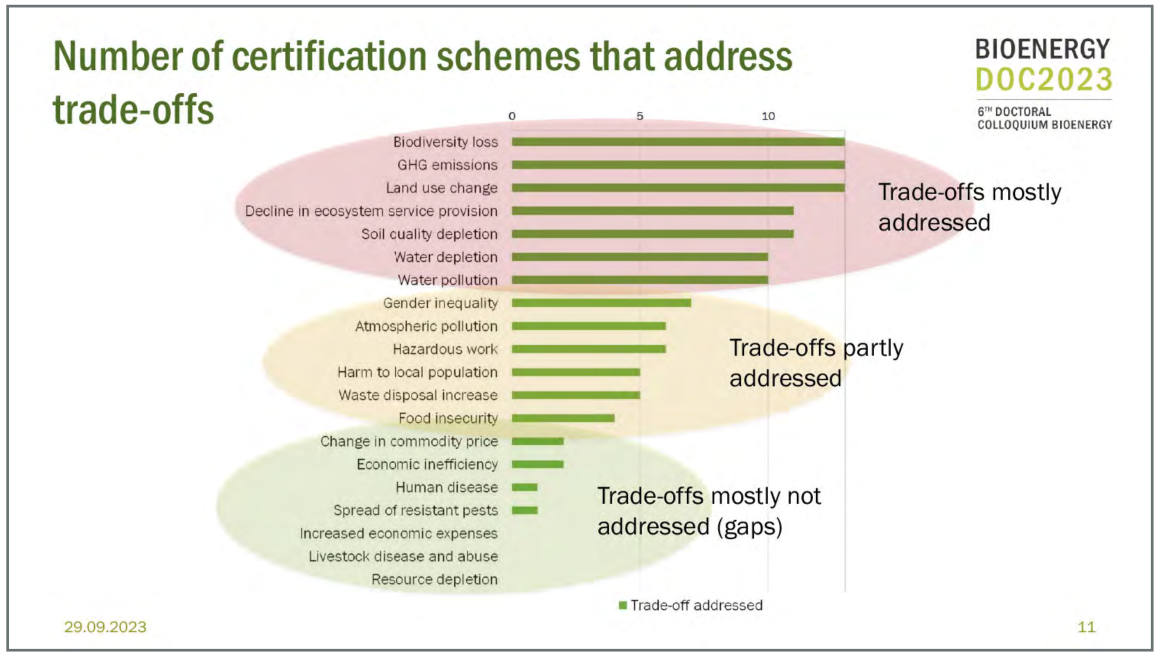
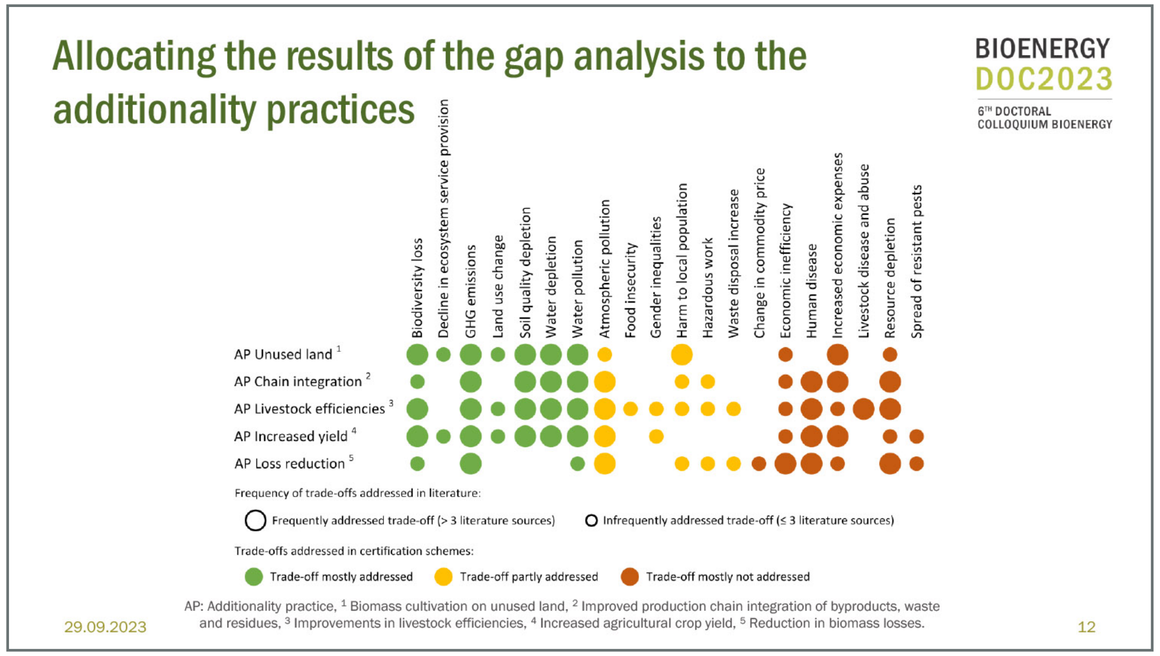
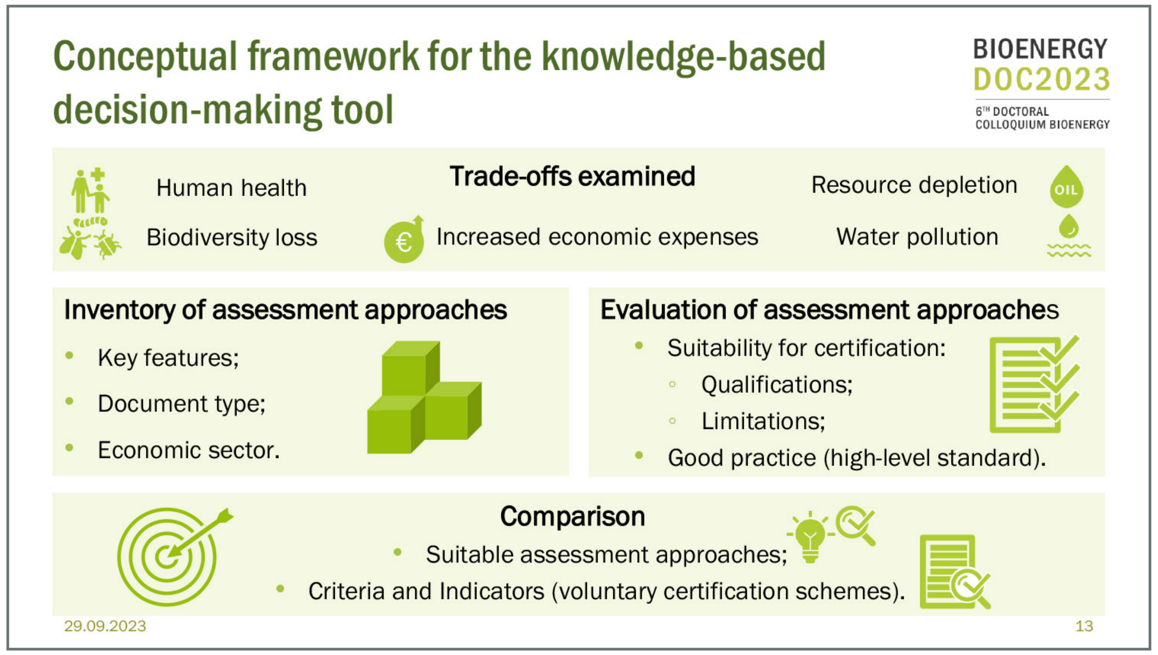
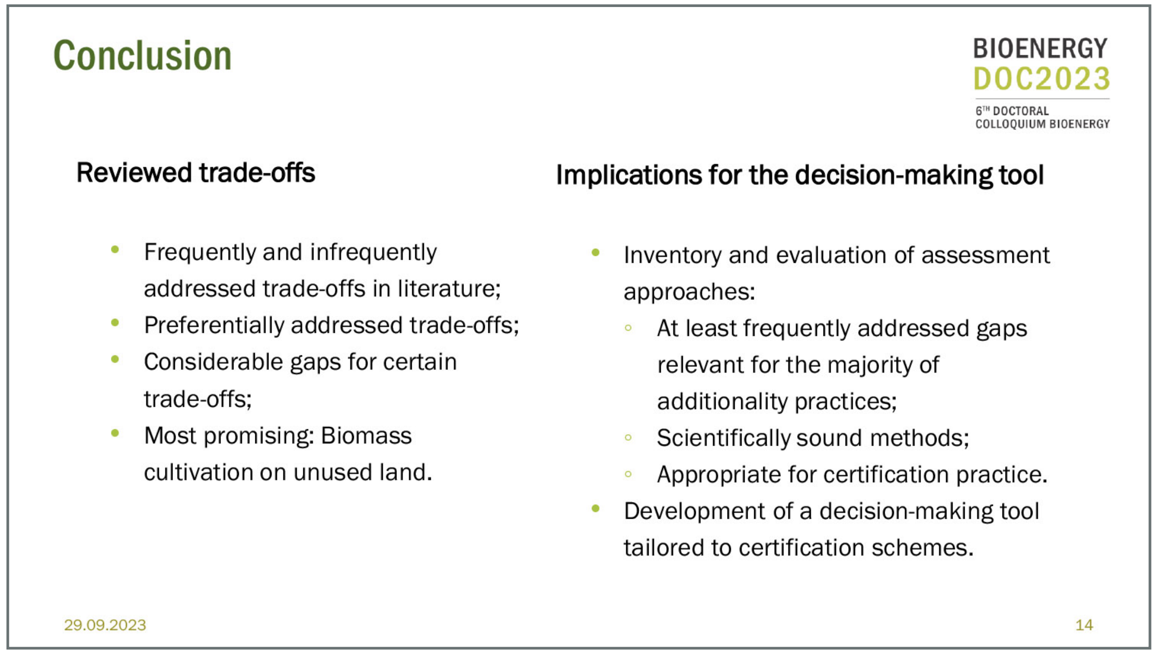
Atmospheric pollution
Biodiversity loss
Change in commodity price
Decline in ecosystem service provision
Economic inefficiency
Food insecurity
Gender inequality
GHG emissions
Harm to local population
Hazardous work
Human disease
Increased economic expenses
Land use change
Livestock disease and abuse
Resource depletion
Soil quality depletion
Spread of resistant pests
Waste disposal increase
Water depletion
Water pollution
20
18
16
14
12
10
8
6
4
2
0
Biomass cultivation on unused land
Improved production chain integration of byproducts, waste, and residues
Improvements in livestock production efficiencies
Increased agricultural crop yield
Reduction in biomass losses
Highest number of trade-offs for improvements in livestock production efficiencies;
Lowest number of trade-offs for reduction in biomass losses;
Frequently addressed trade-offs (e.g., GHG emissions);
Infrequently addressed trade-offs (e.g., food insecurity).
29.09.2023
10


Number of certification schemes that address trade-offs
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
0
5
10
Biodiversity loss
GHG emissions
Land use change
Decline in ecosystem service provision
Soil cuality depletion
Water depletion
Water pollution
Gender inequality
Atmospheric pollution
Hazardous work
Harm to local population
Waste disposal increase
Food insecurity
Change in commodity price
Economic inefficiency
Human disease
Spread of resistant pests
Increased economic expenses
Livestock disease and abuse
Resource depletion
Trade-offs mostly addressed
Trade-offs partly addressed
Trade-offs mostly not addressed (gaps)
Trade-off addressed
29.09.2023
11


Allocating the results of the gap analysis to the additionality practices
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Biodiversity loss
Decline in ecosystem service provision
GHG emissions
Land use change
Soil quality depletion
Water depletion
Water pollution
Atmospheric pollution
Food insecurity
Gender inequalities
Harm to local population
Hazardous work
Waste disposal increase
Change in commodity price
Economic inefficiency
Human disease
Increased economic expenses
Livestock disease and abuse
Resource depletion
Spread of resistant pests
AP Unused land 1
AP Chain integration 2
AP Livestock efficiencies 3
AP Increased yield 4
AP Loss reduction 5
Frequency of trade-offs addressed in literature:
Frequently addressed trade-off (> 3 literature sources)
Infrequently addressed trade-off (≤ 3 literature sources)
Trade-offs addressed in certification schemes:
Trade-off mostly addressed
Trade-off partly addressed
Trade-off mostly not addressed
AP: Additionality practice, 1 Biomass cultivation on unused land, 2 Improved production chain integration of byproducts, waste and residues, 3 Improvements in livestock efficiencies, 4 Increased agricultural crop yield, 5 Reduction in biomass losses.
29.09.2023
12


Conceptual framework for the knowledge-based decision-making tool
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Trade-offs examined
Human health
Biodiversity loss
Increased economic expenses
Resource depletion
Water pollution
OIL
Inventory of assessment approaches
Key features;
Document type;
Economic sector.
Evaluation of assessment approaches
Suitability for certification:
Qualifications;
Limitations;
Good practice (high-level standard).
Comparison
Suitable assessment approaches;
Criteria and Indicators (voluntary certification schemes).
29.09.2023
13


Conclusion
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Reviewed trade-offs
Frequently and infrequently addressed trade-offs in literature;
Preferentially addressed trade-offs;
Considerable gaps for certain trade-offs;
Most promising: Biomass cultivation on unused land.
Implications for the decision-making tool
Inventory and evaluation of assessment approaches:
At least frequently addressed gaps relevant for the majority of additionality practices;
Scientifically sound methods;
Appropriate for certification practice.
Development of a decision-making tool tailored to certification schemes.
29.09.2023
14

BIOENERGY DOC2023 | 6TH DOCTORAL COLLOQUIUM BIOENERGY

Contact

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D-04347 Leipzig
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Email: info@dbfz.de
www.dbfz.de

SESSION
BIOREFINERIES

Prof. Dr. Andrea Kruse
Prof. Dr. Nicolaus Dahmen
Dr. Markus Wolperdinger

6TH DOCTORAL COLLOQUIUM BIOENERGY

Lili Sophia Röder, Deutsches Biomasseforschungszentrum

Demand Side Management Implementation – A Descision Support Tool Demonstration on Biorefineries

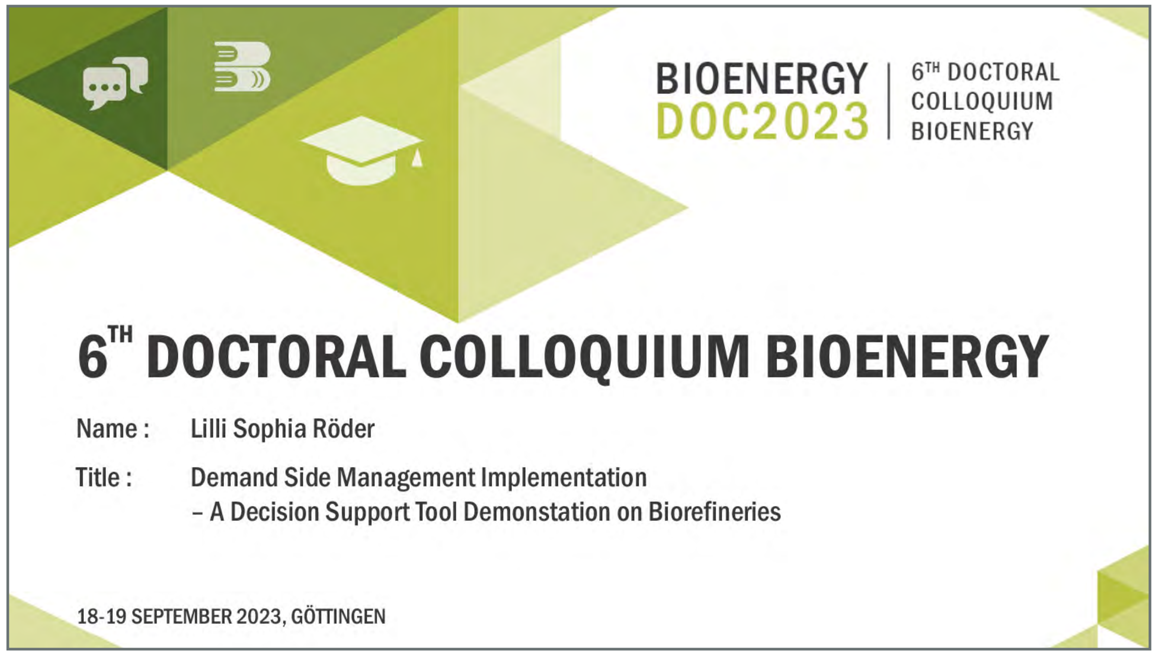
Lilli Sophia Röder
DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH
Torgauer Str. 116
D - 04347 Leipzig
Phone +49 (0)341 2434-424
E-Mail: lilli.sophia.roeder@dbfz.de

For the conversion of process energy to renewable energies such as solar and wind, the energy demand of biomass processing must be flexibly adjustable to this fluctuating electricity. The adjustment of a system's power demand to follow the current power generation is commonly referred to as demand side management (DSM).

Increasing the flexibility of continuously operated processes inevitably entails oversizing the process. DSM strategies result in shutting down a process and thus electricity being purchased at times of low prices which can in turn lead to monetary benefits. From an economic point of view, this however leads to an increase in investment and thus capital costs. Only when these monetary benefits exceed the increase in capital costs does the implementation of a DSM serve an economic purpose.

A framework that evaluates the most important economic parameters for the decision of a DSM implementation for continuously operated processes is proposed. The framework is based on a multistep analysis of processes within an industrial plant investigated for mass flows, energy demand theoretical DSM potential and several economic aspects of DSM implementation. In a case study, the functionality of the framework is demonstrated on a biomethane production plant. The framework evaluates and ranks processes concerning their economic DSM potential. This results in the possibility of assessing the plant or processes determining whether DSM implementation is economically viable.

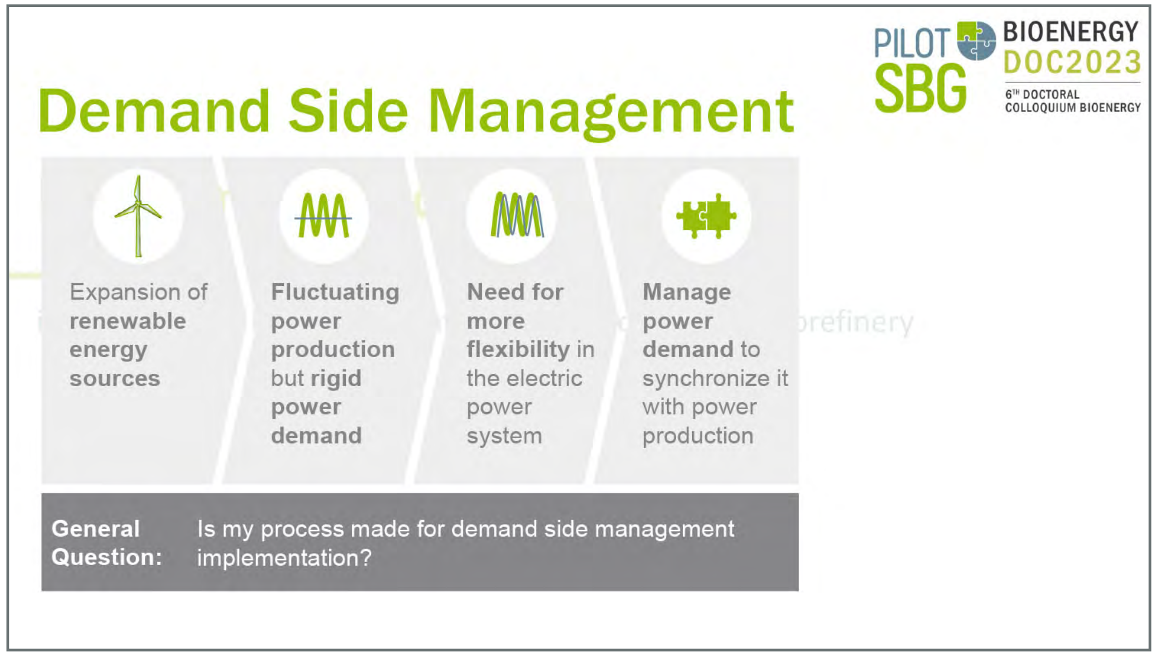
The results show that in downstream digestate treatment DSM implementation is especially feasible. In further studies the focus of dynamic scheduling and optimization will therefore be put on the separation cascade of fermentation digestate broth. A detailed analysis of the processes that have been identified feasible for DSM implementation will be conducted taking shut down and switch on duration into account. The modelled processes will react time dependently to fluctuating electricity prices analyzing the real time economic effects and ecological advantages that the DSM implementation could entail.

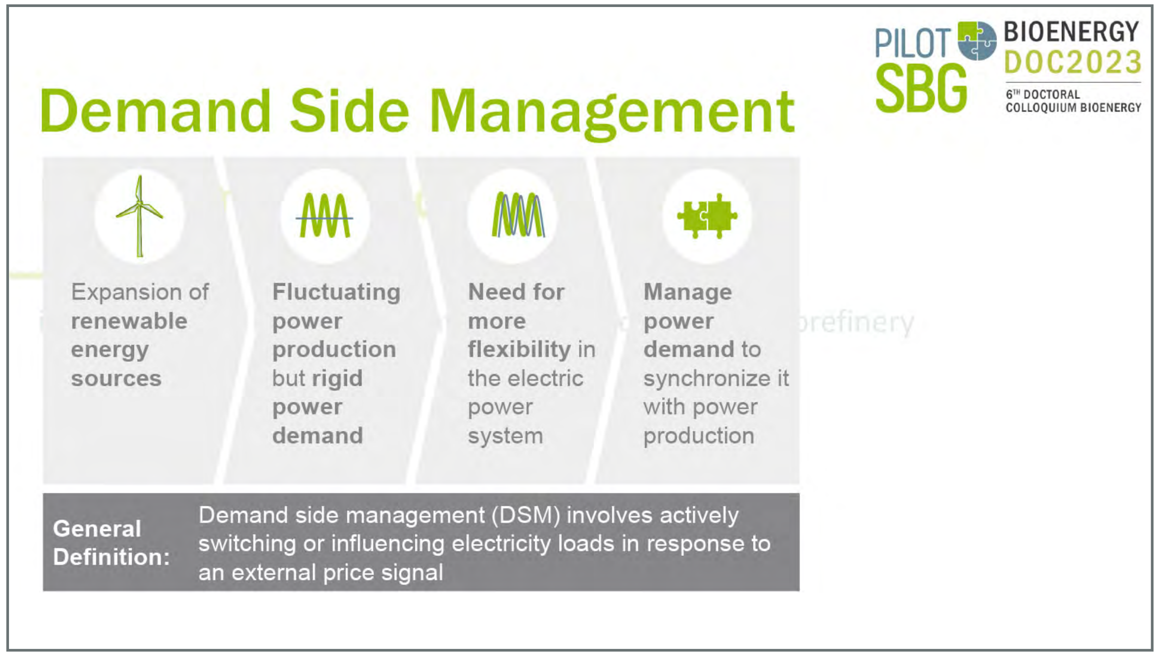


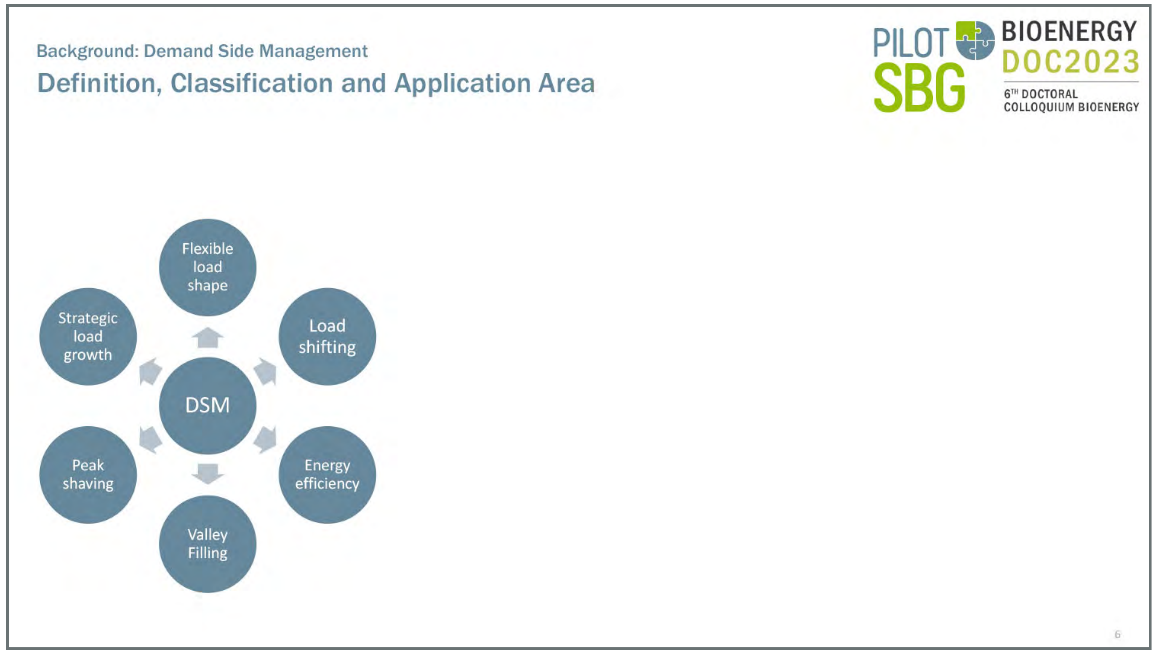
Short introduction

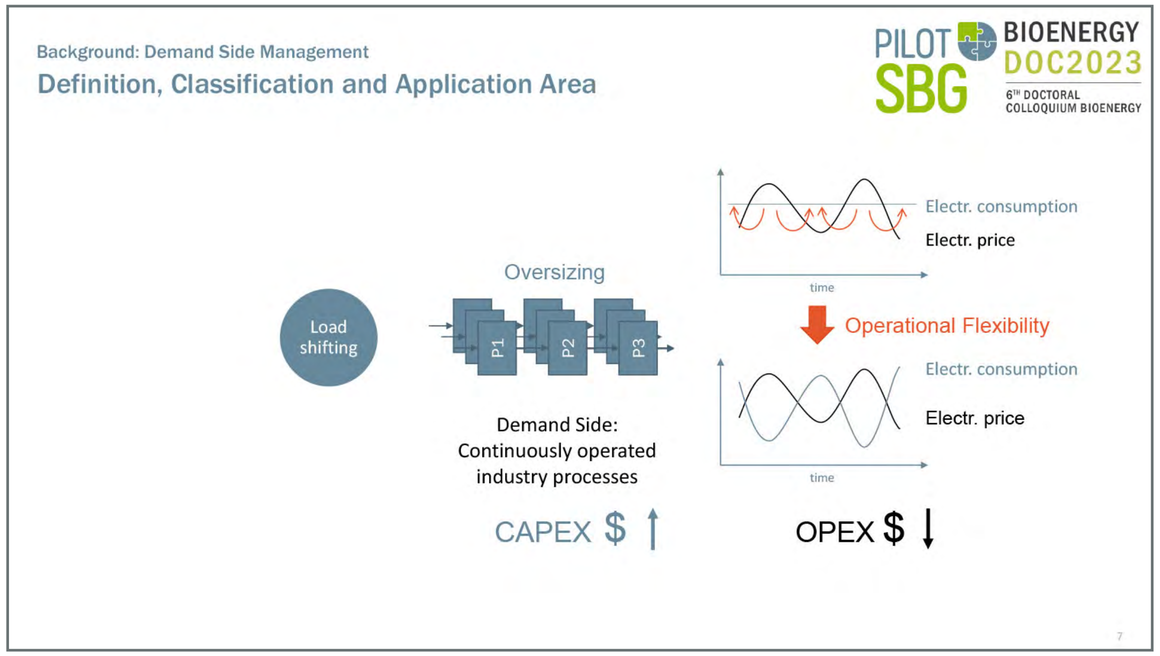
Title of the Doctoral Project:	Demand Side Management Implemenation in Biorefineries
Doctoral Student:	Lilli Sophia Röder
DBFZ Supervisor:	Arne Gröngröft
Cooperating University:	Ruhr University Bochum
University Supervisor:	Prof. Dr. Marcus Grünewald
Funding / Scholarship provider:	Federal Ministry for Digital and Transport (ger. Bundesministerium für Digitales und Verkehr - BMDV)
Logo:	
Duration:	10/2019 – 12/2023

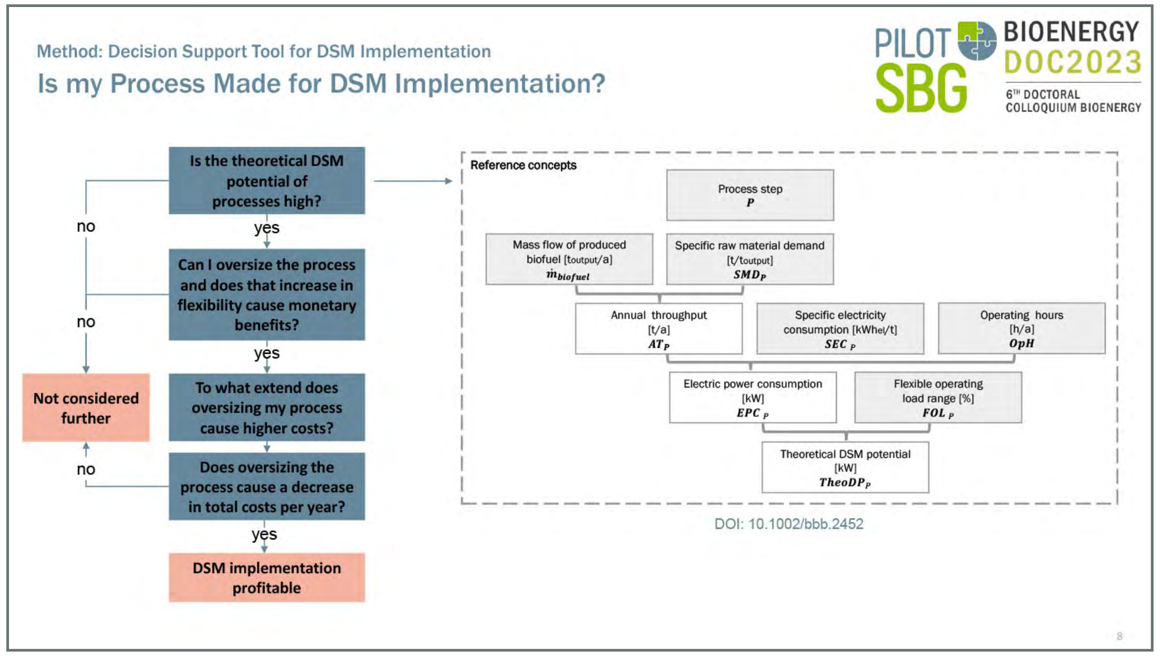

Demand Side Management Implementation
A Decision Support Tool Demonstration on Biorefineries

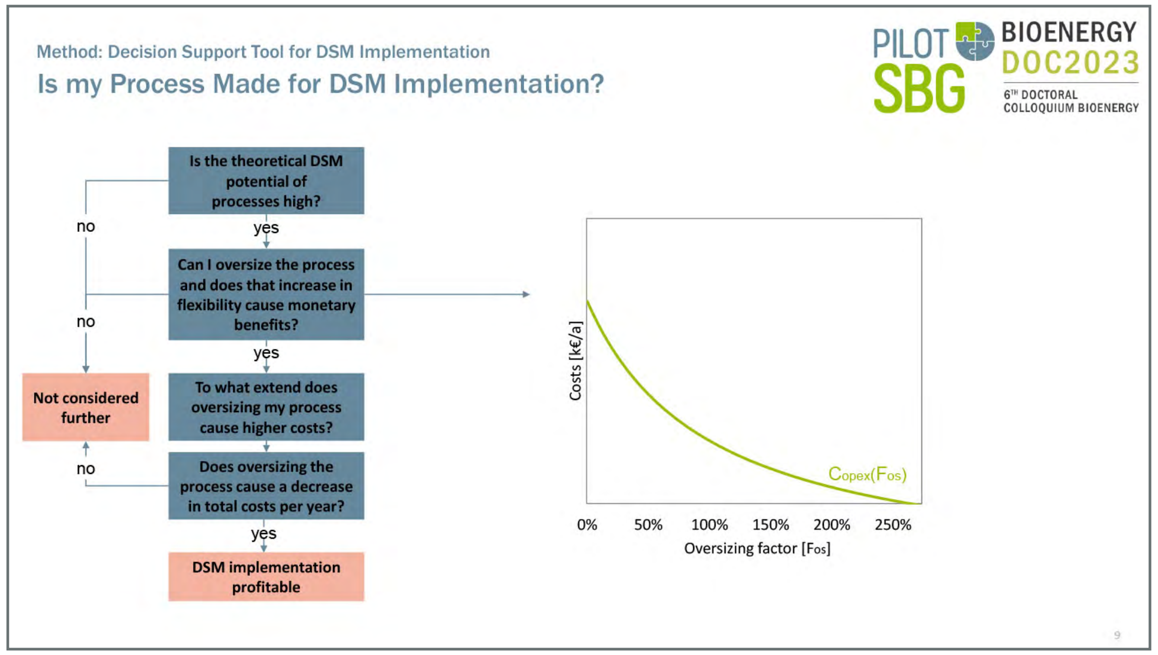

Demand Side Management
Expansion of renewable energy sources
Fluctuating power production but rigid power demand
Need for more flexibility in the electric power system
Manage power demand to synchronize it with power production
General Question:
Is my process made for demand side management implementation?


Demand Side Management
Expansion of renewable energy sources
Fluctuating power production but rigid power demand
Need for more flexibility in the electric power system
Manage power demand to synchronize it with power production
General Definition:
Demand side management (DSM) involves actively switching or influencing electricity loads in response to an external price signal


Background: Demand Side Management
Definition, Classification and Application Area
Flexible load shape
Strategic load growth
Load shifting
DSM
Peak shaving
Energy efficiency
Valley Filling


Background: Demand Side Management
Definition, Classification and Application Area
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Load shifting
Oversizing
P1
P2
P3
Demand Side: Continuously operated industry processes
CAPEX $
Electr. consumption
Electr. price
time
Operational Flexibility
Electr. consumption
Electr. price
time
OPEX $


Method: Decision Support Tool for DSM Implementation
Is my Process Made for DSM Implementation?
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Is the theoretical DSM potential of processes high?
yes
no
Can I oversize the process and does that increase in flexibility cause monetary benefits?
yes
no
Not considered further
To what extend does oversizing my process cause higher costs?
Does oversizing the process cause a decrease in total costs per year?
no
yes
DSM implementation profitable
Reference concepts
Process step P
Mass flow of produced biofuel
Specific raw material demand
Annual throughput
Specific electricity consumption
Operating hours
Electric power consumption
Flexible operating load range [%]
Theoretical DSM potential
DOI: 10.1002/bbb.2452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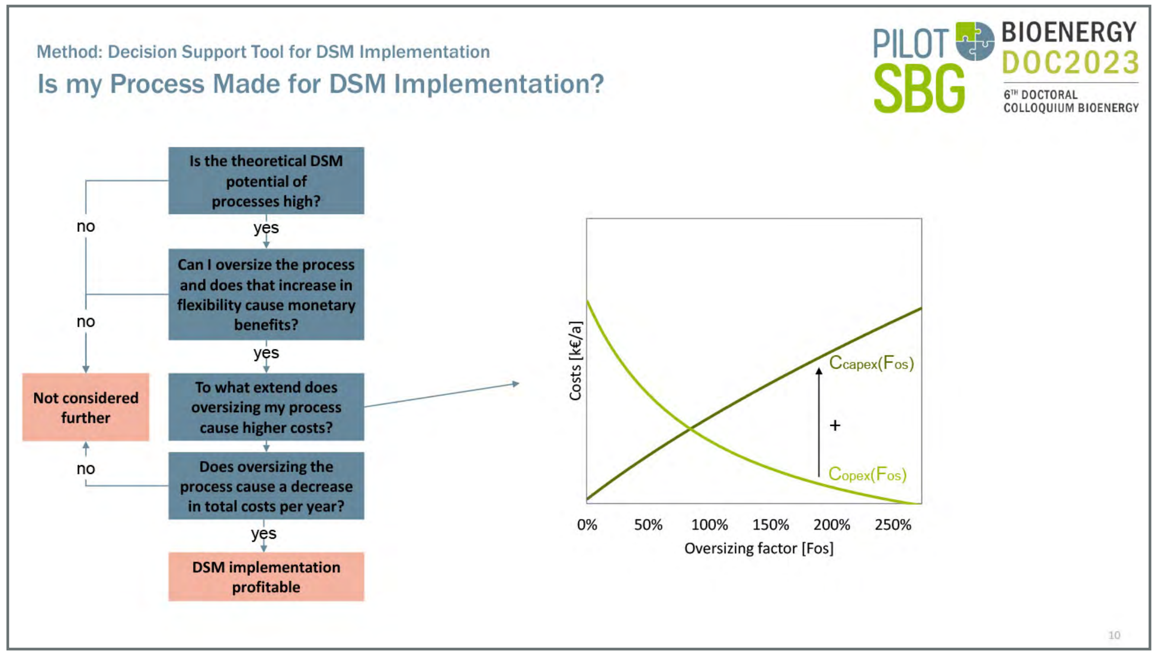
DSM implementation profitable
Costs [k€/a]
Copex(Fos)
0% 50% 100% 150% 200% 250%
Oversizing factor [Fos]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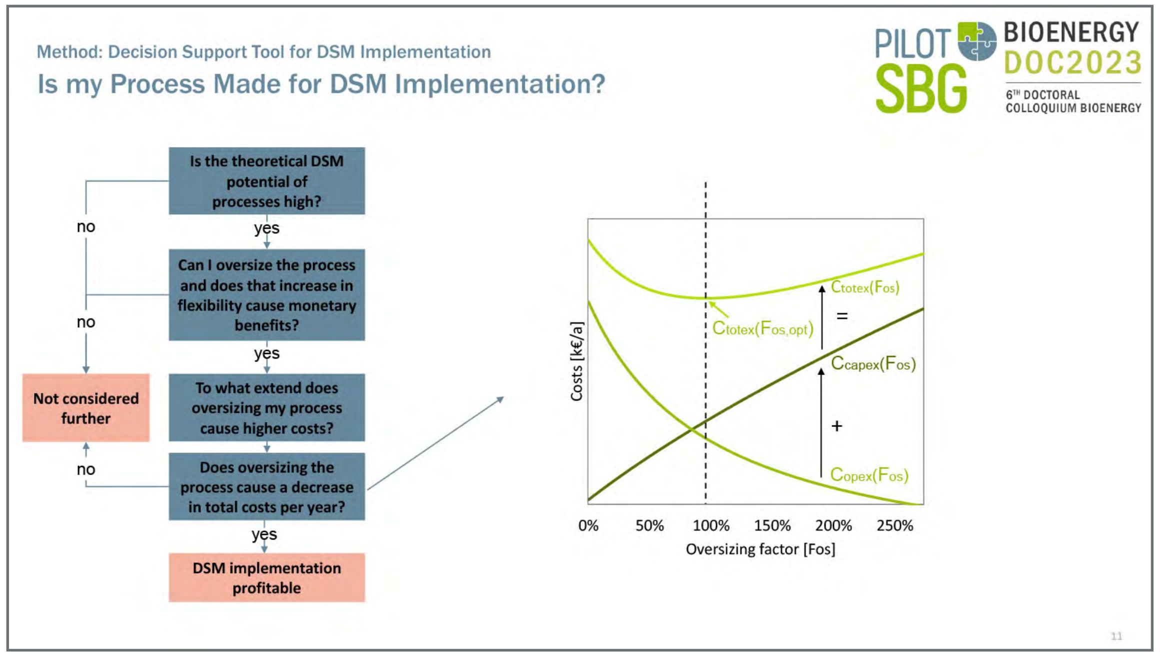
Ccapex(Fos)
+
Copex(Fos)
0% 50% 100% 150% 200% 250%
Oversizing factor [Fos]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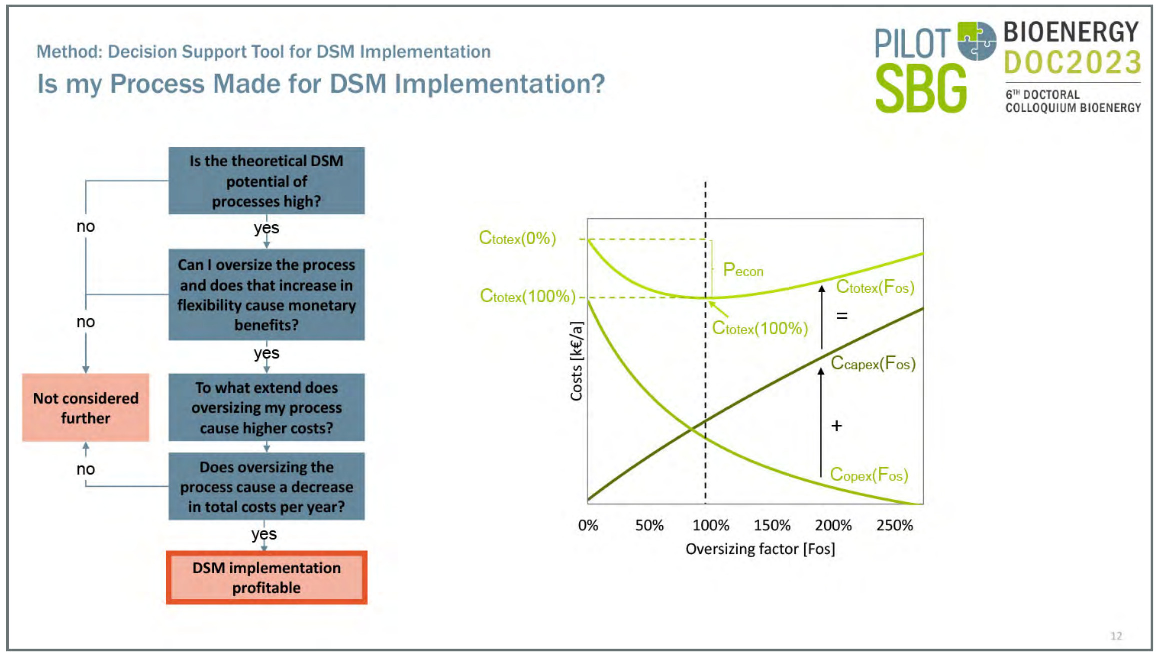
DSM implementation profitable
Ctotex(Fos)
Ctotex(Fos,opt)
=
Ccapex(Fos)
+
Copex(Fos)
Costs [k€/a]
0% 50% 100% 150% 200% 250%
Oversizing factor [Fos]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Does oversizing the process cause a decrease in total costs per year?
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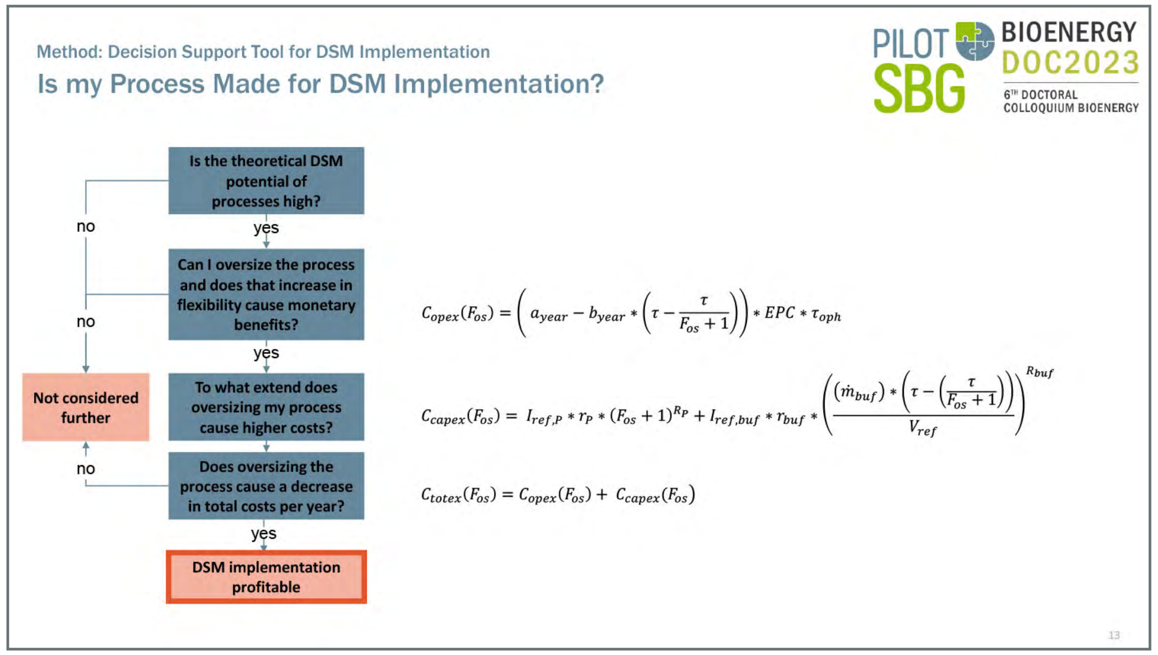
DSM implementation profitable
Ctotex(0%)
Ctotex(100%)
Pecon
Ctotex(Fos)
Ctotex(100%)
=
Ccapex(Fos)
+
Copex(Fos)
Costs [k€/a]
0% 50% 100% 150% 200% 250%
Oversizing factor [Fos]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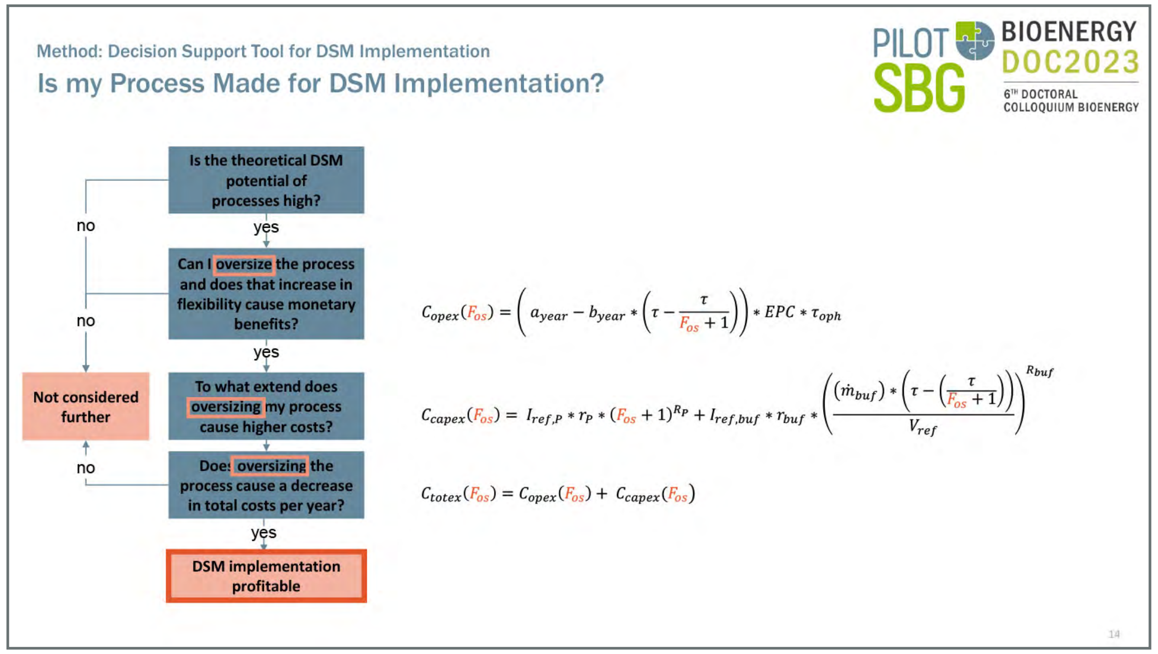
$C_{opex}(F_{os}) = \left(a_{year} - b_{year} * \left(\tau - \frac{\tau}{F_{os}+1}\right)\right) * EPC * \tau_{oph}$
$C_{capex}(F_{os}) = I_{ref,P} * r_P * (F_{os}+1)^{R_P} + I_{ref,buf} * r_{buf} * \left(\frac{(\dot{m}_{buf}) * \left(\tau - \left(\frac{\tau}{F_{os}+1}\right)\right)}{V_{ref}}\right)^{R_{buf}}$
$C_{totex}(F_{os}) = C_{opex}(F_{os}) + C_{capex}(F_{os})$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$C_{capex}(F_{os}) = I_{ref,P} * r_P * (F_{os}+1)^{R_P} + I_{ref,buf} * r_{buf} * \left(\frac{(\dot{m}_{buf}) * \left(\tau - \left(\frac{\tau}{F_{os}+1}\right)\right)}{V_{ref}}\right)^{R_{buf}}$
$C_{totex}(F_{os}) = C_{opex}(F_{os}) + C_{capex}(F_{os})$


Demand Side Management
Implementation
A Decision Support Tool Demonstration on Biorefineries
PILOT SBG
BIOENERGY DOC2023
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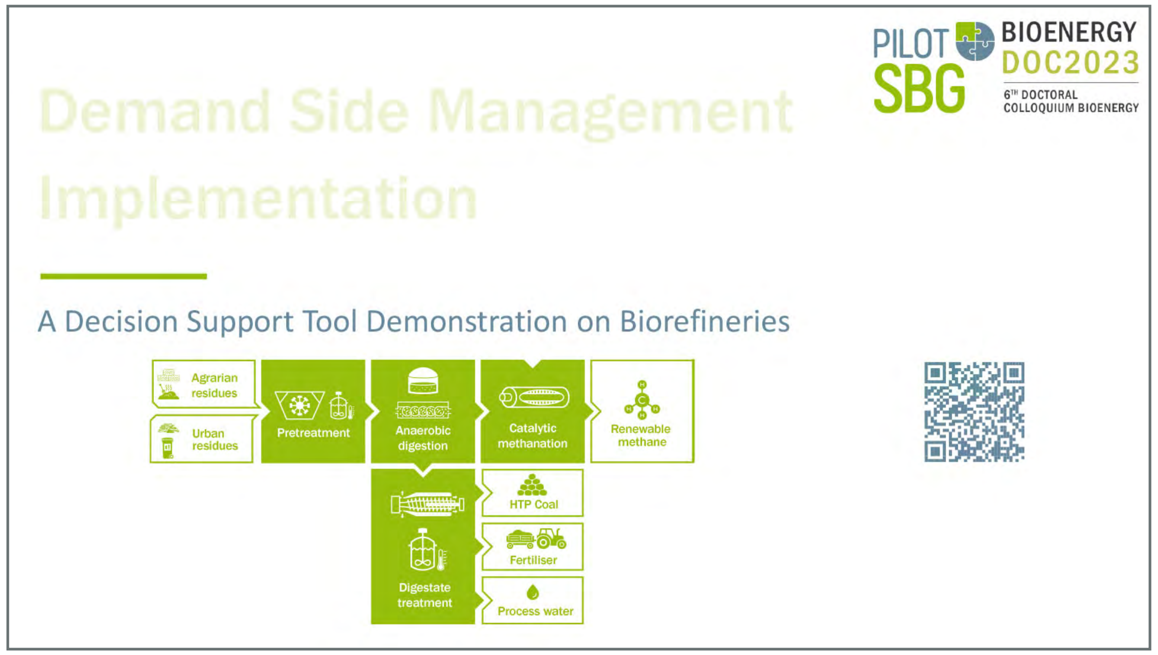
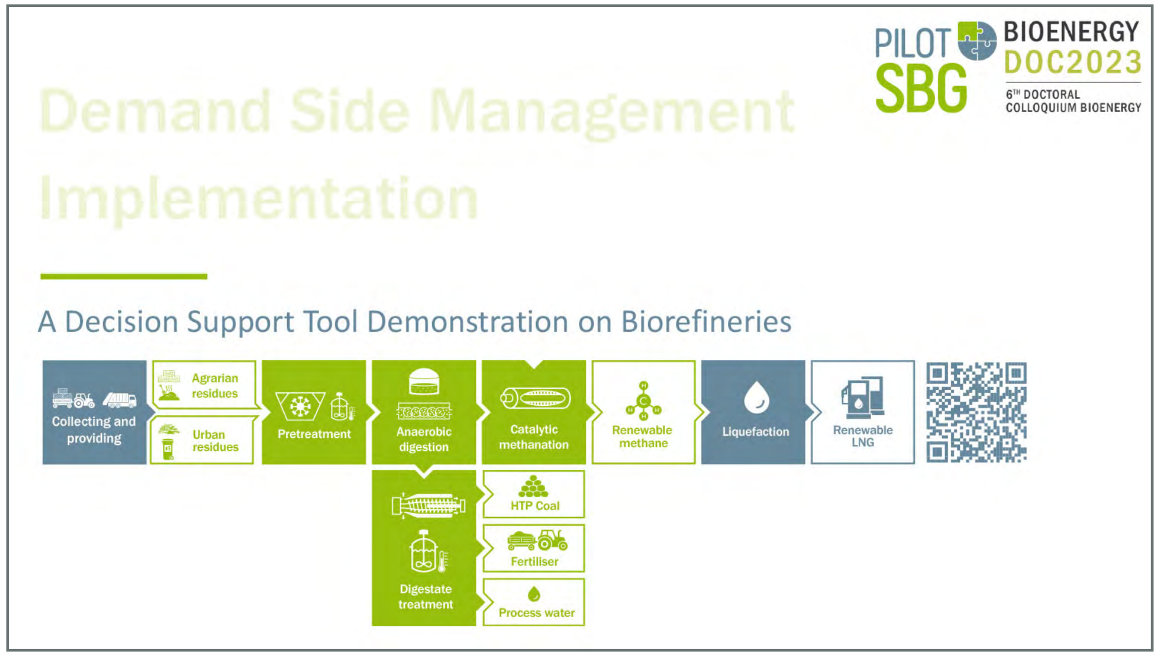

Demand Side Management
Implementation
A Decision Support Tool Demonstration on Biorefineries
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Agrarian residues
Urban residues
Pretreatment
Anaerobic digestion
Catalytic methanation
Renewable methane
HTP Coal
Fertiliser
Process water
Digestate treatment


Demand Side Management
Implementation
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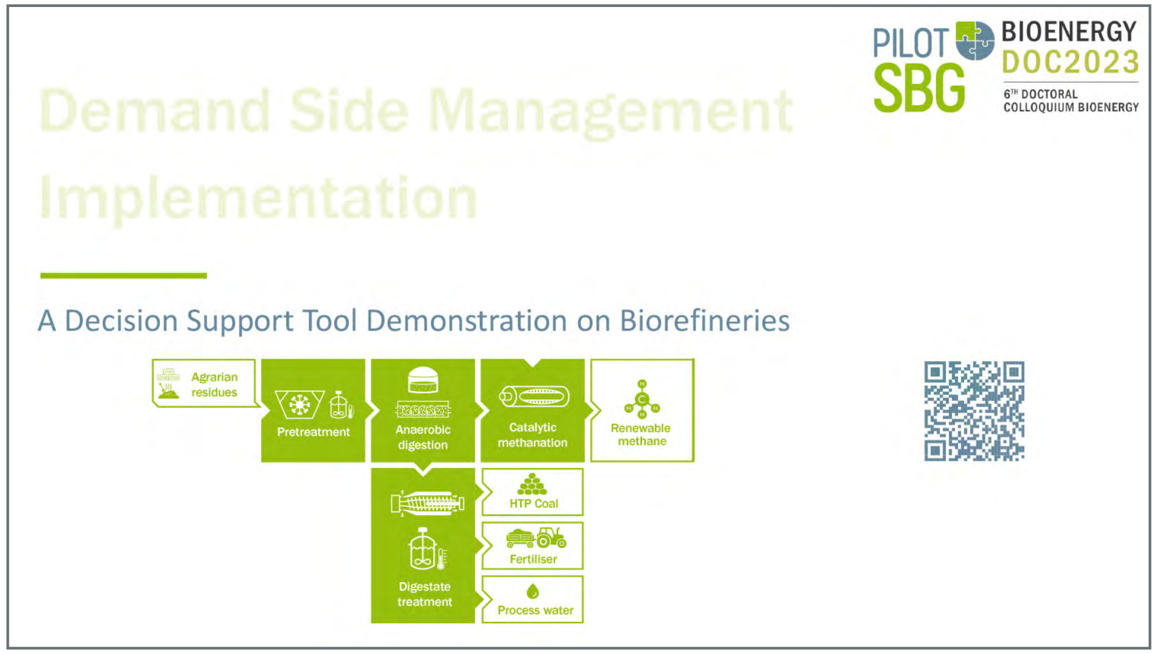
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Collecting and providing
Agrarian residues
Urban residues
Pretreatment
Anaerobic digestion
Catalytic methanation
Renewable methane
Liquefaction
Renewable LNG
HTP Coal
Fertiliser
Process water
Digestate treatment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Pretreatment
Anaerobic digestion
Catalytic methanation
Renewable methane
HTP Coal
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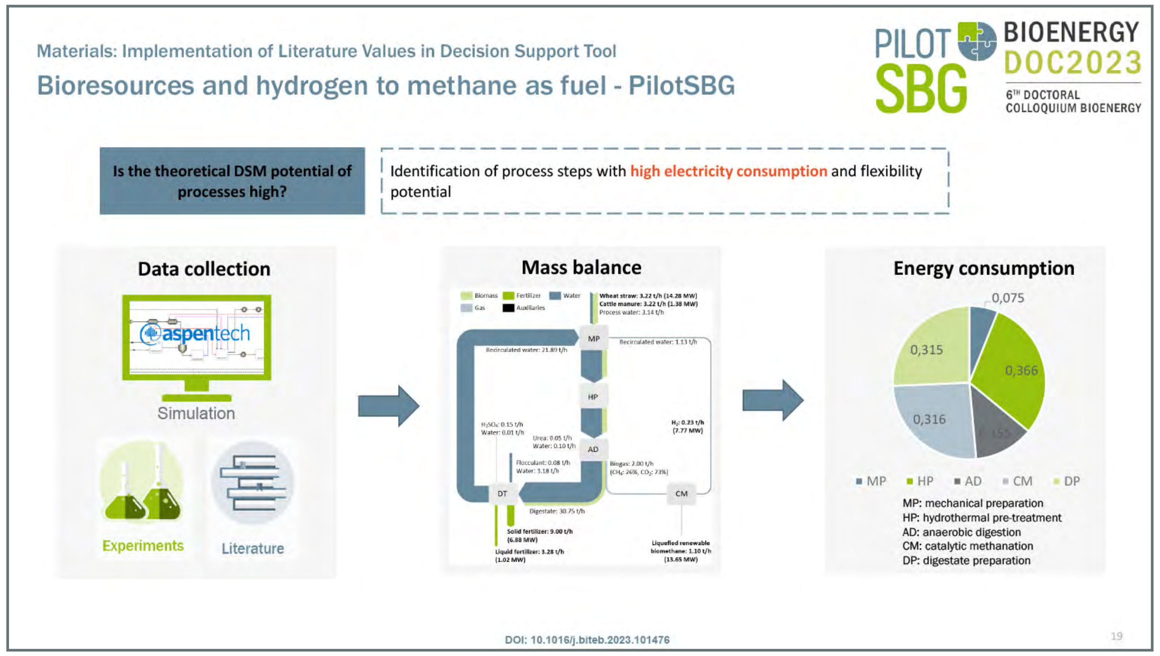
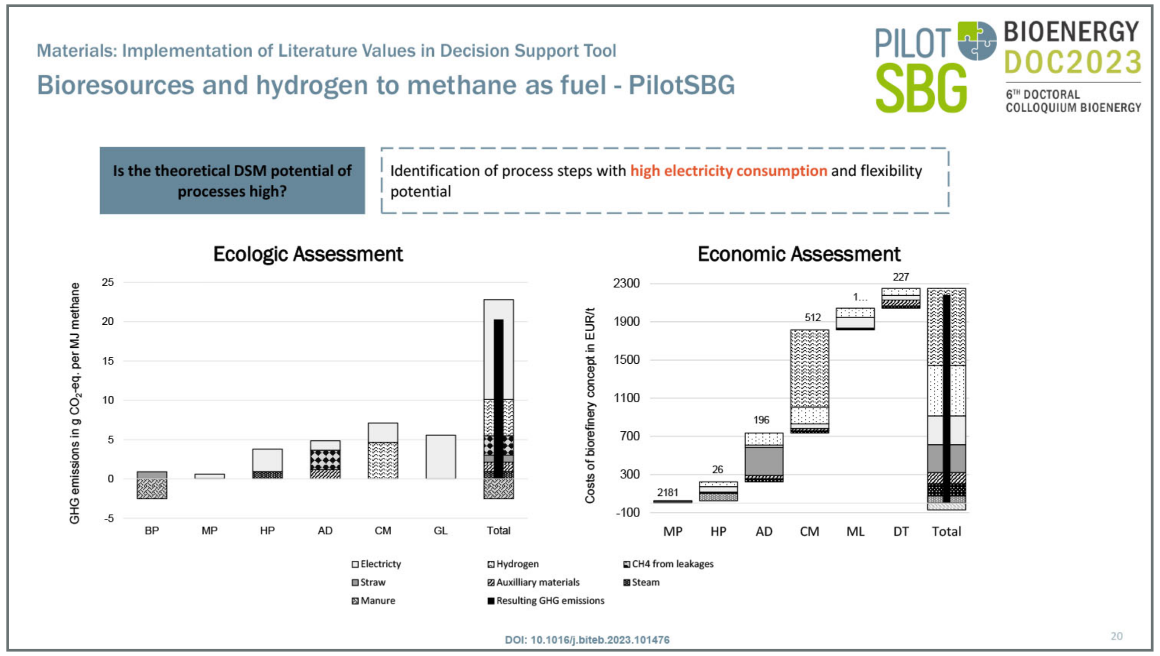

Materials: Implementation of Literature Values in Decision Support Tool
Bioresources and hydrogen to methane as fuel - PilotSBG
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Is the theoretical DSM potential of processes high?
Identification of process steps with high electricity consumption and flexibility potential
Data collection
aspentech
Simulation
Experiments
Literature
Mass balance
Energy consumption
0,075
0,315
0,366
0,316
MP
HP
AD
CM
DP
MP: mechanical preparation
HP: hydrothermal pre-treatment
AD: anaerobic digestion
CM: catalytic methanation
DP: digestate preparation
DOI: 10.1016/j.biteb.2023.101476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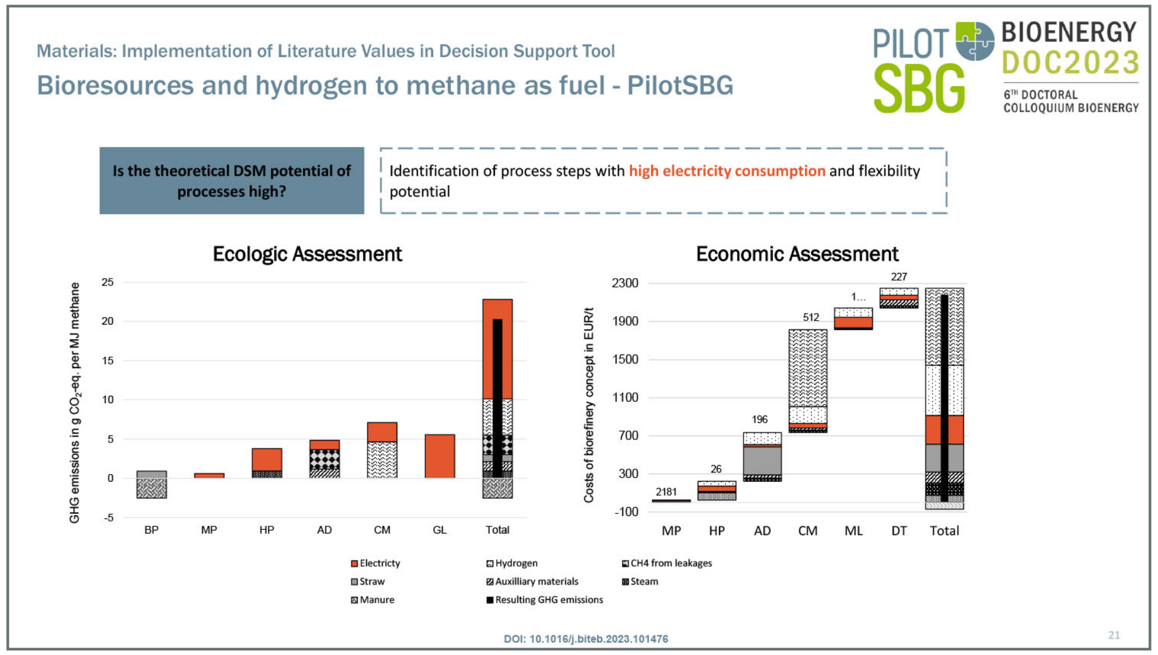
GHG emissions in g CO2-eq. per MJ methane
BP
MP
HP
AD
CM
GL
Total
Electricty
Straw
Manure
Hydrogen
Auxilliary materials
Resulting GHG emissions
CH4 from leakages
Steam
Economic Assessment
Costs of biorefinery concept in EUR/t
2300
1900
1500
1100
700
300
-100
2181
26
196
512
227
MP
HP
AD
CM
ML
DT
Total
DOI: 10.1016/j.biteb.2023.101476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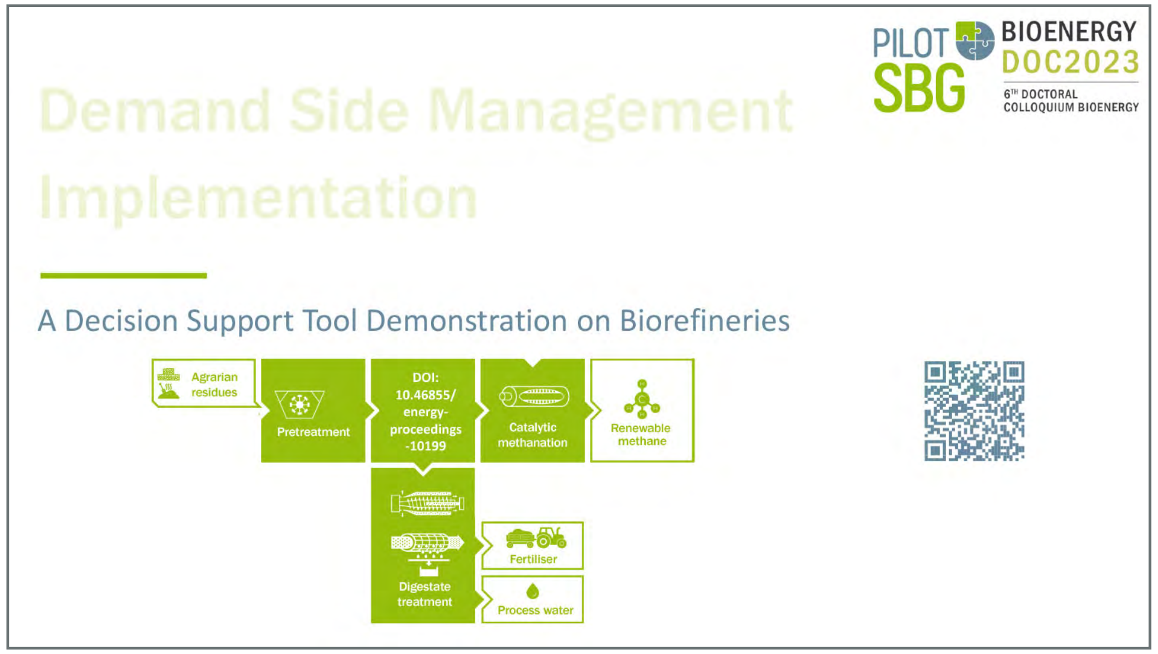
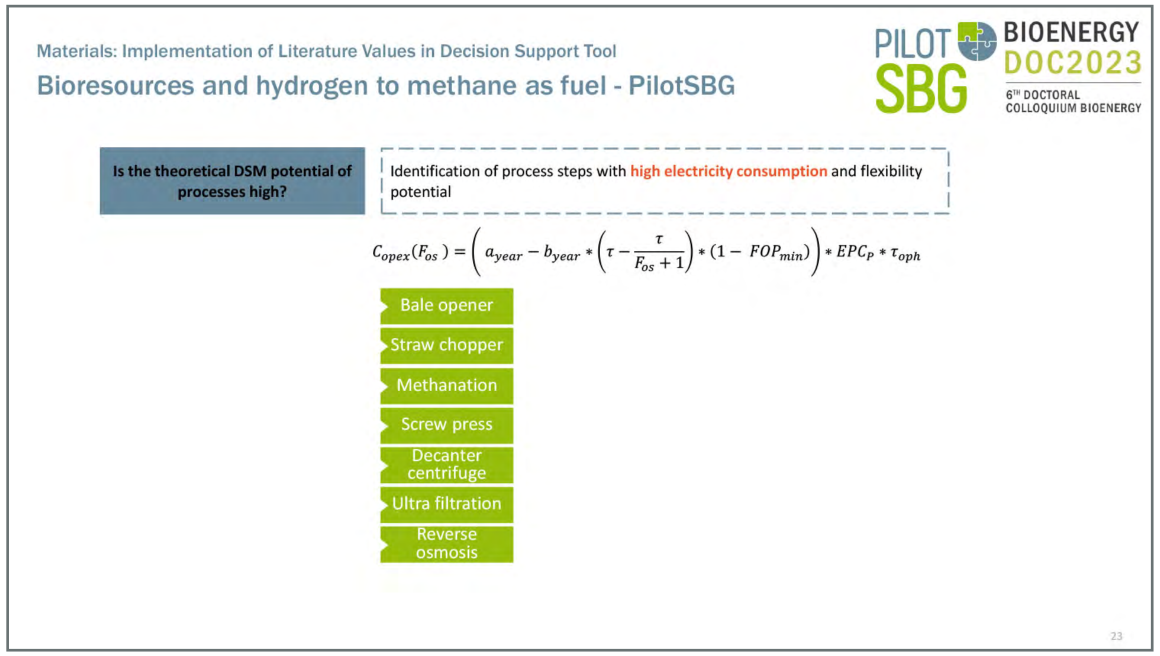
GHG emissions in g CO2-eq. per MJ methane
BP
MP
HP
AD
CM
GL
Total
Electricty
Straw
Manure
Hydrogen
Auxilliary materials
Resulting GHG emissions
CH4 from leakages
Steam
Economic Assessment
Costs of biorefinery concept in EUR/t
2300
1900
1500
1100
700
300
-100
2181
26
196
512
227
MP
HP
AD
CM
ML
DT
Total
DOI: 10.1016/j.biteb.2023.101476


PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Demand Side Management Implementation
A Decision Support Tool Demonstration on Biorefineries
Agrarian residues
Pretreatment
DOI: 10.46855/ energy-proceedings -10199
Catalytic methanation
Renewable methane
Fertiliser
Digestate treatment
Process water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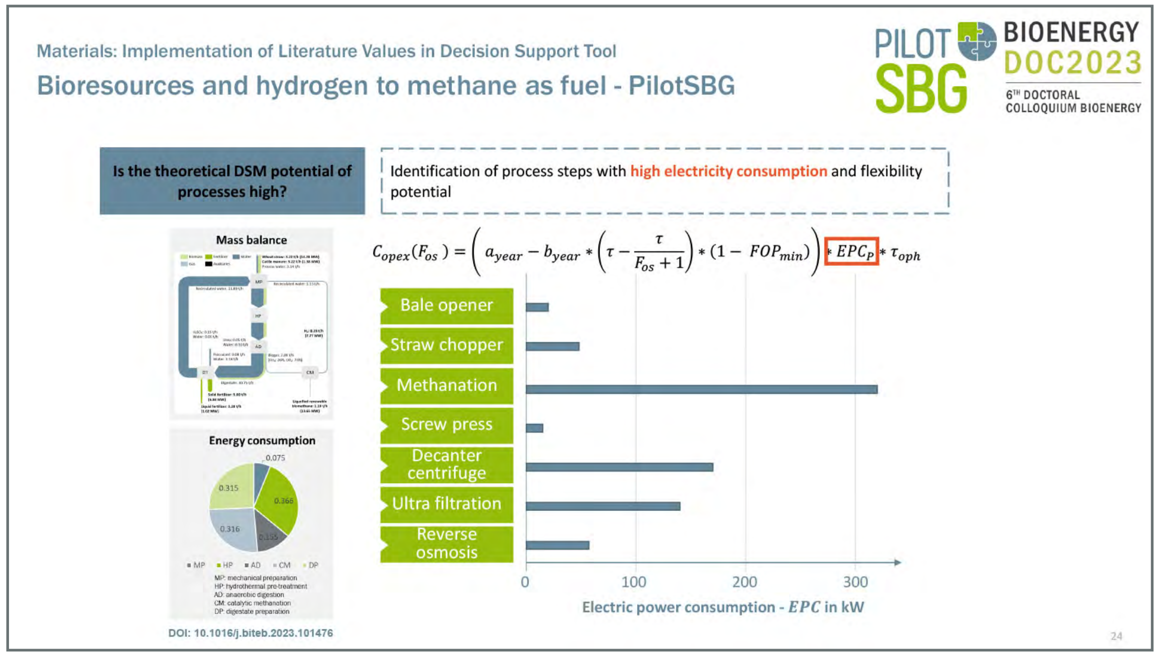
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Is the theoretical DSM potential of processes high?
Identification of process steps with high electricity consumption and flexibility potential
$C_{opex}(F_{os}) = \left(a_{year} - b_{year} * \left(\tau - \frac{\tau}{F_{os}+1}\right) * (1 - FOP_{min})\right) * EPC_P * \tau_{oph}$
Bale opener
Straw chopper
Methanation
Screw press
Decanter centrifuge
Ultra filtration
Reverse osmosis
23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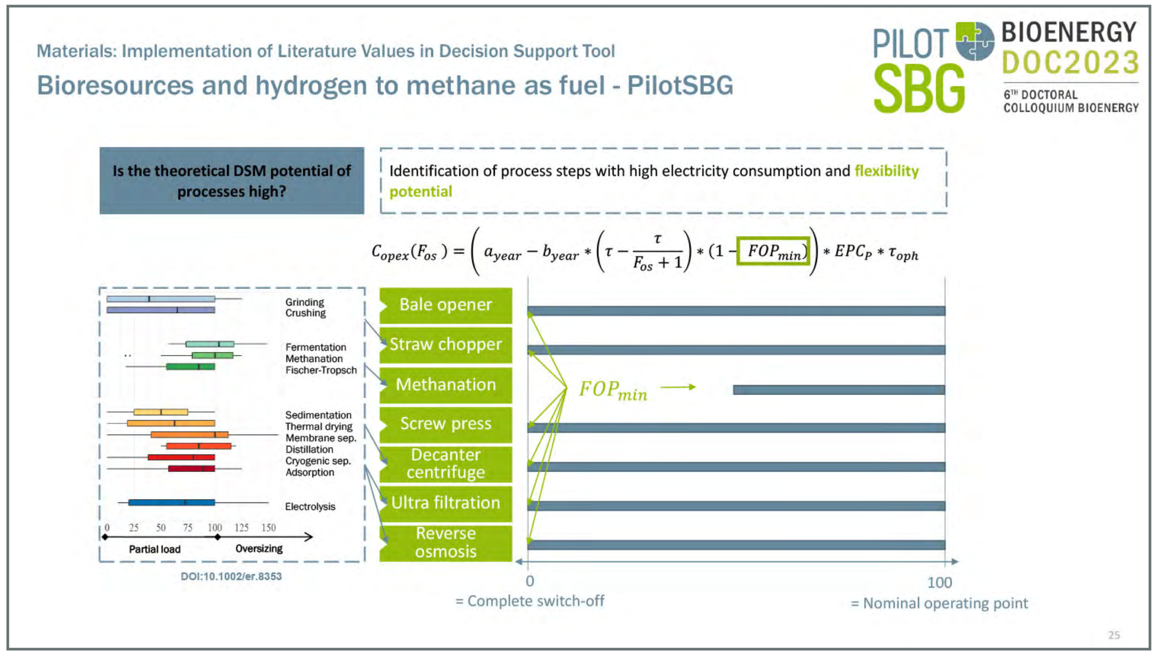
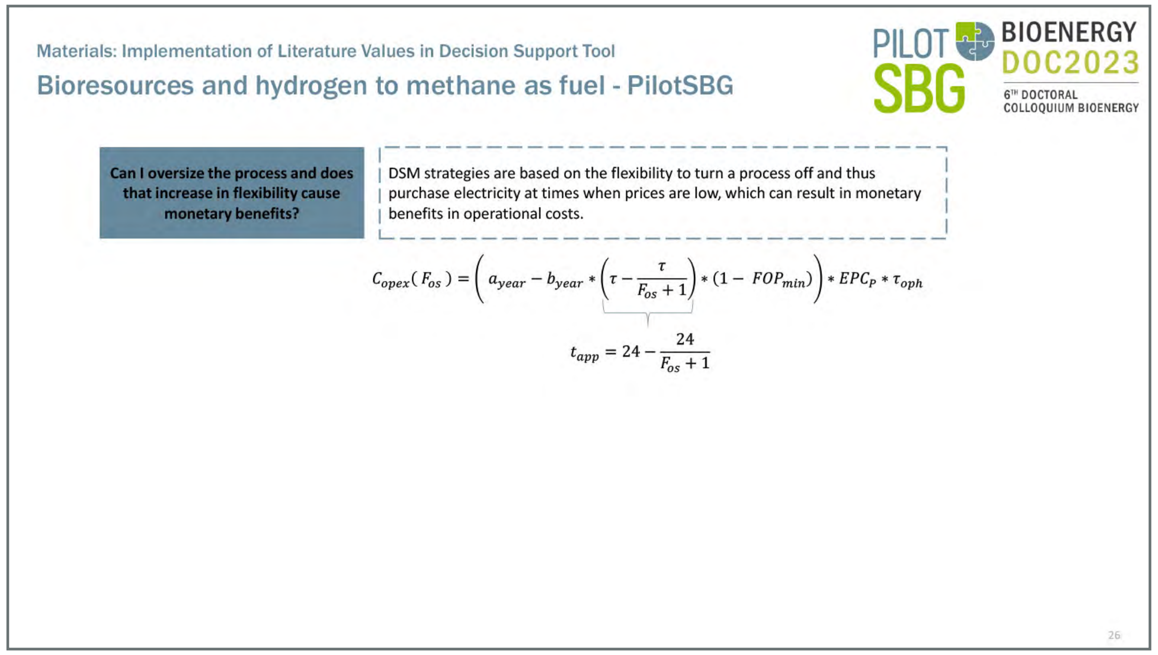
Mass balance
Energy consumption
Bale opener
Straw chopper
Methanation
Screw press
Decanter centrifuge
Ultra filtration
Reverse osmosis
0
100
200
300
Electric power consumption - EPC in kW
DOI: 10.1016/j.biteb.2023.101476
24


Materials: Implementation of Literature Values in Decision Support Tool
Bioresources and hydrogen to methane as fuel - PilotSBG
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Is the theoretical DSM potential of processes high?
Identification of process steps with high electricity consumption and flexibility potential
$C_{opex}(F_{os}) = \left(a_{year} - b_{year} * \left(\tau - \frac{\tau}{F_{os}+1}\right) * (1 - FOP_{min})\right) * EPC_P * \tau_{oph}$
Grinding Crushing
Fermentation Methanation Fischer-Tropsch
Sedimentation Thermal drying Membrane sep. Distillation Cryogenic sep. Adsorption
Electrolysis
Partial load
Oversizing
DOI:10.1002/er.8353
Bale opener
Straw chopper
Methanation
Screw press
Decanter centrifuge
Ultra filtration
Reverse osmosis
FOP_{min}
0
100
= Complete switch-off
= Nominal operating point
25


Materials: Implementation of Literature Values in Decision Support Tool
Bioresources and hydrogen to methane as fuel - PilotSBG
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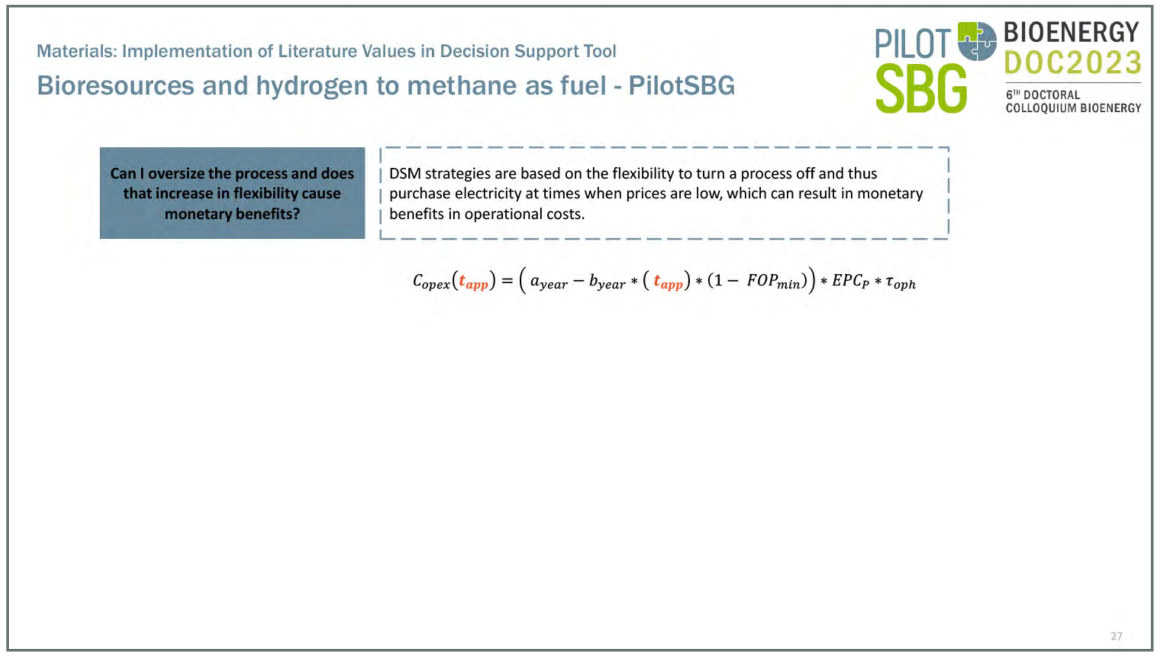
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Can I oversize the process and does that increase in flexibility cause monetary benefits?
DSM strategies are based on the flexibility to turn a process off and thus purchase electricity at times when prices are low, which can result in monetary benefits in operational costs.
$C_{opex}(F_{os}) = \left(a_{year} - b_{year} * \left(\tau - \frac{\tau}{F_{os}+1}\right) * (1 - FOP_{min})\right) * EPC_P * \tau_{oph}$
$t_{app} = 24 - \frac{24}{F_{os}+1}$
26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6TH DOCTORAL COLLOQUIUM BIOENERGY
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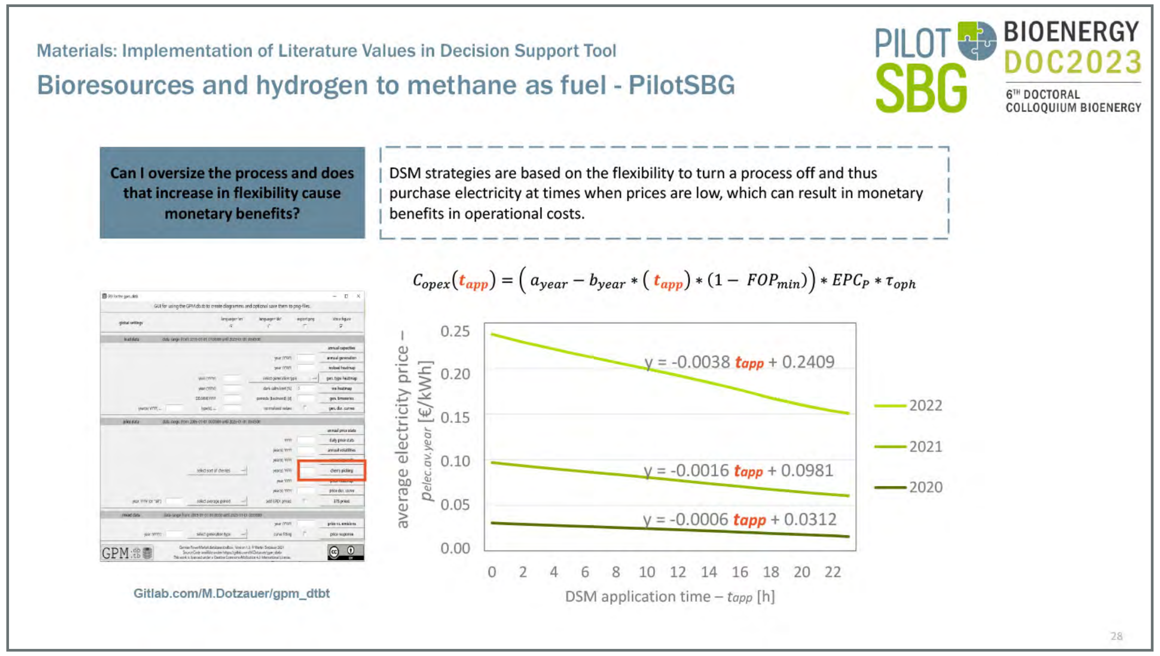
27


Materials: Implementation of Literature Values in Decision Support Tool
Bioresources and hydrogen to methane as fuel - PilotSBG
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BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
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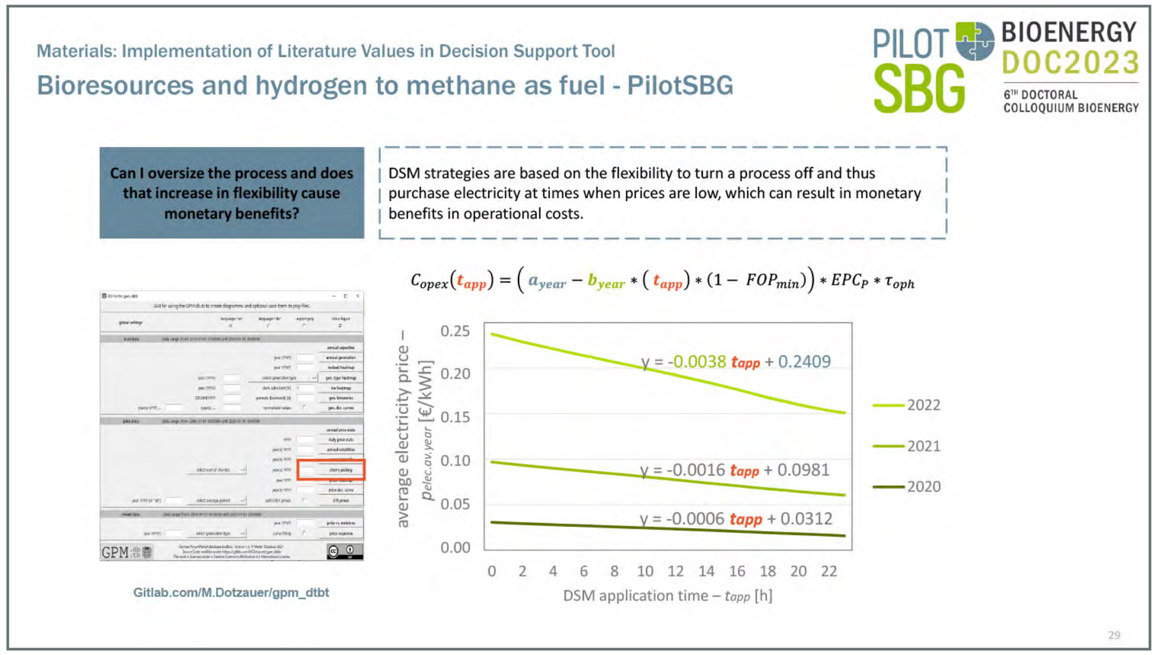
Gitlab.com/M.Dotzauer/gpm_dtbt
average electricity price – $p_{elec.av.year}$ [€/kWh]
y = -0.0038 tapp + 0.2409
y = -0.0016 tapp + 0.0981
y = -0.0006 tapp + 0.0312
0.25
0.20
0.15
0.10
0.05
0.00
0 2 4 6 8 10 12 14 16 18 20 22
DSM application time – tapp [h]
2022
2021
2020
28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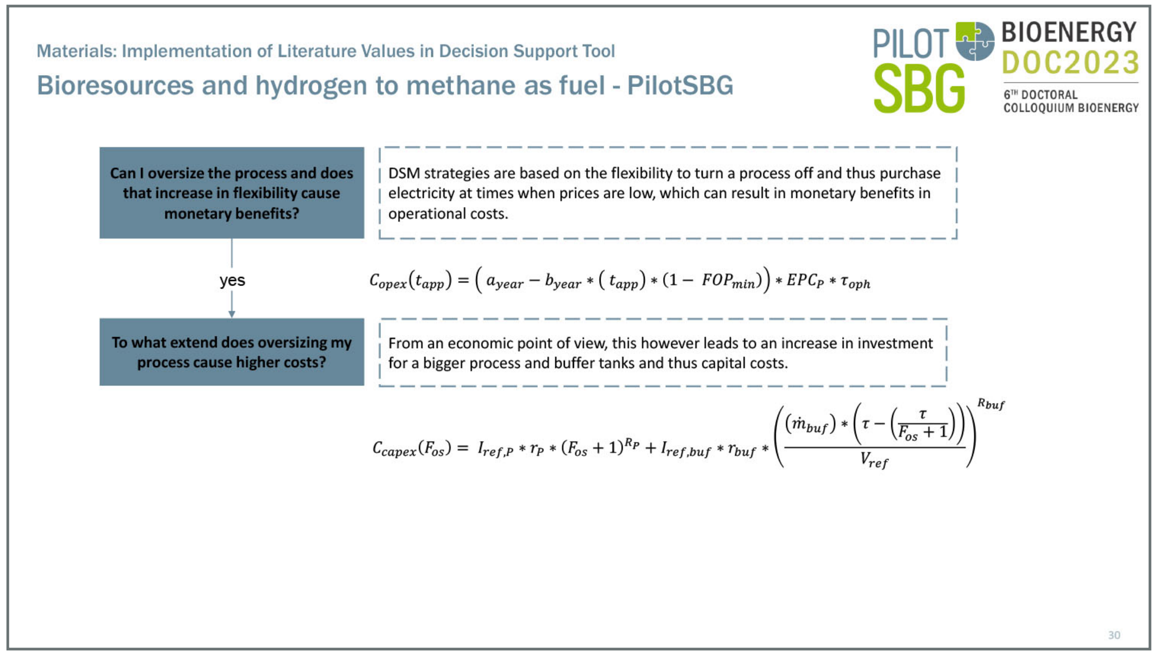
0.20
0.15
0.10
0.05
0.00
0 2 4 6 8 10 12 14 16 18 20 22
DSM application time – tapp [h]
2022
2021
2020
29


Materials: Implementation of Literature Values in Decision Support Tool
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PILOT SBG
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6TH DOCTORAL COLLOQUIUM BIOENERGY
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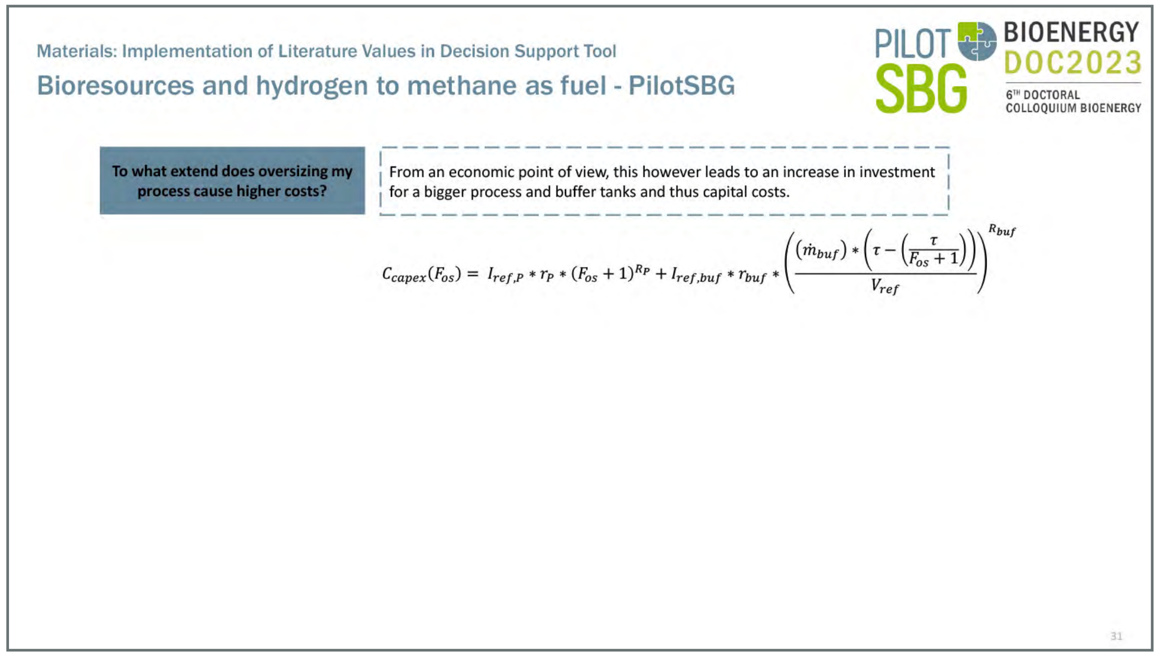
yes
$C_{opex}(t_{app}) = (a_{year} - b_{year} * (t_{app}) * (1 - FOP_{min})) * EPC_P * \tau_{oph}$
To what extend does oversizing my process cause higher costs?
From an economic point of view, this however leads to an increase in investment for a bigger process and buffer tanks and thus capital costs.
$C_{capex}(F_{os}) = I_{ref,P} * r_P * (F_{os}+1)^{R_P} + I_{ref,buf} * r_{buf} * \left(\frac{(\dot{m}_{buf}) * \left(\tau - \left(\frac{\tau}{F_{os}+1}\right)\right)}{V_{ref}}\right)^{R_{buf}}$
30


Materials: Implementation of Literature Values in Decision Support Tool
Bioresources and hydrogen to methane as fuel - PilotSBG
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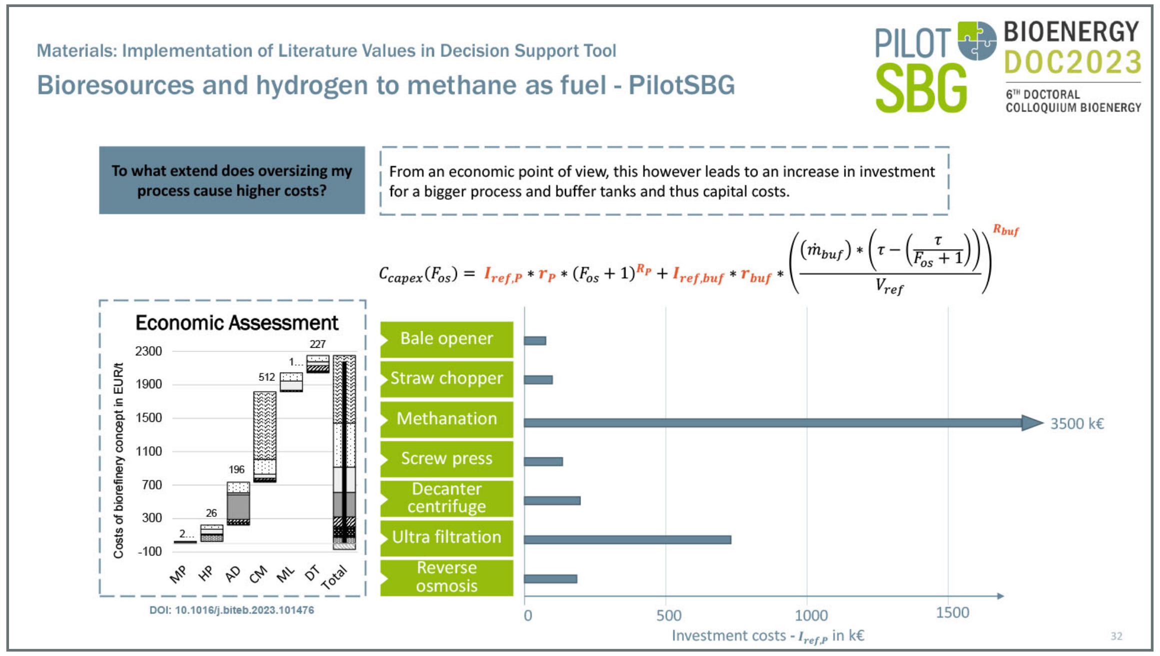
31


Materials: Implementation of Literature Values in Decision Support Tool
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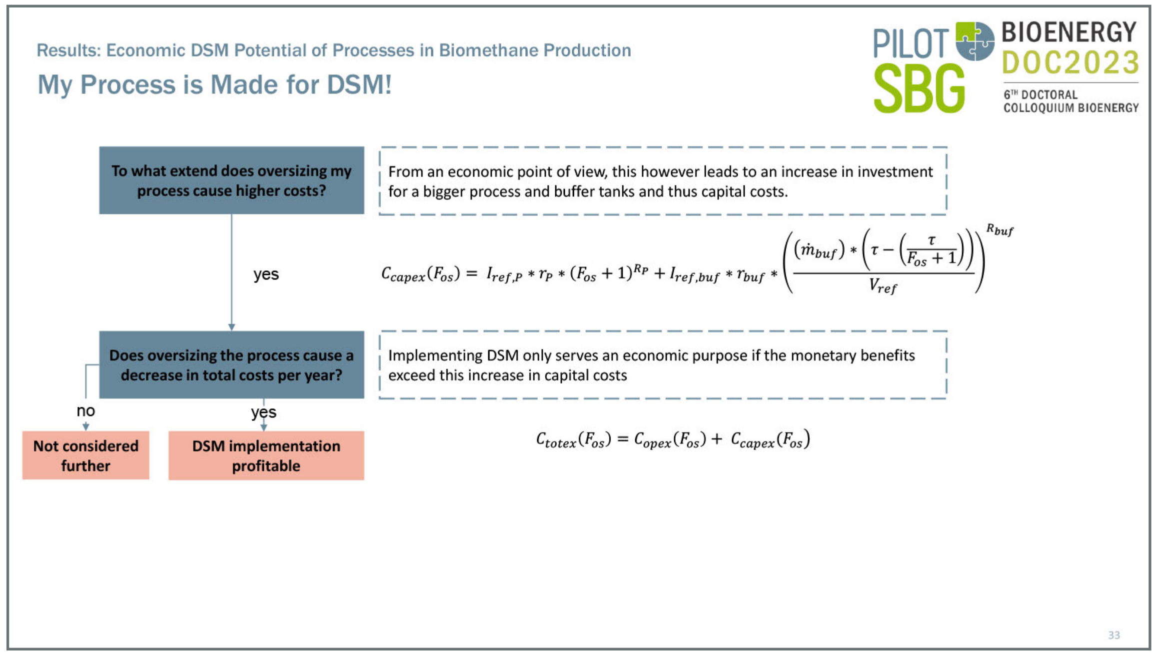
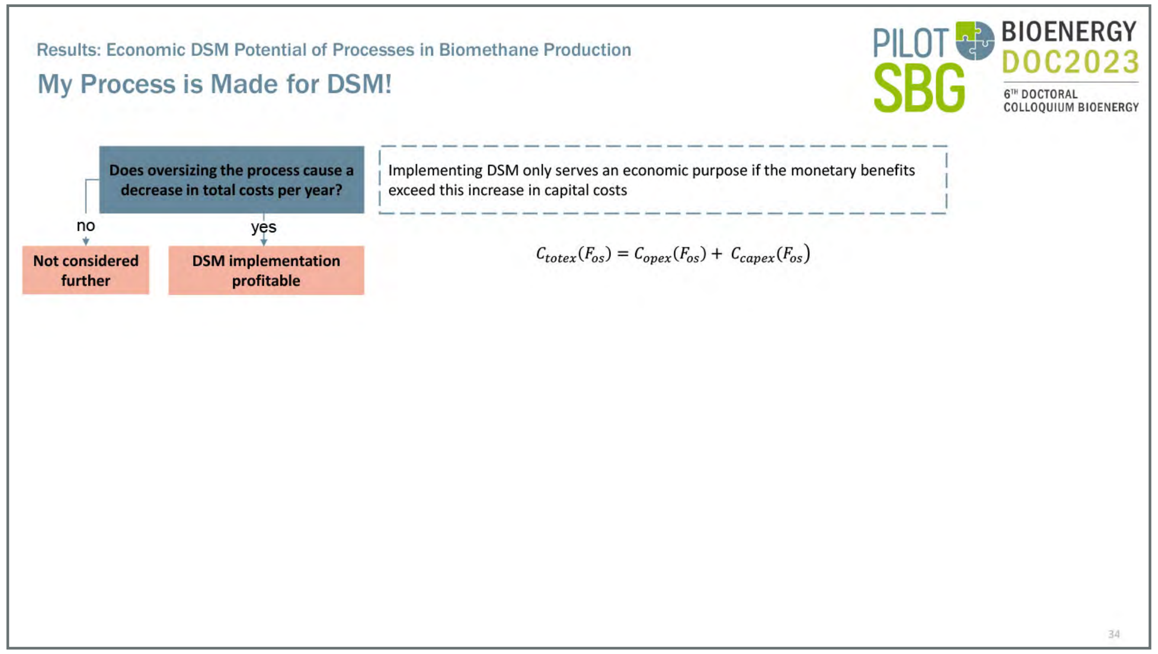
Economic Assessment
Costs of biorefinery concept in EUR/t
MP HP AD CM ML DT Total
DOI: 10.1016/j.biteb.2023.101476
Bale opener
Straw chopper
Methanation
Screw press
Decanter centrifuge
Ultra filtration
Reverse osmosis
3500 k€
0 500 1000 1500
Investment costs - $I_{ref,P}$ in k€
32


Results: Economic DSM Potential of Processes in Biomethane Production
My Process is Made for DSM!
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
To what extend does oversizing my process cause higher costs?
yes
From an economic point of view, this however leads to an increase in investment for a bigger process and buffer tanks and thus capital costs.
$C_{capex}(F_{os}) = I_{ref,P} * r_P * (F_{os}+1)^{R_P} + I_{ref,buf} * r_{buf} * \left(\frac{(\dot{m}_{buf}) * \left(\tau - \left(\frac{\tau}{F_{os}+1}\right)\right)}{V_{ref}}\right)^{R_{buf}}$
Does oversizing the process cause a decrease in total costs per year?
Implementing DSM only serves an economic purpose if the monetary benefits exceed this increase in capital costs
no
yes
Not considered further
DSM implementation profitable
$C_{totex}(F_{os}) = C_{opex}(F_{os}) + C_{capex}(F_{os})$
33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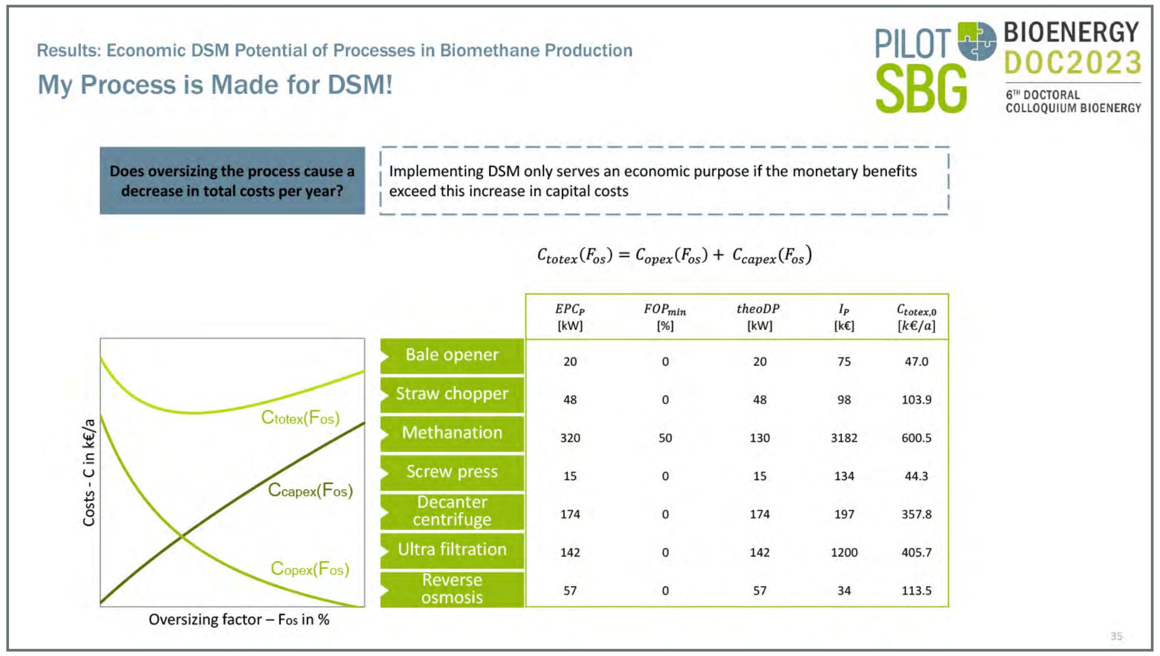
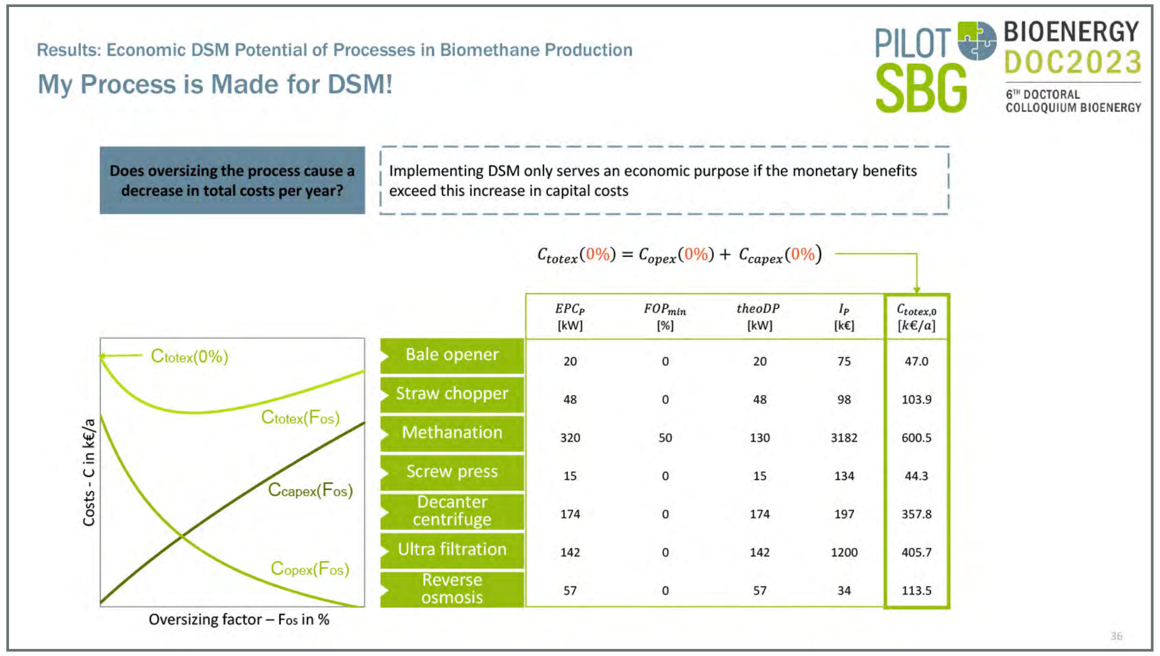
$C_{totex}(F_{os}) = C_{opex}(F_{os}) + C_{capex}(F_{os})$
34



$$C_{totex}(F_{os}) = C_{opex}(F_{os}) + C_{capex}(F_{os})$$

	EPC_P [kW]	FOP_{min} [%]	$theoDP$ [kW]	I_P [k€]	$C_{totex,0}$ [k€/a]
Bale opener	20	0	20	75	47.0
Straw chopper	48	0	48	98	103.9
Methanation	320	50	130	3182	600.5
Screw press	15	0	15	134	44.3
Decanter centrifuge	174	0	174	197	357.8
Ultra filtration	142	0	142	1200	405.7
Reverse osmosis	57	0	57	34	113.5



$$C_{totex}(0\%) = C_{opex}(0\%) + C_{capex}(0\%)$$

	EPC_P [kW]	FOP_{min} [%]	$theoDP$ [kW]	I_P [k€]	$C_{totex,0}$ [k€/a]
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Straw chopper	48	0	48	98	103.9
Methanation	320	50	130	3182	600.5
Screw press	15	0	15	134	44.3
Decanter centrifuge	174	0	174	197	357.8
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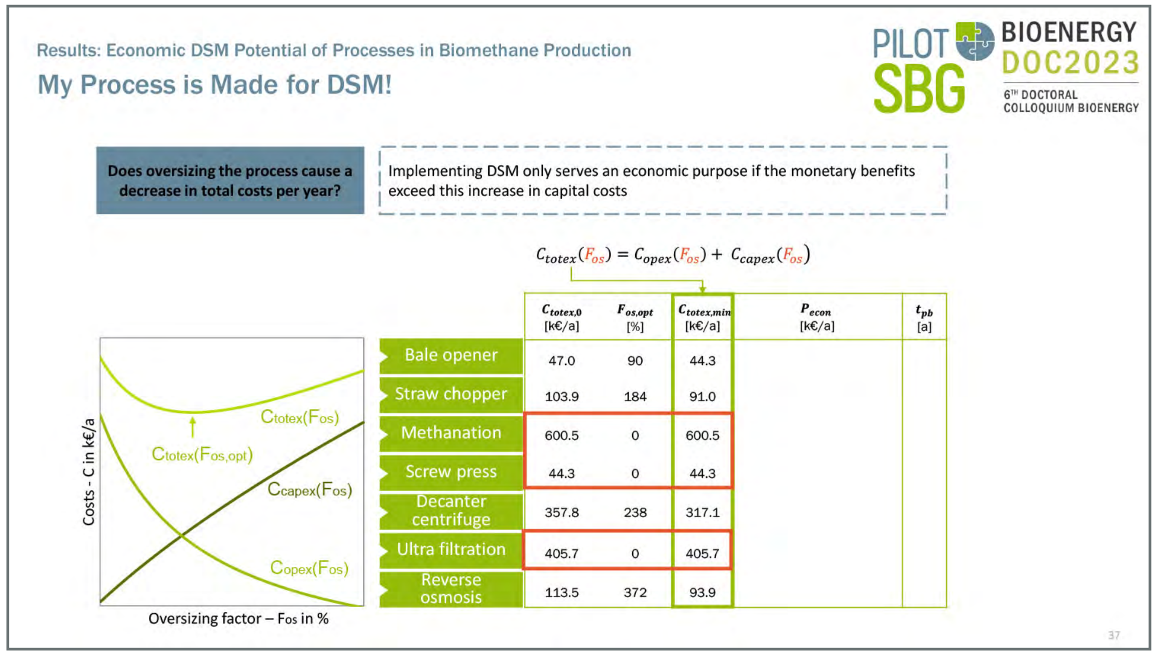
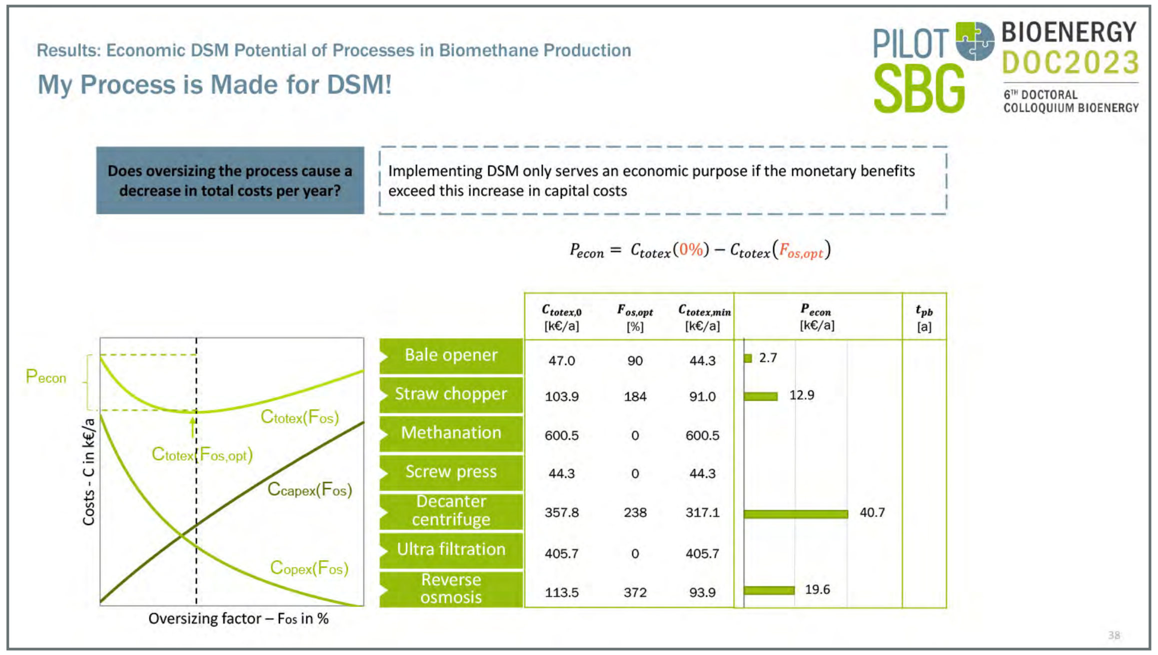


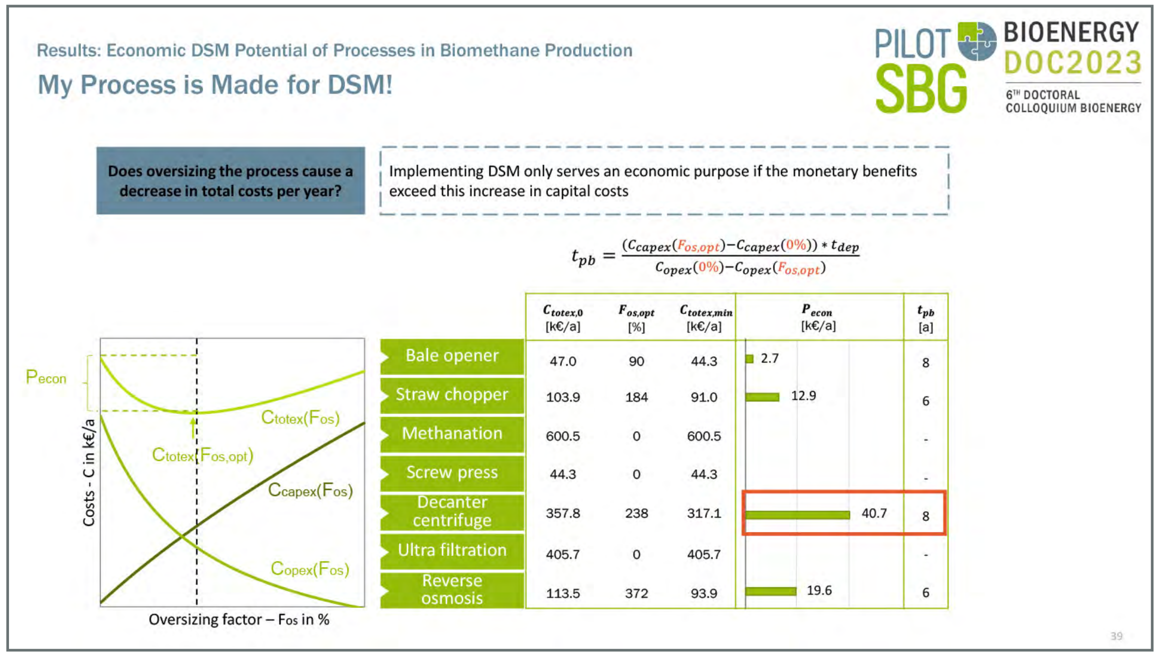
$$C_{totex}(F_{os}) = C_{opex}(F_{os}) + C_{capex}(F_{os})$$

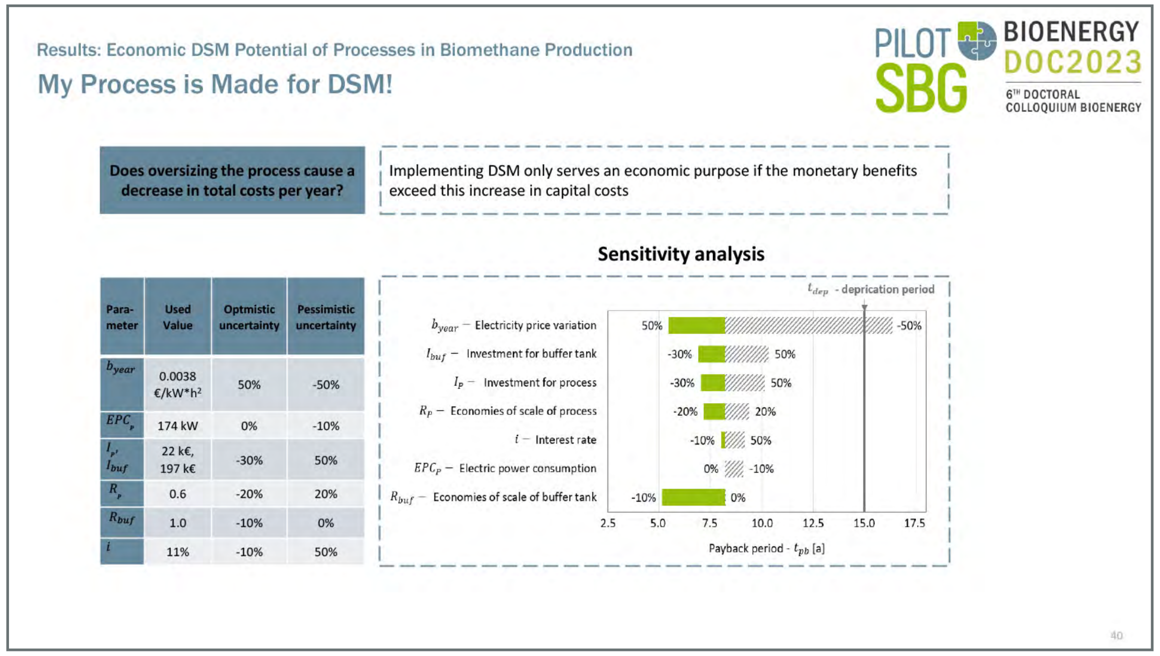
	$C_{totex,0}$ [k€/a]	$F_{os,opt}$ [%]	$C_{totex,min}$ [k€/a]	P_{econ} [k€/a]	t_{pb} [a]
Bale opener	47.0	90	44.3		
Straw chopper	103.9	184	91.0		
Methanation	600.5	0	600.5		
Screw press	44.3	0	44.3		
Decanter centrifuge	357.8	238	317.1		
Ultra filtration	405.7	0	405.7		
Reverse osmosis	113.5	372	93.9		



$$P_{econ} = C_{totex}(0\%) - C_{totex}(F_{os,opt})$$

	$C_{totex,0}$ [k€/a]	$F_{os,opt}$ [%]	$C_{totex,min}$ [k€/a]	P_{econ} [k€/a]	t_{pb} [a]
Bale opener	47.0	90	44.3	2.7	
Straw chopper	103.9	184	91.0	12.9	
Methanation	600.5	0	600.5		
Screw press	44.3	0	44.3		
Decanter centrifuge	357.8	238	317.1	40.7	
Ultra filtration	405.7	0	405.7		
Reverse osmosis	113.5	372	93.9	19.6	


Results: Economic DSM Potential of Processes in Biomethane Production
My Process is Made for DSM!
PILOT SBG BIOENERGY DOC2023 6TH DOCTORAL COLLOQUIUM BIOENERGY
Does oversizing the process cause a decrease in total costs per year?
Implementing DSM only serves an economic purpose if the monetary benefits exceed this increase in capital costs
$t_{pb} = \frac{(C_{capex}(F_{os,opt}) - C_{capex}(0\%)) * t_{dep}}{C_{opex}(0\%) - C_{opex}(F_{os,opt})}$
Pecon
Ctotex(Fos)
Ctotex(Fos,opt)
Ccapex(Fos)
Copex(Fos)
Costs - C in k€/a
Oversizing factor – Fos in %
Ctotex,0 [k€/a]
Fos,opt [%]
Ctotex,min [k€/a]
Pecon [k€/a]
tpb [a]
Bale opener 47.0 90 44.3 2.7 8
Straw chopper 103.9 184 91.0 12.9 6
Methanation 600.5 0 600.5 -
Screw press 44.3 0 44.3 -
Decanter centrifuge 357.8 238 317.1 40.7 8
Ultra filtration 405.7 0 405.7 -
Reverse osmosis 113.5 372 93.9 19.6 6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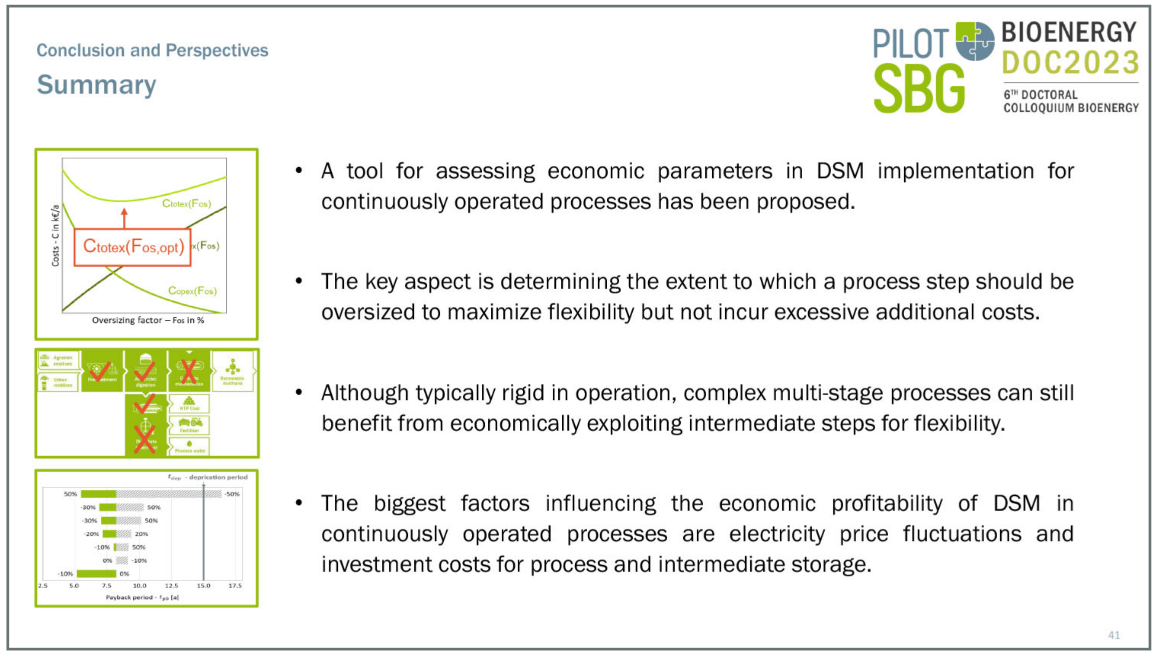
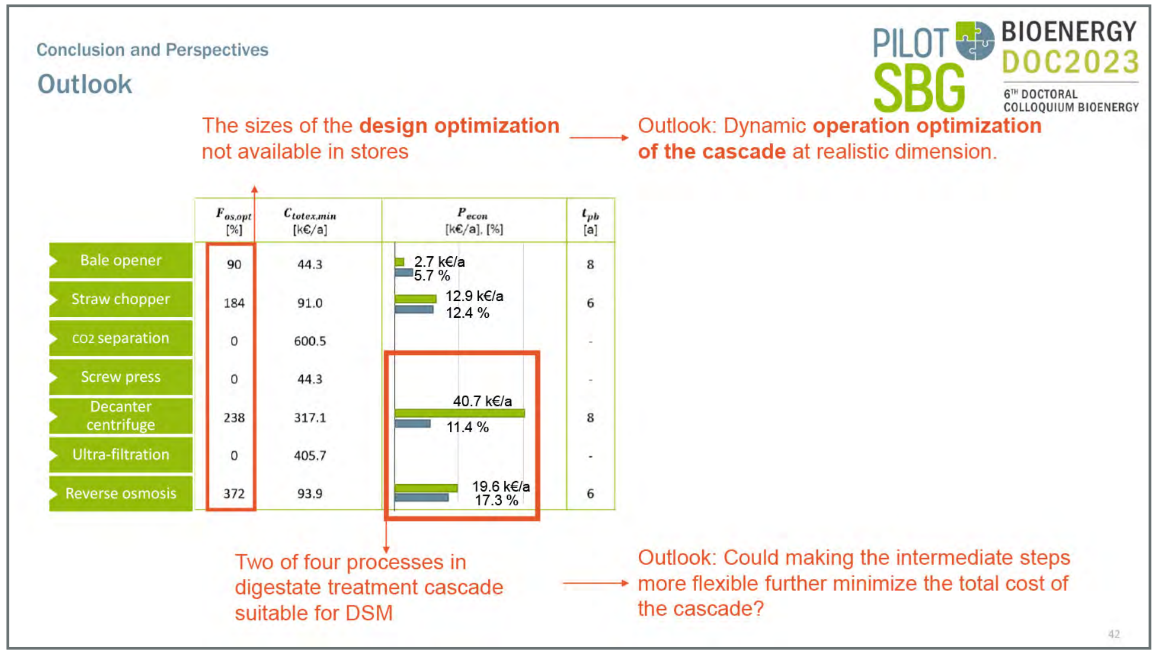
Does oversizing the process cause a decrease in total costs per year?
Implementing DSM only serves an economic purpose if the monetary benefits exceed this increase in capital costs
Sensitivity analysis
Parameter | Used Value | Optmistic uncertainty | Pessimistic uncertainty
byear | 0.0038 €/kW*h² | 50% | -50%
EPCp | 174 kW | 0% | -10%
Ip, Ibuf | 22 k€, 197 k€ | -30% | 50%
Rp | 0.6 | -20% | 20%
Rbuf | 1.0 | -10% | 0%
i | 11% | -10% | 50%
tdep - deprication period
byear – Electricity price variation 50% -50%
Ibuf – Investment for buffer tank -30% 50%
Ip – Investment for process -30% 50%
Rp – Economies of scale of process -20% 20%
i – Interest rate -10% 50%
EPCp – Electric power consumption 0% -10%
Rbuf – Economies of scale of buffer tank -10% 0%
2.5 5.0 7.5 10.0 12.5 15.0 17.5
Payback period - tpb [a]


Conclusion and Perspectives
Summary
PILOT SBG BIOENERGY DOC2023 6TH DOCTORAL COLLOQUIUM BIOENERGY
• A tool for assessing economic parameters in DSM implementation for continuously operated processes has been proposed.
• The key aspect is determining the extent to which a process step should be oversized to maximize flexibility but not incur excessive additional costs.
• Although typically rigid in operation, complex multi-stage processes can still benefit from economically exploiting intermediate steps for flexibility.
• The biggest factors influencing the economic profitability of DSM in continuously operated processes are electricity price fluctuations and investment costs for process and intermediate storage.


Conclusion and Perspectives
Outlook
PILOT SBG BIOENERGY DOC2023 6TH DOCTORAL COLLOQUIUM BIOENERGY
The sizes of the design optimization not available in stores
Outlook: Dynamic operation optimization of the cascade at realistic dimension.
Fos,opt [%] | Ctotex,min [k€/a] | Pecon [k€/a], [%] | tpb [a]
Bale opener 90 44.3 2.7 k€/a 5.7 % 8
Straw chopper 184 91.0 12.9 k€/a 12.4 % 6
CO2 separation 0 600.5 -
Screw press 0 44.3 -
Decanter centrifuge 238 317.1 40.7 k€/a 11.4 % 8
Ultra-filtration 0 405.7 -
Reverse osmosis 372 93.9 19.6 k€/a 17.3 % 6
Two of four processes in digestate treatment cascade suitable for DSM
Outlook: Could making the intermediate steps more flexible further minimize the total cost of the cascade?

6TH DOCTORAL COLLOQUIUM BIOENERGY

Selina Nieß, Deutsches Biomasseforschungszentrum / Technical University of Berlin

Investigation of materials for an integrated methanation process in a biorefinery

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Torgauer Str. 116
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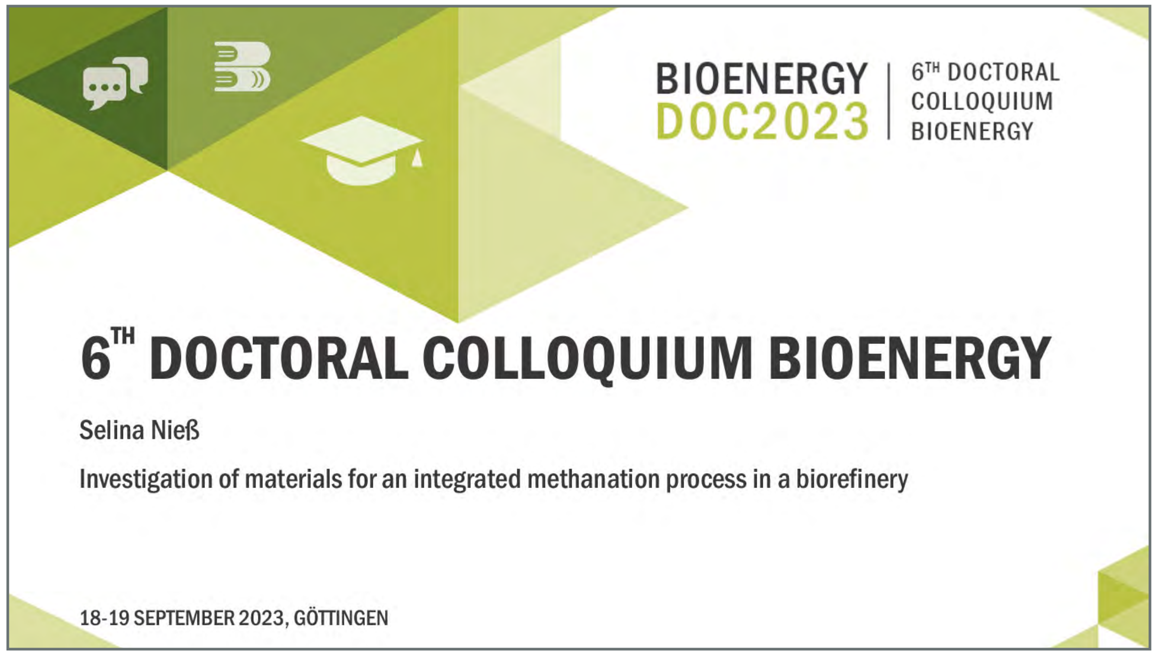
E-Mail: selina.niess@dbfz.de

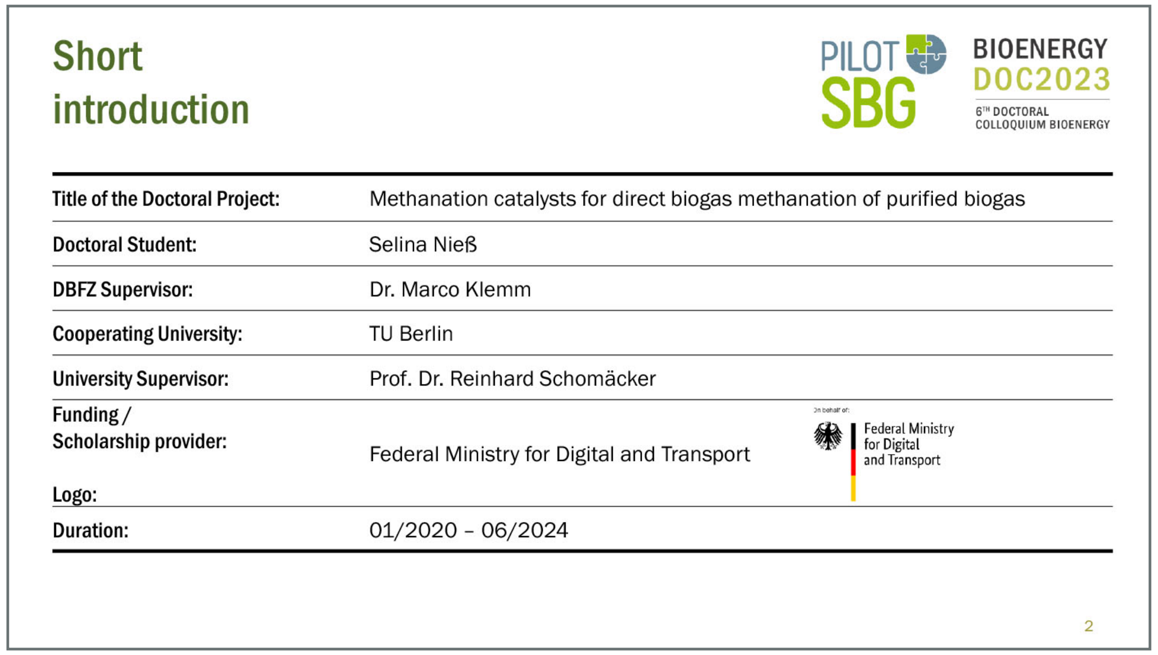
Introduction
The Pilot-SBG project is financed by the Federal Ministry for Digital and Transport and will establish a pilot-scale biorefinery in Leipzig, Germany, using agricultural and urban biogenic residues and wastes and green hydrogen (H_2) to produce methane (CH_4) as a transport fuel. Anaerobic digestion of biomass produces biogas, which consists mainly of CH_4 and carbon dioxide (CO_2). By adding H_2, the CO_2 in the biogas can react on a catalyst to form more CH_4. The methanation process takes place without separating CO_2 from the biogas-CH_4. Prior to methanation, the biogas must be cleaned of catalyst-damaging components like hydrogen sulfide (H_2S). Preliminary laboratory-scale tests will identify suitable adsorbents for biogas cleaning and catalysts for direct biogas methanation under pilot plant conditions. The product should be a gas with high CH_4 and low CO_2 content and a concentration of H_2 < 2 vol%, which meets the transport fuel requirements of DIN EN 16723 2.

Approach and Methods
Adsorbents: Six commercial activated carbons and a non-commercial metal oxide were investigated for biogas purification, as well as a commercial metal oxide as a reference. Each adsorbent was tested in a 22 cm³ fixed bed with a model biogas of CH_4, CO_2, H_2O, O_2 and H_2S until H_2S breakthrough, which was defined as 50 ppm in the product gas. Based on the breakthrough time, the adsorption capacity was calculated as the uptake of H_2S per mass of adsorbent to compare the different materials.
Catalysts: Six catalysts based on Ni or Ru on Al2O3 or CeO_2 and a commercial Ru-based catalyst as a reference are tested. In a preliminary test, the most suitable combination of three process parameters (temperature, gas hourly space velocity and H_2/CO_2 ratio), which can be easily adjusted in the pilot plant, were determined for each catalyst using a Design of Experiment approach. In a subsequent series of tests, the stability of each catalyst is tested over 70 h. A gas containing 500 ppm H_2S is then used to determine how long it takes for the catalysts to lose all activity due to H_2S poisoning.

Results
Adsorbents: Compared to the reference, five of the seven materials tested show a higher H_2S adsorption capacity. All activated carbons except the one impregnated with KI, which is not suitable for the pilot plant conditions, perform better than the two metal oxides.
Catalysts: The preliminary tests have shown that five of the seven catalysts, with their individually best parameter combination, meet the transport fuel requirements. One of the two catalysts not suitable for fuel production is the reference catalyst. So far, only the two Ni-based catalysts have been tested over 70 h and with H_2S in the input gas. These tests suggest that CeO_2 as a support material improves the H_2S tolerance.

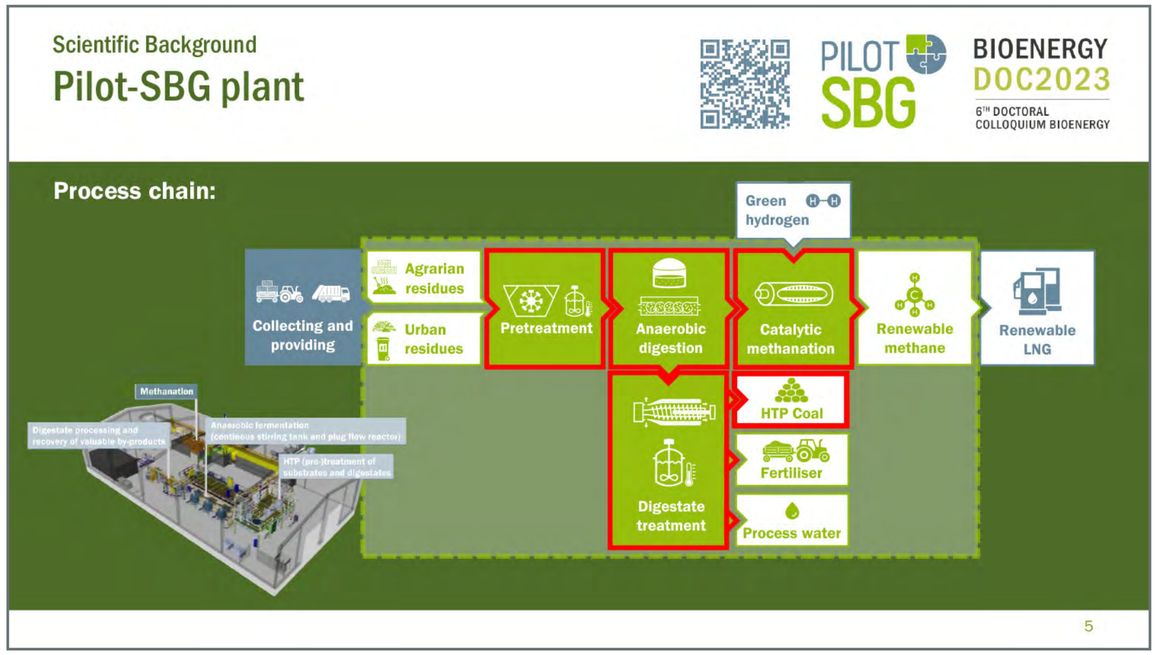
Outlook
The remaining catalysts are currently being tested for stability and H_2S poisoning. A suitable combination of adsorption material and catalyst will then be proposed for the pilot plant.

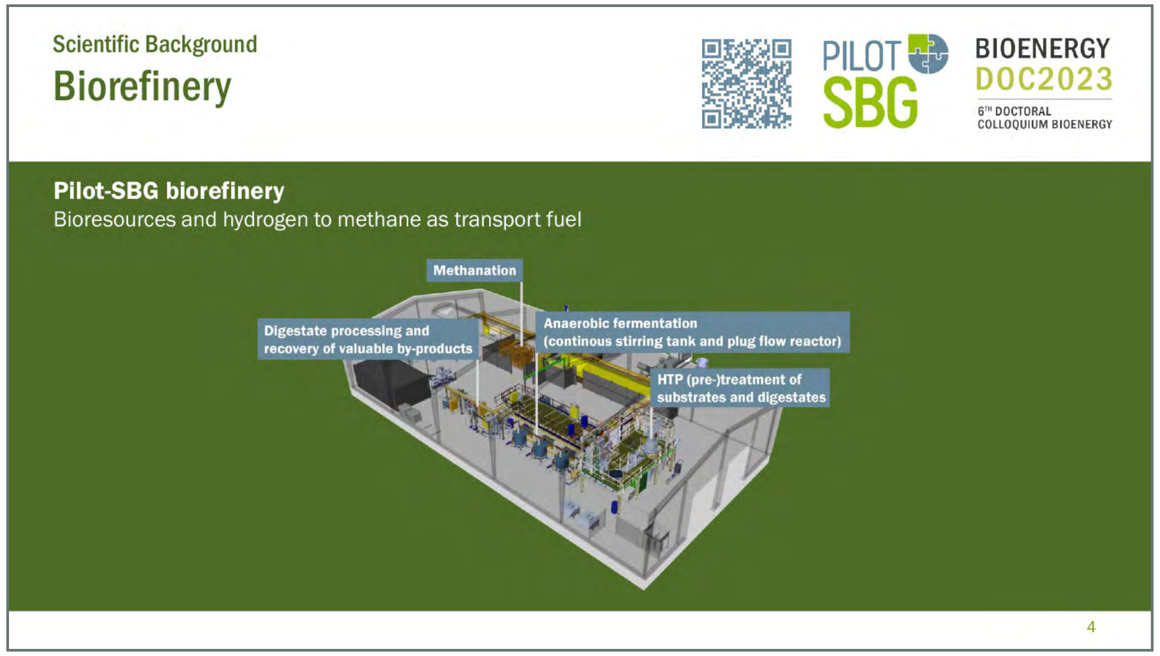


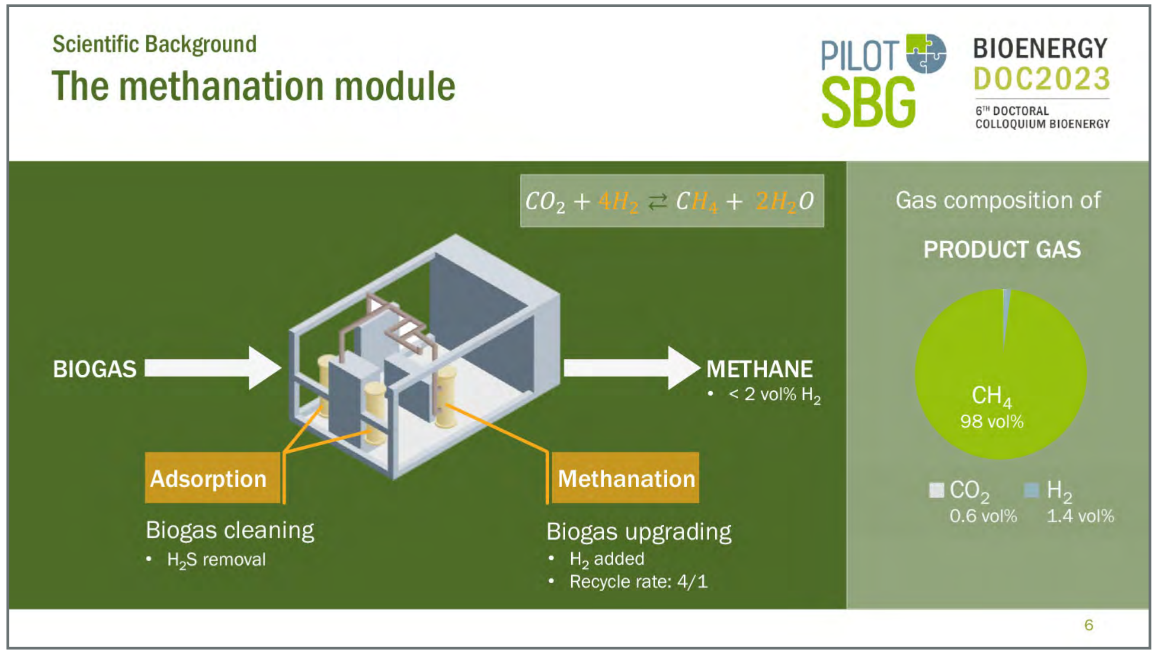


Title of the Doctoral Project:	Methanation catalysts for direct biogas methanation of purified biogas
Doctoral Student:	Selina Nieß
DBFZ Supervisor:	Dr. Marco Klemm
Cooperating University:	TU Berlin
University Supervisor:	Prof. Dr. Reinhard Schomäcker
Funding / Scholarship provider:	Federal Ministry for Digital and Transport
Logo:	Federal Ministry for Digital and Transport
Duration:	01/2020 – 06/2024

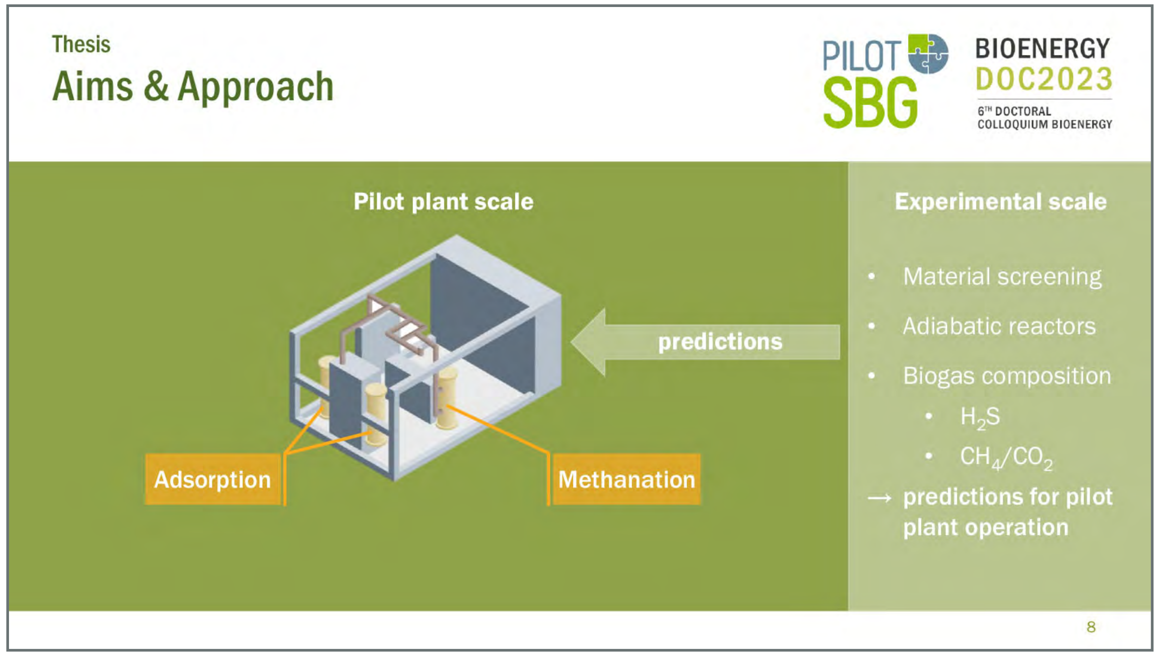

PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Scientific Background
3


Scientific Background
Pilot-SBG plant
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Process chain:
Green hydrogen
Collecting and providing
Agrarian residues
Urban residues
Pretreatment
Anaerobic digestion
Catalytic methanation
Renewable methane
Renewable LNG
HTP Coal
Fertiliser
Process water
Digestate treatment
Methanation
Digestate processing and recovery of valuable by-products
Anaerobic fermentation (continous stirring tank and plug flow reactor)
HTP (pre-)treatment of substrates and digestates
5


Scientific Background
Biorefinery
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Pilot-SBG biorefinery
Bioresources and hydrogen to methane as transport fuel
Methanation
Digestate processing and recovery of valuable by-products
Anaerobic fermentation (continous stirring tank and plug flow reactor)
HTP (pre-)treatment of substrates and digestates
4


Scientific Background
The methanation module
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
$CO_2 + 4H_2 \rightleftarrows CH_4 + 2H_2O$
BIOGAS
METHANE
• < 2 vol% H_2
Adsorption
Biogas cleaning
• H_2S removal
Methanation
Biogas upgrading
• H_2 added
• Recycle rate: 4/1
Gas composition of
PRODUCT GAS
CH_4 98 vol%
CO_2 0.6 vol%
H_2 1.4 vol%
6


PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Aim of the Thesis
7


Thesis
Aims & Approach
PILOT SBG
BIOENERGY DOC2023
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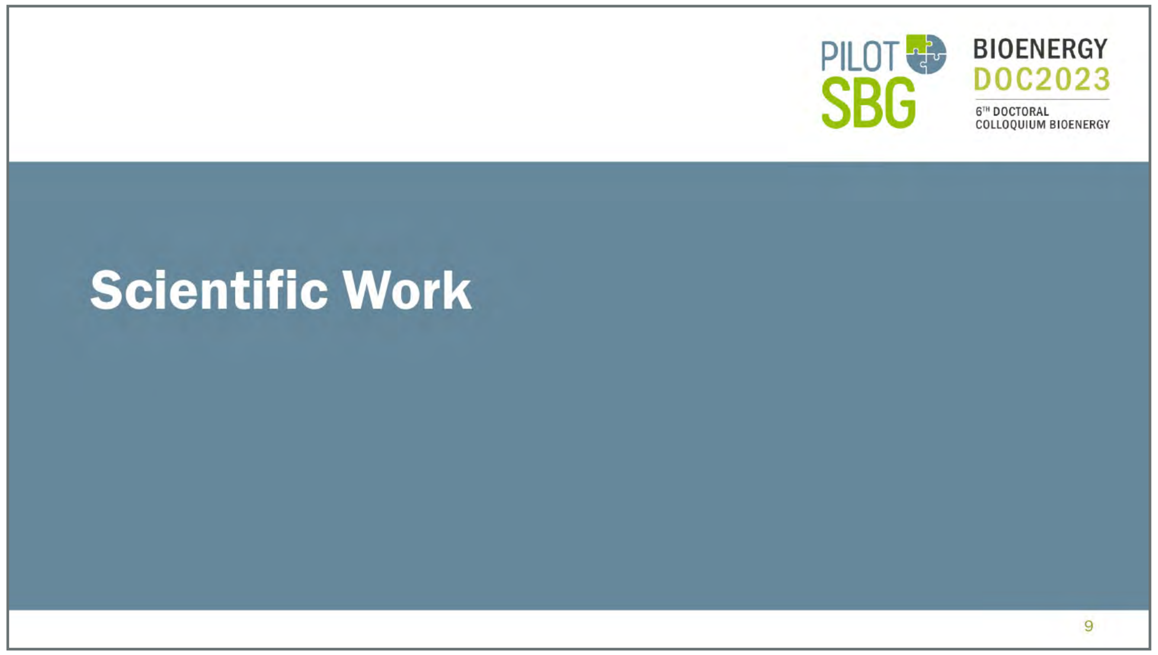
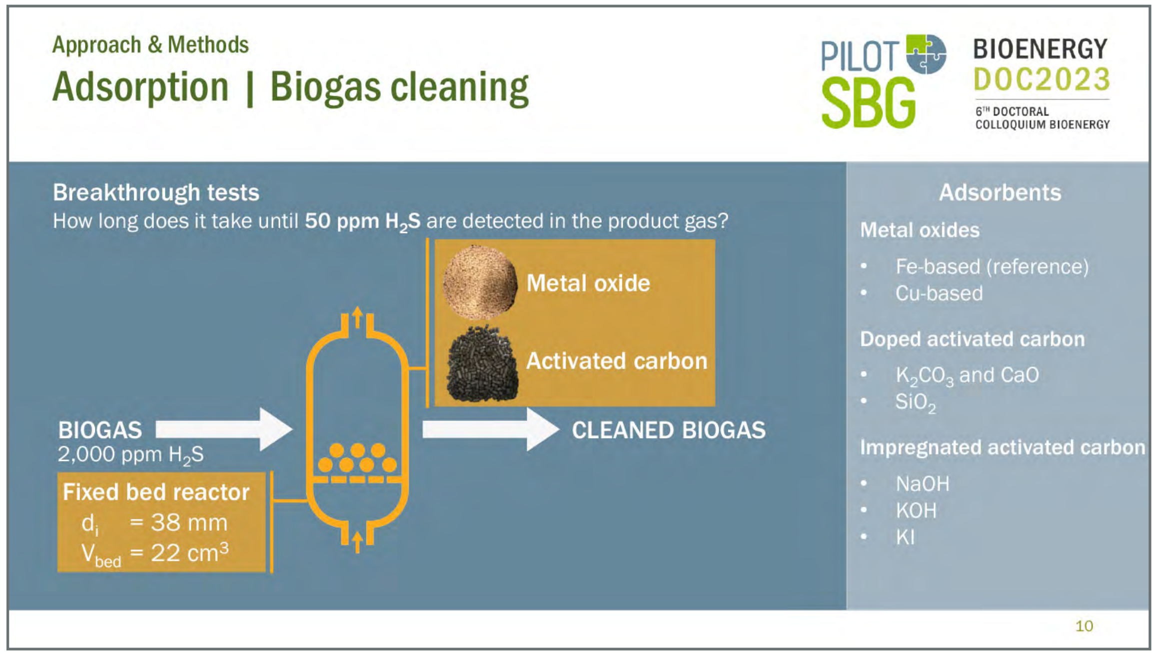
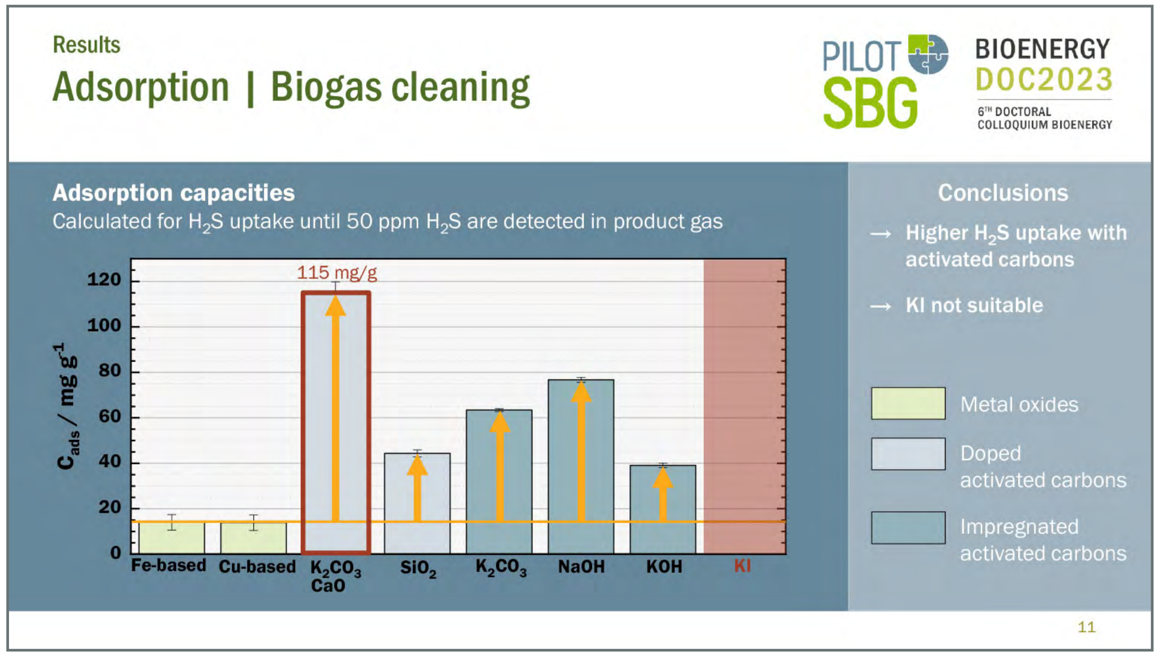
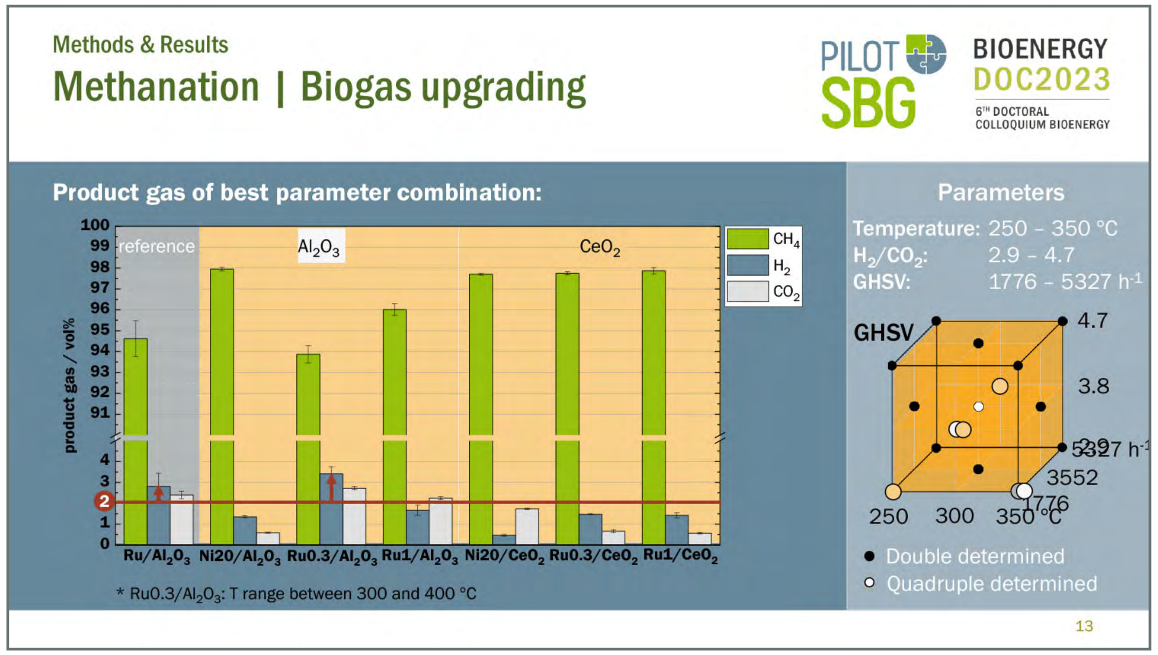
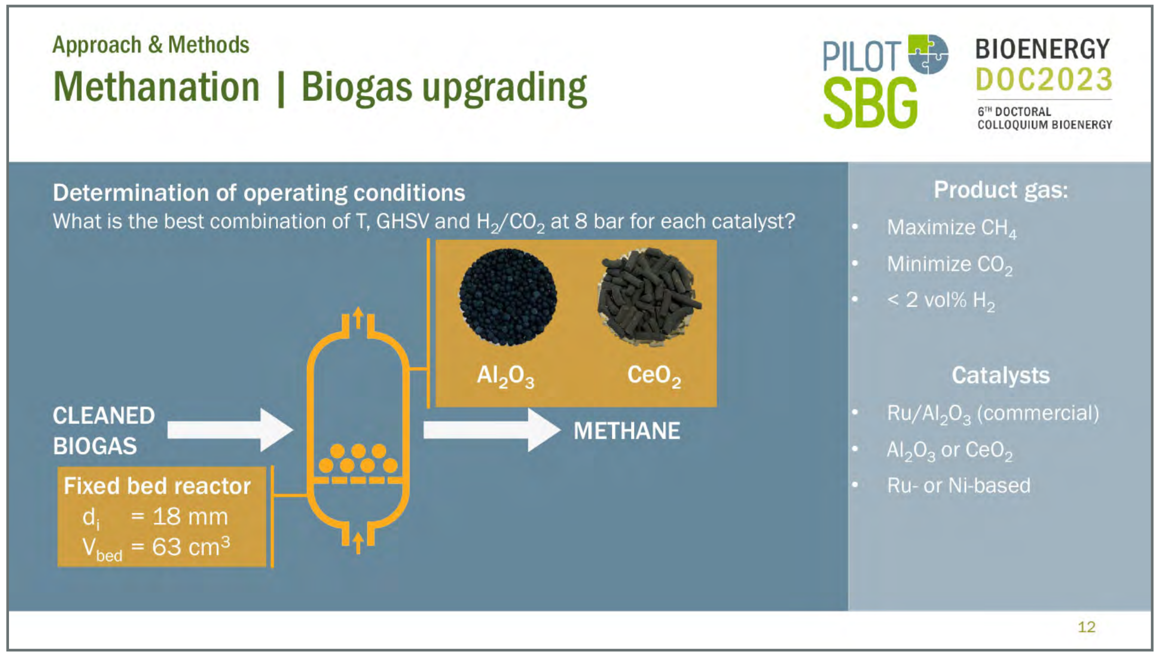
Pilot plant scale
predictions
Adsorption
Methanation
Experimental scale
• Material screening
• Adiabatic reactors
• Biogas composition
• H_2S
• CH_4/CO_2
→ predictions for pilot plant operation
8

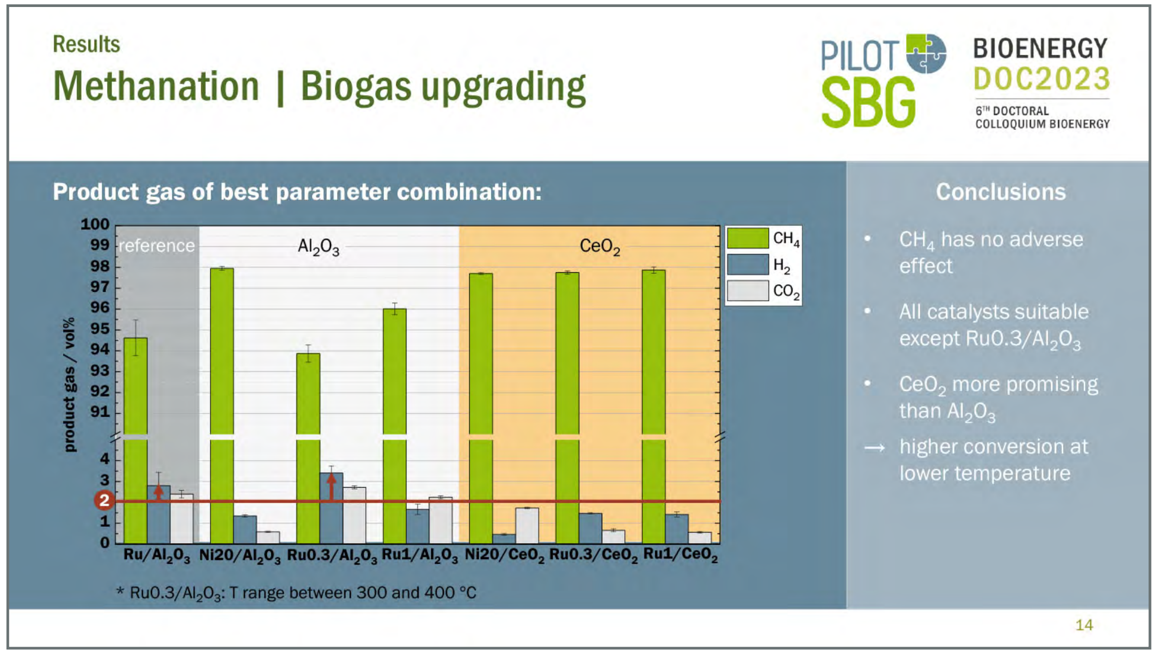

PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Scientific Work
9

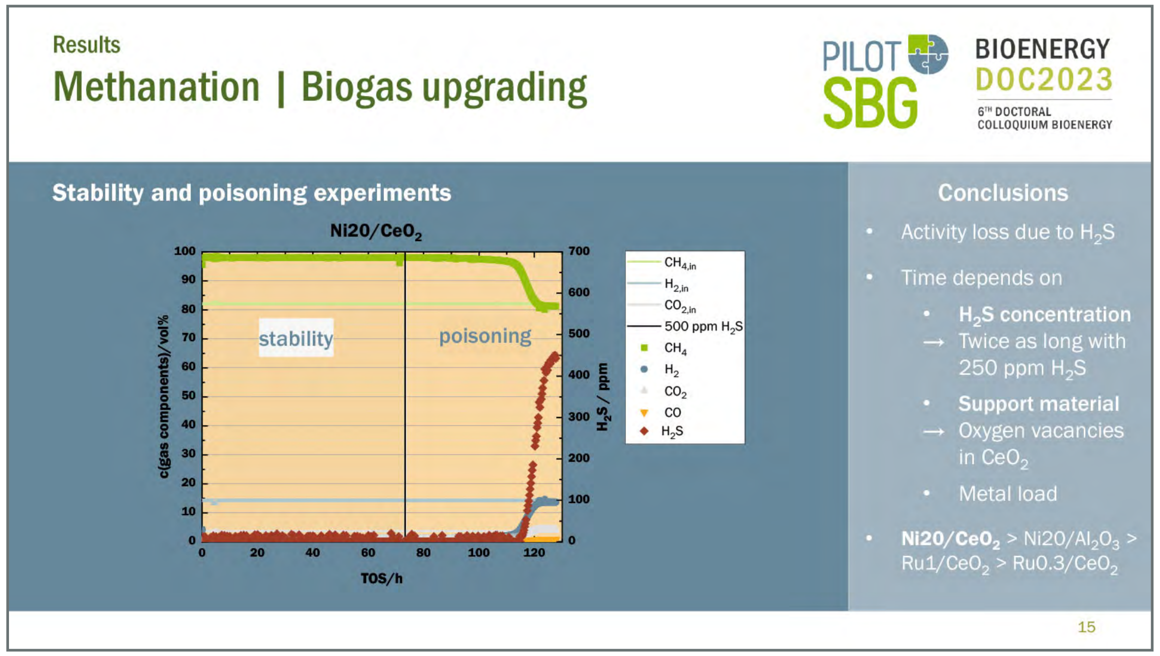

Approach & Methods
Adsorption | Biogas cleaning
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Breakthrough tests
How long does it take until 50 ppm H_2S are detected in the product gas?
Metal oxide
Activated carbon
BIOGAS
2,000 ppm H_2S
CLEANED BIOGAS
Fixed bed reactor
d_i = 38 mm
V_{bed} = 22 cm^3
Adsorbents
Metal oxides
• Fe-based (reference)
• Cu-based
Doped activated carbon
• K_2CO_3 and CaO
• SiO_2
Impregnated activated carbon
• NaOH
• KOH
• KI
10


Results
Adsorption | Biogas cleaning
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Adsorption capacities
Calculated for H2S uptake until 50 ppm H2S are detected in product gas
Cads / mg g-1
115 mg/g
Fe-based
Cu-based
K2CO3 CaO
SiO2
K2CO3
NaOH
KOH
KI
Conclusions
→ Higher H2S uptake with activated carbons
→ KI not suitable
Metal oxides
Doped activated carbons
Impregnated activated carbons
11


Methods & Results
Methanation | Biogas upgrading
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Product gas of best parameter combination:
product gas / vol%
reference
Al2O3
CeO2
CH4
H2
CO2
Ru/Al2O3
Ni20/Al2O3
Ru0.3/Al2O3
Ru1/Al2O3
Ni20/CeO2
Ru0.3/CeO2
Ru1/CeO2
* Ru0.3/Al2O3: T range between 300 and 400 °C
Parameters
Temperature: 250 – 350 °C
H2/CO2: 2.9 – 4.7
GHSV: 1776 – 5327 h-1
GHSV
4.7
3.8
5327 h-1
3552
1776
250 300 350 °C
Double determined
Quadruple determined
13


Approach & Methods
Methanation | Biogas upgrading
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Determination of operating conditions
What is the best combination of T, GHSV and H2/CO2 at 8 bar for each catalyst?
Al2O3
CeO2
CLEANED BIOGAS
METHANE
Fixed bed reactor
di = 18 mm
Vbed = 63 cm3
Product gas:
Maximize CH4
Minimize CO2
< 2 vol% H2
Catalysts
Ru/Al2O3 (commercial)
Al2O3 or CeO2
Ru- or Ni-based
12


Results
Methanation | Biogas upgrading
PILOT SBG
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Product gas of best parameter combination:
product gas / vol%
reference
Al2O3
CeO2
CH4
H2
CO2
Ru/Al2O3
Ni20/Al2O3
Ru0.3/Al2O3
Ru1/Al2O3
Ni20/CeO2
Ru0.3/CeO2
Ru1/CeO2
* Ru0.3/Al2O3: T range between 300 and 400 °C
Conclusions
CH4 has no adverse effect
All catalysts suitable except Ru0.3/Al2O3
CeO2 more promising than Al2O3
→ higher conversion at lower temperature
14


Results
Methanation | Biogas upgrading
PILOT SBG
BIOENERGY DOC2023
Stability and poisoning experiments
Ni20/CeO2
stability
poisoning
c(gas components)/vol%
H2S / ppm
TOS/h
500 ppm H2S
Conclusions
Activity loss due to H2S
Time depends on
H2S concentration
→ Twice as long with 250 ppm H2S
Support material
→ Oxygen vacancies in CeO2
Metal load
Ni20/CeO2 > Ni20/Al2O3 > Ru1/CeO2 > Ru0.3/CeO2
15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6TH DOCTORAL COLLOQUIUM BIOENERGY
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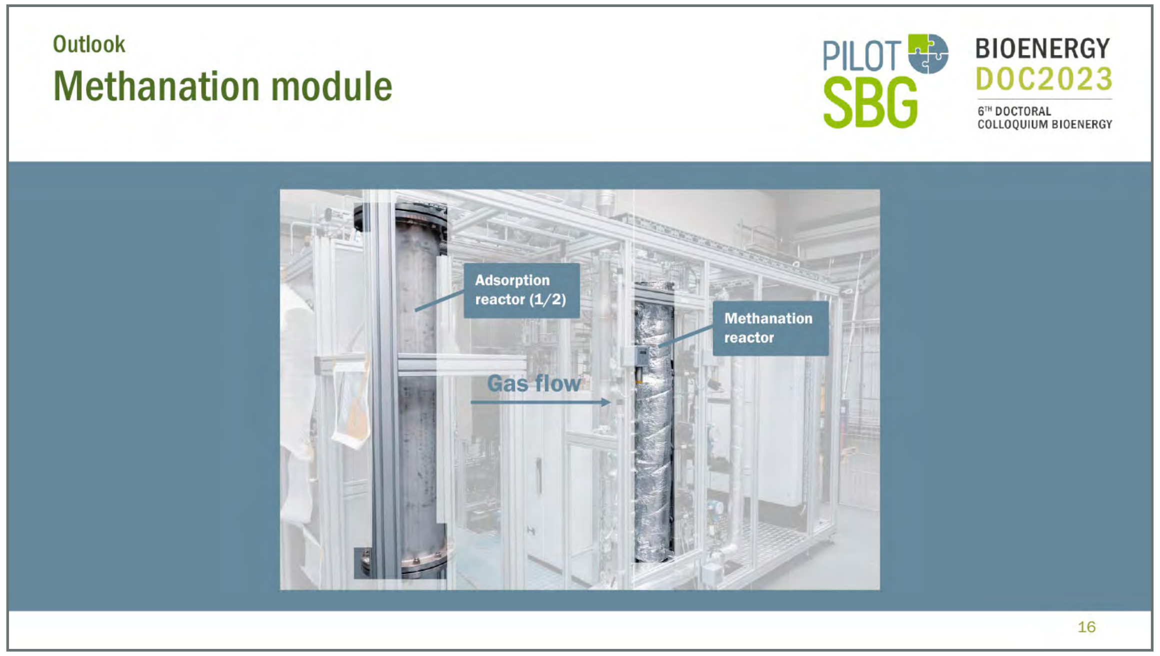
Outlook
Methanation module
PILOT SBG
BIOENERGY DOC2023
Adsorption reactor (1/2)
Methanation reactor
Gas flow
16

Theresa Manzel, Technical University of Berlin

On-line **gradient monitoring for the flexibilization of anaerobic hydrolysis in plug-flow reactors**

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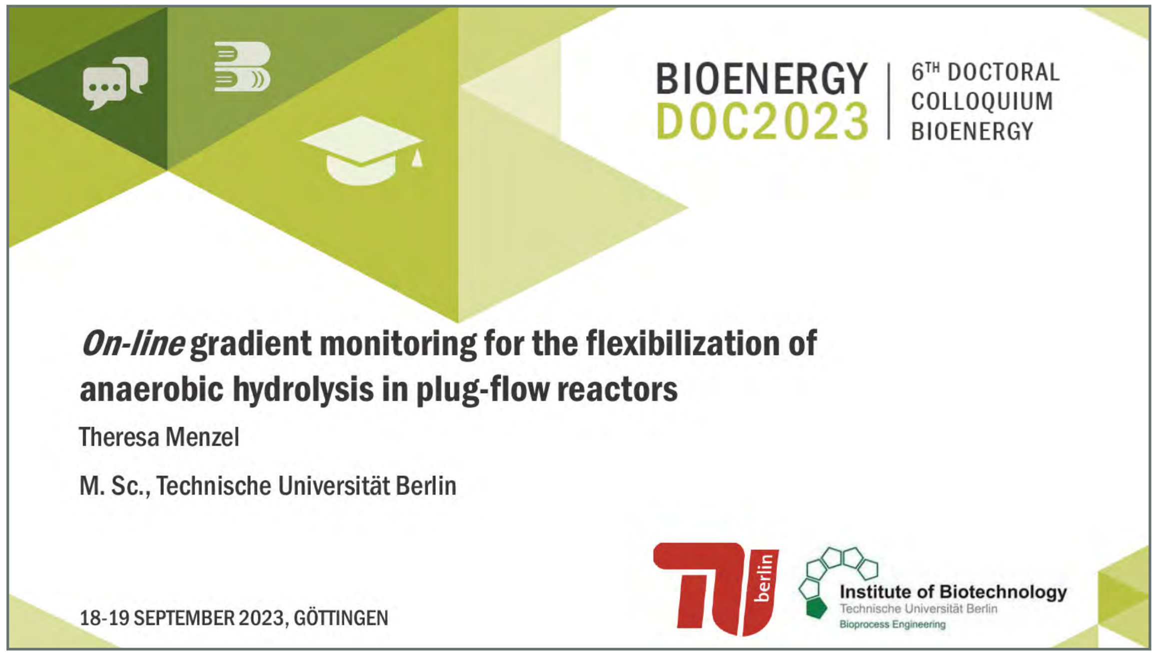
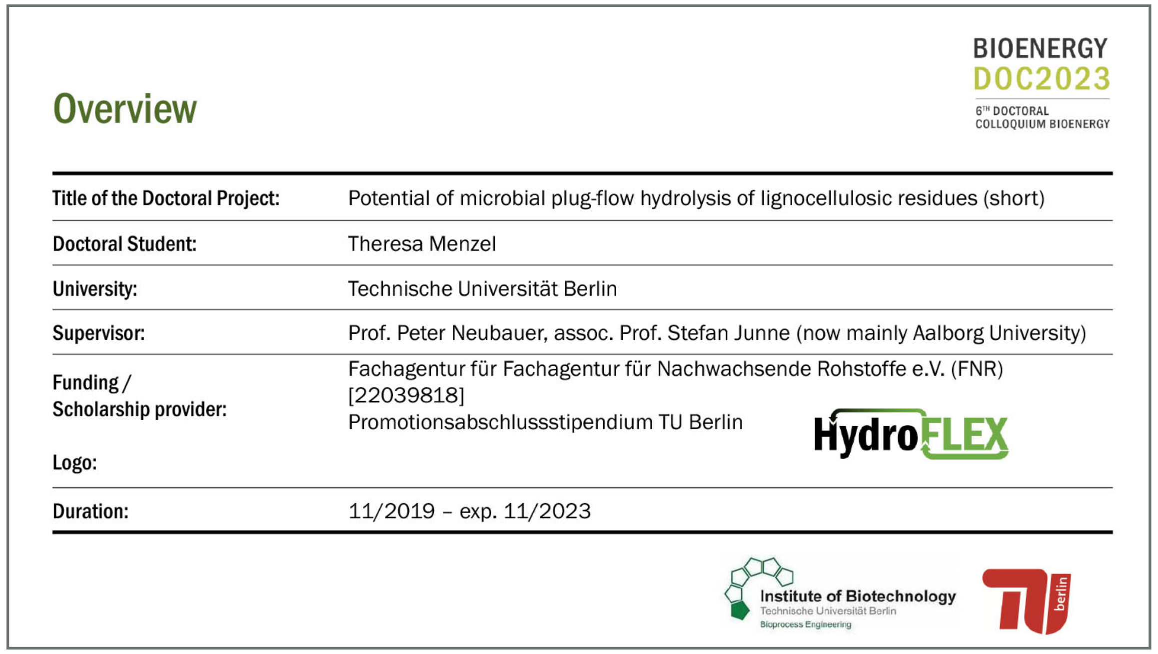
D - 10623 Berlin
E-Mail: t.menzel@tu-berlin.de

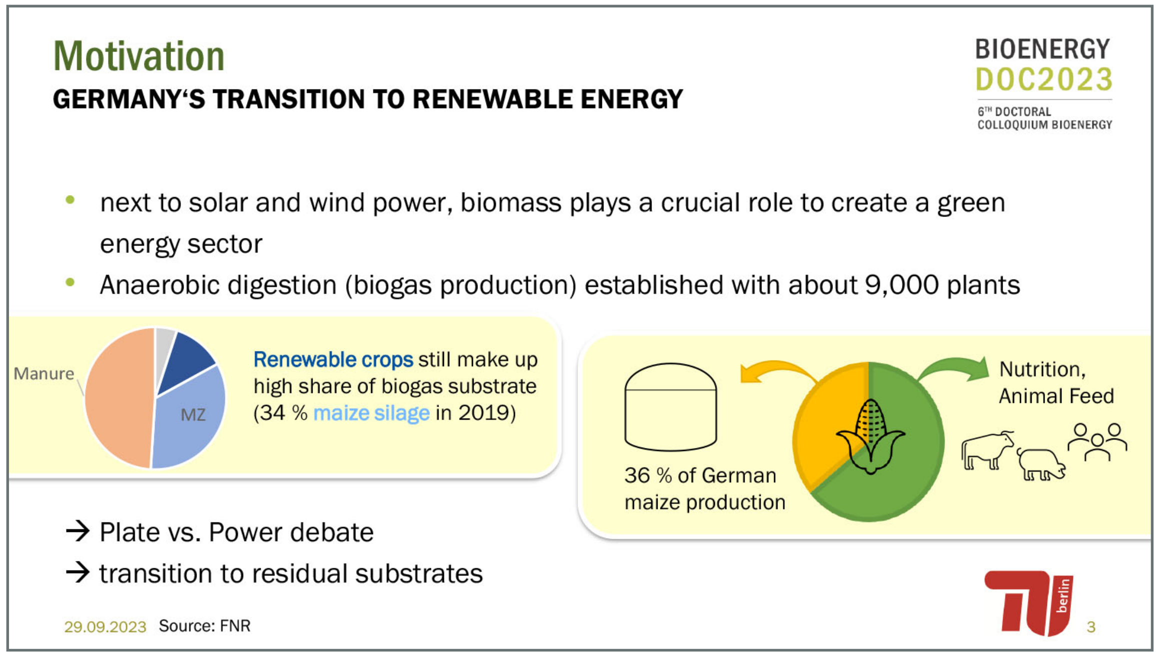
Residual biomass is a valuable resource for the production of bioenergy (CH_4, H_2) and biomass-based products like carboxylic acids. However, locally available biomass can show high variation in quality and composition over time (e.g., seasonal changes or biomass availability). To enable the flexible use of changing feedstock, a stable and adaptable digestion of biogenic residues is required. In anaerobic digestion, stage separation into hydrolysis/acidogenesis and methanogenesis offers higher stability, due to the great adaptability and resistance of hydrolytic microorganisms. Plug-flow digestion further supports the enrichment of microbial species in the first stage by the formation of microenvironments 3. In this study, the continuous hydrolytic digestion in two plug-flow reactors (PFRs) was evaluated under changes of process operation (hydraulic retention time, recirculation), feedstock variation (maize silage, bedding straw) and microbial changes (bioaugmentation, microbial adaption) for a total of 123 weeks.

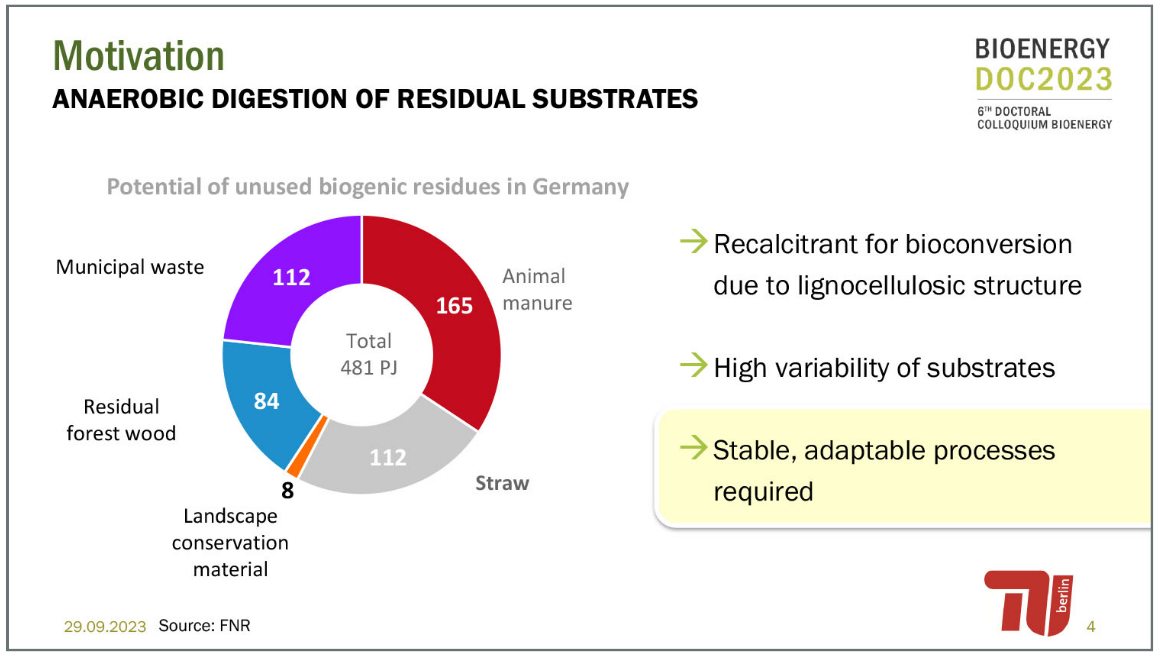
Multi-position on-line monitoring of the pH-value, conductivity and the oxidation-reduction potential was applied in three different spots along the reactors to detect gradient formation, identify the best measurements points and evaluate possibilities for process control via on-line monitoring. By this, we could confirm phase formation of different metabolic zones along the reactor with hydrolysis at the in- and outlet, lactic acid fermentation at the inlet and acidogenesis (butyric/acetic acid) in the center of the reactors. With the described monitoring strategy, the on-line determination of the acidogenic fermentation pattern, acid concentration, acidification and acid yield are possible and stable over a wide variety of process conditions. This could extensively simplify the installation and control of hydrolytic PFRs in a large scale, where instabilities due to feedstock variation, operational changes and more could be quickly recognized and predicted.





Title of the Doctoral Project:	Potential of microbial plug-flow hydrolysis of lignocellulosic residues (short)
Doctoral Student:	Theresa Menzel
University:	Technische Universität Berlin
Supervisor:	Prof. Peter Neubauer, assoc. Prof. Stefan Junne (now mainly Aalborg University)
Funding / Scholarship provider:	Fachagentur für Fachagentur für Nachwachsende Rohstoffe e.V. (FNR) [22039818] Promotionsabschlussstipendium TU Berlin
Logo:	HydroFLEX
Duration:	11/2019 – exp. 11/2023


Motivation
GERMANY‘S TRANSITION TO RENEWABLE ENERGY
BIOENERGY
DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
next to solar and wind power, biomass plays a crucial role to create a green energy sector
Anaerobic digestion (biogas production) established with about 9,000 plants
Manure
MZ
Renewable crops still make up high share of biogas substrate (34 % maize silage in 2019)
36 % of German maize production
Nutrition, Animal Feed
→ Plate vs. Power debate
→ transition to residual substrates
29.09.2023 Source: FNR
3


Motivation
ANAEROBIC DIGESTION OF RESIDUAL SUBSTRATES
BIOENERGY
DOC2023
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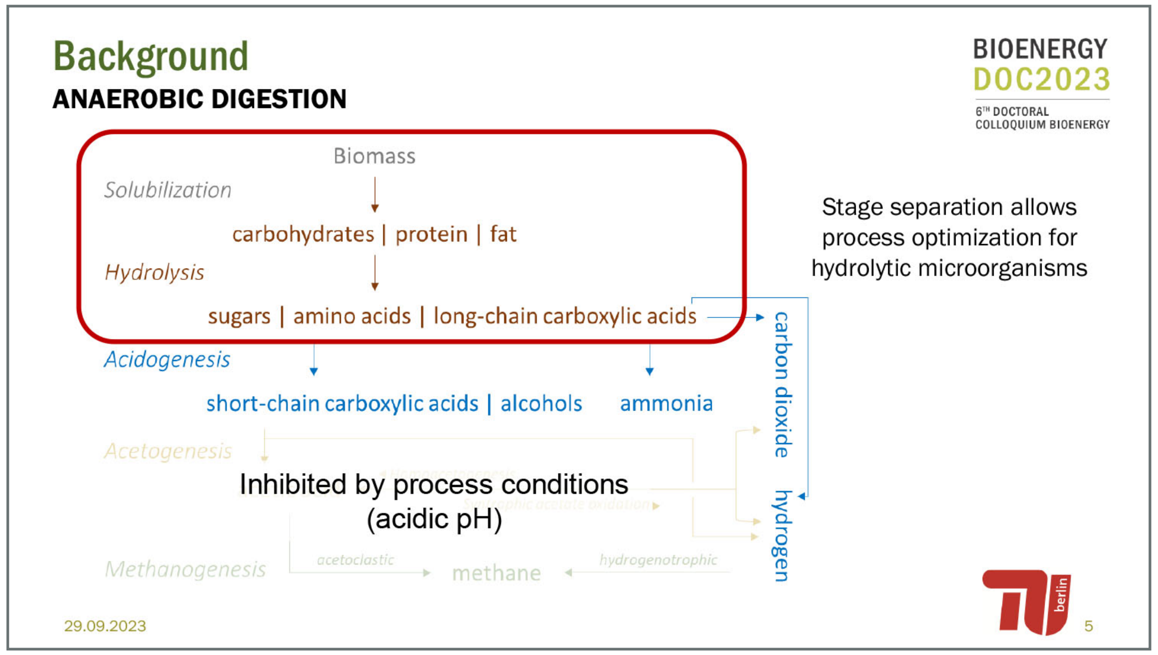
Potential of unused biogenic residues in Germany
Municipal waste
112
165
Animal manure
Total
481 PJ
Residual forest wood
84
112
Straw
8
Landscape conservation material
→ Recalcitrant for bioconversion due to lignocellulosic structure
→ High variability of substrates
→ Stable, adaptable processes required
29.09.2023 Source: FNR
4


Background
ANAEROBIC DIGESTION
BIOENERGY
DOC2023
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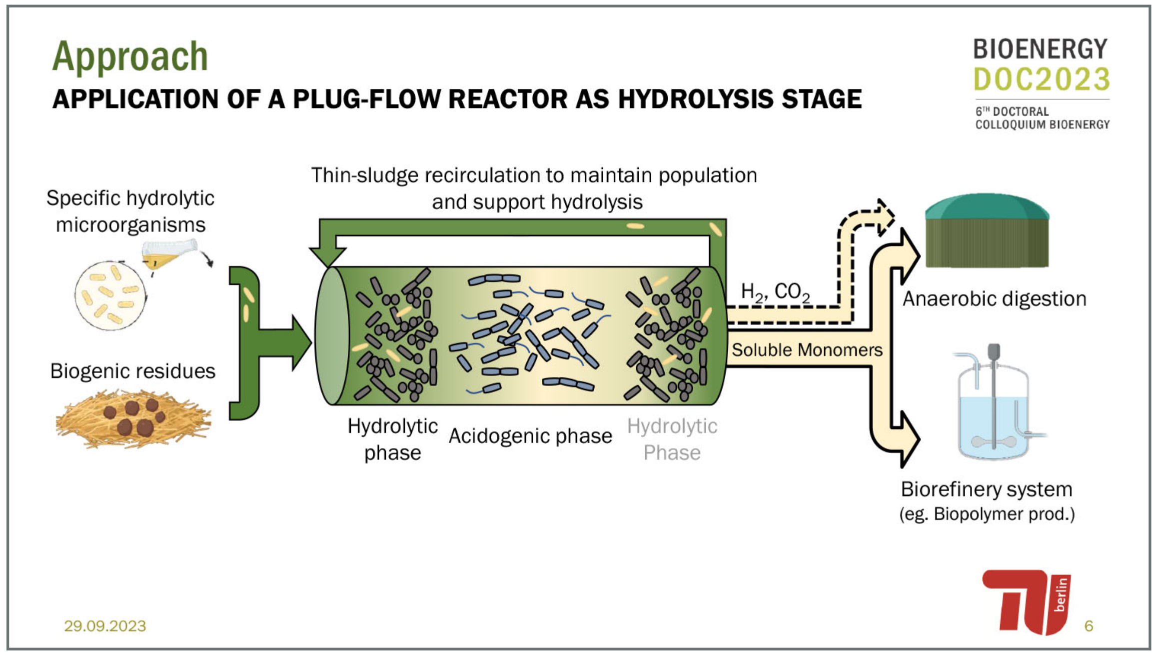
Biomass
Solubilization
carbohydrates | protein | fat
Hydrolysis
sugars | amino acids | long-chain carboxylic acids
Acidogenesis
short-chain carboxylic acids | alcohols
ammonia
Acetogenesis
Inhibited by process conditions (acidic pH)
Methanogenesis
acetoclastic
methane
hydrogenotrophic
carbon dioxide
hydrogen
Stage separation allows process optimization for hydrolytic microorganisms
29.09.2023
5


Approach
APPLICATION OF A PLUG-FLOW REACTOR AS HYDROLYSIS STAGE
BIOENERGY
DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Specific hydrolytic microorganisms
Biogenic residues
Thin-sludge recirculation to maintain population and support hydrolysis
Hydrolytic phase
Acidogenic phase
Hydrolytic Phase
H2, CO2
Soluble Monomers
Anaerobic digestion
Biorefinery system (eg. Biopolymer prod.)
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6

Approach
APPLICATION OF A PLUG-FLOW REACTOR AS HYDROLYSIS STAGE

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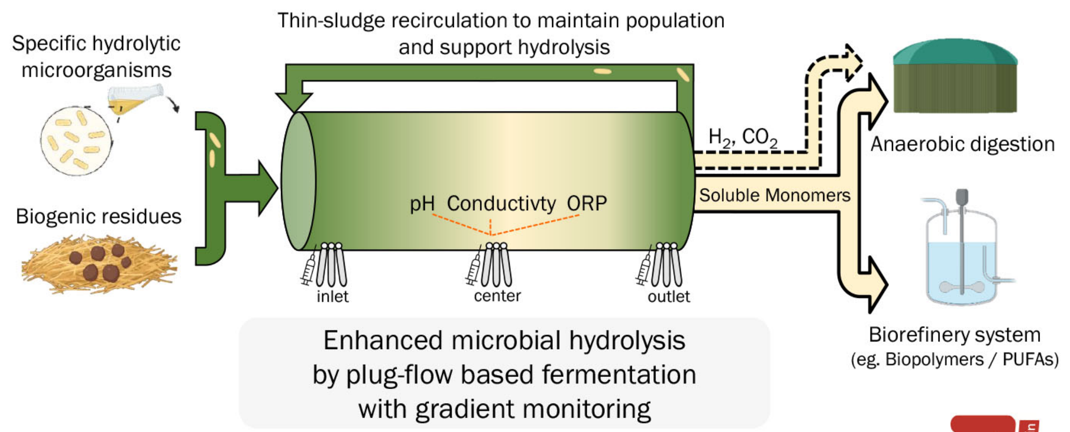


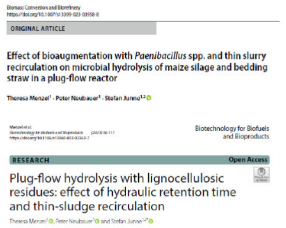
29.09.2023 ORP – oxdiation-reduction potential 7

Approach
EXPERIMENTAL SETUP

BIOENERGY DOC2023 6TH DOCTORAL COLLOQUIUM BIOENERGY

- Dynamic operation of two parallel PFR with variation of
  - Substrate: Maize silage pure and with 30 % & 66 % of bedding straw (horse stable)
  - Hydraulic retention time - HRT (7, 14, 21 d)
  - Thin-sludge recirculation (none, 10 %, 20 %)
  - Bioaugmentation with *Paenibacillus* spp.

Effect on reactor performance described in publications:



- Evaluation for 2 – 3 HRT
- 123 weeks of operation
- *On-line* gradient monitoring, spatially resolved sampling

What can we learn from gradient process monitoring?

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Method
LOCAL CORRELATION ANALYSIS

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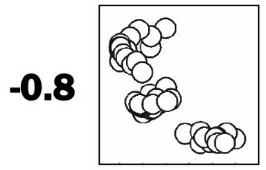
- Is there a relation between *on-line* gradient data and process performance?
- Normalization of weekly averaged data per port
- Linear Pearson correlation between all measured *on- / off-line* parameters
- Plotted data points for non-linear correlations



29.09.2023 9

Results
PRIMARY DATA

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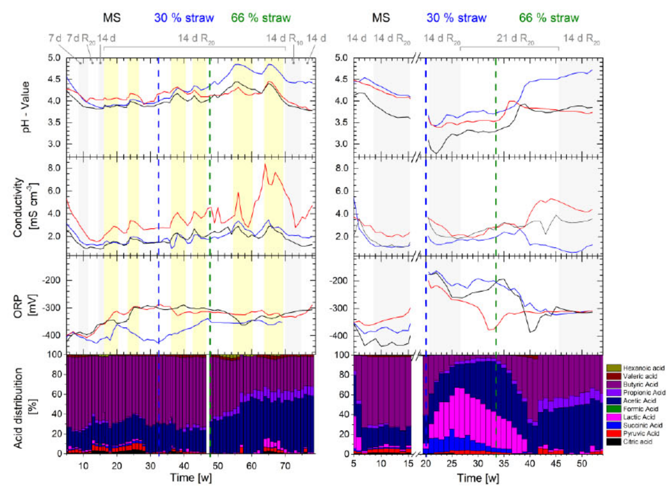

PFR 1 PFR 2

Gradients between inlet, center and outlet

Changes in microbial activity / community
→ composition of acid fraction varies

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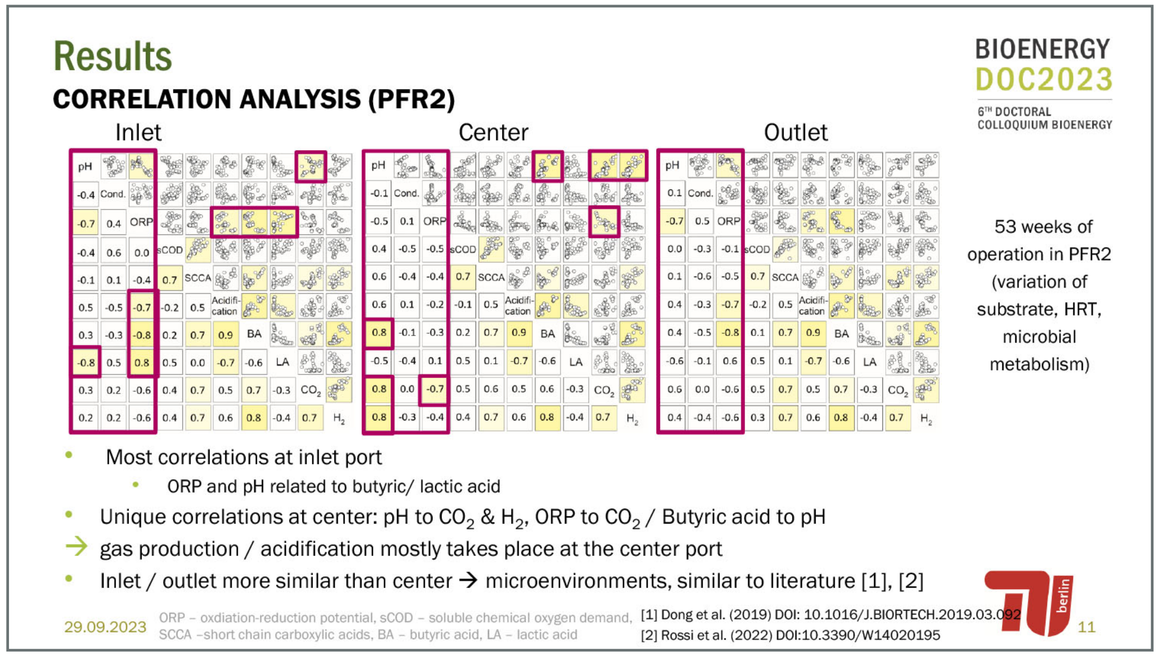
Results
CORRELATION ANALYSIS (PFR2)
BIOENERGY DOC2023
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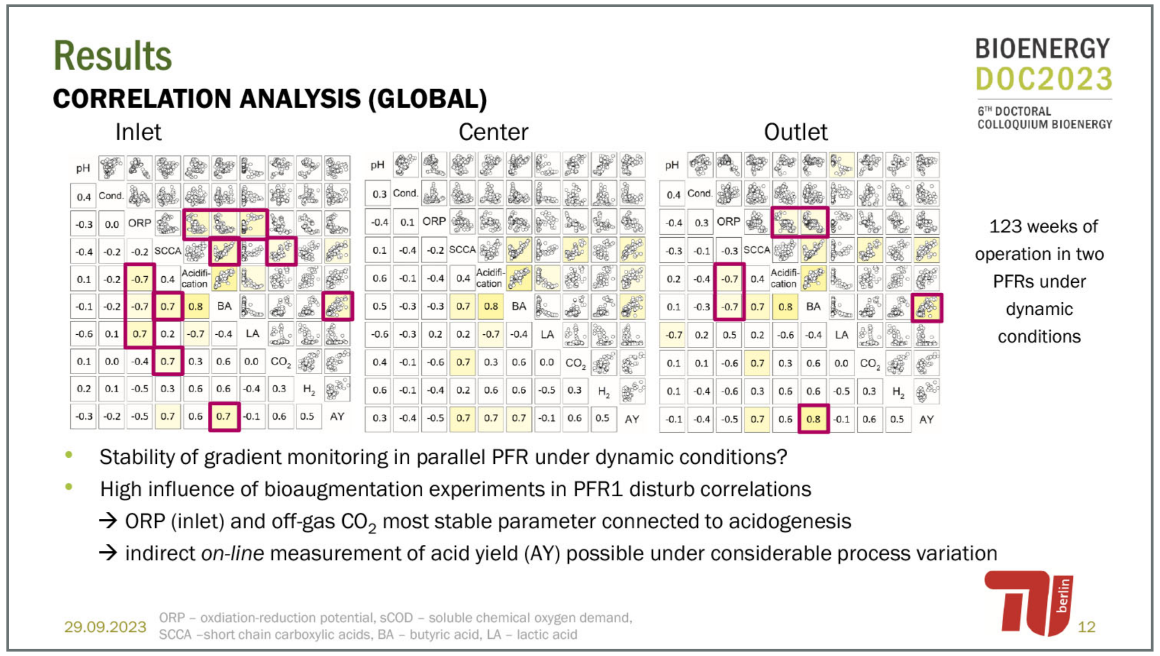
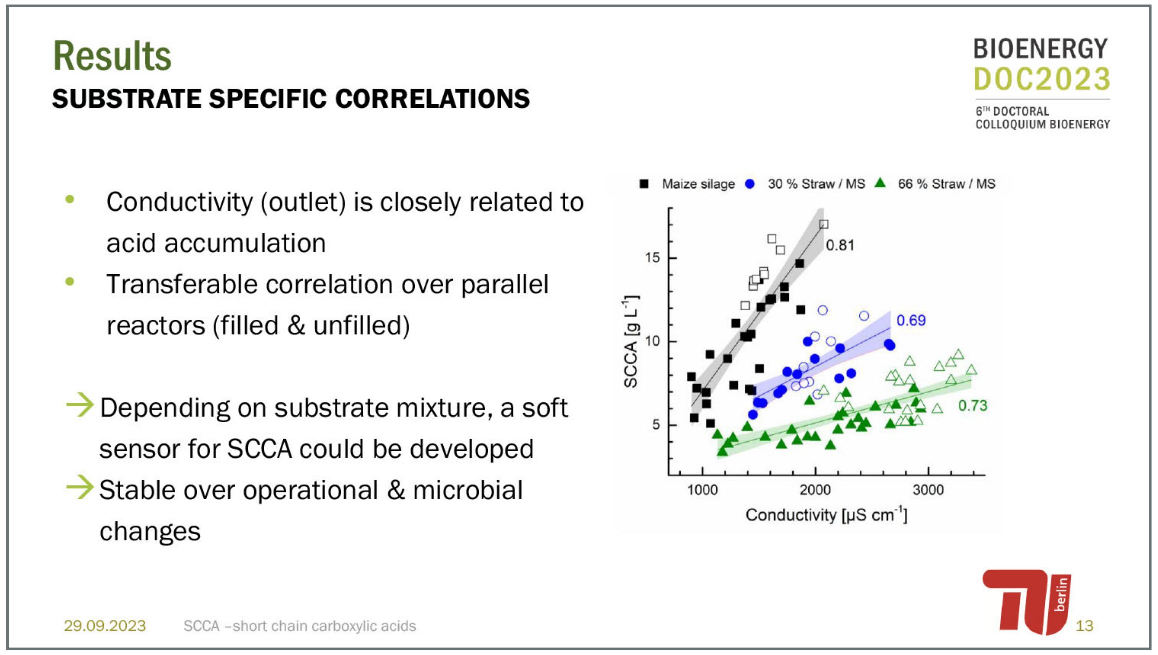
Inlet
Center
Outlet
53 weeks of operation in PFR2 (variation of substrate, HRT, microbial metabolism)
Most correlations at inlet port
ORP and pH related to butyric/ lactic acid
Unique correlations at center: pH to CO_2 & H_2, ORP to CO_2 / Butyric acid to pH
→ gas production / acidification mostly takes place at the center port
Inlet / outlet more similar than center → microenvironments, similar to literature [1], [2]
29.09.2023
ORP – oxidation-reduction potential, sCOD – soluble chemical oxygen demand,
SCCA –short chain carboxylic acids, BA – butyric acid, LA – lactic acid
[1] Dong et al. (2019) DOI: 10.1016/J.BIORTECH.2019.03.092
[2] Rossi et al. (2022) DOI:10.3390/W14020195
11


Results
CORRELATION ANALYSIS (GLOBAL)
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Inlet
Center
Outlet
123 weeks of operation in two PFRs under dynamic conditions
Stability of gradient monitoring in parallel PFR under dynamic conditions?
High influence of bioaugmentation experiments in PFR1 disturb correlations
→ ORP (inlet) and off-gas CO_2 most stable parameter connected to acidogenesis
→ indirect on-line measurement of acid yield (AY) possible under considerable process variation
29.09.2023
ORP – oxidation-reduction potential, sCOD – soluble chemical oxygen demand,
SCCA –short chain carboxylic acids, BA – butyric acid, LA – lactic acid
12


Results
SUBSTRATE SPECIFIC CORRELATIONS
BIOENERGY DOC2023
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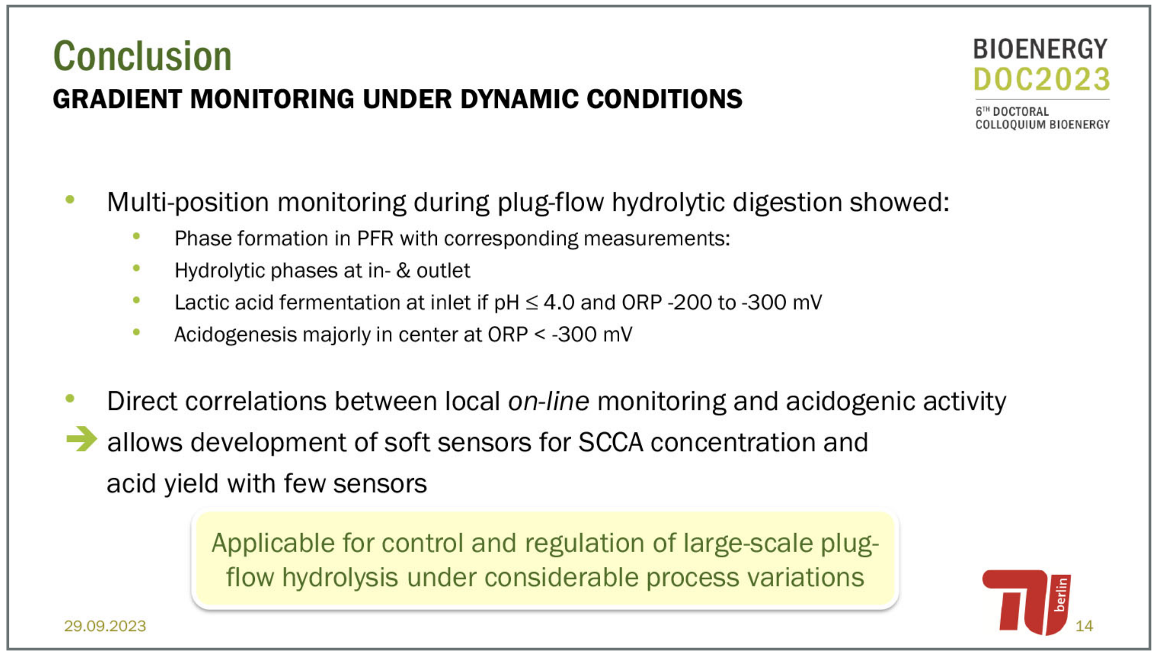
Conductivity (outlet) is closely related to acid accumulation
Transferable correlation over parallel reactors (filled & unfilled)
→ Depending on substrate mixture, a soft sensor for SCCA could be developed
→ Stable over operational & microbial changes
Maize silage
30 % Straw / MS
66 % Straw / MS
SCCA [g L⁻¹]
Conductivity [µS cm⁻¹]
0.81
0.69
0.73
29.09.2023
SCCA –short chain carboxylic acids
13


Conclusion
GRADIENT MONITORING UNDER DYNAMIC CONDITIONS
BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Multi-position monitoring during plug-flow hydrolytic digestion showed:
Phase formation in PFR with corresponding measurements:
Hydrolytic phases at in- & outlet
Lactic acid fermentation at inlet if pH ≤ 4.0 and ORP -200 to -300 mV
Acidogenesis majorly in center at ORP < -300 mV
Direct correlations between local on-line monitoring and acidogenic activity
→ allows development of soft sensors for SCCA concentration and acid yield with few sensors
Applicable for control and regulation of large-scale plug-flow hydrolysis under considerable process variations
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14


BIOENERGY DOC2023
6TH DOCTORAL COLLOQUIUM BIOENERGY
Thank you
for your attention!
t.menzel@tu-berlin.de
sju@bio.aau.dk
www.bioprocess.tu-berlin.de
FKZ: 22141818
HydroFLEX
FNR
Fachagentur Nachwachsende Rohstoffe e.V.
berlin
FWE
energy solutions
BIOGASTIGER®
Fickert + Winterling
Publications:
• Menzel, T.; Neubauer, P. & Junne, S.; Plug-flow hydrolysis with lignocellulosic residues: effect of hydraulic retention time and thin-sludge recirculation. *Biotechnol Biofuels* 16, 111 (2023)
• Menzel, T.; Neubauer, P. & Junne, S.; Effect of bioaugmentation with *Paenibacillus* spp. and thin slurry recirculation on microbial hydrolysis of maize silage and bedding straw in a plug-flow reactor. *Biomass Conv. Bioref.* 2023
• Menzel, T.; Neubauer, P. & Junne, S.; On-line gradient monitoring during plug-flow hydrolysis: a tool to support flexible operation? **Preprint** at https://doi.org/10.21203/rs.3.rs-3286576/v1

SESSION

BIOCHEMICAL CONVERSION

Prof. Dr. Michael Nelles
Dr. Hans Oechsner
Prof. Dr. Achim Loewen

6TH DOCTORAL COLLOQUIUM BIOENERGY

Alberto Meola, Deutsches Biomasseforschungszentrum

AI upscaling: Modeling a full-scale biogas reactor using lab-scale data with machine learning algorithms

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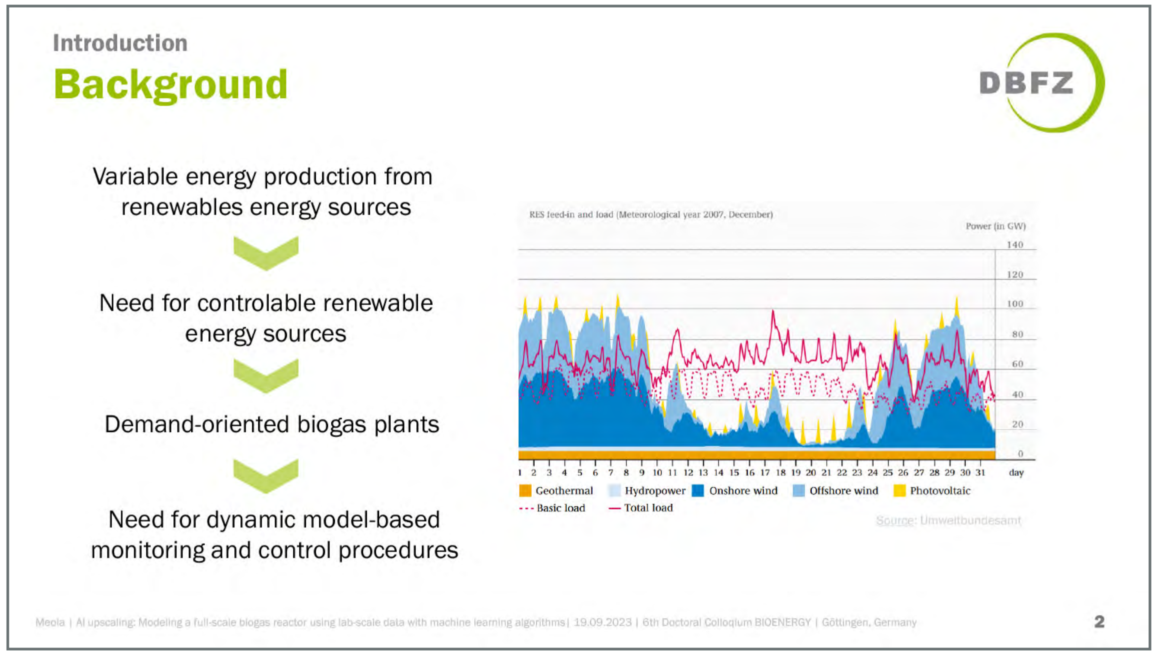
Anaerobic Digestion (AD) processes can provide demand-oriented power and compensate for the irregularity of renewable energy conversion. Model-based automation procedures offer efficient and robust concepts for non-linear AD process optimization. Typically, the Anaerobic Digestion Model No. 1 (ADM1) is applied for AD process modelling. However, it cannot be implemented during regular operation of industrial AD plants due to the lack of reliable and sufficient measurements.

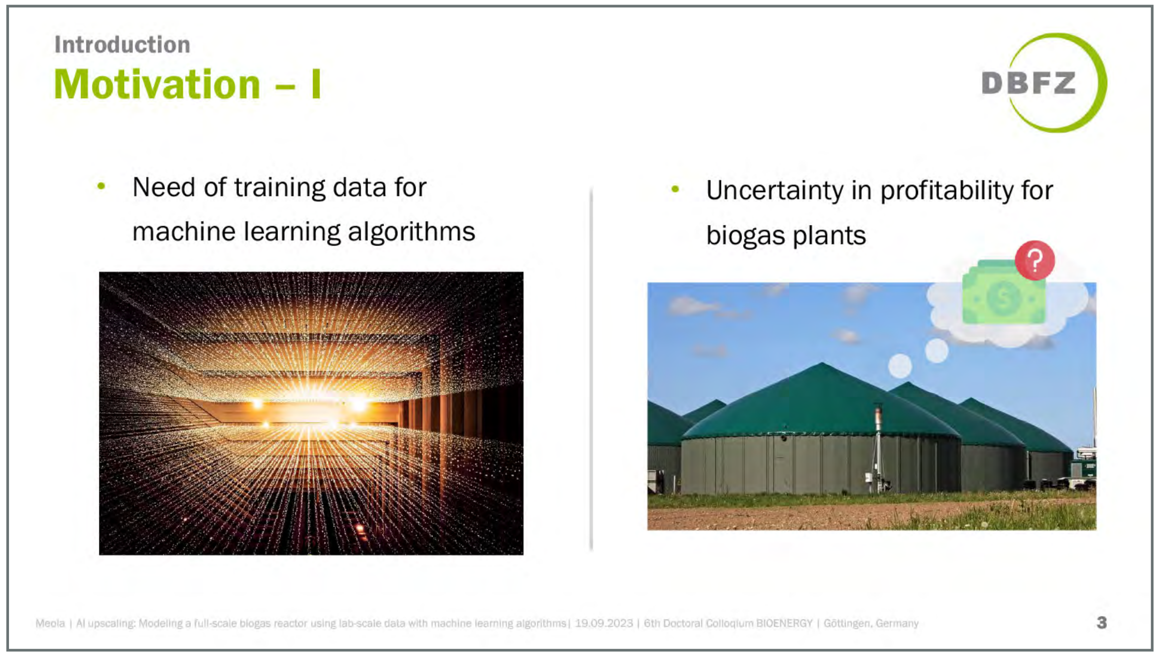
Stochastic modeling techniques, such as Machine Learning (ML), show great potential for non-linear process prediction of AD plants, as they do not require previous knowledge regarding process properties. However, ML algorithms need datasets to be trained on. Normally, the modelling of full-scale biogas reactors makes use of training, validation and test data measured from the target reactor. In this study, the capabilities of ML algorithms to model full-scale AD processes while trained on lab-scale data are evaluated.

Several ML algorithms were trained on data generated from a 20 L lab-scale CSTR reactor and tested on a 188 m3 CSTR reactor fed with corn silage and cattle manure at a constant Organic Loading Rate (OLR) of 1.1 kg VS m-3 d-1 and a constant Hydraulic Retention Time (HRT) of 100 days. The study utilized three simulation scenarios with varying percentages of lab-scale and full-scale datasets for training, validation, and testing of machine learning algorithms. The scenarios were designed to explore the optimal balance of data usage and algorithm performance.

Both reactors were equipped with various sensors (such as gas meters and gas composition sensors), and bi-weekly measurements for pH, VFAs, TS and VS were performed. TS and VS measurements for the feed substrate were used as input data for the models. Data was resampled to 12h resolution. Several ML models, including bayesian and linear regression, k-nearest neighbors, and Adaboost regressor, were tested and optimized through a standardized data optimization pipeline. Results showed that bayesian linear regression could predict the methane production of the full-scale reactor one day ahead with an RMSSE of 90 %.

This research demonstrates the successful use of ML models, particularly bayesian linear regression, to predict methane production one day ahead from full-scale AD while trained with lab-scale data. The application of these models to dynamic AD processes shall in the future be tested and possibly set the basis for stochastic model-based control of full-scale biogas reactors with minimal resources expenditure.




Introduction
Motivation – I
DBFZ
Need of training data for machine learning algorithms
Uncertainty in profitability for biogas plants
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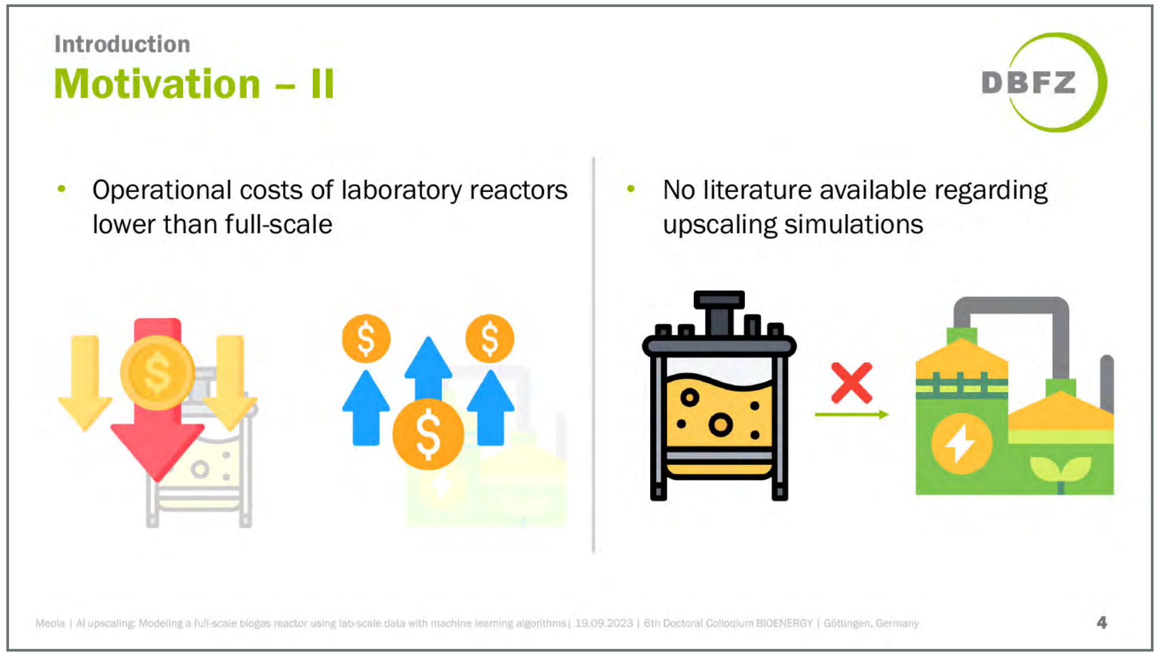
3


Introduction
Motivation – II
DBFZ
Operational costs of laboratory reactors lower than full-scale
No literature available regarding upscaling simulations
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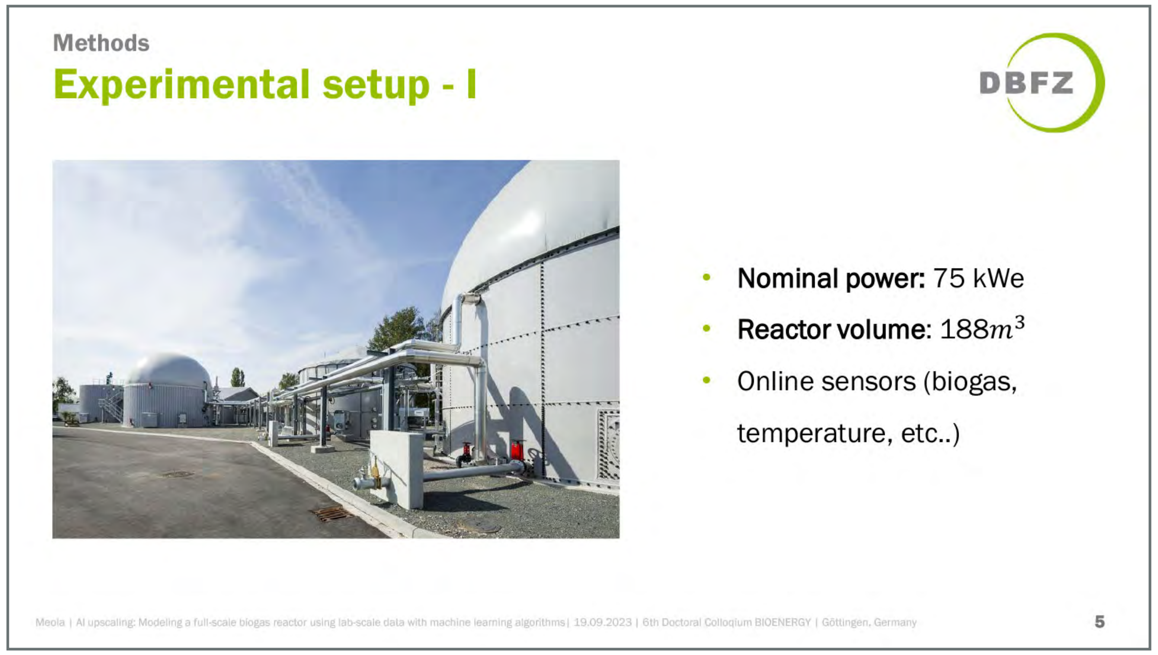
Methods
Experimental setup - I
DBFZ
Nominal power: 75 kWe
Reactor volume: $188m^3$
Online sensors (biogas, temperature, etc..)
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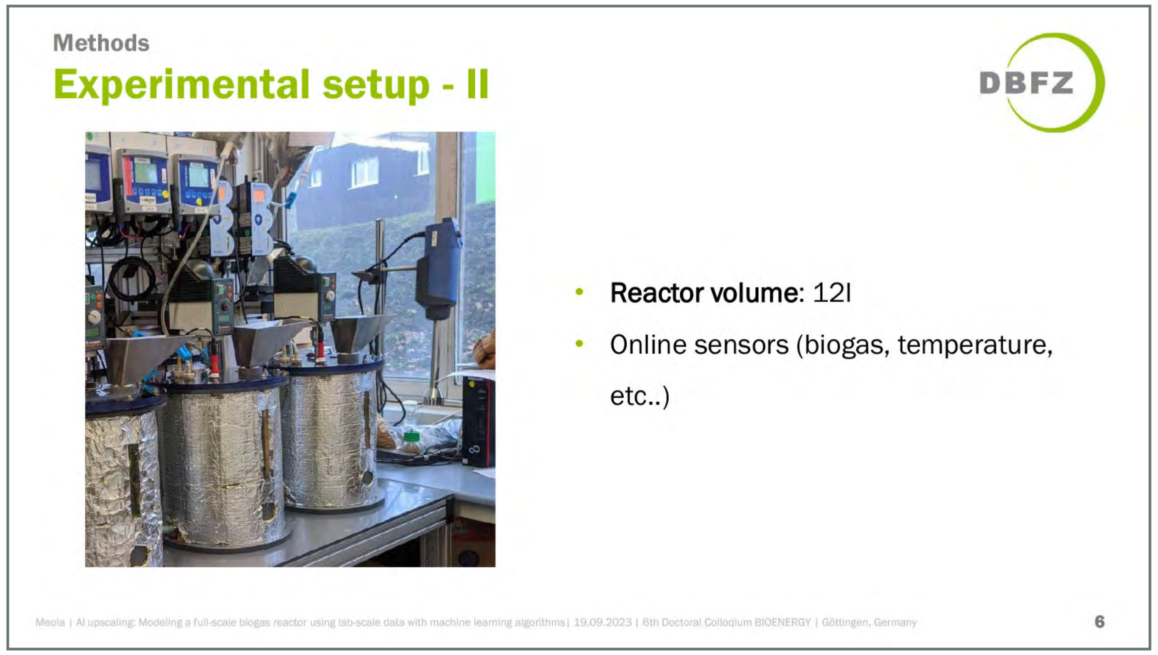
Methods
Experimental setup - II
DBFZ
Reactor volume: 12l
Online sensors (biogas, temperature, etc..)
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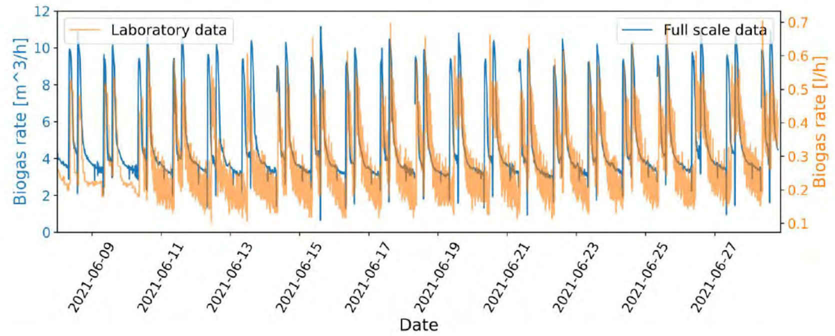
Methods

Data availability - I

DBFZ

- Observation distance: 24h
- Resolution: 1h
- OLR: 1.2 $\frac{kg_{vs}}{m^3 \cdot day}$
- Substrate: Mais silage and cow manure
- Duration: 55 days

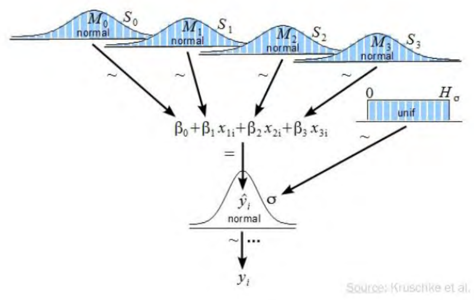


Methods

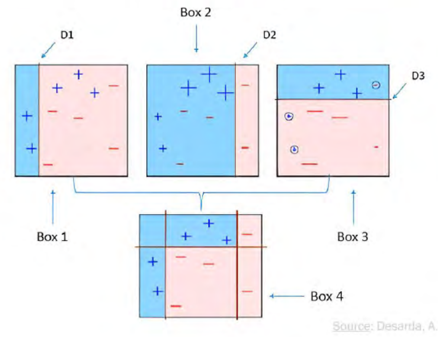
Prediction algorithms

DBFZ

Bayesian Ridge



AdaBoost Regressor



Methods

Data availability - II

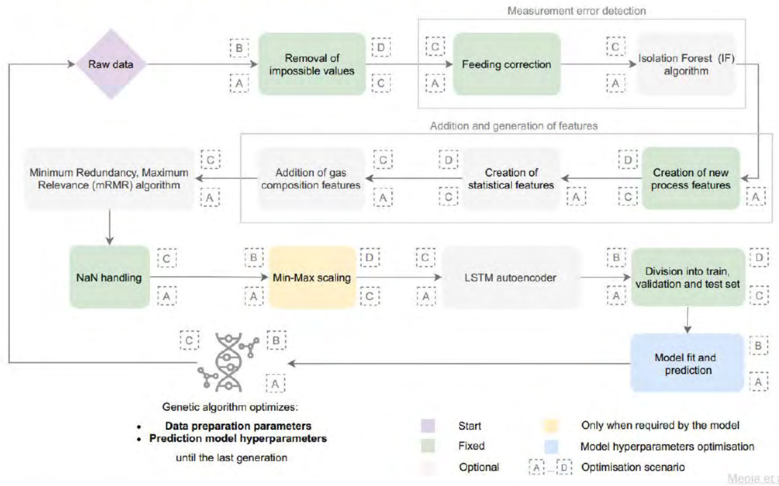
DBFZ

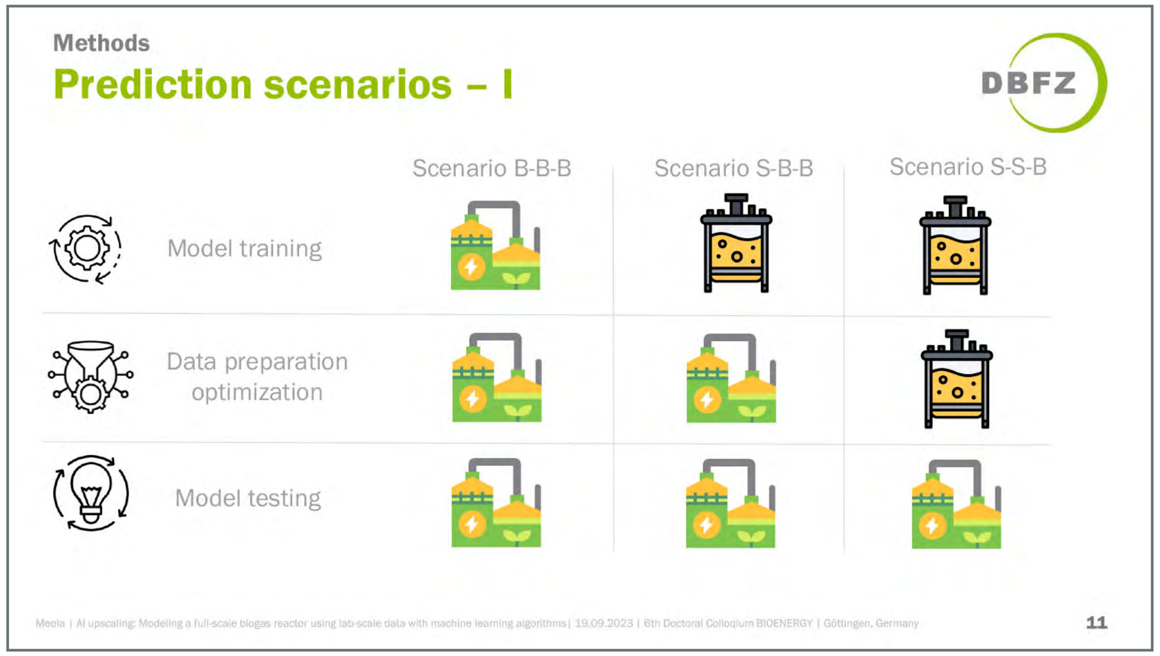
<table>
<tr><th></th><th>Full-scale dataset</th><th>Laboratory dataset</th></tr>
<tr><td>Biogas composition (CH4, CO2, H2S, H2, O2)</td><td>5 variables
2h-resolution</td><td>5 variables
24h-resolution</td></tr>
<tr><td>Biogas rate</td><td colspan="2">1 variable
1h-resolution</td></tr>
<tr><td>Substrate composition (Lab analytics, feed quantity..)</td><td colspan="2">6 variables
1h-resolution</td></tr>
<tr><td>Operational parameters (temperature, pressure..)</td><td colspan="2">4 variables
1h-resolution</td></tr>
<tr><td>Digestate composition (VS, pH..)</td><td colspan="2">6 variables
1w-resolution</td></tr>
</table>

Methods

Optimisation Procedure

DBFZ




Methods
Prediction scenarios – I
DBFZ
Scenario B-B-B
Scenario S-B-B
Scenario S-S-B
Model training
Data preparation optimization
Model testing
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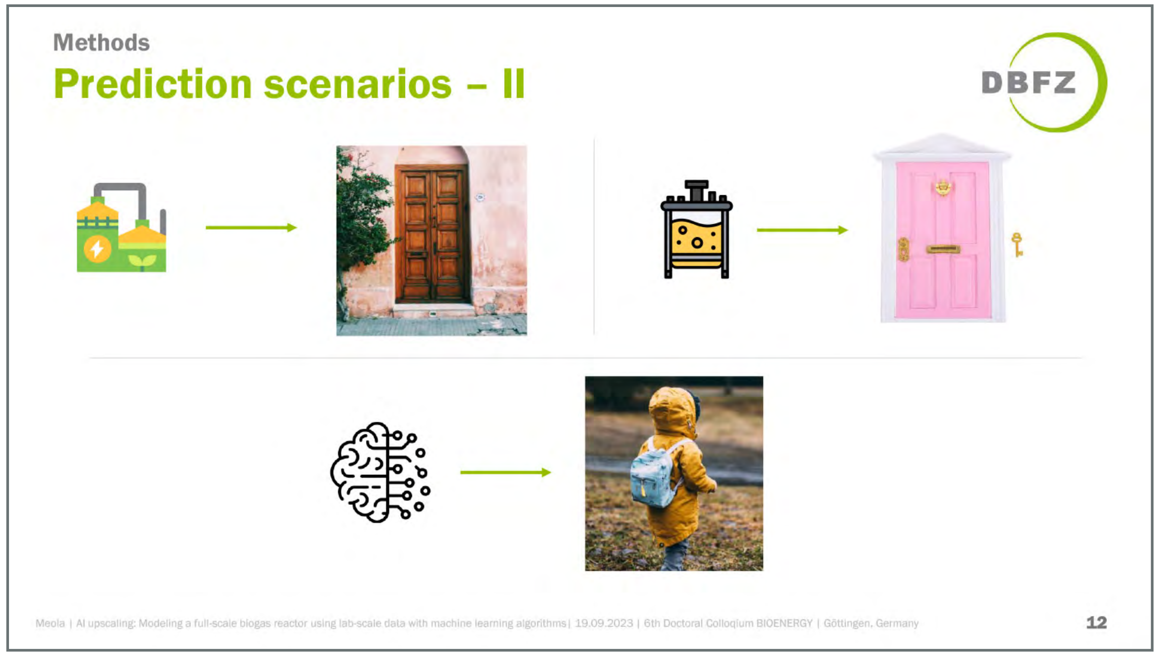
Methods
Prediction scenarios – II
DBFZ
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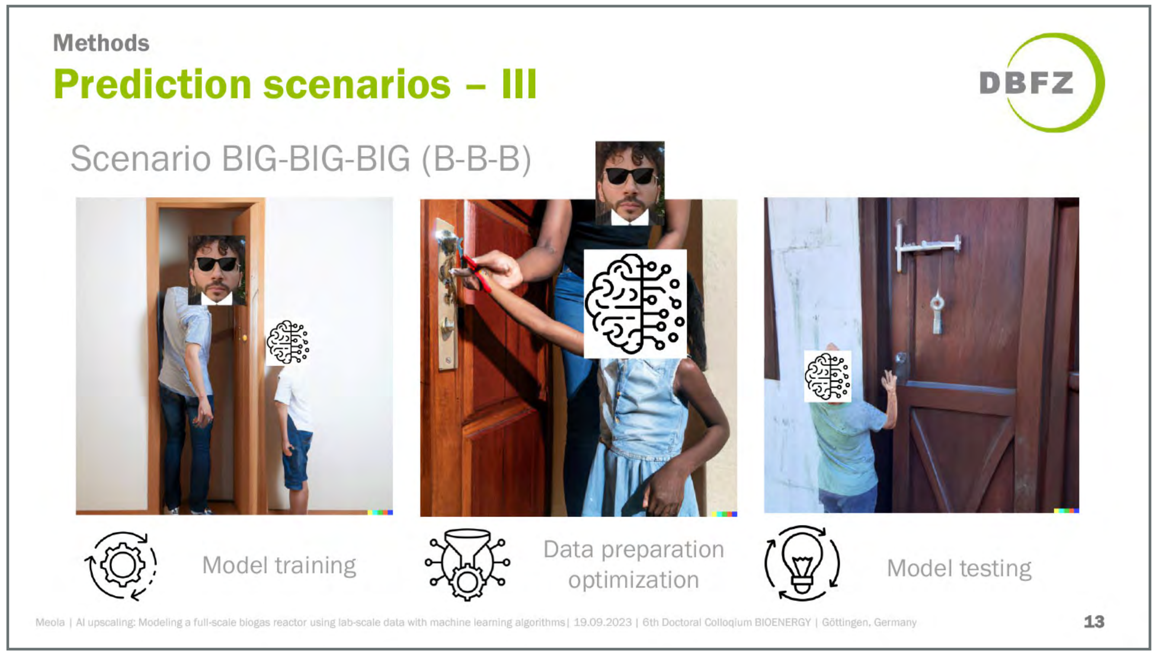
Methods
Prediction scenarios – III
DBFZ
Scenario BIG-BIG-BIG (B-B-B)
Model training
Data preparation optimization
Model testing
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Methods
Prediction scenarios – IV
DBFZ
Scenario SMALL-BIG-BIG (S-B-B)
Model training
Data preparation optimization
Model testing
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Methods

Prediction scenarios – V

DBFZ

Scenario SMALL-SMALL-BIG (S-S-B)

Model training

Data preparation optimization

Model testing

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Results

Results - Overview

DBFZ

Scenario	Validation results	Best Test results	Realistic test results
B-B-B	42%	18%	31%
S-B-B	46%	58%	94%
S-S-B	43%	82%	119%

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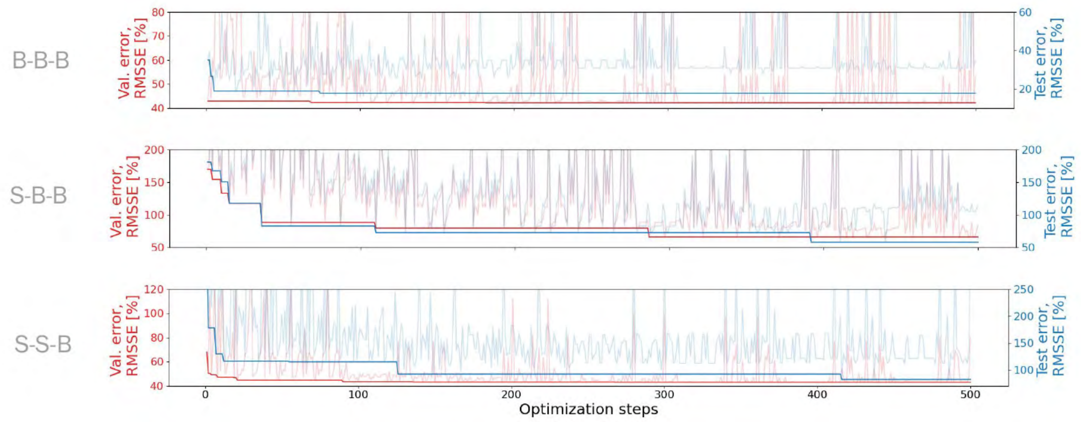
Results

Results – Optimization process

DBFZ



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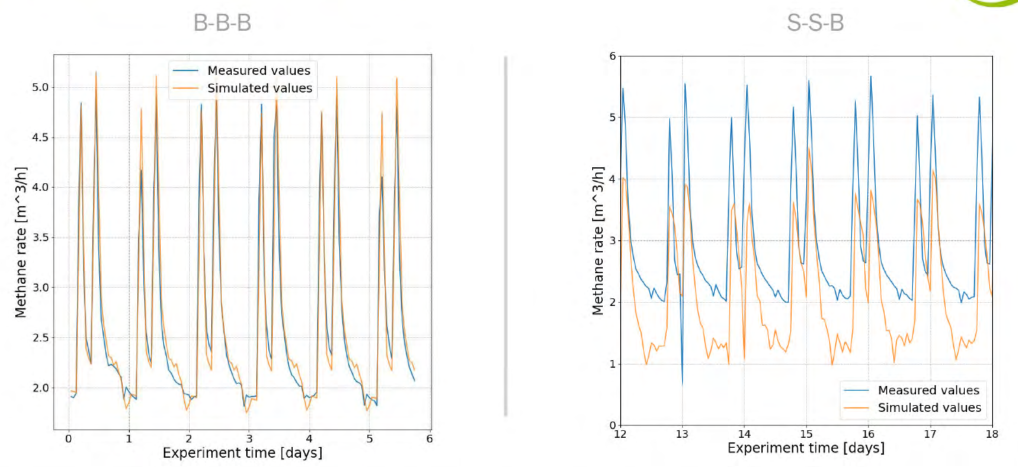
Results

Results – Simulations

DBFZ



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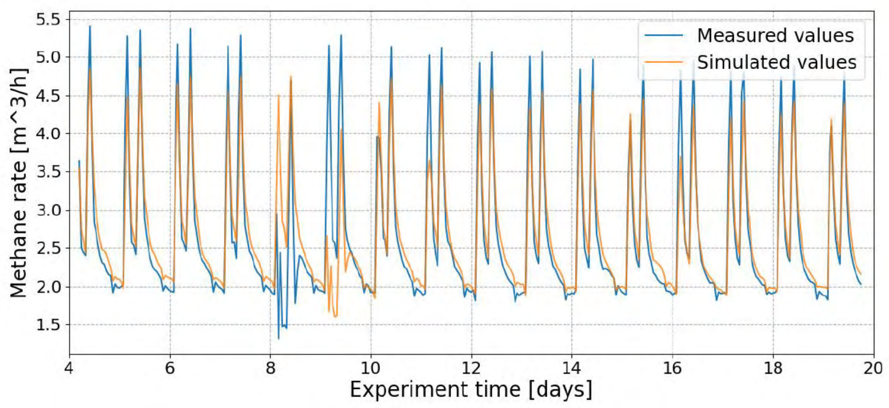
Results

Results – Simulations

S-B-B



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Results

Used features

B-B-B

Many features including Methane production at previous step (24h before), Liquid and Solid Feed, OLR, Temperature, TS/VS substrate measurements…

S-B-B

- Methane production at previous step (24h before)
- Statistical values derived from biogas prouction rate
- Time of the day

S-S-B

- Methane production at previous steps (until 24h before)
- Statistical values derived from biogas prouction rate
- Total feed
- OLR
- Active volume

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Conclusions

Conclusions

- AI is able to predict biogas production from industrial-scale reactor when trained with lab-scale reactor data
- Validation data needs to be part of full-scale dataset
- Only 17 days of full-scale data are needed for precise prediction

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Conclusions

Outlook

- Scenario S-S-B might work better with more complex models (LSTM neural networks)
- A scaling factor might be implemented for better results
- A longer training dataset might improve model prediction performances
- More laboratory analysis on the substrates might improve model accuracy

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Shabnam Pouresmaeil, Deutsches Biomasseforschungszentrum

Biochar-based cathode catalyzing H_2 evolution in methane-producing bioelectrochemical systems (CH_4-BES)

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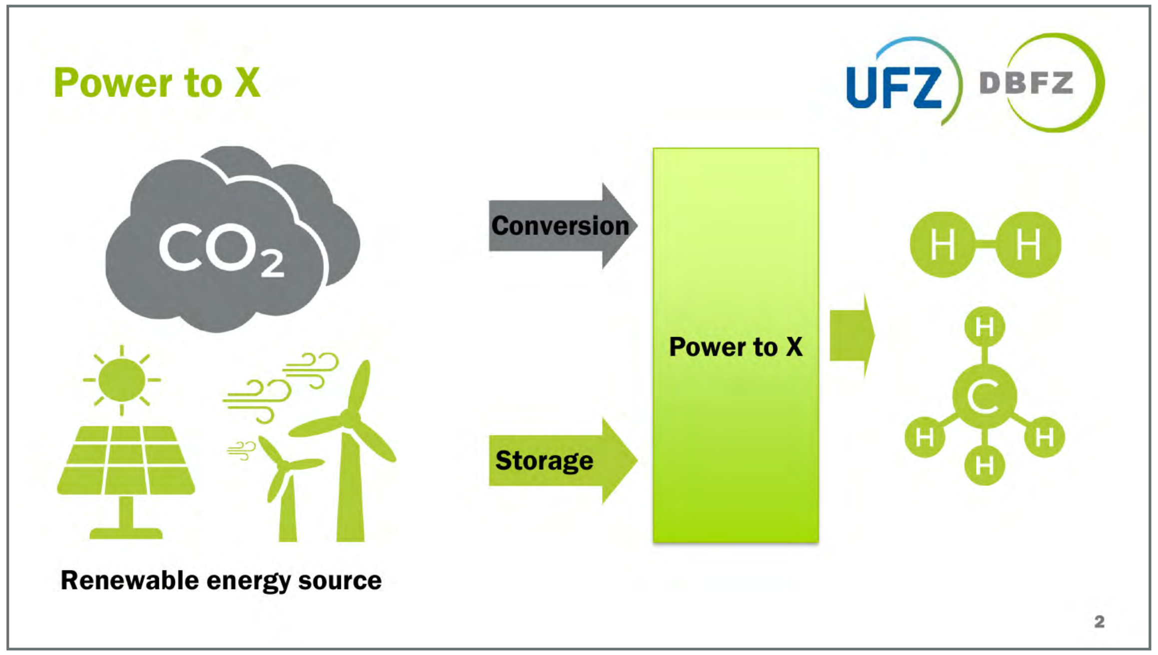
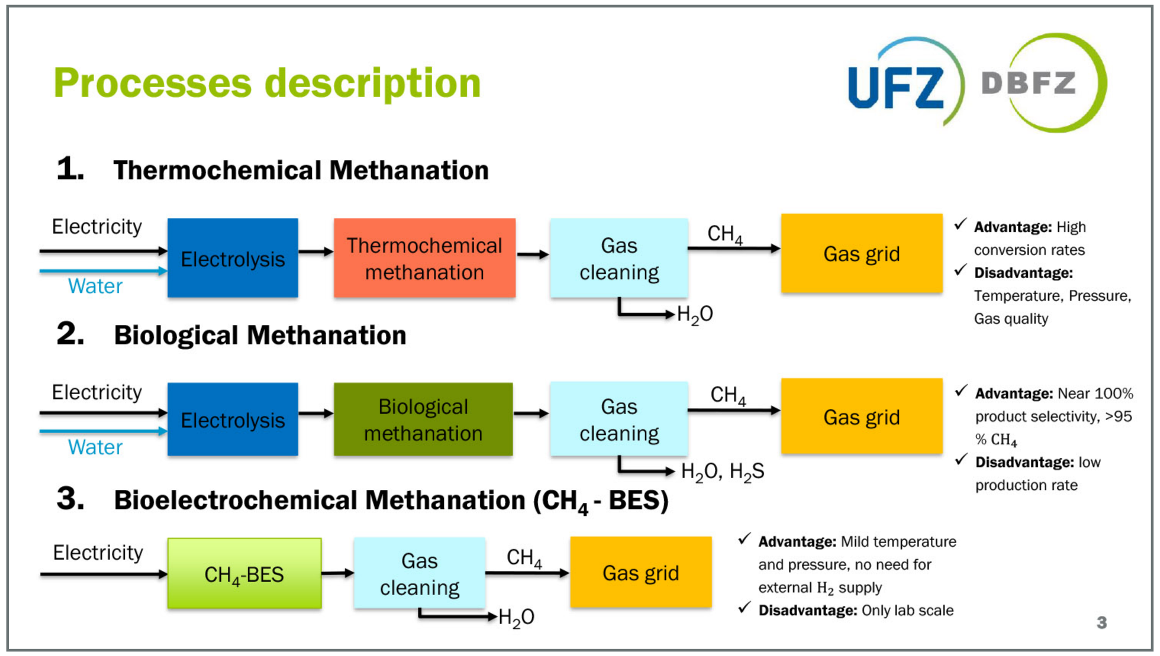
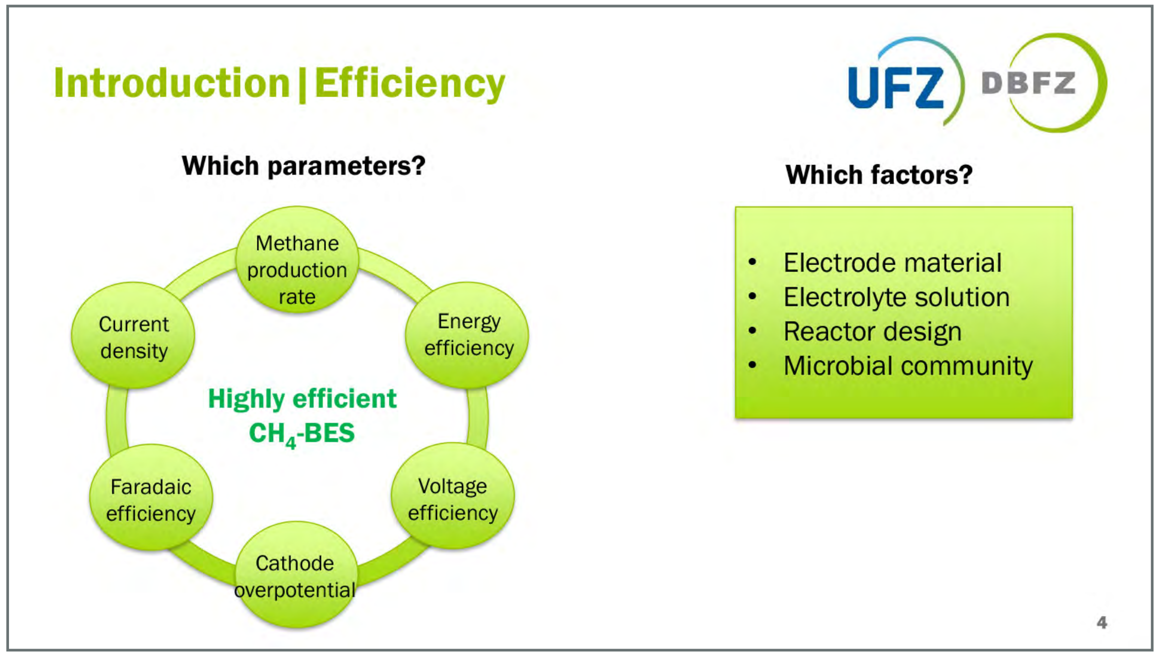
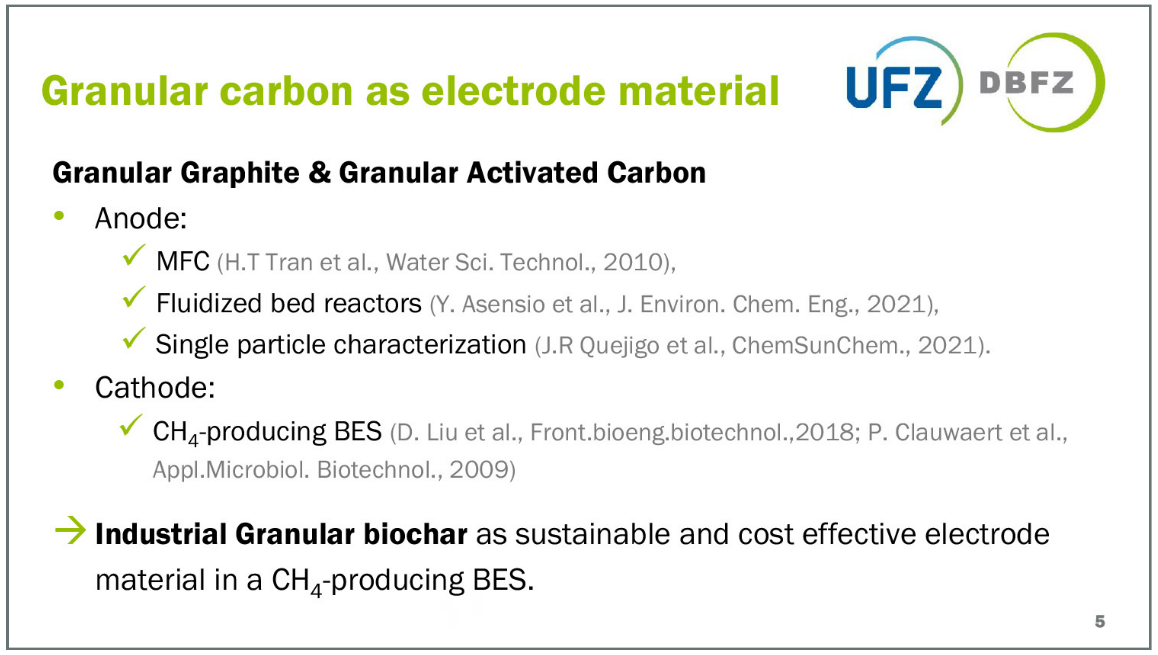
Methane-producing bio-electrochemical systems (CH_4-BES) have become a promising technology to capture and convert CO_2. Research on CH_4- BES shows its potential advantages over bio-methanation technologies, where a bioreactor is directly fed with H_2 and CO_2 or biogas. In a CH_4-BES, H_2 is generated directly in the bioreactor at the cathode in close proximity to hydrogenotrophic methanogens. Consequently, challenges related to the low solubility and the mass transfer of H_2 in the liquid phase can be mitigated. Furthermore, external storage and transport of H_2 is avoided as it is produced in situ and at a rate sufficient for microbial conversion. Most recent technoeconomic analysis shows high costs due to expensive bio-electrochemical reactor components, such as electrode material.

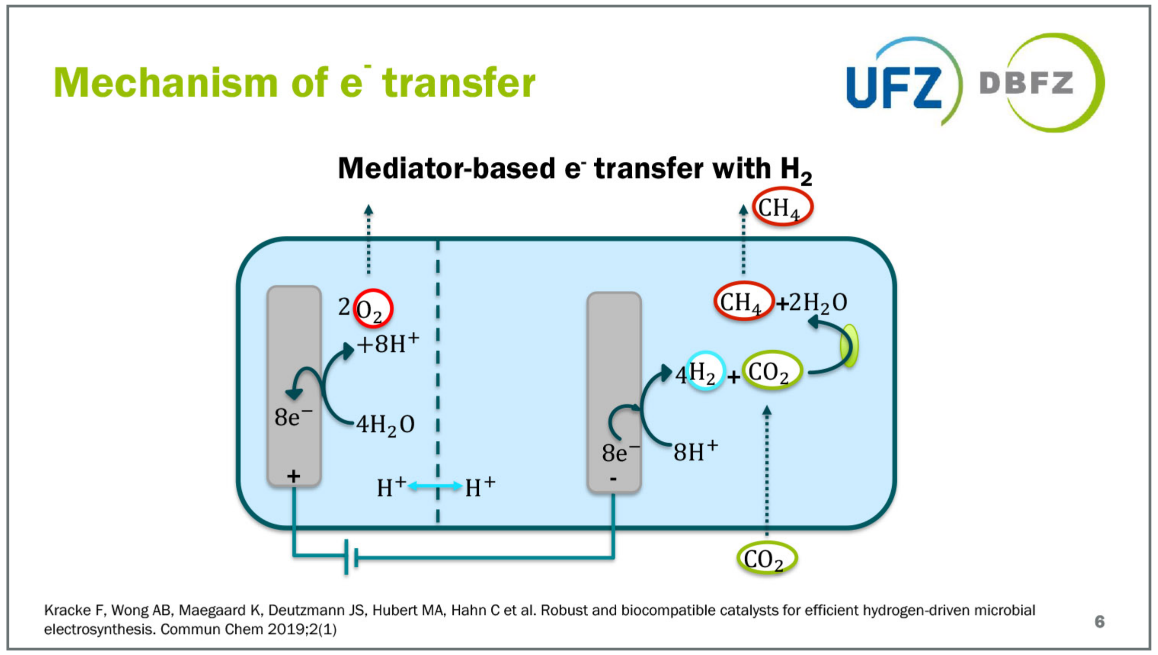
Biochar is a cheap biomass-derived black carbon, produced by e.g. pyrolysis of woody biomass, which has been widely studied in wastewater treatment, gas separation, and soil remediation. The high performance of biochar as an electrode material was reported by some studies; however, the systematic characterization of commercial biochar granules for biocathodes is missing. Therefore, the main aims of this study were first, the electrochemical characterization of commercial granular biochar-based cathodes in term of overpotential for hydrogen evolution reaction (HER) and second, the physicochemical characterization of biochar granules (BG) to investigate the root reasons of incongruity in their electrochemical performance. Pyrolysis process and the nature of wood affects produced biochar in terms of, specific surface area, and degree of carbonization which explain the electrochemical performance of material. BG produced via pyrolysis from hardwood species at 740 °C (BEW740) was selected as the best-performing cathode. Cyclic voltammetry (CV) tests revealed that its overpotential is 2.5 orders of magnitude less than granular graphite-based cathode at low current densities, -1mA cm-2. Here, we showed that BEW740 has higher carbon content; however, there is no linear correlation between the overpotential for HER and surface area of BGs. The knowledge achieved from this study will provide a scientific basis to select and/or produce high-performance biochar granules for applications in cathodic reactions.

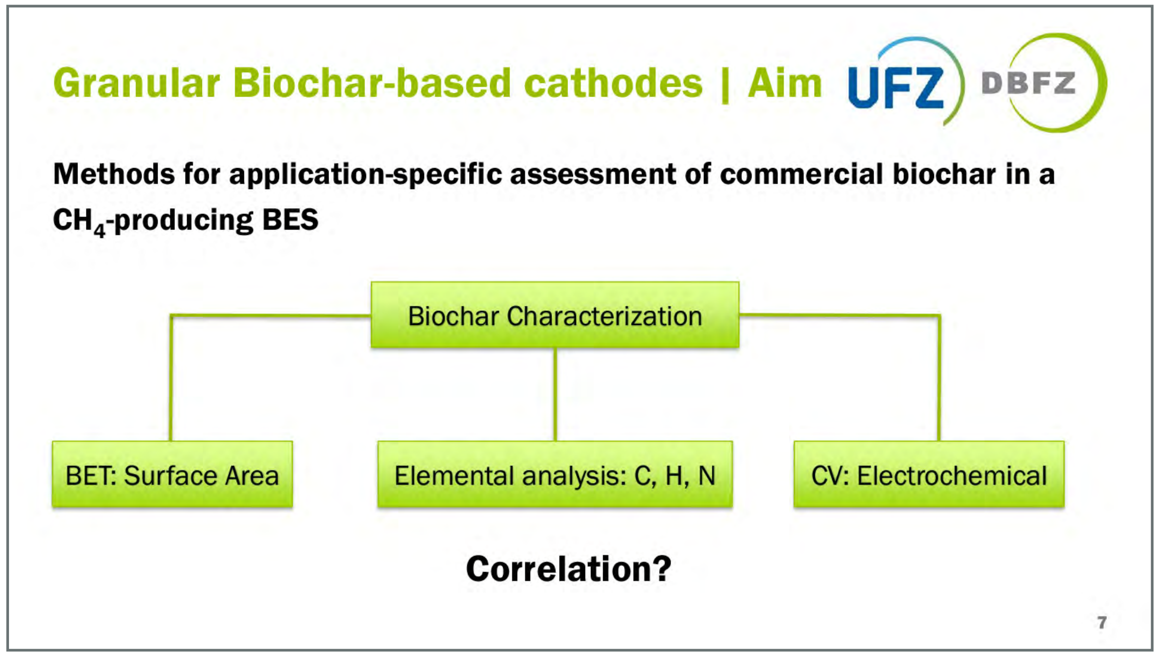


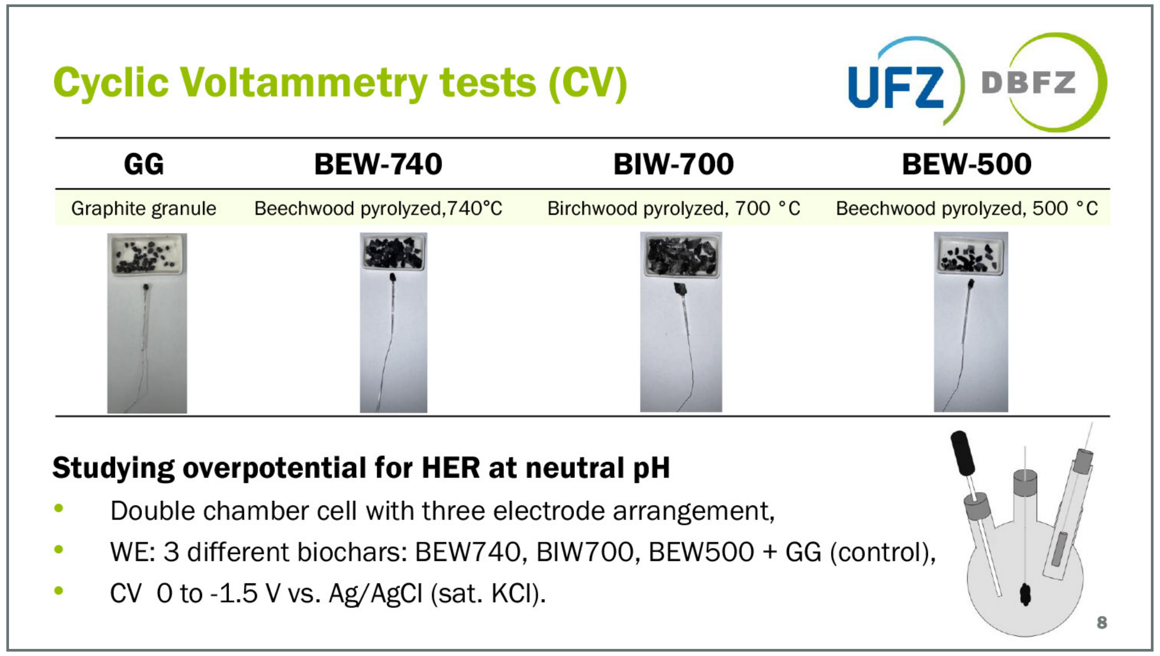

Processes description
UFZ DBFZ
1. Thermochemical Methanation
Electricity
Water
Electrolysis
Thermochemical methanation
Gas cleaning
CH_4
H_2O
Gas grid
Advantage: High conversion rates
Disadvantage: Temperature, Pressure, Gas quality
2. Biological Methanation
Electricity
Water
Electrolysis
Biological methanation
Gas cleaning
CH_4
H_2O, H_2S
Gas grid
Advantage: Near 100% product selectivity, >95 % CH_4
Disadvantage: low production rate
3. Bioelectrochemical Methanation (CH_4 - BES)
Electricity
CH_4-BES
Gas cleaning
CH_4
H_2O
Gas grid
Advantage: Mild temperature and pressure, no need for external H_2 supply
Disadvantage: Only lab scale
3

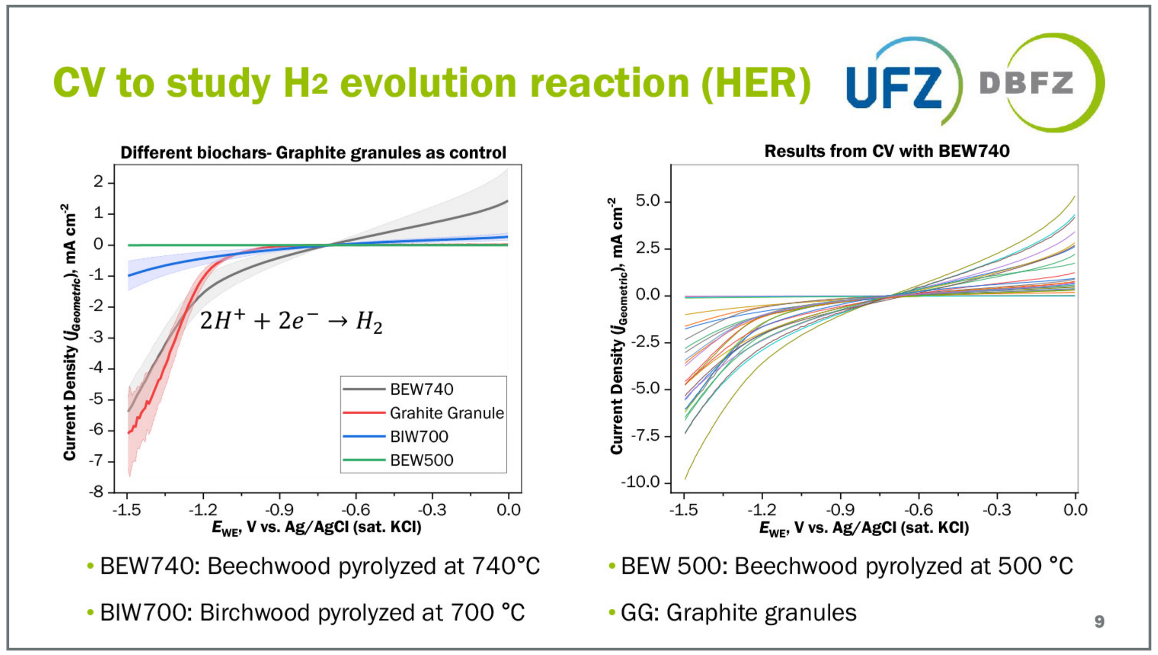

Introduction | Efficiency
UFZ DBFZ
Which parameters?
Methane production rate
Energy efficiency
Voltage efficiency
Cathode overpotential
Faradaic efficiency
Current density
Highly efficient CH_4-BES
Which factors?
• Electrode material
• Electrolyte solution
• Reactor design
• Microbial community
4

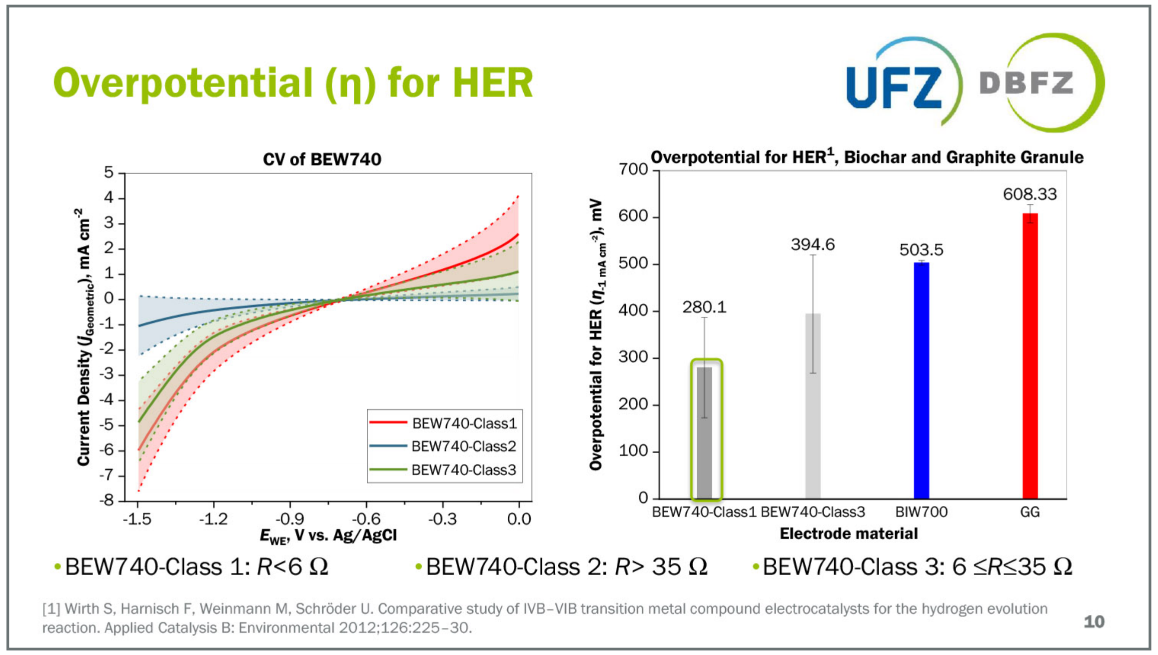

Granular carbon as electrode material
UFZ DBFZ
Granular Graphite & Granular Activated Carbon
• Anode:
✓ MFC (H.T Tran et al., Water Sci. Technol., 2010),
✓ Fluidized bed reactors (Y. Asensio et al., J. Environ. Chem. Eng., 2021),
✓ Single particle characterization (J.R Quejigo et al., ChemSunChem., 2021).
• Cathode:
✓ CH_4-producing BES (D. Liu et al., Front.bioeng.biotechnol.,2018; P. Clauwaert et al., Appl.Microbiol. Biotechnol., 2009)
→ Industrial Granular biochar as sustainable and cost effective electrode material in a CH_4-producing BES.
5

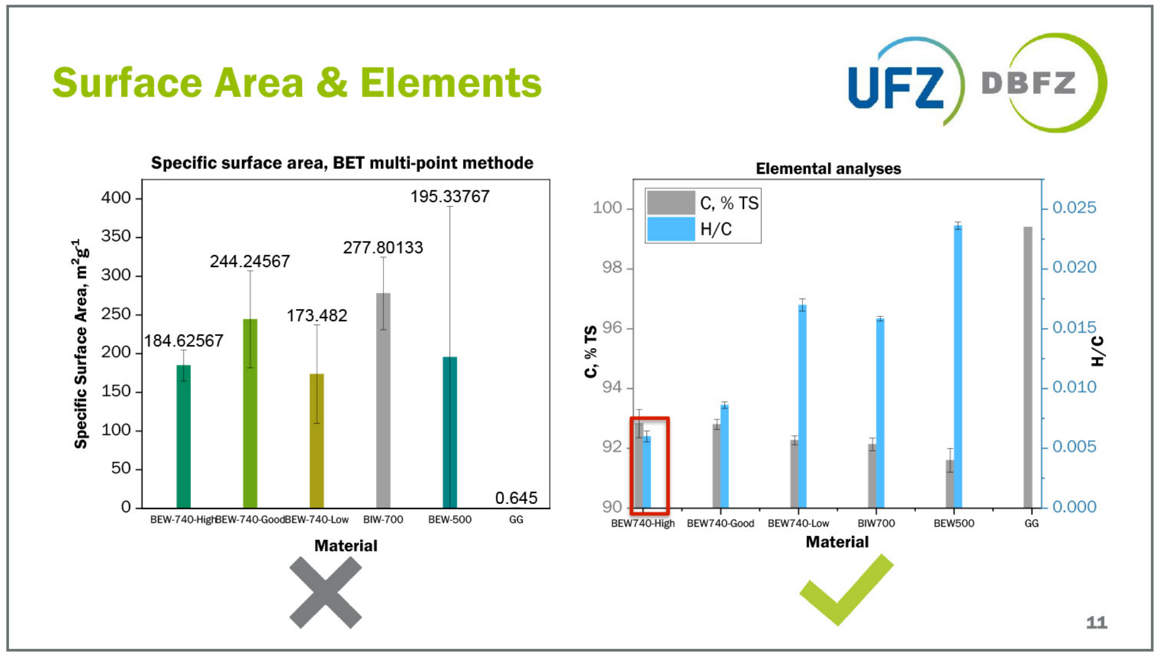

Mechanism of e⁻ transfer
UFZ DBFZ
Mediator-based e⁻ transfer with H_2
CH_4
$2O_2$
$+8H^+$
$8e^-$
$4H_2O$
+
H^+
H^+
CH_4 $+2H_2O$
$4H_2$ + CO_2
$8e^-$
$8H^+$
-
CO_2
Kracke F, Wong AB, Maegaard K, Deutzmann JS, Hubert MA, Hahn C et al. Robust and biocompatible catalysts for efficient hydrogen-driven microbial electrosynthesis. Commun Chem 2019;2(1)
6


Granular Biochar-based cathodes | Aim
UFZ
DBFZ
Methods for application-specific assessment of commercial biochar in a CH4-producing BES
Biochar Characterization
BET: Surface Area
Elemental analysis: C, H, N
CV: Electrochemical
Correlation?
7

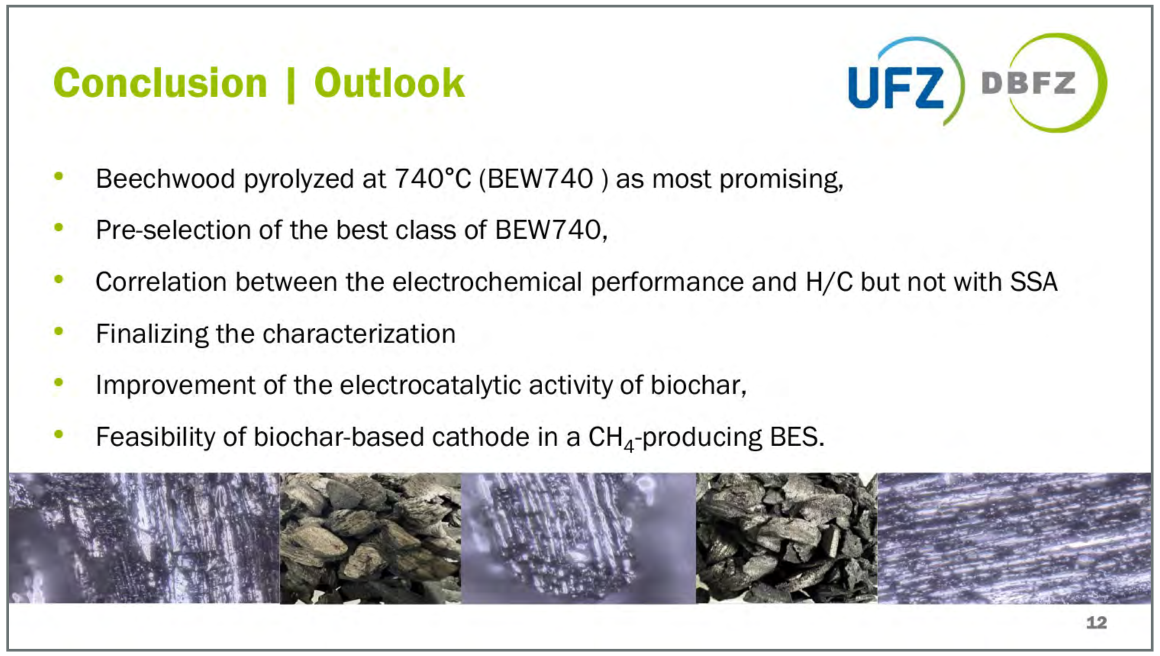

Cyclic Voltammetry tests (CV)
UFZ
DBFZ
GG
BEW-740
BIW-700
BEW-500
Graphite granule
Beechwood pyrolyzed,740°C
Birchwood pyrolyzed, 700 °C
Beechwood pyrolyzed, 500 °C
Studying overpotential for HER at neutral pH
Double chamber cell with three electrode arrangement,
WE: 3 different biochars: BEW740, BIW700, BEW500 + GG (control),
CV 0 to -1.5 V vs. Ag/AgCl (sat. KCl).
8


CV to study H2 evolution reaction (HER)
UFZ
DBFZ
Different biochars- Graphite granules as control
Results from CV with BEW740
Current Density (jGeometric), mA cm-2
EWE, V vs. Ag/AgCl (sat. KCl)
2H+ + 2e− → H2
BEW740
Grahite Granule
BIW700
BEW500
BEW740: Beechwood pyrolyzed at 740°C
BIW700: Birchwood pyrolyzed at 700 °C
BEW 500: Beechwood pyrolyzed at 500 °C
GG: Graphite granules
9


Overpotential (η) for HER
UFZ
DBFZ
CV of BEW740
Current Density (jGeometric), mA cm-2
EWE, V vs. Ag/AgCl
BEW740-Class1
BEW740-Class2
BEW740-Class3
Overpotential for HER1, Biochar and Graphite Granule
Overpotential for HER (η1 mA cm-2), mV
280.1
394.6
503.5
608.33
BEW740-Class1
BEW740-Class3
BIW700
GG
Electrode material
BEW740-Class 1: R<6 Ω
BEW740-Class 2: R> 35 Ω
BEW740-Class 3: 6 ≤R≤35 Ω
[1] Wirth S, Harnisch F, Weinmann M, Schröder U. Comparative study of IVB–VIB transition metal compound electrocatalysts for the hydrogen evolution reaction. Applied Catalysis B: Environmental 2012;126:225–30.
10


Surface Area & Elements
UFZ
DBFZ
Specific surface area, BET multi-point methode
Specific Surface Area, m²g⁻¹
184.62567
244.24567
173.482
277.80133
195.33767
0.645
BEW-740-High
BEW-740-Good
BEW-740-Low
BIW-700
BEW-500
GG
Material
Elemental analyses
C, % TS
H/C
BEW740-High
BEW740-Good
BEW740-Low
BIW700
BEW500
GG
Material
11


Deutsches Biomasseforschungszentrum
gemeinnützige GmbH
DBFZ
DAAD
UFZ
Thank you for your attention!
Shabnam.pouresmaeil@dbfz.de
Funding:
DAAD Deutscher Akademischer Austauschdienst German Academic Exchange Service


Conclusion | Outlook
UFZ
DBFZ
Beechwood pyrolyzed at 740°C (BEW740) as most promising,
Pre-selection of the best class of BEW740,
Correlation between the electrochemical performance and H/C but not with SSA
Finalizing the characterization
Improvement of the electrocatalytic activity of biochar,
Feasibility of biochar-based cathode in a CH4-producing BES.
12

Organizer:

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