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7TH DOCTORAL COLLOQUIUM

BIOENERGY & BIOBASED PRODUCTS

7TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

24TH/25TH SEPTEMBER, 2024

DBFZ, LEIPZIG

TAGUNGSREADER

#DOC2024

WWW.DOC-BIOENERGY.DE

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KEYNOTE DAY I

POSTERSESSION / POSTER SPEED PRESENTATION

WELCOME / GREETINGS

Welcome note from our patron, Prof. Dr. Daniela Thrän

Dear Participants of the 7th Doctoral Colloquium,

i would like to take this opportunity to thank you for your active participation in the 7th edition of our international Doctoral Colloquium BIOENERGY AND BIOBASED PRODUCTS, the networking event for young scientists in the field of bioenergy and bioeconomy.

Biomass is a valuable resource in a climate friendly future and can provide much more than energy. We have discussed this issue during the last Colloquia and also saw more and more cases of integrated production of biomaterials and bioenergy. The changed title of the event, we have decided, together with our extensive programme advisory board, in order to expand the focus of the colloquium to include the aspect of 'bio-based products' and thus also take into account the changed topics and developments in research, but also in industry, policy and societal perception. We have also endeavoured to integrate this aspect more strongly into the programme and thus make the Doctoral Colloquium even broader and more future-oriented in terms of content.

Last year, together with the University of Applied Sciences and Arts Hildesheim/Holzminden/Göttingen (HAWK), we were able to experience a very exciting programme of events with a variety of innovative research topics. Many thanks once again to Prof. Dr. Achim Loewen and his team!

This year's event once again took place in Leipzig at the DBFZ in keeping with tradition and offered a total of six sessions, an extensive poster session, two keynotes and a supporting programme with plenty of scope for new scientific findings and making new scientific contacts. This point in particular makes the Doctoral Colloquium BIOENERGY AND BIOBASED PRODUCTS an important event platform for you as young scientists.

Prof. Dr. Daniela Thrän (UFZ/University of Leipzig)

Our aim is to bring together future researchers, industry leaders and political decision-makers at an early stage in order to exchange knowledge and discuss research gaps and challenges. At the same time, networking between scientific institutions that are already intensively involved in bioenergy research must be further expanded.

As patron of the event, I would like to take this opportunity to thank you once again. Not only for your participation, but also for your intensive contribution on a professional scientific level, many new impulses and insights into your research topics. With your help, we have got the Doctoral Colloquium off to a good start. Against this background, I am delighted to be able to hand over the patronage to Prof. Michael Nelles.

With kind regards,
Prof. Dr. Daniela Thrän
Helmholtz Centre for Environmental Research / University of Leipzig

Greetings from Myrsini Christou (EERA Bioenergy)

Dear Participants of the 7th Doctoral Colloquium,

On behalf of the EERA Bioenergy, I would also like to welcome you in the International Doctoral Colloquium on Bioenergy and Biobased products that is being successfully organised by DBFZ for a 7th subsequent year.

For EERA Bioenergy, as an Alliance of European universities, technology centres and institutes involved in Excellent Research on sustainable bioenergy, it's of utmost importance to define strategic areas of research and the key questions that need further research efforts, in order to meet the ambitious targets of the EU policies (Fit for 55, REPowerEU, ReFuelEU Aviation and FuelEU Maritime).

For this purpose, a position paper '**Bioenergy, biogas and biofuels: Research and innovation gaps in the EU**' was prepared by our members and published in June 2024.
As this event is followed by you scientists in the field of bioenergy I take the opportunity to list a few takeaway messages from our position paper on key energy topics we have identified. For further reading I invite you to visit http://www.eera-bioenergy.eu/publications/#position-paper and send us your comments.

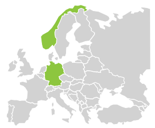
- Bioenergy (power, heat, fuels) will always be an integral part of optimised biomass valorisation strategies, either being the main product in bioenergy/biofuel-based biorefineries or being secondary product(s) in bioproducts-based biorefineries.
- Defossilisation means that more biobased carbon is needed. Too often the focus is on maximizing carbon yield and the option of CO_2 sequestration or biochar use as a means towards negative emissions is forgotten.
- When developing bioenergy systems it shouldn't be forgotten that materials and energy go hand in hand; thus production of biofuels with biobased products should be further addressed.
- To meet future biomass demands required in the various sectors of the European biobased economy, European non-food crops, aquatic feedstocks and agro- process and post-consumer residues should be used circularly and sustainably. Also, sustainably sourced non-European biomass feedstocks should be made available to ensure security of supply. Biomass commodities, or bioenergy carriers, made from a wide range of feedstocks can mobilise larger shares of biomass to support the large biorefinery plants.
- Access to commercial data and proper upscaling of technologies will increase the credibility of LCA studies, which should also consider the future technological changes in the value chains.
- Public awareness of bioenergy in Europe is low, as compared to other renewables. Some of the main concerns are related to water scarcity and competition with existing food supply and price.

Myrsini Christou (EERA Bioenergy)

I hope you enjoy the event, gain knowledge and inspirational insights, and build creative collaborations.

Myrsini Christou
EERA Bioenergy

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	5st Doctoral Colloquium BIOENERGY 2022	6nd Doctoral Colloquium BIOENERGY 2023	7nd Doctoral Colloquium BIOENERGY 2024
Initiator and host: DBFZ, Leipzig	Host: FAU, Nuremberg	Host: DBFZ, Leipzig	Host: KIT, Karlsruhe	Host: DBFZ, Leipzig	Host: HAWK, Goettingen	Host: DBFZ, Leipzig
71 Participants	51 Participants	185 Participants	70 Participants	75 Participants	42 Participants	85 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	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	Participants from Austria, China, Colombia, Denmark, Germany, Iran, Italy, Mali, Sweden and Switzerland
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	Scientific Advisory Board 46 Members representing 37 Institutions	Scientific Advisory Board 46 Members representing 37 Institutions	Scientific Advisory Board 46 Members representing 37 Institutions

7TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Impressions



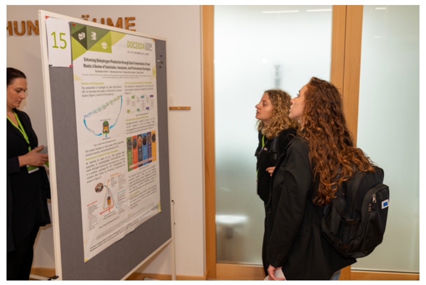


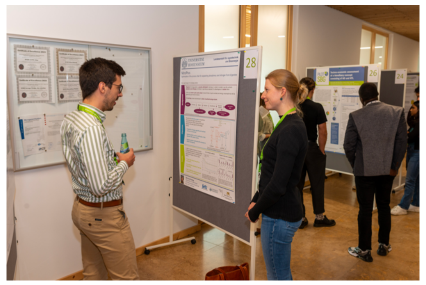












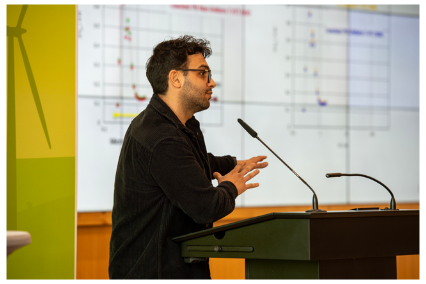














KEYNOTE DAY I

7TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Sina Leipold, Helmholtz Centre for Environmental Research

Turbulent Waters: Can We Navigate Narratives of Sustainability Transformation?

Prof. Dr. Sina Leipold
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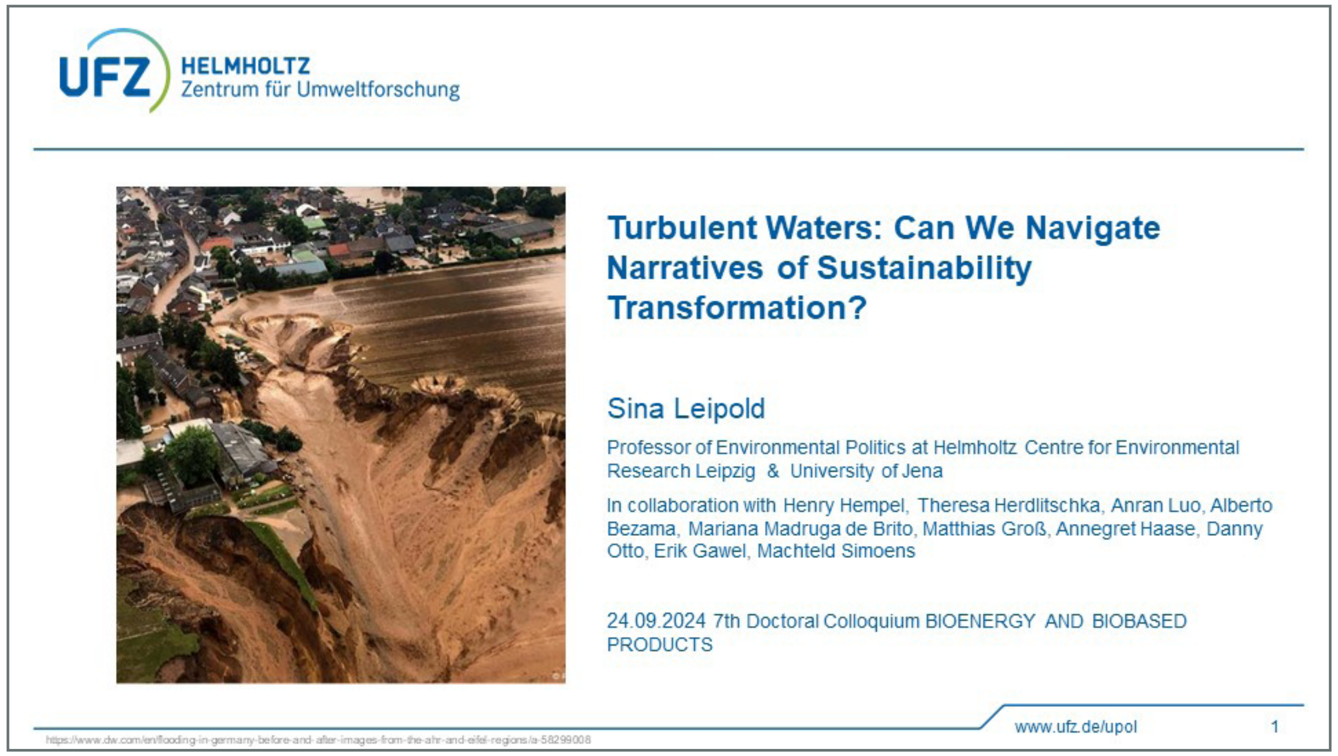
04318 Leipzig
Phone: +49 (0)341 235 - 1215
E-Mail: sina.leipold@ufz.de

Keywords: Strategies, Narratives, Sustainability, Transformation

Narratives guide us like currents through the turbulent waters of social, political and ecological change. This talk highlights how actors from business, civil society, science and politics can use strategic practices to skillfully navigate narratives or react to stormy events to build new dams and direct the narratives of the future. At the same time, the talk warns of the dangers of unpredictable waters that can sweep away dams and canals, along with their architects.



What are narratives anyway?

A simple story that condenses, structures and gives meaning to complex information

(e.g. Foucault 1971, Hajer 1995)

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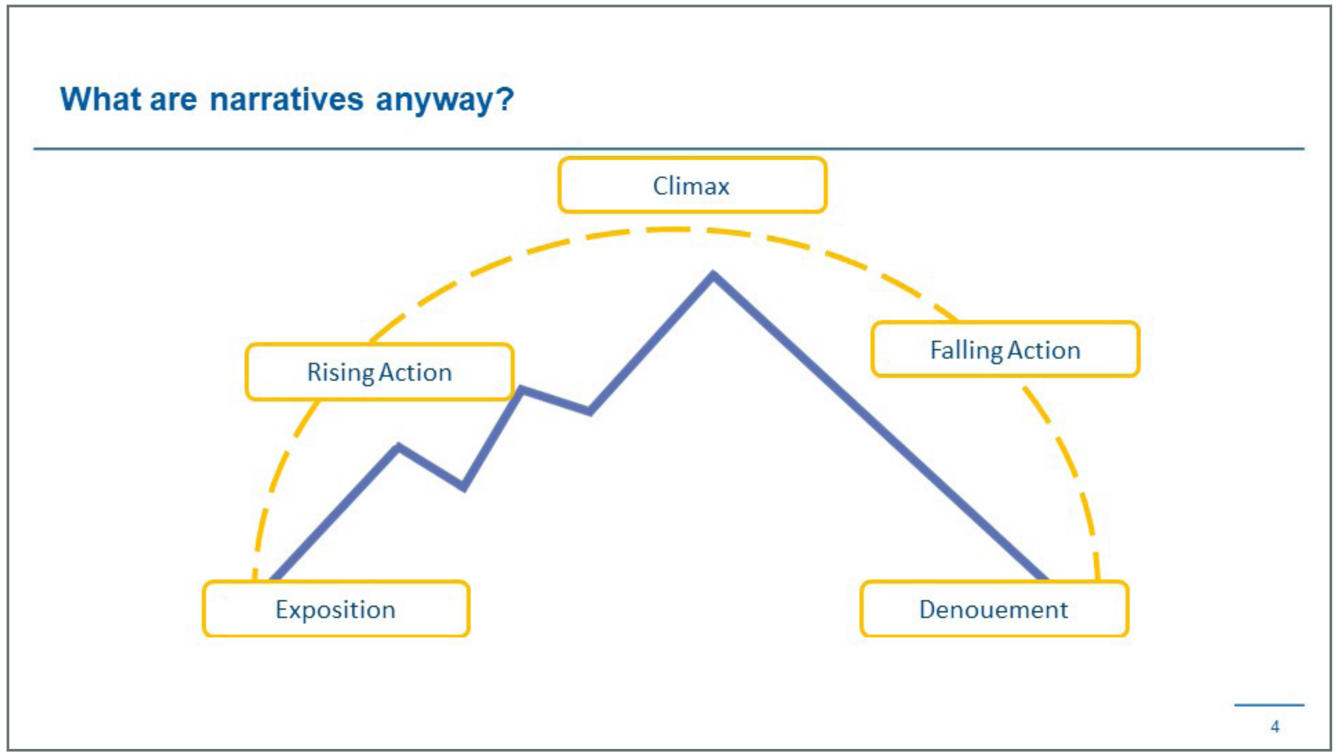

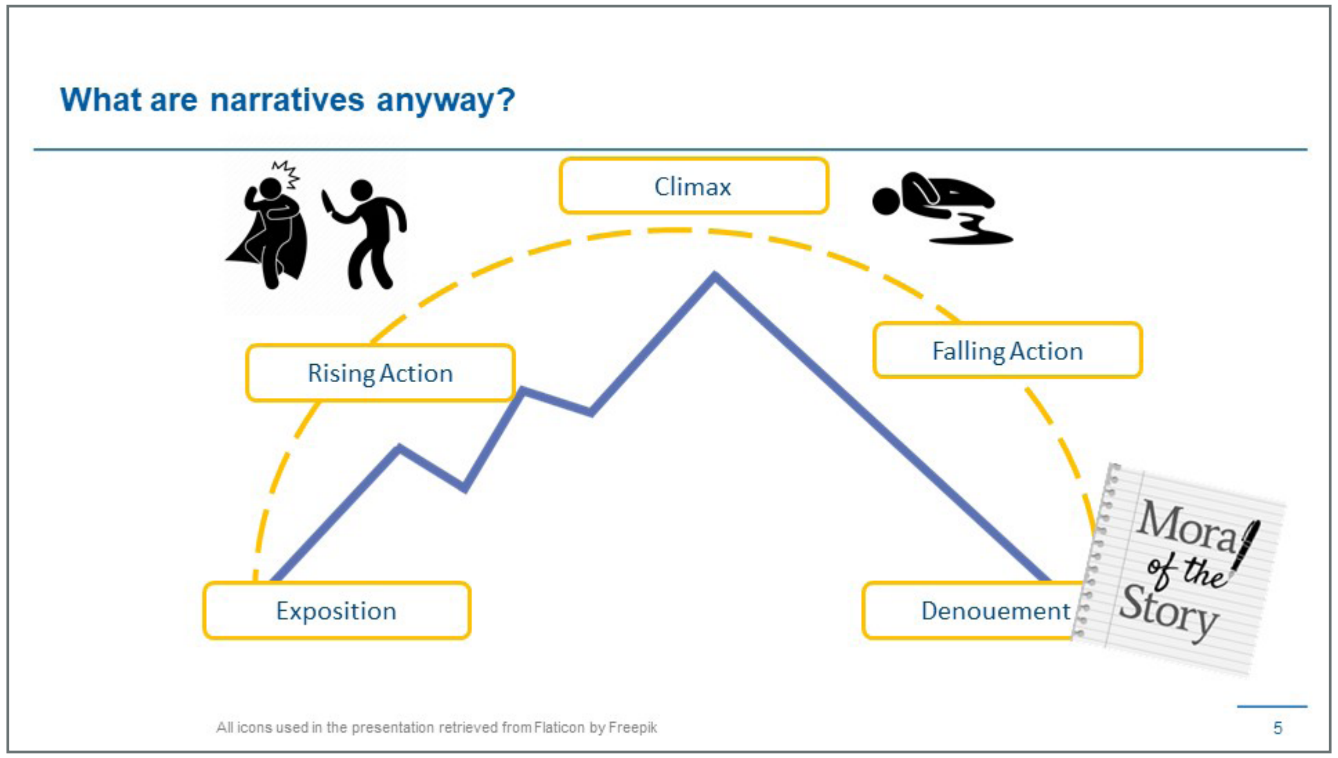

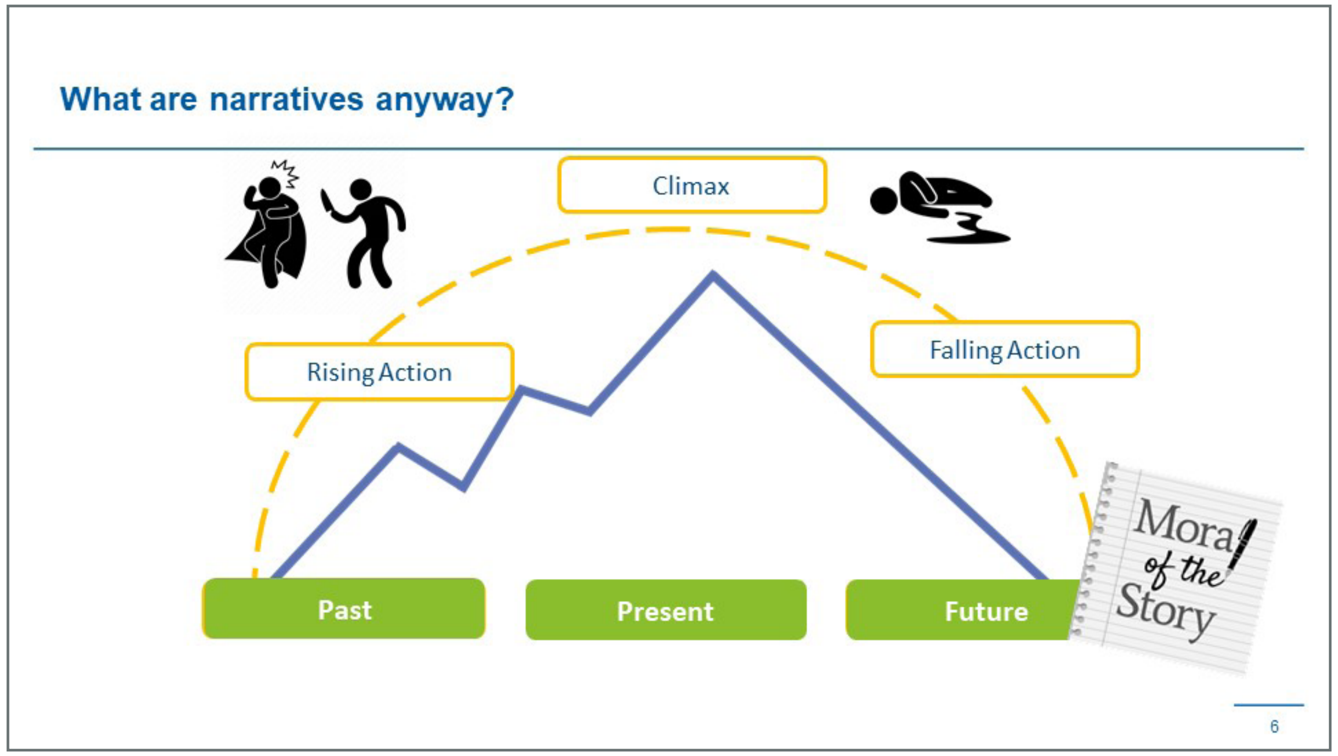

Why should I care?

- Most effective communication tool (Lakoff & Johnson 1980, Dahlstrom 2014)
- They are everywhere around us – in society & science
- Like river currents, not always visible but powerful and sometimes dangerous

https://www.caryinstitute.org/eco-inquiry/teaching-materials/hudson-river-ecology/natural-history-hudson-river/how-much-water

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Why should I care?

- Help navigate social, political, and environmental changes
- Fundamental change in mindsets → Change in policy & practice
- Can either facilitate or hinder change (e.g., legitimize or contest policies)

Weland et al. (2018); Korten (2015)

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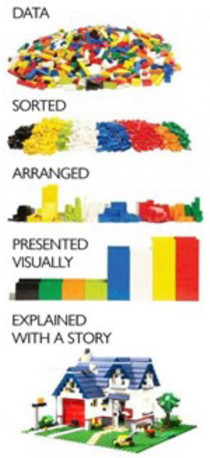
Why should I care?

- Help you explain your research



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Why should I care?

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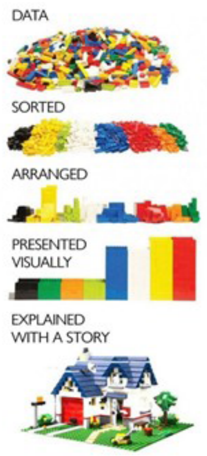

- Situate your research in the "ocean" of science
- Identify its strengths and limitations
- Guide you to new "coasts"

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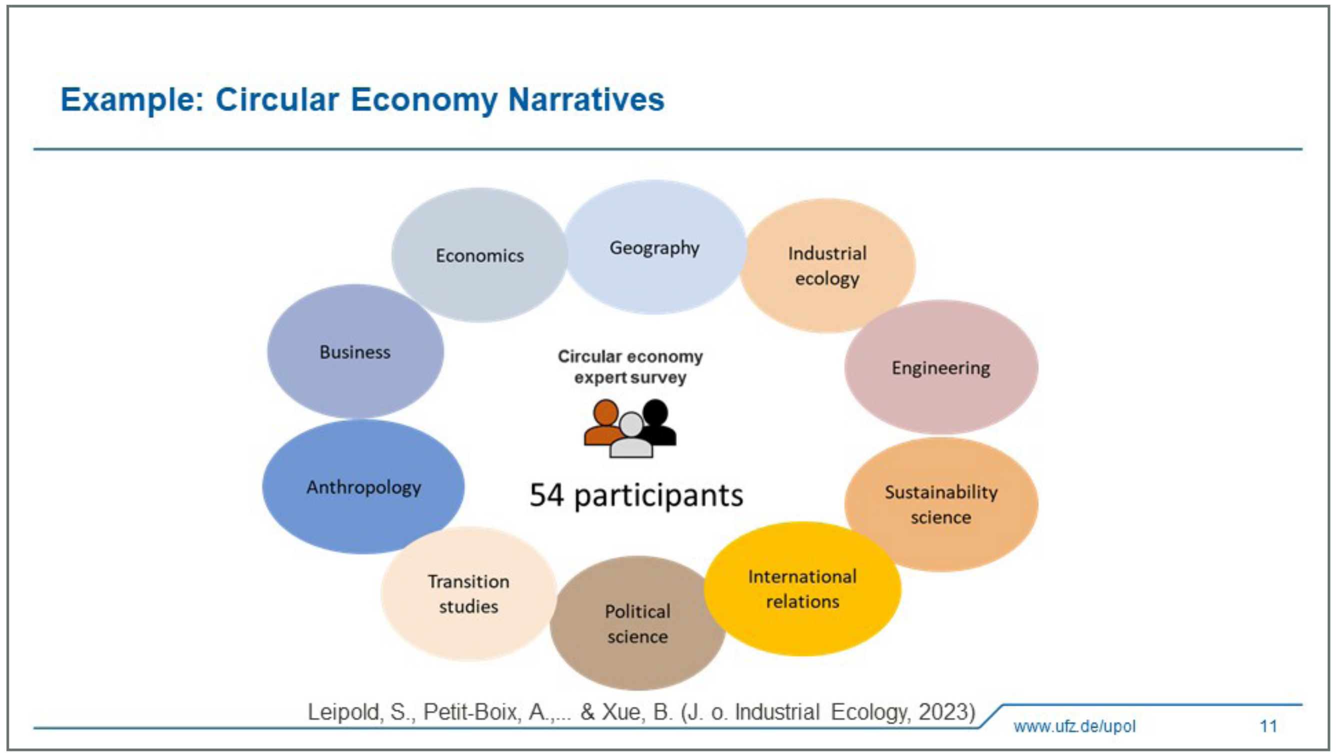
Example: Circular Economy Narratives
Economics
Geography
Industrial ecology
Business
Circular economy expert survey
Engineering
Anthropology
54 participants
Sustainability science
Transition studies
Political science
International relations
Leipold, S., Petit-Boix, A.,... & Xue, B. (J. o. Industrial Ecology, 2023)
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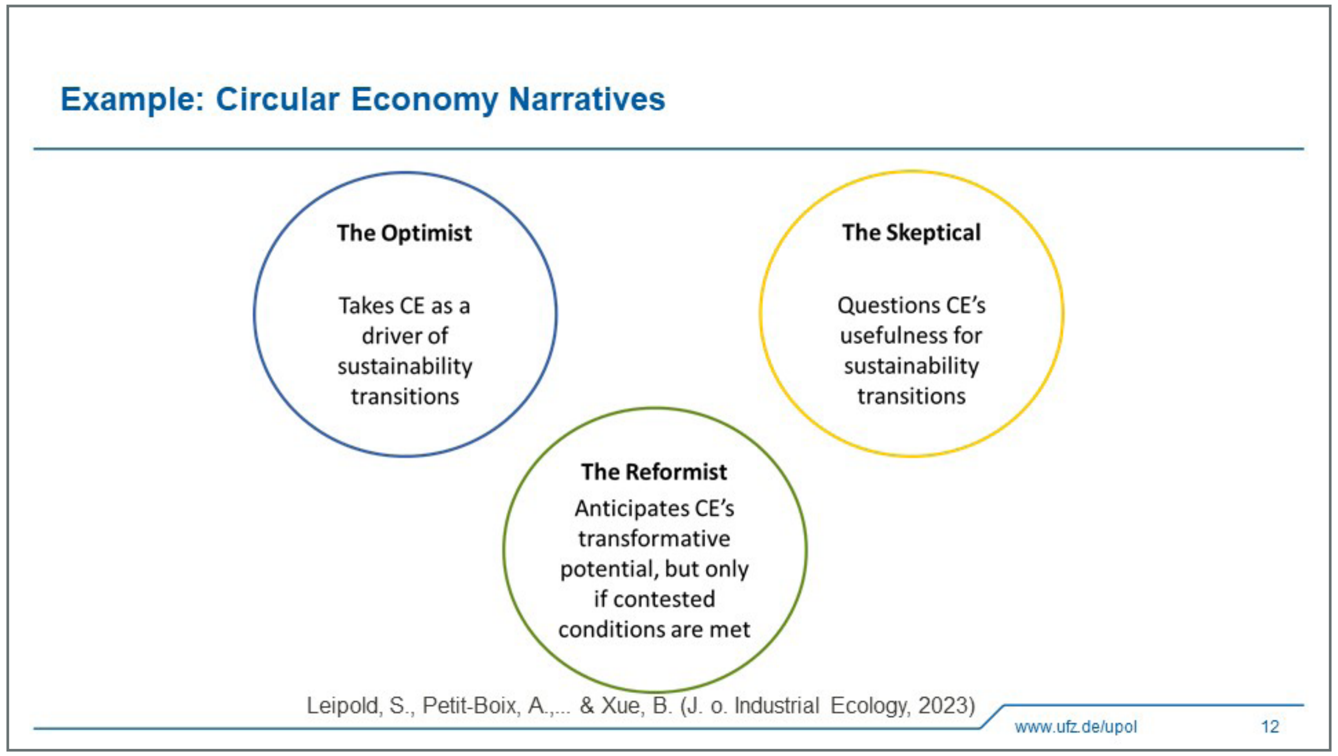
Example: Circular Economy Narratives
The Optimist
Takes CE as a driver of sustainability transitions
The Skeptical
Questions CE's usefulness for sustainability transitions
The Reformist
Anticipates CE's transformative potential, but only if contested conditions are met
Leipold, S., Petit-Boix, A.,... & Xue, B. (J. o. Industrial Ecology, 2023)
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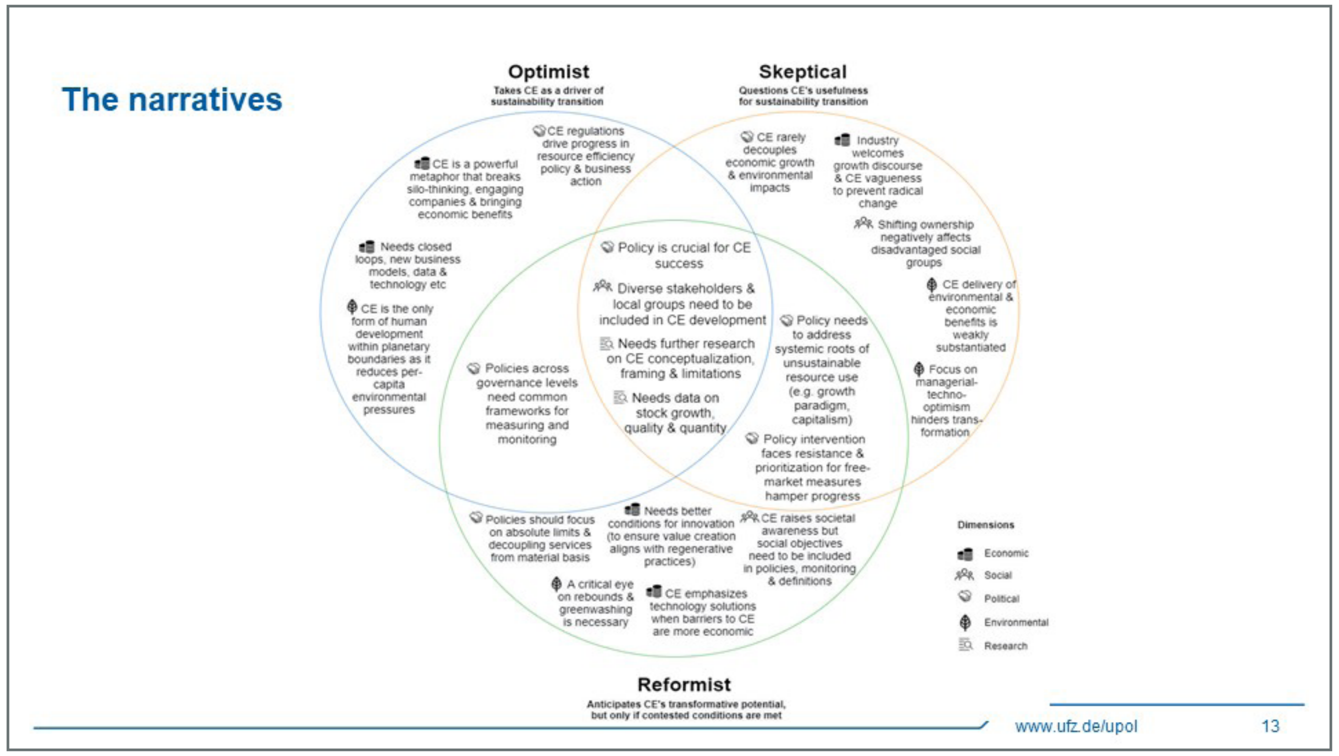
The narratives
Optimist
Takes CE as a driver of sustainability transition
Skeptical
Questions CE's usefulness for sustainability transition
CE regulations drive progress in resource efficiency policy & business action
CE is a powerful metaphor that breaks silo-thinking, engaging companies & bringing economic benefits
Needs closed loops, new business models, data & technology etc
CE is the only form of human development within planetary boundaries as it reduces per-capita environmental pressures
CE rarely decouples economic growth & environmental impacts
Industry welcomes growth discourse & CE vagueness to prevent radical change
Shifting ownership negatively affects disadvantaged social groups
CE delivery of environmental & economic benefits is weakly substantiated
Focus on managerial-techno-optimism hinders trans-formation
Policy is crucial for CE success
Diverse stakeholders & local groups need to be included in CE development
Needs further research on CE conceptualization, framing & limitations
Needs data on stock growth, quality & quantity
Policies across governance levels need common frameworks for measuring and monitoring
Policy needs to address systemic roots of unsustainable resource use (e.g. growth paradigm, capitalism)
Policy intervention faces resistance & prioritization for free-market measures hamper progress
Policies should focus on absolute limits & decoupling services from material basis
Needs better conditions for innovation (to ensure value creation aligns with regenerative practices)
CE raises societal awareness but social objectives need to be included in policies, monitoring & definitions
A critical eye on rebounds & greenwashing is necessary
CE emphasizes technology solutions when barriers to CE are more economic
Dimensions
Economic
Social
Political
Environmental
Research
Reformist
Anticipates CE's transformative potential, but only if contested conditions are met
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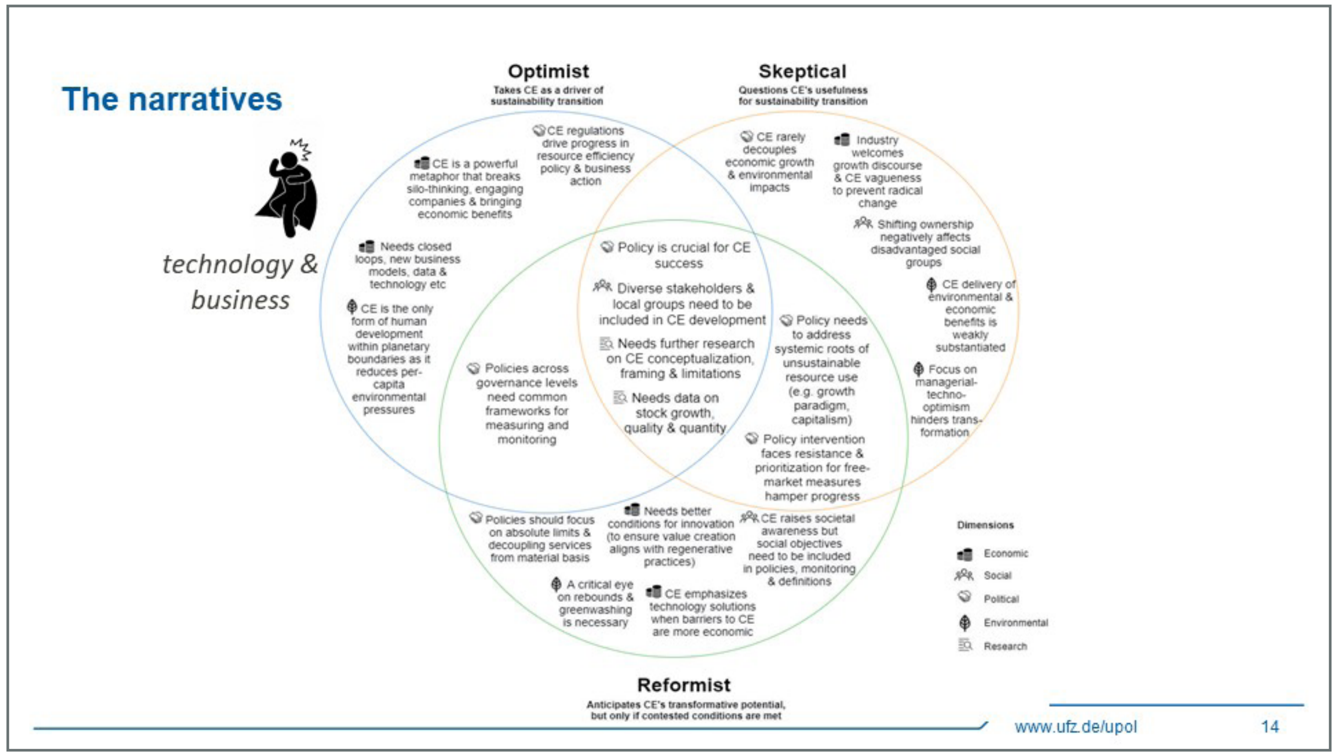
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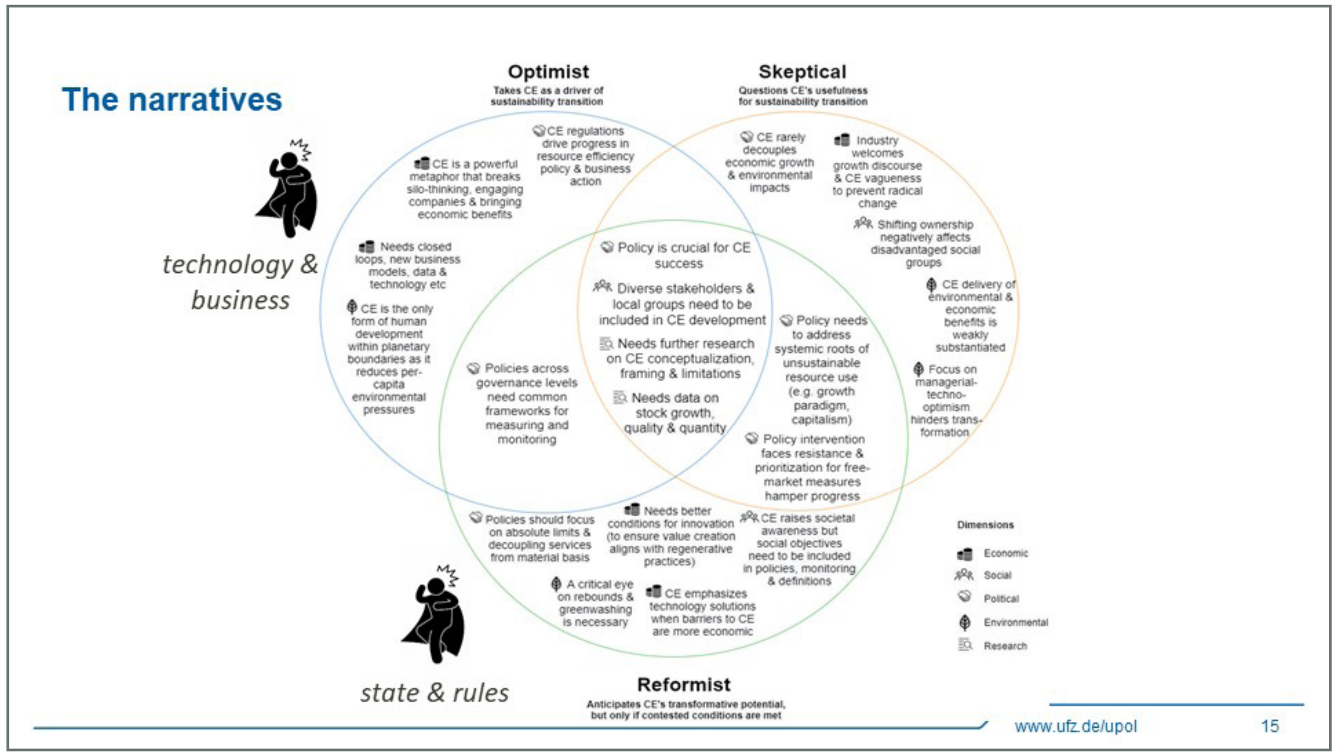

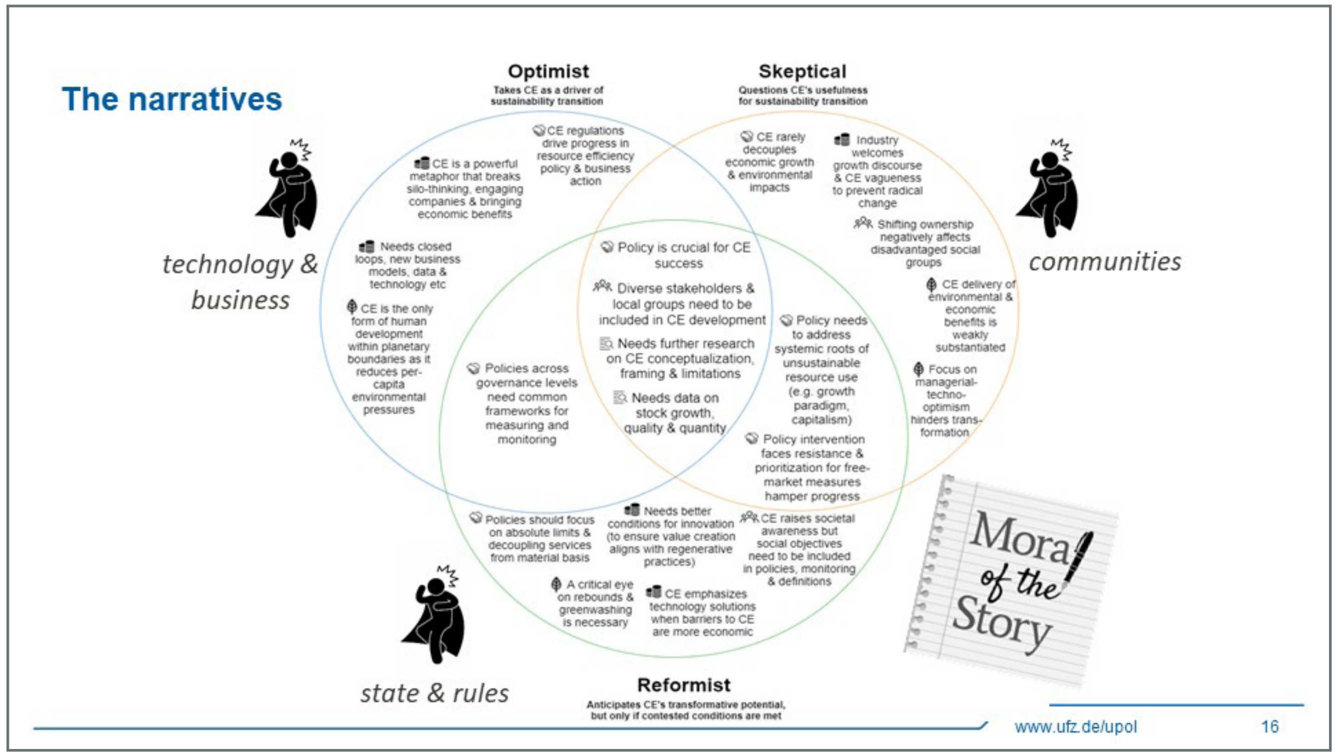

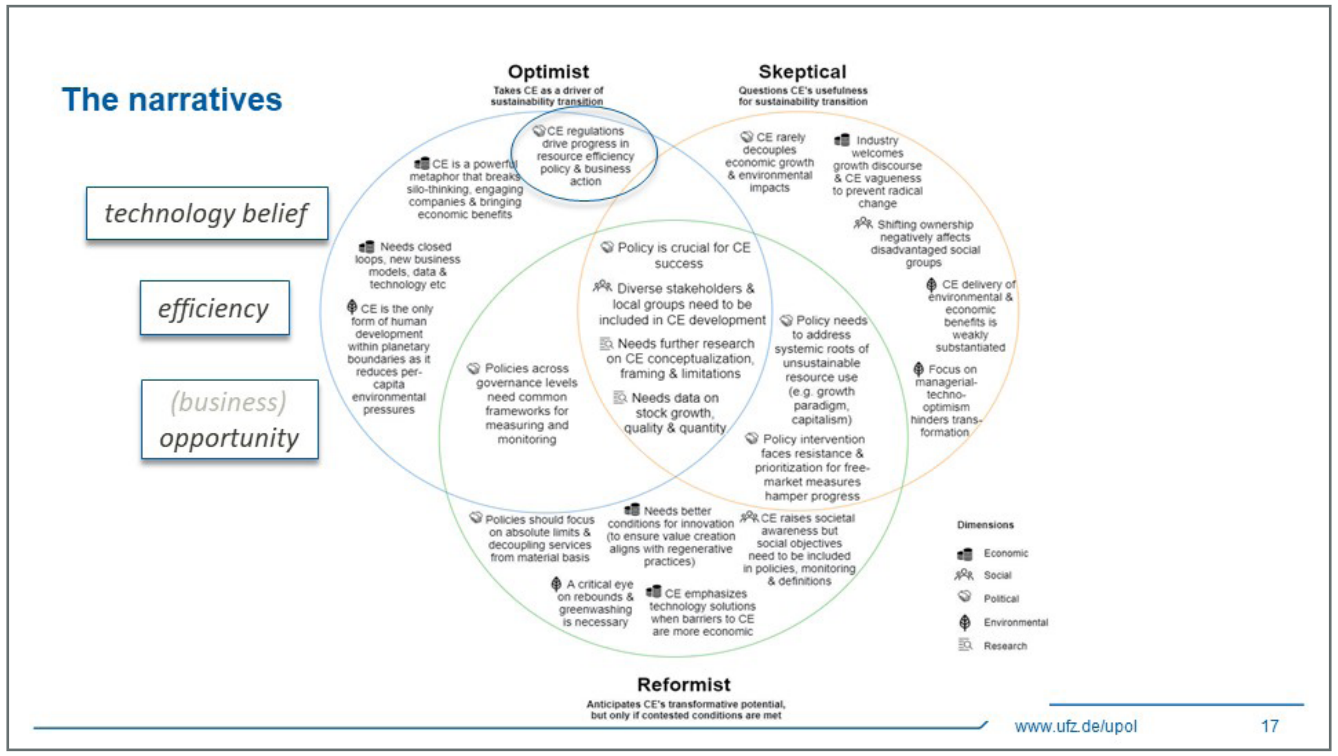

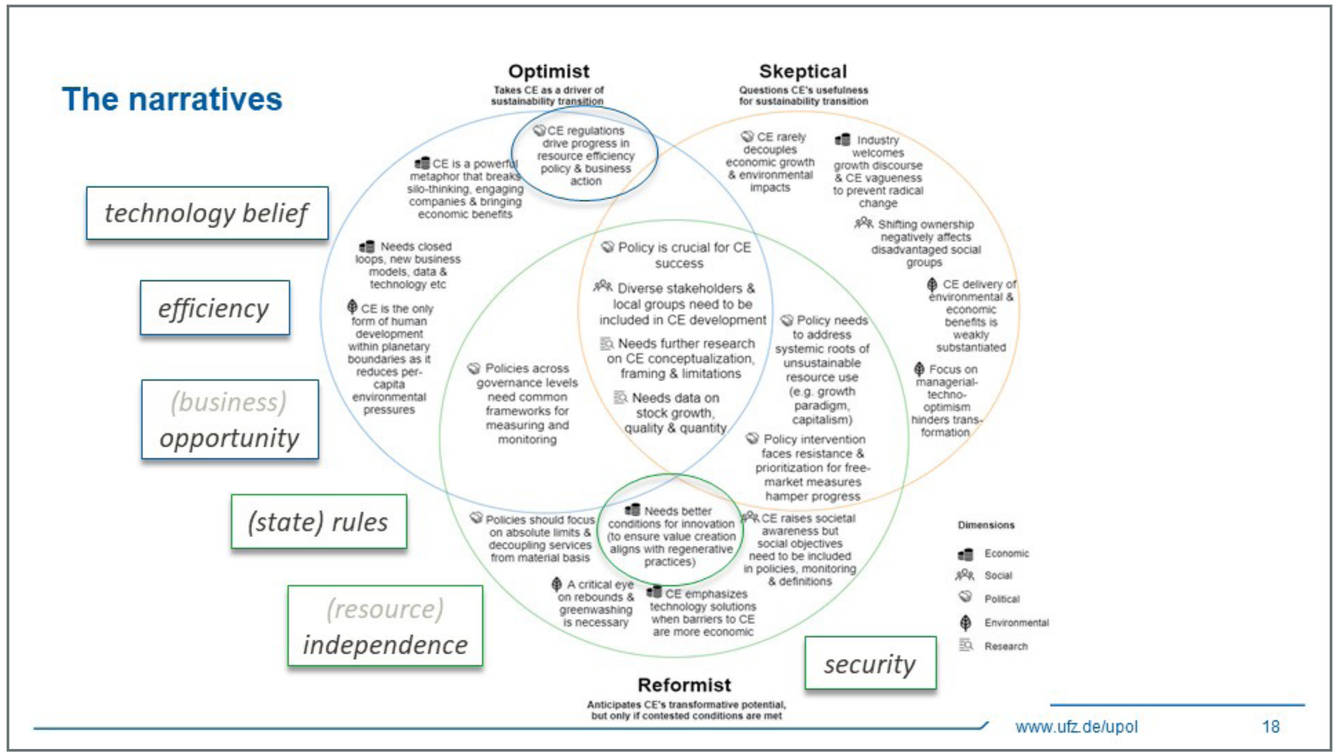

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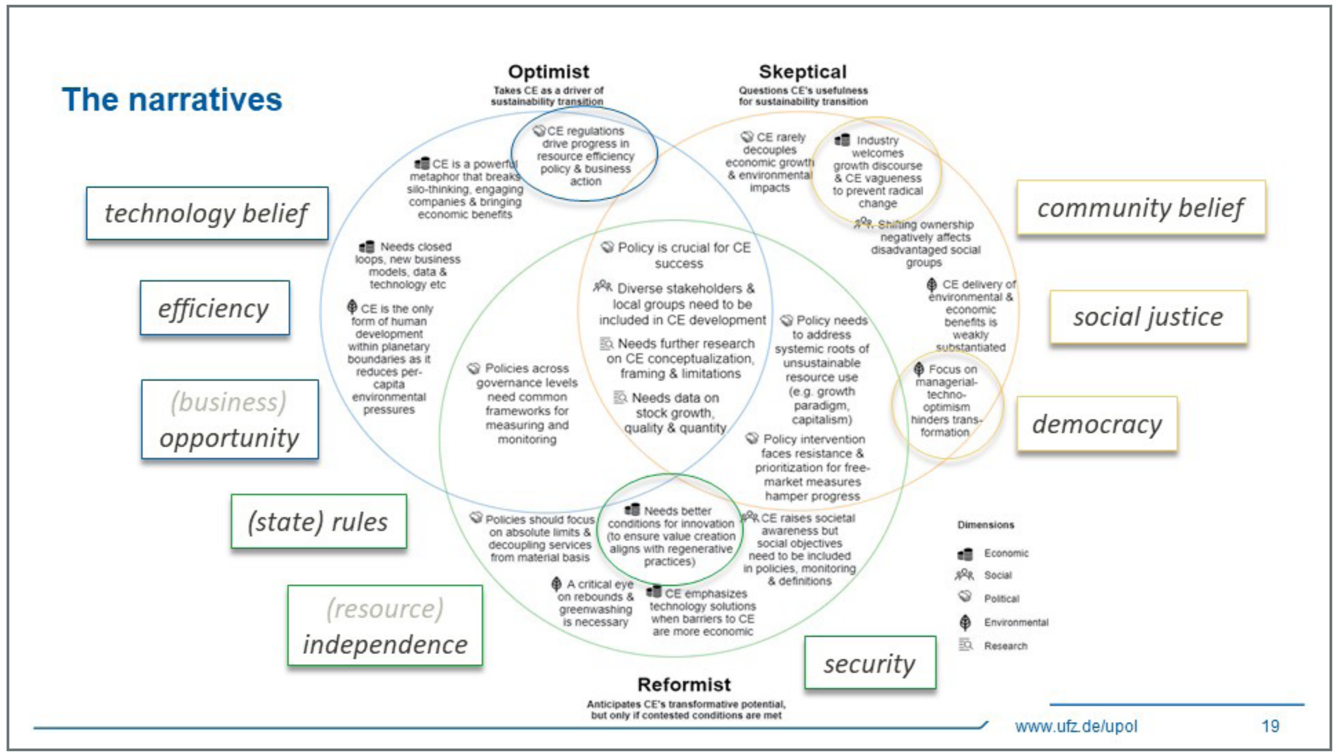
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technology belief
efficiency
(business) opportunity
(state) rules
(resource) independence
community belief
social justice
democracy
security
Dimensions
Economic
Social
Political
Environmental
Research
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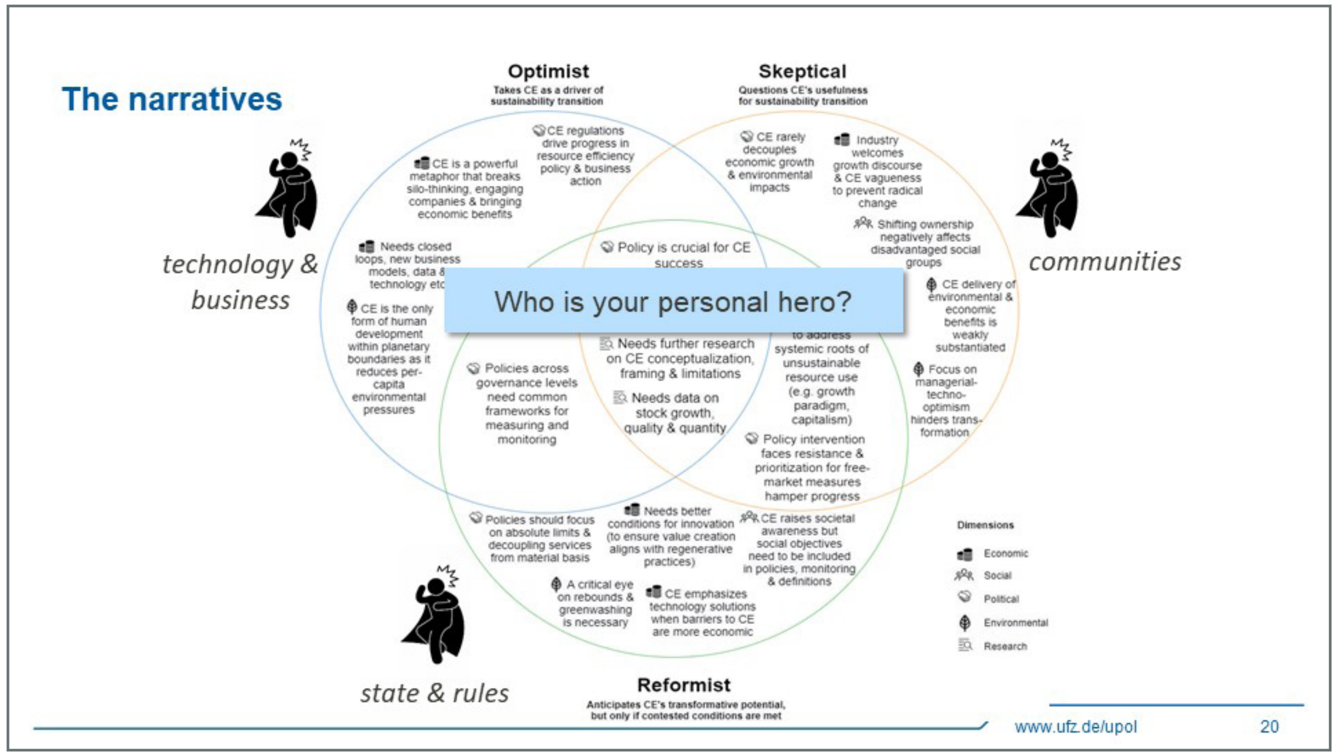
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Questions CE's usefulness for sustainability transition
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technology & business
communities
state & rules
Who is your personal hero?
Dimensions
Economic
Social
Political
Environmental
Research
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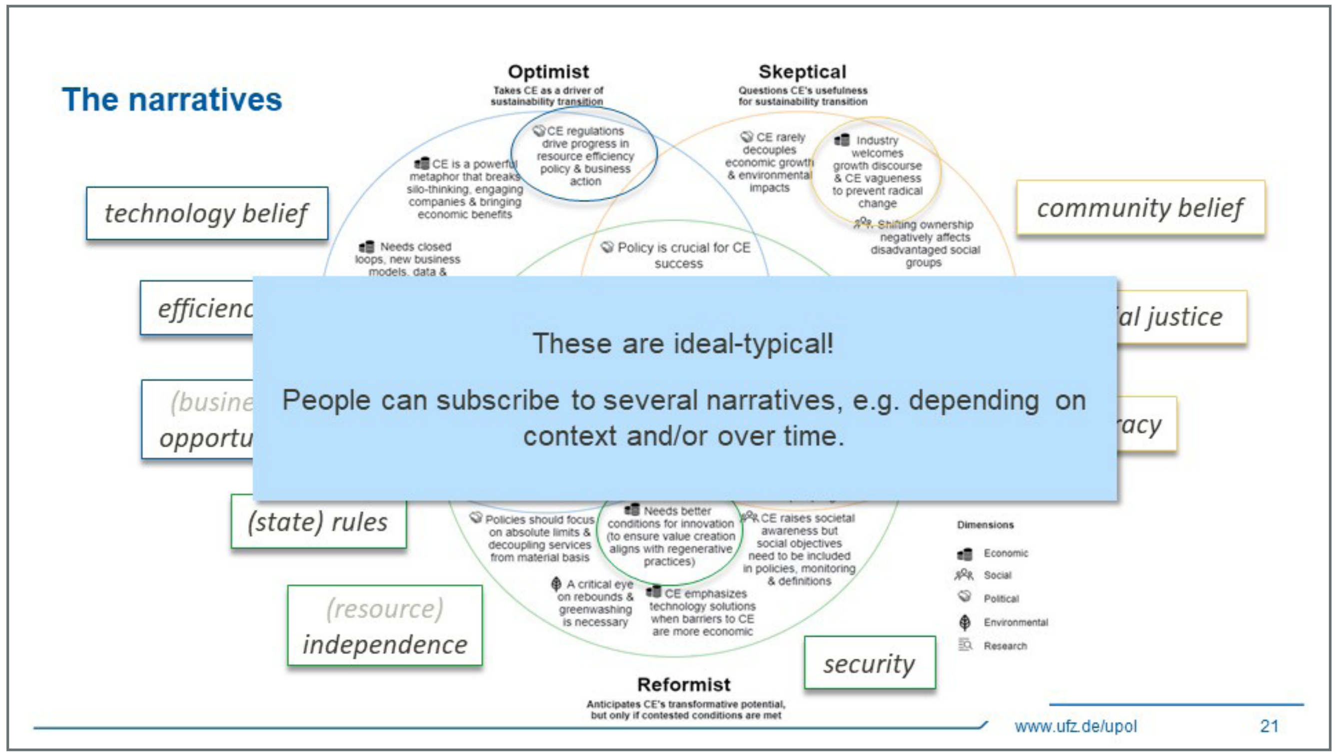
The narratives
Optimist
Skeptical
Reformist
technology belief
community belief
security
(state) rules
(resource) independence
These are ideal-typical!
People can subscribe to several narratives, e.g. depending on context and/or over time.
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Can I navigate narratives and create “relevance” for my research?
▪ Form and Content
▪ Discursive Agency & Strategic Practices
▪ Events
Leipold, S., Hempel, H., … Simoens, M. (in preparation)
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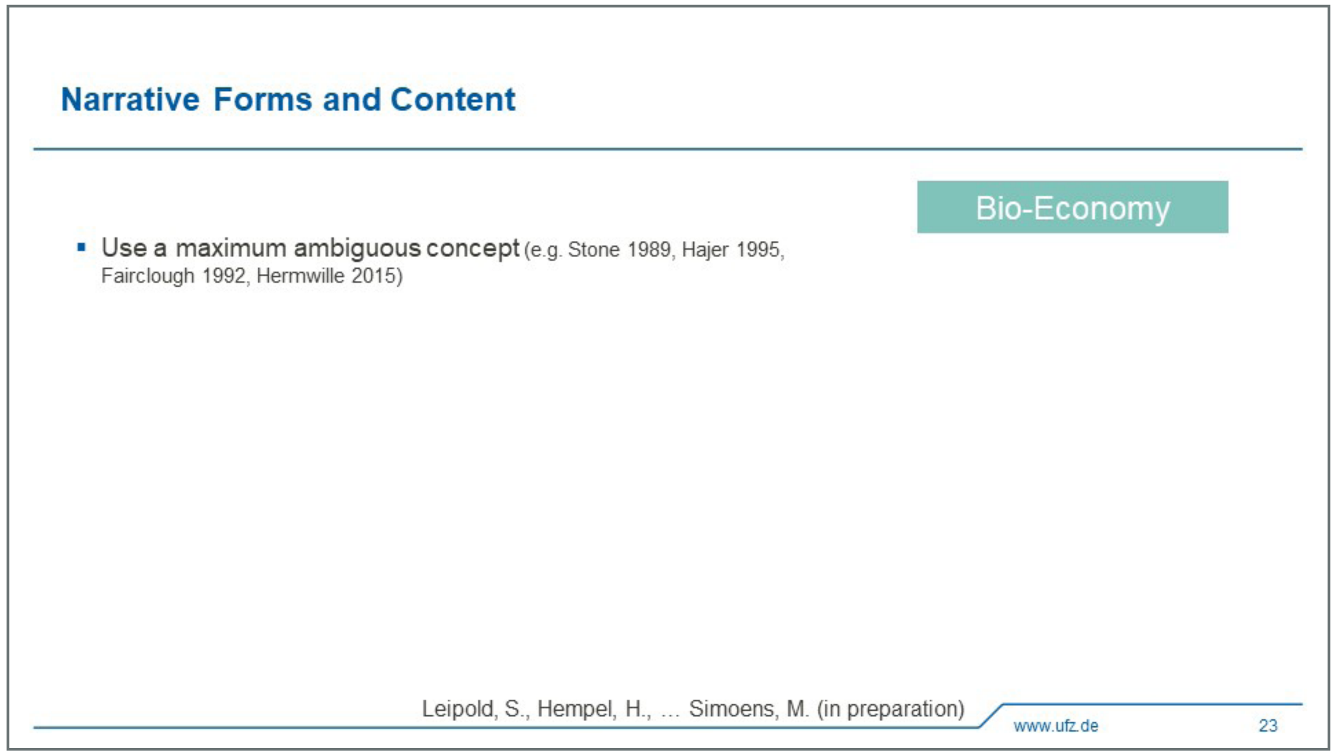
Narrative Forms and Content
Bio-Economy
Use a maximum ambiguous concept (e.g. Stone 1989, Hajer 1995, Fairclough 1992, Hermwille 2015)
Leipold, S., Hempel, H., … Simoens, M. (in preparation)
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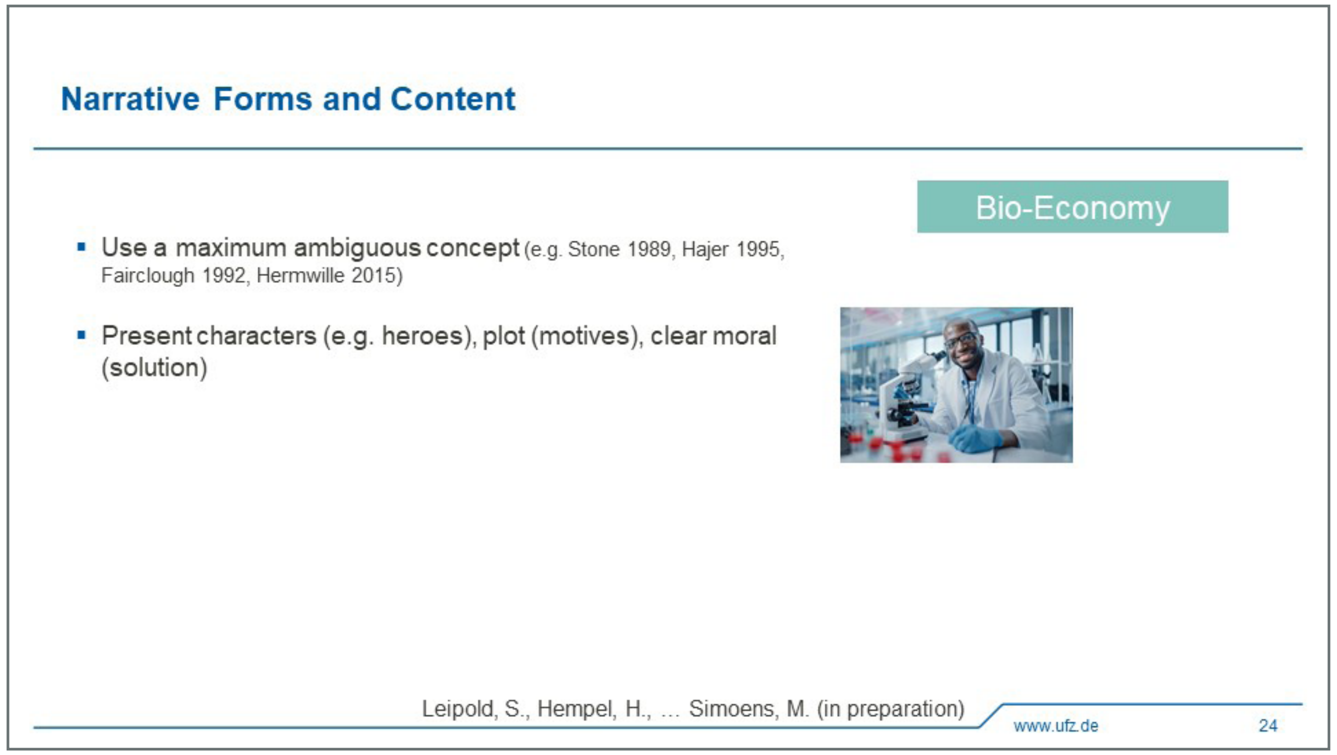
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Use a maximum ambiguous concept (e.g. Stone 1989, Hajer 1995, Fairclough 1992, Hermwille 2015)
Present characters (e.g. heroes), plot (motives), clear moral (solution)
Leipold, S., Hempel, H., … Simoens, M. (in preparation)
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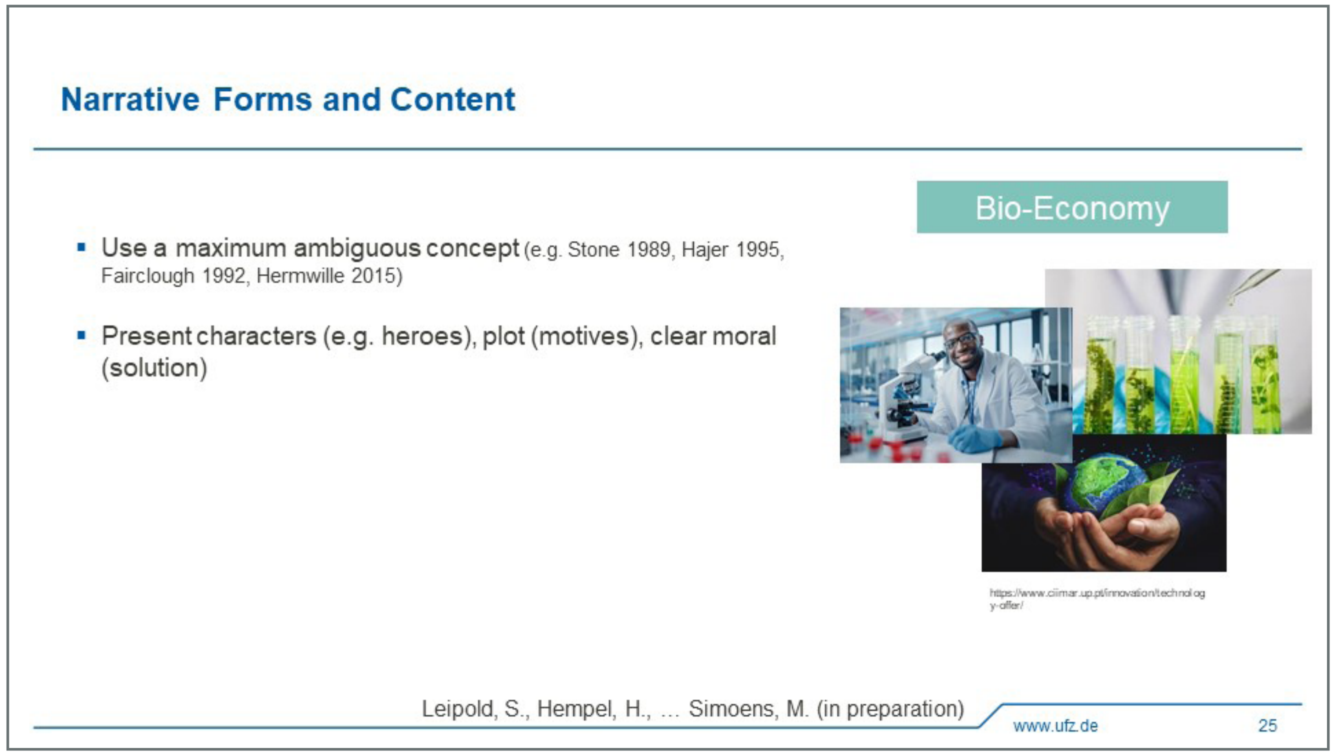
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https://www.ciimar.up.pt/innovation/technology-offer/
Leipold, S., Hempel, H., … Simoens, M. (in preparation)
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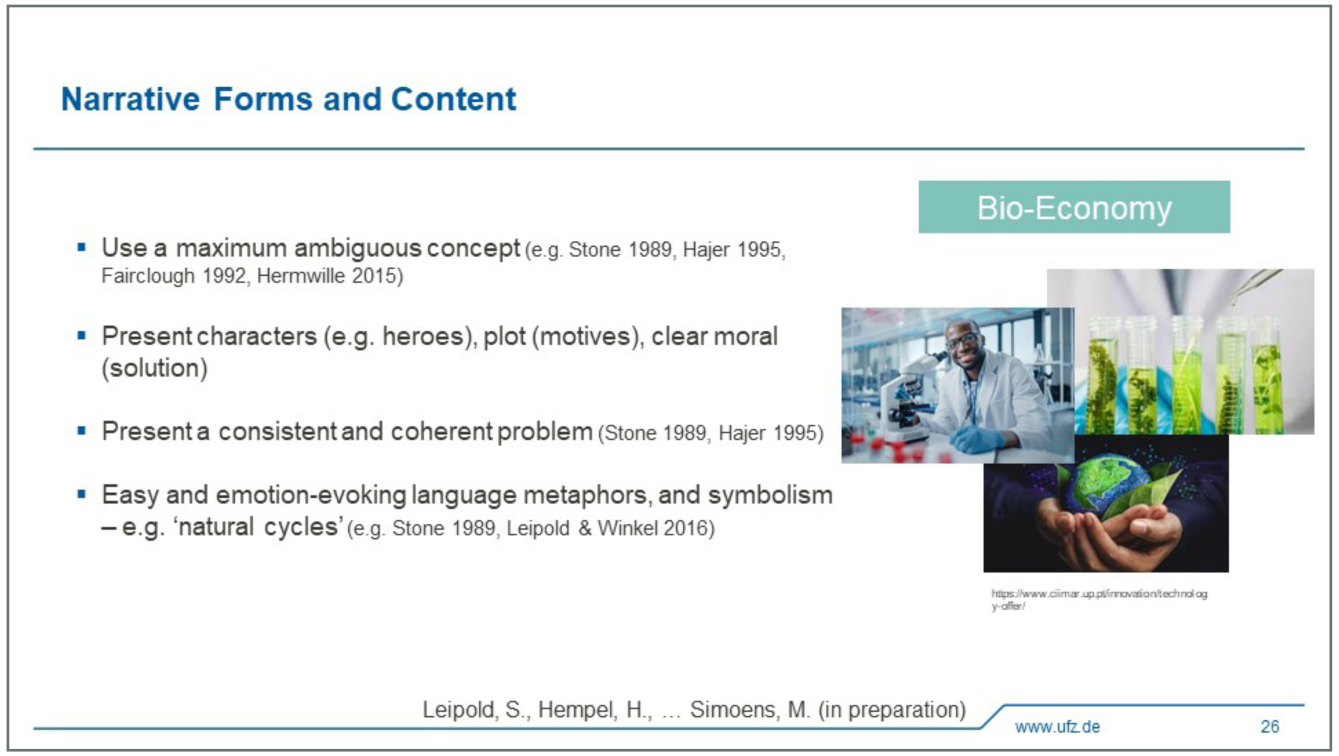
Narrative Forms and Content
Bio-Economy
Use a maximum ambiguous concept (e.g. Stone 1989, Hajer 1995, Fairclough 1992, Hermwille 2015)
Present characters (e.g. heroes), plot (motives), clear moral (solution)
Present a consistent and coherent problem (Stone 1989, Hajer 1995)
Easy and emotion-evoking language metaphors, and symbolism – e.g. 'natural cycles' (e.g. Stone 1989, Leipold & Winkel 2016)
https://www.ciimar.up.pt/innovation/technology-offer/
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Discursive Agency and Strategic Practices

- Form discourse coalition united by shared story 

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Discursive Agency and Strategic Practices

- Form discourse coalition united by shared story 

- Acquire individual (e.g. rhetoric abilities) or positional (e.g. institutional reputation) characteristics (e.g. Weihrauch et al. 2022)

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Discursive Agency and Strategic Practices

- Form discourse coalition united by shared story 

- Acquire individual (e.g. rhetoric abilities) or positional (e.g. institutional reputation) characteristics (e.g. Weihrauch et al. 2022)
- Employ strategic practices (e.g. Holmgren et al. 2022, Lang et al. 2019, Leipold & Winkel 2016)

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Events

- Use events (e.g. natural disasters, industrial accidents, disruptive papers) to re-interpret narratives and open spaces for change (Buschmann and Oels 2019, Hermwille 2016)

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https://www.dw.com/en/flooding-in-germany-before-and-after-images-from-the-ahr-and-eifel-regions/a-58299008

Do not underestimate others' ignorance and creativity!

- Many people & continuous debates, always changing and uncertain (Dryzek 1997, Hajer 2006)

Leipold, S., Hempel, H., … Simoens, M. (in preparation)

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Do not underestimate others' ignorance and creativity!

- Many people & continuous debates, always changing and uncertain (Dryzek 1997, Hajer 2006)

- Simplification can change message, co-opotation can re-interpret (Simoens et al. 2022) → greenwash

Leipold, S., Hempel, H., … Simoens, M. (in preparation)

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Do not underestimate others' ignorance and creativity!

- Many people & continuous debates, always changing and uncertain (Dryzek 1997, Hajer 2006)

- Simplification can change message, co-opotation can re-interpret (Simoens et al. 2022) → greenwash

- Emotionalization or exclusion not without costs (Leipold et al. 2016, Weihrauch et al. 2022) → backlash or fatigue

Leipold, S., Hempel, H., … Simoens, M. (in preparation)

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Navigate turbulent waters together!

- In science & society, use narratives wisely

https://pixnio.com/sport/sailing/sailboat-watercraftpeople-crowd-wind-sail-race-yacht-vehicle-boat

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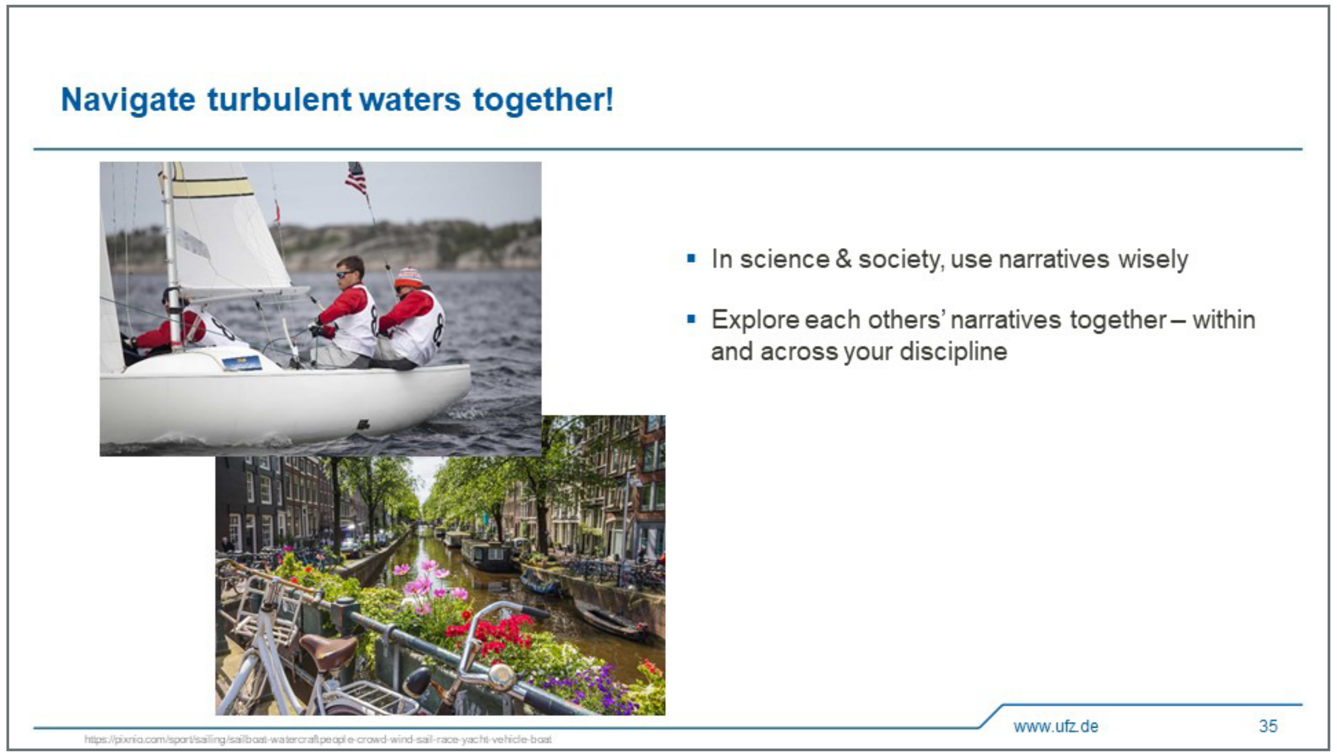
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Explore each others' narratives together – within and across your discipline
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Explore each others' narratives together – within and across your discipline
Method that helps groups (of scientists) do it – in 6 easy steps
Environmental Science & Policy
Can we talk? Disrupting science circles with narrative-led dialogs
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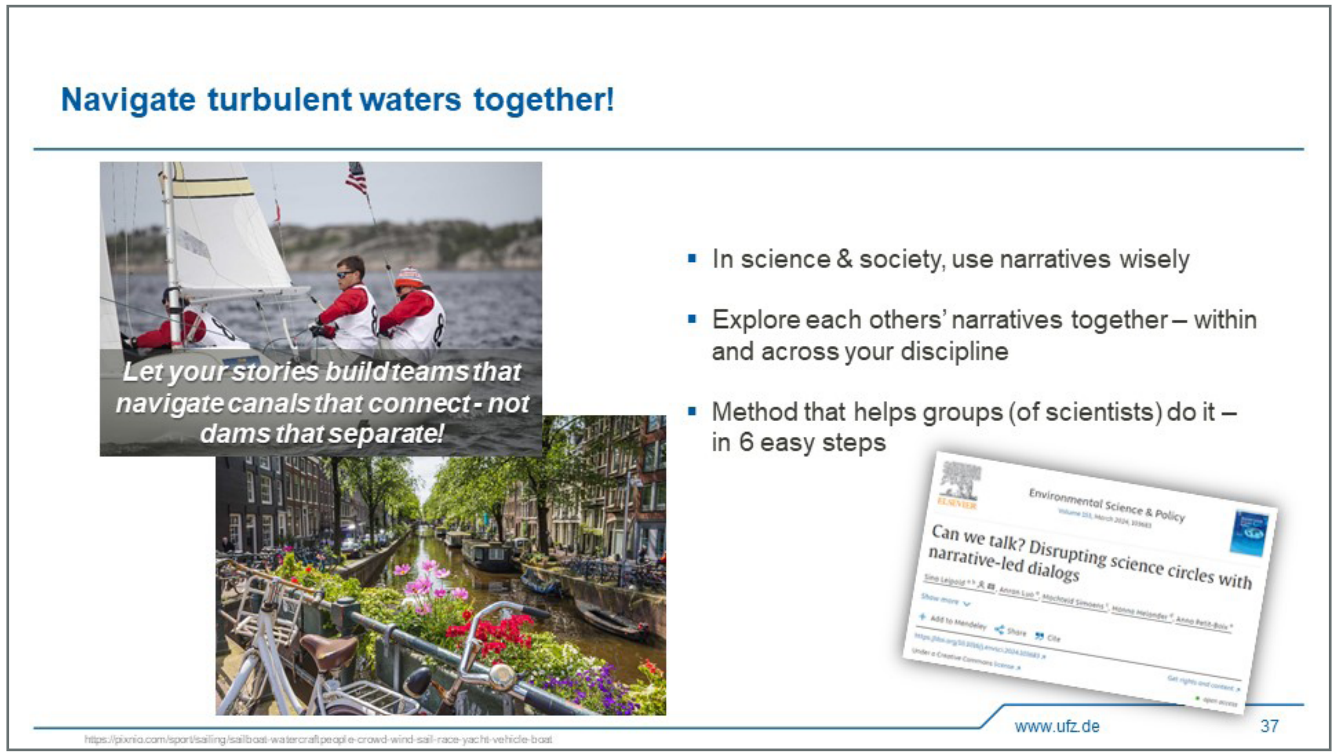
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Explore each others' narratives together – within and across your discipline
Method that helps groups (of scientists) do it – in 6 easy steps
Let your stories build teams that navigate canals that connect - not dams that separate!
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Does "circular" mean "sustainable"? The case of urban farming
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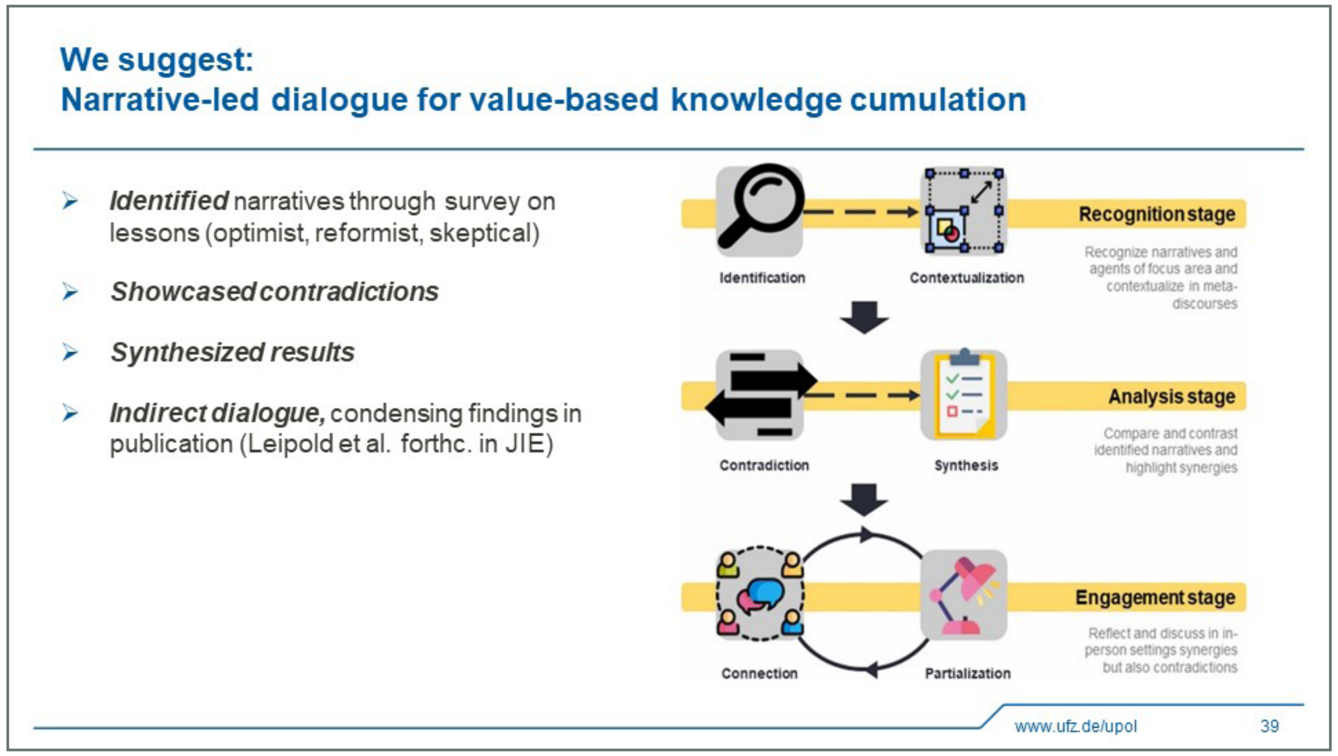
We suggest:
Narrative-led dialogue for value-based knowledge cumulation
Identified narratives through survey on lessons (optimist, reformist, skeptical)
Showcased contradictions
Synthesized results
Indirect dialogue, condensing findings in publication (Leipold et al. forthc. in JIE)
Identification
Contextualization
Recognition stage
Recognize narratives and agents of focus area and contextualize in meta-discourses
Contradiction
Synthesis
Analysis stage
Compare and contrast identified narratives and highlight synergies
Connection
Partialization
Engagement stage
Reflect and discuss in in-person settings synergies but also contradictions
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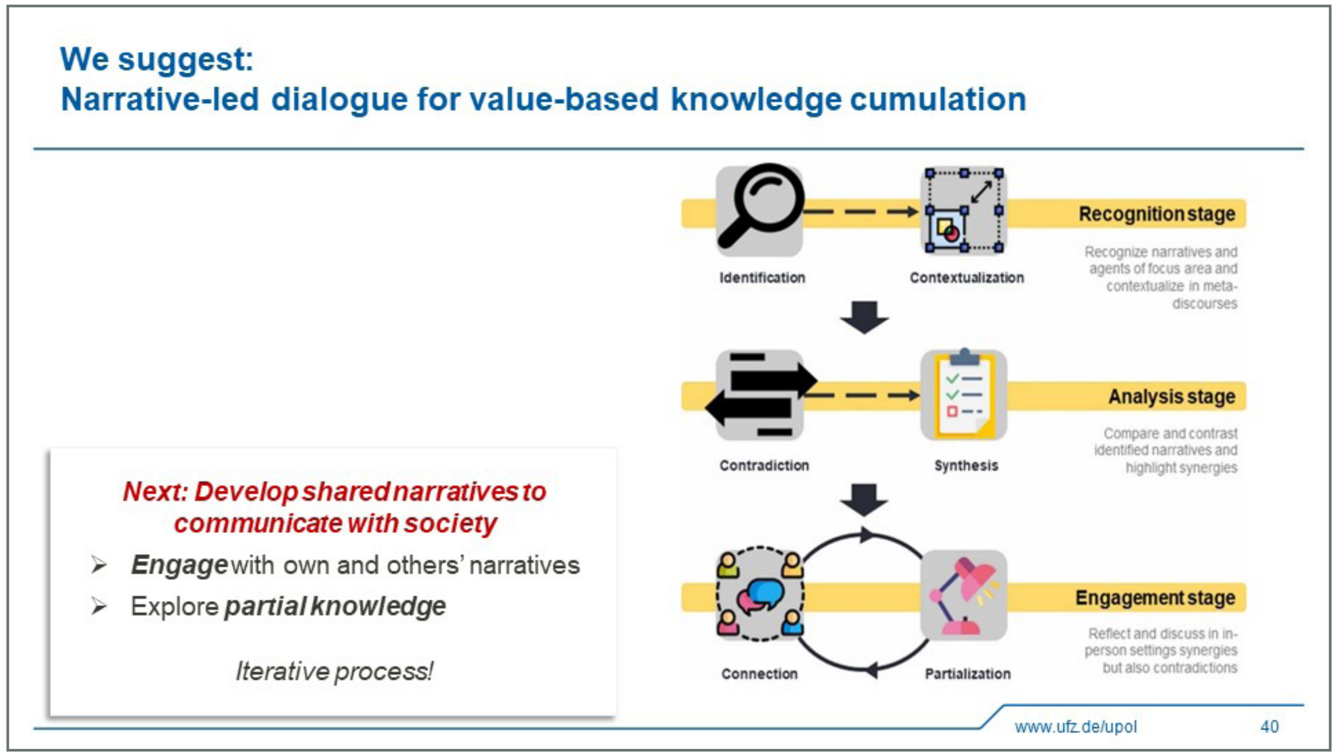
We suggest:
Narrative-led dialogue for value-based knowledge cumulation
Next: Develop shared narratives to communicate with society
Engage with own and others' narratives
Explore partial knowledge
Iterative process!
Identification
Contextualization
Recognition stage
Recognize narratives and agents of focus area and contextualize in meta-discourses
Contradiction
Synthesis
Analysis stage
Compare and contrast identified narratives and highlight synergies
Connection
Partialization
Engagement stage
Reflect and discuss in in-person settings synergies but also contradictions
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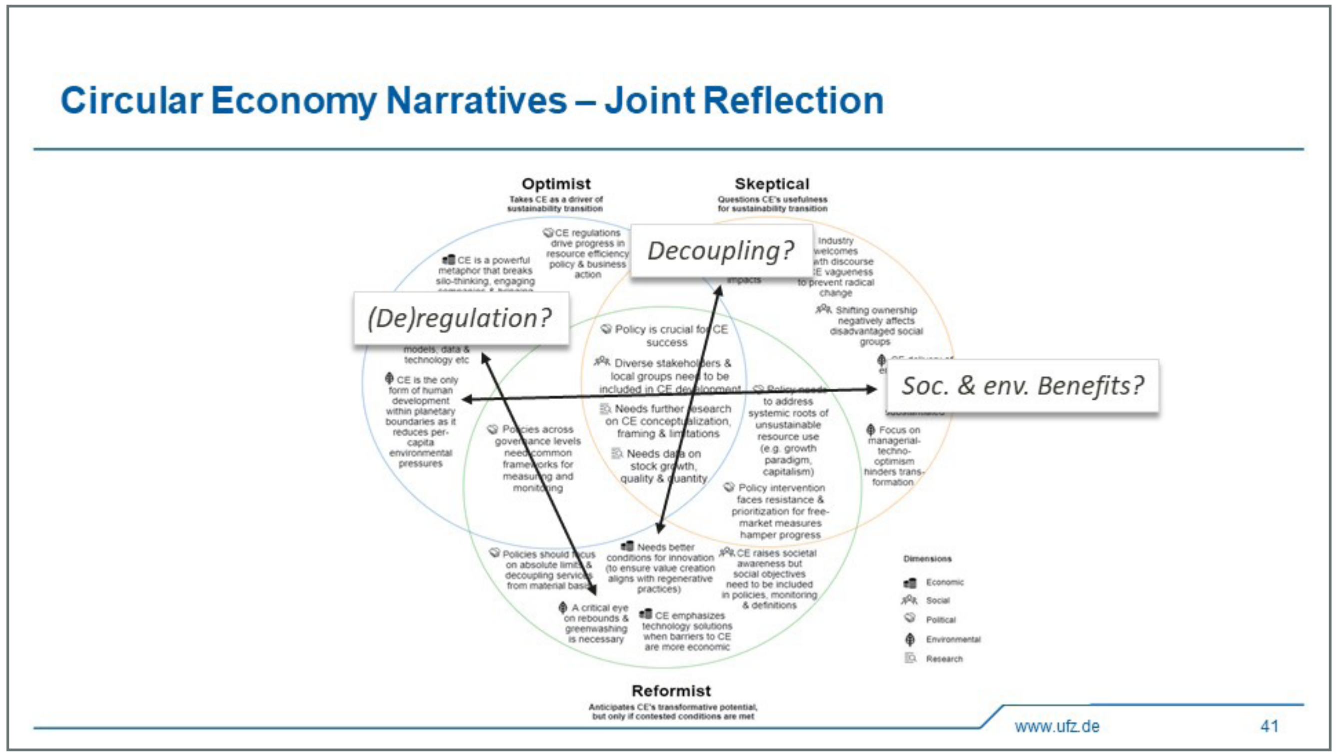
Circular Economy Narratives – Joint Reflection
Optimist
Skeptical
Decoupling?
(De)regulation?
Soc. & env. Benefits?
Reformist
Dimensions
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POSTERSESSION /
POSTER SPEED PRESENTATION

Marcel Dossow, Technical University of Munich

Electrification of gasification-based biomass-to-Liquid processes

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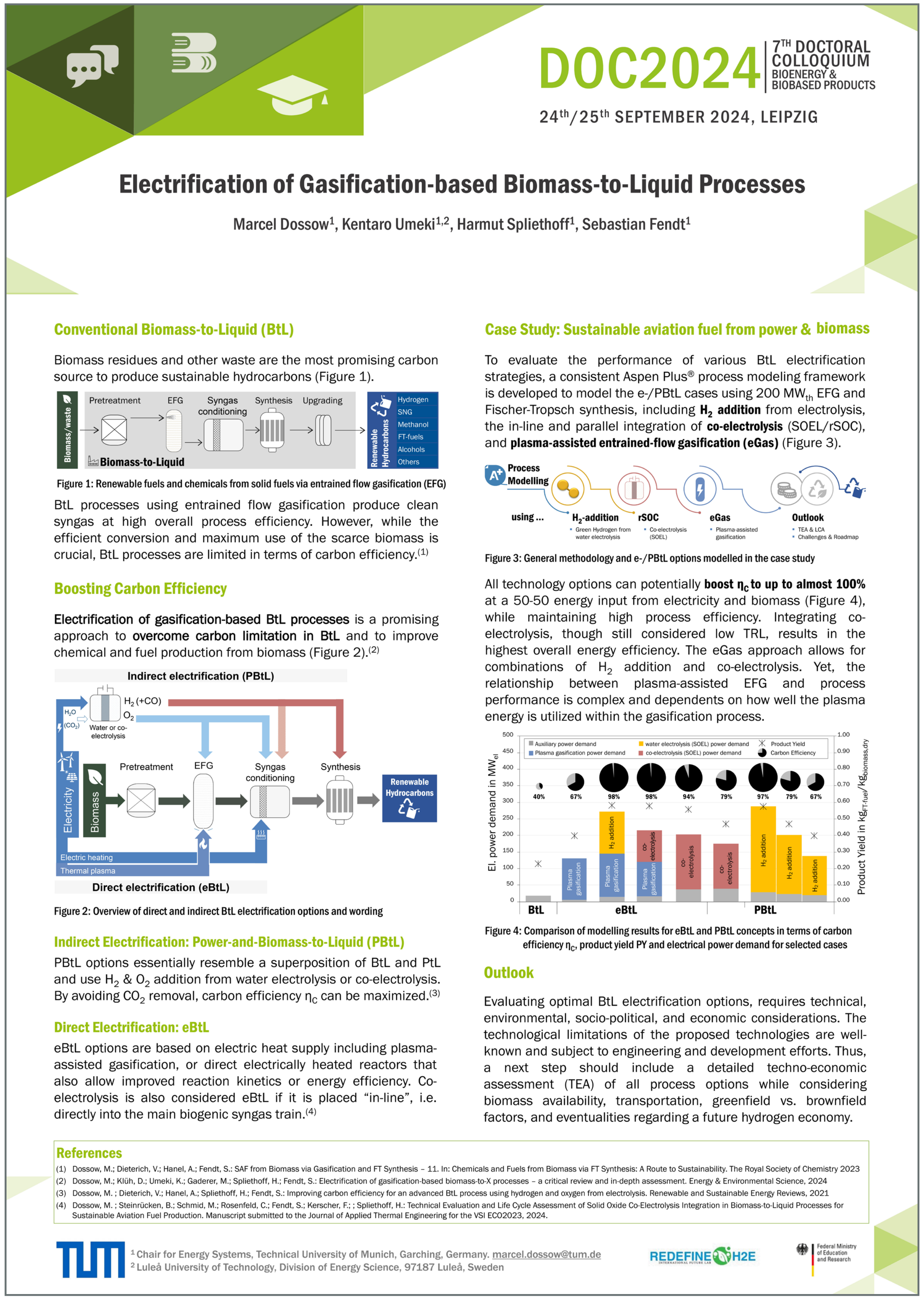
Keywords: Biomass-to-Liquid, Power-and-Biomass-to-Liquid, Electrification, Advanced Biofuels

To decrease anthropogenic greenhouse gas emissions and mitigate climate change, biomass-based fuels and chemicals will play a crucial role. Biomass-to-Liquid (BtL) processes using gasification to produce syngas followed by synthesis producing chemicals and fuels are promising pathway to produce high quantatites of fuels and chemicals in the medium term, i.e. before 2040. With biomass being a scarce resource, its efficient utilization is key. To maximize product yield in BtL processes, electrification of such can play a major role.

Electrification options are classified into direct and indirect processes. While indirect electrification comprises mostly the addition of H_2 from water electrolysis (Power-and-Biomass-to-L, PBtL), direct electrification refers to power integration into specific processing steps by converting electricity into the required form of energy such as heat, electrochemical energy or plasma used (eBtL). After and overview of state-of-the-art technologies and possible P-/eBtL processes, the most promising process routes are selected for further analysis. Based on process models, the selected pathways are discussed in terms of process performance, maturity, feasibility, plant location, land requirement, and dynamic operation. Electrified BtL processes show many advantages compared to BtX and electricity-based processes (Power-to-Liquid, PtL). The analysis shows that H_2 addition is widely investigated in the literature with process simulations confirming significantly increased carbon efficiency and product yield.

Similar studies on direct electrification (eBtL) are limited in the literature due to low technological maturity. Novel process models indicate, that, though technologically less mature, the integration of co-electrolysis or plasma gasification or combinations of all might be even more suitbale for BtL electrification. From a system level, plant location plays a major role. The location dependant boundary conditions, spanning from biomass avaiabilty, over energy system implications and political regulations, also massively influence the feasibilty of the employed technology.

Further research is required on both, equipment level technology development, as well as process and system level, to compare process options and evaluate performance, economics, environmental impact and future legislation.



René Bindig, Deutsches Biomasseforschungszentrum

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

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Keywords: Catalyst development, small-scale combustion

Catalyst development remains a highly relevant topic due to the need for process optimizations and adaptations to changing boundary conditions, such as those in industrial processes or flue gas treatment, which necessitate new and advanced catalysts. Significant challenges in catalyst development often occur during the transition from one stage of development to the next. A reliable estimation of the behavior of newly developed catalysts in real-world applications, based on laboratory results, could minimize the risk of having to repeat the final, particularly costly development steps multiple times. This approach could significantly reduce overall development costs.

Additionally, laboratory-scale experiments under conditions similar to those in an actual plant allow for more precise temperature control and recording of temperature distribution across a catalyst sample. This enables a more accurate investigation of the various factors influencing the observed effective kinetics of a catalyst sample. The objective of this thesis is to develop a multistage method that can be used to reliably estimate the full-scale behavior of a catalyst under development.

For this purpose, specialized test rigs have been developed to obtain the necessary experimental data from laboratory-scale samples. These data will be incorporated into a mathematical model. This model is intended to describe the conversion-temperature behavior of the catalyst at full scale under the conditions of an actual combustion plant. Initially, the applicability of this process is limited to the development of catalysts for the exhaust gas aftertreatment of combustion plants in the small power range, such as combined heat and power plants and small-scale combustion units.

The necessary test rigs have been designed and constructed. To determine the suitability of these test rigs for the intended procedure, a commercially available catalyst was used, and a mathematical model was developed. This paper presents and discusses the test rigs, the experimental data obtained with them, and the developed mathematical model.

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CATALYST DEVELOPMENT PROCEDURE FOR EXHAUST GAS AFTERTREATMENT OF SMALL-SCALE COMUBSTION PLANTS

René Bindig[1,2]

BACKGROUND AND GOAL

Catalyst development takes place over several stages, i.e. from the pure, catalytically active phase (powdered sample) to the monolithic specimen (supported catalyst; real scale). Most difficulties arise at the transitions from stage to stage because of the increasing influence of mass and heat transfer effects on the activity of the samples. Within the context of this work, a method is to be developed with the aid of which the behavior of catalyst specimens in real applications can be reliably estimated.

APPROACH

A multi-stage procedure was derived for determination of kinetic parameters and other influences on the reaction engineering parameters (mass and heat transfer) under conditions that are as close to realty as possible but on a laboratory scale.

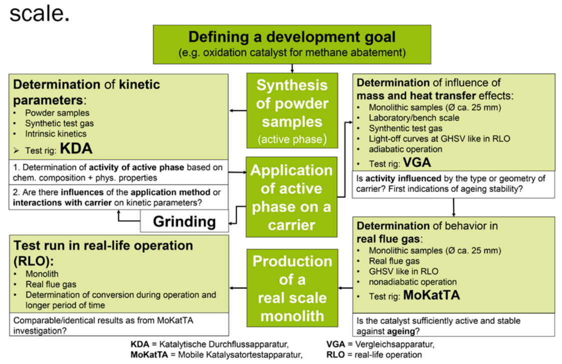

Figure 1: Scheme of the developed procedure (KDA = Katalytische Durchflussapparatur, VGA = Vergleichsapparatur, MoKatTA = Mobile Katalysatortestapparatur, RLO = real-life operation)

The results are to be incorporated into a as simple as possible mathematical model which can describe the behavior (e.g. CO conversion, X_{CO}) of a corresponding monolith (real scale) in practical operation.

TECHNICAL SET-UP

In accordance with the developed procedural diagram in figure 1, the necessary three test reactors and test rigs were assembled, which are shown schematically in figure 2. Details of the purposes of the test rigs and their modes of operation can be found in figure 1.

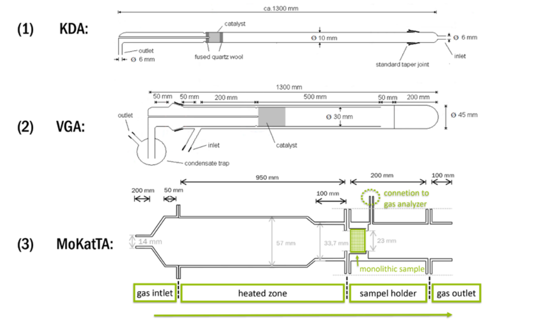

Figure 2: Schematic drawings of the reactors for the three test rigs

RESULTS

Using the parameters derived at a specific operating point, the model was able to describe the behavior at this operating point and also the behavior at other operating points (changed flow velocity, GHSV; see figure 3 and 4). The agreement with the behavior in the real system was given.

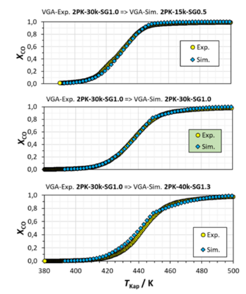

Figure 3: comparison of experimentally determined (Exp.) and simulated *X*-*T*-curves (Sim.) for the VGA reactor

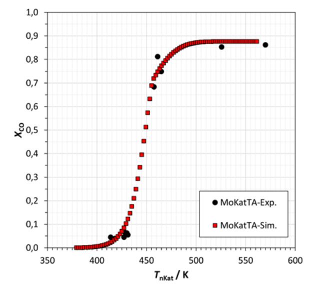

Figure 4: comparison of experimentally determined and simulated *X*-*T*-curve for the MoKatTA reactor

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MARTIN-LUTHER-UNIVERSITÄT HALLE-WITTENBERG

Sören Richter, Deutsches Biomasseforschungszentrum

Dynamic scenario driver framework for systematic formulation of bioeconomy scenarios

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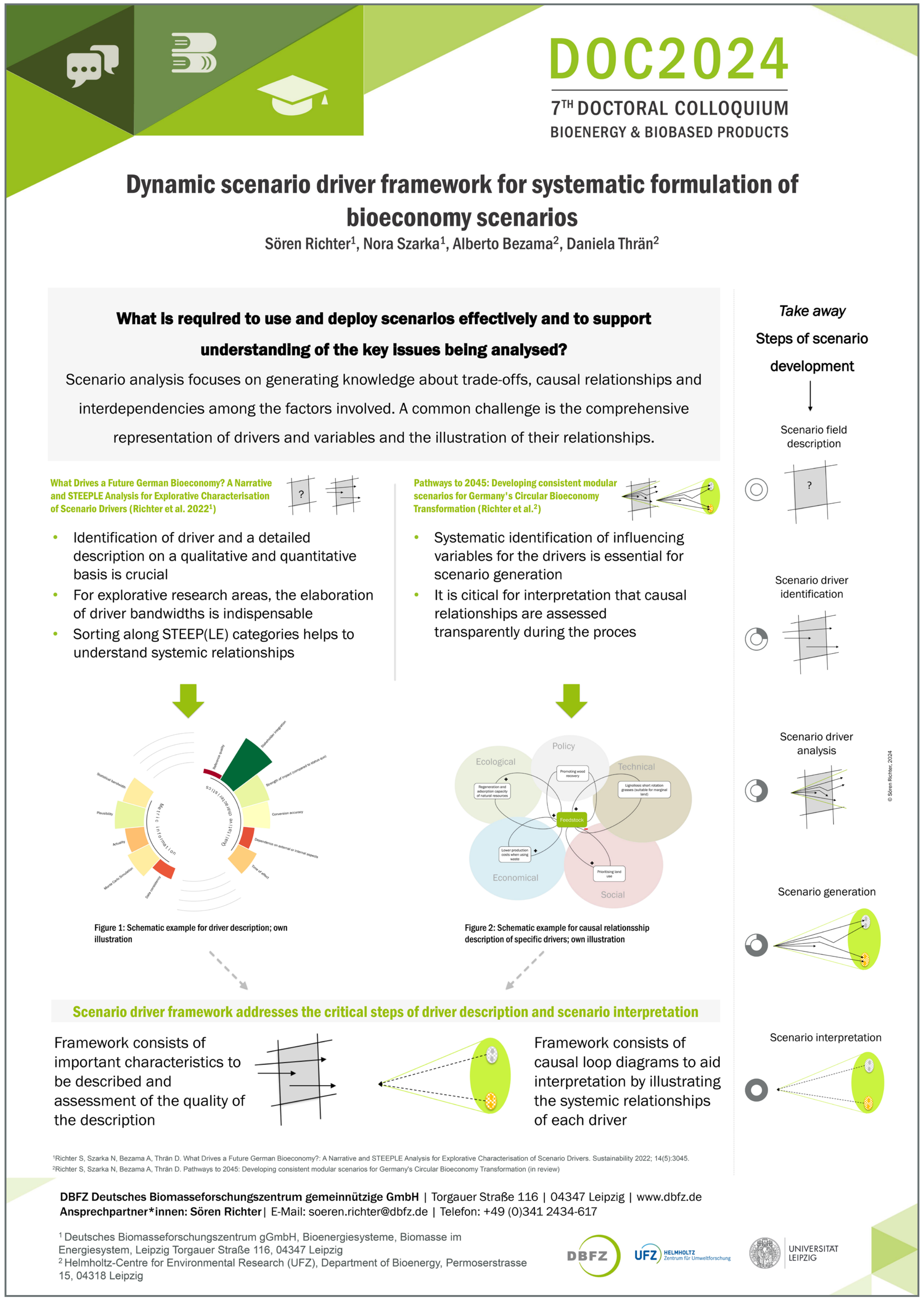
Keywords: Circular Bioeconomy, Scenario development, Framework, Scenario Drivers and assumptions

The circular bioeconomy concept addresses several challenges facing the linear fossil fuel industry in an era of accelerating climate change. The pursuit of a more sustainable economic system leads to the integration of more renewable resources for energy and material application. This integrates multi-level systemic transformation aspects that need to be assessed to avoid and minimise trade-offs. Scenario methods are supportive and established for this task and are used for the systemic identification of key aspects in the circular bioeconomy [1] and the rational compilation of drivers and variables of the systems under study (Richter et al. not published yet). Based on these methods, different possible future system states could be analysed and provide new knowledge about influencing systemic drivers. For the support of the energy transition in Germany and Europe several scenarios [2] have been developed.

For the bioeconomy in general, scenarios are quite limited. To accelerate scenario development in the field of bioeconomy, in previous work steps, scenario drivers and scenarios have been developed. The process reveals that especially in the bioeconomy field a clear framework how to describe the integrated drivers and assumptions is missing. Within the presented work, the lessons learned in the process will be used to elaborate a framework as guiding tool. The systemic categorization of the drivers is done with the STEEPLE method, while the driver description is broken down to the specific influencing variables. These variables itself, are integrate metric data such as ranges of possible developments into the future, conversion factors, number of scientific empirical references, different future timestamps, strength of impacts, timeliness of data etc. Based on these qualitative and quantitative data, within causal-loop diagrams the interrelation between the different analysed drivers is visualized and can be used for supporting the scenario interpretation.

The work illustrates a first approach for such a framework. Based on the combination of different methods, the framework integrates qualitative and quantitative scales of driver characteristics that will support comprehensive, transparent scenario generation and interpretation. This guidance tool would not only support scenario generation, but also interpretation and transferability, as it would be clear to what extent assumptions are made. Based on this description, scenario quality criteria in the field of bioeconomy could be assessed and scenario comparison as such could be supported.



Mohammad Sadr, Helmholtz-Centre for Environmental Research

Assessing the potential of negative emission technologies for Germany's netzero target: A techno-economic analysis of forest-based solutions

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Keywords: Bioenergy system, Negative emissions, Forest-based, technoeconomic

Methane-producing bioelectrochemical systems (CH_4-BES) have become a promising technology to capture and convert CO_2. In a CH4-BES, methanogens in cathode compartment metabolizes cathode-derived electrons either directly or indirectly via in-situ-produced molecular hydrogen. Hydrogen evolution at cathode in a close proximity to hydrogenotrophic methanogens mitigates H_2 low solubility and mass transfer limitations. 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 that high cost of electrode material is a major drawback of CH_4-BES and the identification of cheaper material is essential for the commercialization of this process. Biochar is an attractive biocompatible, costeffective, environmentally friendly, and electroconductive material, produced from various biomass feedstocks via reductive pyrolysis under anoxic atmosphere.

Pyrolysis process and the nature of wood affects produced biochar in terms of porosity, surface area, electrical conductivity, and degree of carbonization, as well as the carbonaceous structure which explains the electrochemical performance of the material. Granular biochar, produced via pyrolysis from beechwood at 740 °C (BEW740) showed highest electrical conductivity (σ); however, samples are utterly incongruous in σ. This study unravels how physicochemical and electrochemical characteristics of BEW740 are influenced by product's heterogeneity. Cyclic voltammograms revealed that some of BEW740 cathodes have lowest overpotential for hydrogen evolution reaction, i.e., ~2.5 orders of magnitude less than granular graphite-based cathode. The knowledge achieved from this study will provide a scientific basis to select and/or produce high-performance granular biochar for applications in biocathodic reactions.

Milad Rousta, University of Stuttgart

System analytical evaluation of post-EEG concepts for biogas plants in future energy markets

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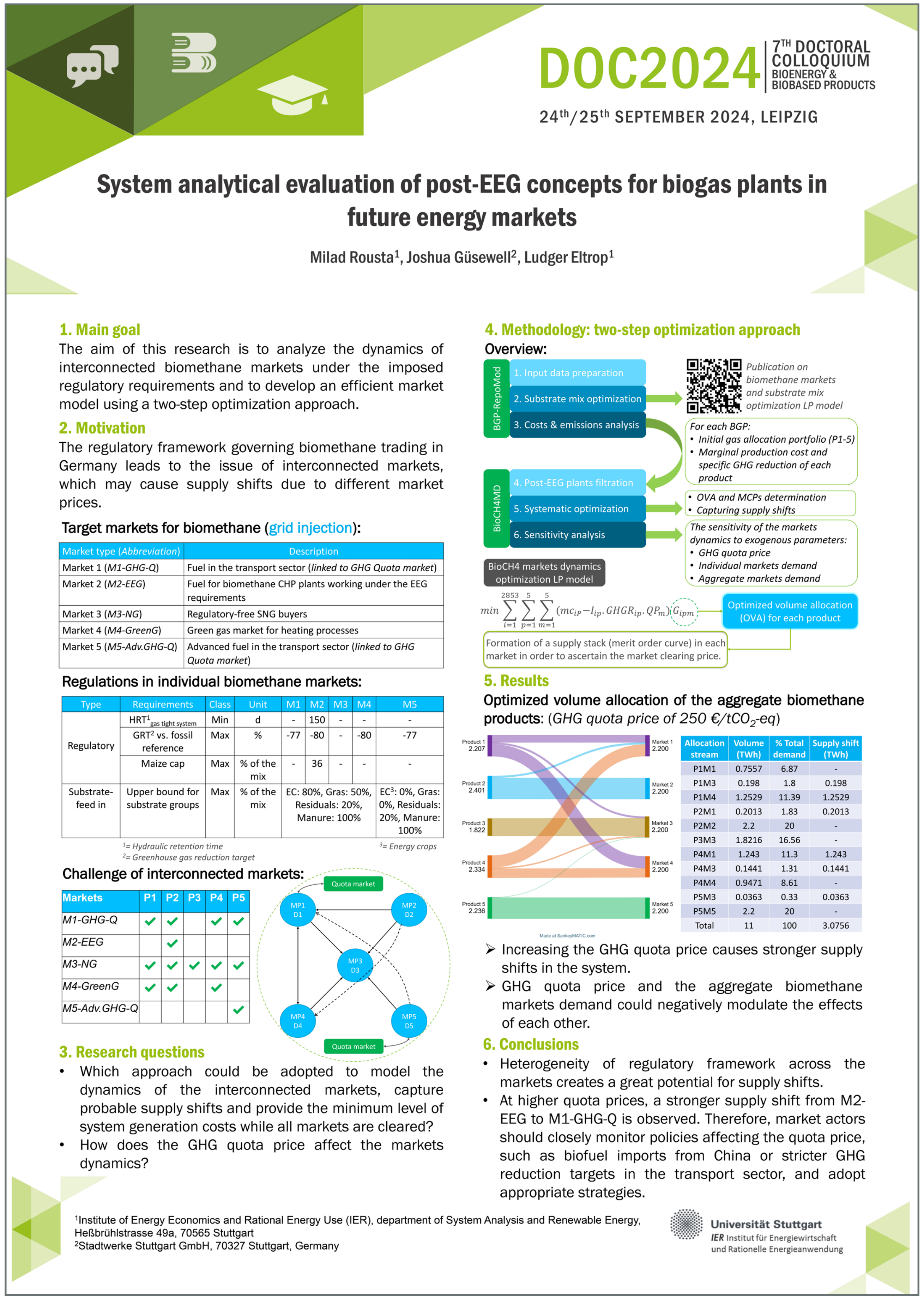
Keywords: Biogas plants, Biomethane markets, Optimization, GHG quota

The regulatory framework conditions, under which biomethane could be traded in Germany, hugely affect the dynamics of the biomethane markets such that the markets are connected. This issue may cause potential supply shifts within the markets due to the market price differences. The GHG quota market plays a crucial role in encouraging biomethane suppliers to contribute more to the transport sector. However, the quota price has shown a great deal of fluctuations in recent years, which could influence the biomethane markets mechanism as well.

The aim of this research is to analyze the dynamics of the future biomethane markets under the imposed regulatory requirements and try to develop an efficient market model in which the interconnected biomethane markets are optimally cleared and the added value of bio methane in the different markets is identified.

A two-step optimization approach was adopted. First, from plant operators' perspective, the biomethane production cost was minimized via a substrate mix optimization model. Second, the whole interconnected biomethane markets were modeled using a systematic optimization model. Linear programming (LP) serves as the foundation for both models. To determine the individual market price, the merit-order approach was adopted. Furthermore, through an in-depth sensitivity analysis, the effects of the GHG quota price on the markets dynamics were investigated.

Under the normative assumptions of the GHG quota price of 250 €/ton and the aggregate biomethane demand of 11 TWh, all biomethane markets are optimally cleared while a significant aggregate supply shift of 3.08 TWh is observed. Elevating the quota price results in the higher allocation of small biogas plants to the transport and EEG sectors. Both externalities, the quota price and the aggregate markets demand, affect the dynamic behavior of the system. However, they neutralize each other's effects. At higher quota prices, a stronger supply shift from M2-EEG to M1-GHG Q is observed. Therefore, market actors should closely monitor policies affecting the quota price, such as biofuel imports from China or stricter GHG reduction targets in the transport sector, and adopt appropriate strategies.



Dirk Kirchner, University of Leipzig

Optimization of stand-alone hybrid Energy System (HRES) with Biogas-Plant with flexible-demand driven biogas production

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Keywords: HRES, demand driven biogas production, microgrid optimization

Stand-alone grids are often supplied by diesel Engines with high emissions. With the use of HRES with high renewable energy production content, pollution can be minimized. In this energy system, the use of a diesel engine is still necessary to balance the fluctuating energy production of wind and solar. With the use of biogas plants for balancing, the use of diesel engines can be reduced. Standard HRES with a biogas plant used a biogas plant with continuous biogas production. For the balanced of the fluctuated energy production with this kind of biogas plant, a big biogas storage or a high demand of energy production of diesel engine is necessary. The gas production and the energy need by them are not in time. With a biogas system with flexible demand-oriented biogas production, the necessary biogas storage and use of diesel engines can be minimized [1]. The biogas production can be controlled through a flexible controlled substrate feeding.

This study presents a method for the optimization of the size of the components of the biogas based HRES Energy system. The method based on the mathematic modelling of the components in Matlab. The biogas process is modelled with the AM2 biogas model with acid inhibition and hydrolysis kinetics by Arzate [2]. For optimization, PSO is employed. For the biomass substrate are used gras and corn silage. The presented standalone HRES consist of biogas plant, PV plant, Lithium batteries and diesel generator.

The presented research show, that biogas plants with demand driven biogas production in comparison with continuous biogas production can more reduce the energy production and pollution of diesel generators. The achieved reduction in this study are two percent. Also, the battery can be reduced about 18 % and the gas storage about 6 %. The LCOE are by 0,27 €/kWh. The LCOE of the energy system can decrease through the using of residual waste and manure. Therefore, a LCOE lover than 0.18 €/kWh are possible [3]. This are considered in future work.

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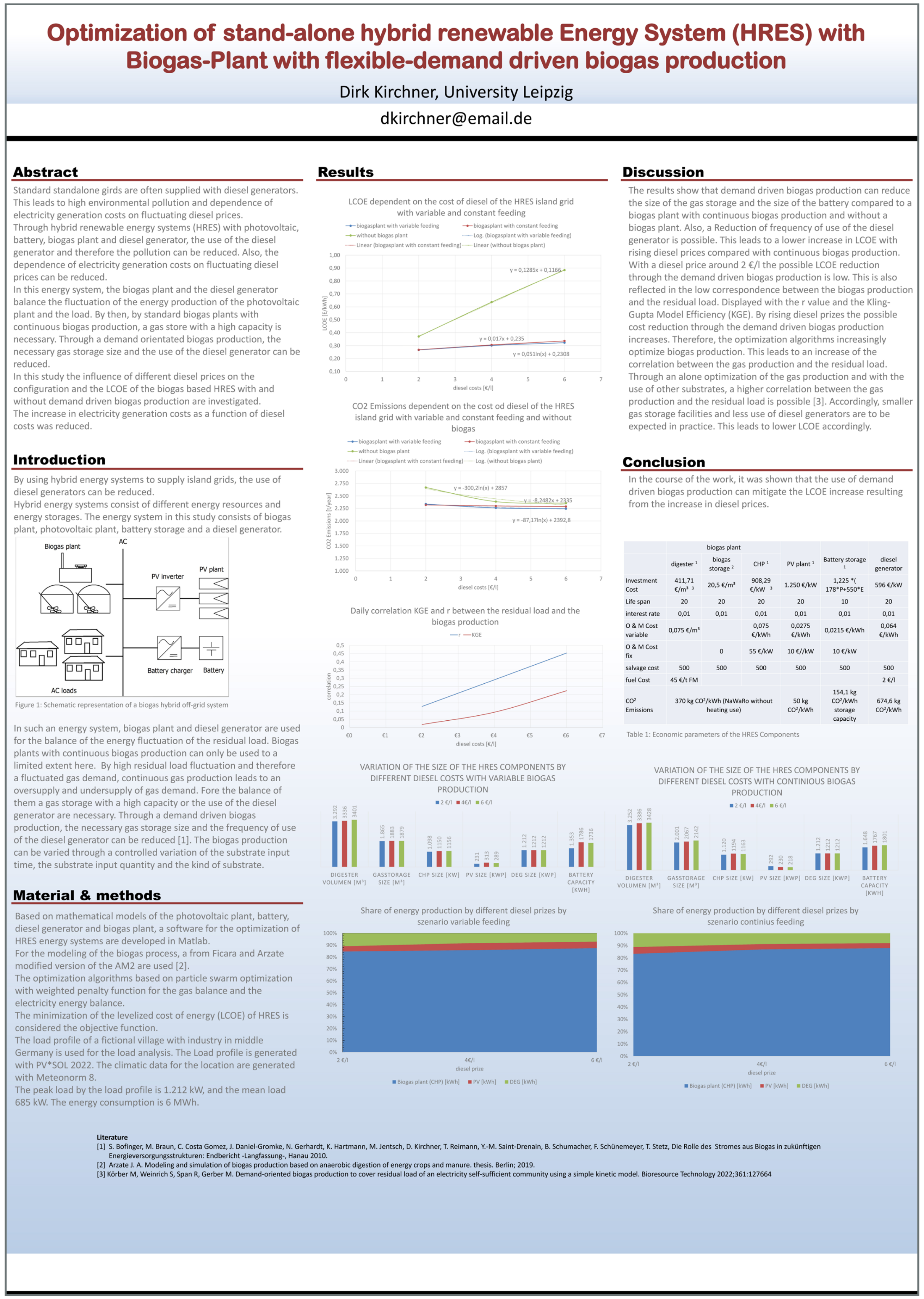

Lukas Richter, Deutsches Biomasseforschungszentrum

Synergizing Investment and Cooperation: An Agent-Based Modelling Framework for Optimized Energy Distribution in Cellular-Structured Systems

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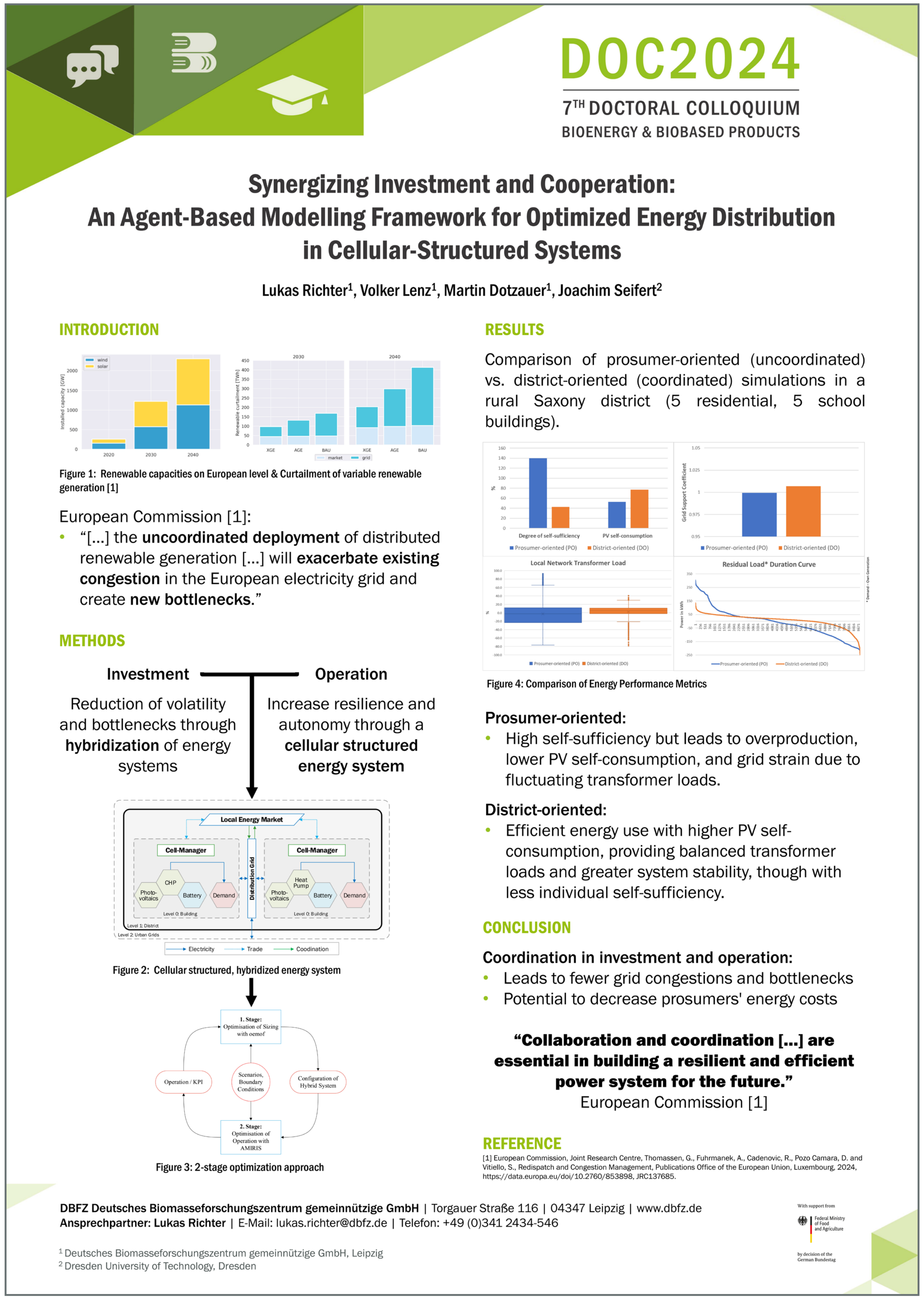
Keywords: Cellular energy system, bioenergy, hybrid systems, agent-based modelling, optimization

Managing energy resources in a decentralized and renewable energy system is becoming increasingly challenging. This system is characterized by individual prosumers who are primarily motivated by self-interest, self-sufficiency, and profit. Prosumers only engage with the energy grid when they require power or have surplus to offload. This behavior contributes to inefficiencies and elevated costs within the system. Consistency in prosumer behavior can result in excess energy during periods of high renewable generation, which may require expensive mechanisms for use or curtailment. Conversely, it can lead to shortages during times of limited renewable output. To address this imbalance, significant investment in storage infrastructure, non-volatile energy generation assets, or a fundamental restructuring of the energy framework towards a more cooperative and communicative distribution of renewable energy may be required.

This study analyzes the impact of solid biomass-based hybrid systems (SBBS) on a multimodal, cellular-structured energy grid. The research employs an iterative optimization approach that considers investment and operational considerations with mutual interference. The algorithm combines a multi-agent system with the adaptability of SBBS, providing insights into the optimal configuration of decentralized energy assets within district-level frameworks. The model also incorporates a local electricity market that facilitates the exchange of electricity between buildings. This analysis is essential in determining the appropriate scale of decentralized energy installations. It ensures a secure supply and mitigates grid constraints caused by excess capacities.

The approach was tested in a rural area of Saxony, Germany, using real demand data. A cellular structured multimodal energy system was used to model the district consisting of up to 30 buildings. The study aimed to explore the feasibility of integrating SBBS into a cellular structured energy grid to optimize decentralized energy systems at the district level. This approach addresses the challenges posed by individual consumer behavior while ensuring grid stability and security of supply.



Marco Selig, Deutsches Biomasseforschungszentrum

Your friendly neighbourhood AI

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Keywords: AI, data, insight

Artificial Intelligence (AI), especially generative AI (genAI), is currently a hot topic in public news and also in academia. Leveraging genAI promises unprecedented solutions to writer's block, code co-piloting, and to many other challenges scientists are struggling with. The actual challenge, however, is to balance euphoric exploitation and skeptical omission while adhering to good scientific practice. One goal of the DBFZ's DataLab is to enable our researchers to harness the potential of genAI in a secure and decent manner.

This presentation outlines the deployment of a modular and flexible genAI framework on-premise for DBFZ, which is (for the most part) build on Open Source and can, thus, be analogously be deployed at your institute. Besides hard- and software aspects, the usage and handling of results are discussed along with ethical aspects. The EU AI act plays hereby a key role as it sets the operational framework that grounds the use of AI in Europe.

It is possible and can be quite beneficial to make use of genAI in academia. There are however pitfalls and a likewise huge potential for abuse, that it is up to our better judgement whether genAI will be a blessing or a curse for scientific practice.

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YOUR FRIENDLY NEIGHBOURHOOD AI

Dr. Andrea Fais[1], Isis Paola Nuñez Franco[1], Dr. Marco Selig[1]

ABSTRACT

Artificial Intelligence (AI), especially generative AI (genAI), is currently a hot topic in public news and also in academia. Leveraging genAI promises unprecedented solutions to writer's block, code co-piloting, and many other challenges scientists are struggling with. The actual challenge, however, is to balance euphoric exploitation and skeptical omission while adhering to good scientific practice.

One goal of the DBFZ's DataLab is to enable our researchers to harness the potential of genAI in a secure and decent manner. This poster outlines the deployment of a modular and flexible genAI framework on-premise for DBFZ, which is (for the most part) build on Open Source and can, thus, be analogously be deployed at your institute.

What is „artificial intelligence"?

There is no definition of „intelligence" in the first place. Artificial intelligence, in its broadest sense, is intelligence exhibited by machines, particularly computer systems.

Can genAI be used safely from an ethical and scientific point of view? And if so how?

Most genAI models do not (or cannot) explicitely state which data sources are used for their training. Therefore, strictly speaking, the model results cannot be considered trustworthy.
It is common practice to cite the exact model version and the prompt used to achieve a tolarable level of reproducibility.

Can you sketch the DBFZ's genAI architecture?

Sure. Have a look at this ...

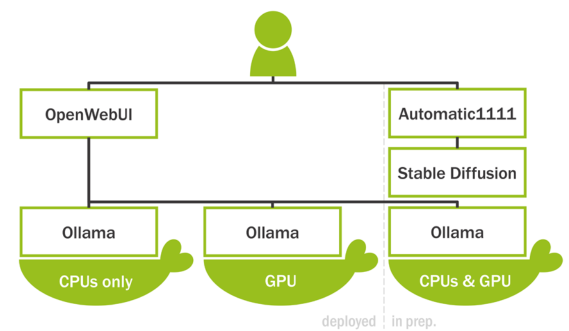

Figure 0: DBFZ's genAI architecture based on Singularity containers

Which genAI models does Ollama run?

At the moment, users can choose between Mixtral 8 (7b), Llama 3.1 (8b), and Gemma 2 (with 9 billion parameters).

What should I bear in mind when using genAI in my daily research work?

First of all, if you are not using a local intance like at DBFZ, you are disclosing your research. Furthermore, you should be aware of the following pitfalls:

- Model results are subject to biases present in the training data, which can be outdated, unbalanced, or plainly wrong.
- Models can fabricate information, an effect also known as „hallucinations".
- There are concerns regarding data privacy and information security.

Therefore, always be critical on model outputs and do not adopt them inconsiderately!

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René Heller, University of Hohenheim

Mechanical Pretreatment of Agricultural Waste and Animal Manure in Full Scale Biogas Process

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Keywords: anaerobic digestion, substrate disintegration, agricultural residue, lignocellulose, methane yield, degradation kinetic

The utilization of agricultural residues for biogas production through anaerobic digestion represents a promising possibility for renewable energy generation and waste valorization at the same time. Nevertheless, a substantial quantity of organic waste and residues remains unexploited due to their high levels of lignocellulose exhibiting slow anaerobic degradation rates. To enhance the biodegradability of lignocellulosic materials and effectively utilize agricultural waste, pretreatment stands as a crucial component for ensuring the economic viability of biogas plants. As part of the „FLEX-CRASH (2020-2024)“ research project, a prototype ball mill for mechanical substrate pretreatment was being investigated. Mechanical pretreatment primarily reduces particle size and increases the particle surface area which makes it easier for microorganisms to break down the material. On the other hand, substrate pretreatment can also lead to energy savings in pumping and mixing operations or a reduction of process related problems like floating layers in the digester.

The aim of the project is to show that agricultural residues can also be suitable for flexible biogas production through substrate management and that these lower-quality substrates can even compete with higher-quality energy crops through mechanical substrate pretreatment. Laboratory results from the Hohenheim biogas yield test (Heller et al. 2023b) with pretreated horse manure were already promising and could be underpinned by trials in larger fermenter systems (Heller et al. 2023a) where landscape management grass was pretreated. In a long-term trial at a practical scale plant one digester is fed with an unprocessed substrate mix whereas the other digester is fed with the same substrate mix but pretreated by the ball mill. The feed mixture consisted mainly of horse manure, cattle manure, and straw. It was already demonstrated here that methane yields were significantly higher (up to 30% compared to the untreated variant) due to substrate pretreatment, and process-related problems such as floating layers could be avoided as a result.

In summary, it can be said that the use of agricultural residues offers an enormous opportunity to provide sustainable bioenergy. However, substrate pretreatment is necessary in order to be able to utilize these residues in large quantities in a biogas plant. Further advantages can result from savings in substrate costs and more efficient and faster conversion of organics into biogas. In addition, process interruptions such as blockages or floating layers can also be reduced and savings in stirring and pumping costs may also be achieved. In addition, the flexibilization of a biogas plant with agricultural residues via feed management can also bring additional benefits for biogas plant operator.

UNIVERSITY OF HOHENHEIM

State Institute of Agricultural Engineering and Bioenergy

FLEX-CRASH

Mechanical Pretreatment of Agricultural Waste and Animal Manure in Full Scale Biogas Process

M.Sc. René Heller, Dr. Benedikt Hülsemann, Dr. Hans Oechsner

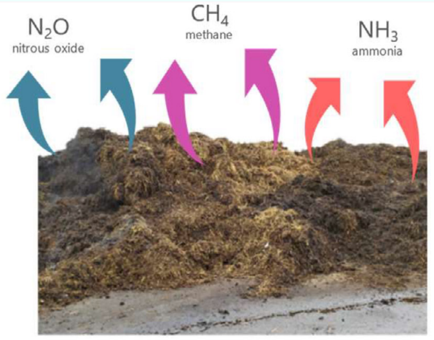
Goals

In Germany around 2/3 of the technical potential of agricultural by-products (including catch crops, residues from vegetable cultivation, straw, liquid and solid manure) is not utilized for material use or energy production.

The use of these residues offers a wide range of advantages:

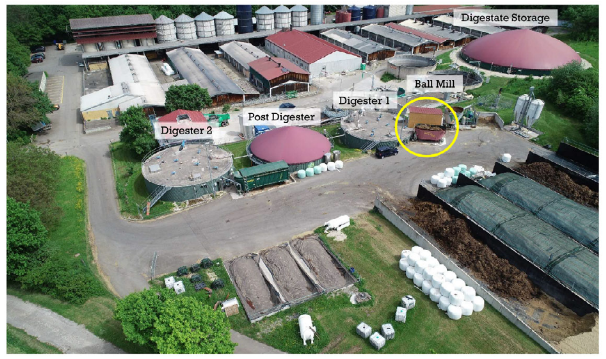
- Sustainable utilisation of agricultural resources to enhance the circular economy
- Valorisation of residual biomass into renewable energy (biogas)
- Replacement of energy crop cultivation
- Reducing greenhouse gas emissions

→ Sustainable, cost-effective and flexible biogas production from agricultural residues through substrate pretreatment



Greenhouse gases emitted by storing manure instead of utilising it for energy production in biogas plants

Experimental Design



Research biogas plant 'Unterer Lindenhof' with integrated ball mill

Long-term trial at research biogas plant:

- High proportion of horse manure, solid cattle manure and liquid manure in the feed
- Same amount and composition of feed in both digesters (D1: pretreated, D2: untreated)
- Investigation of the effects of mechanical pretreatment with a ball mill on the methane yield and the degradation processes under continuous and shock feeding scenarios

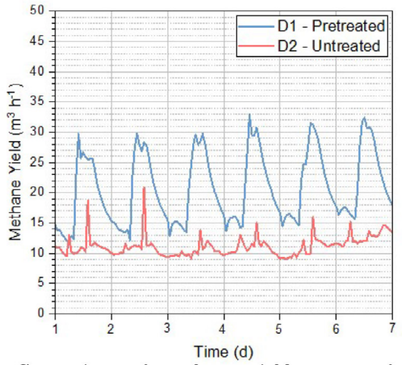
→ Mechanical pretreatment in full scale trial

Results

Mechanical substrate pretreatment of agricultural residues using a ball mill offers both economic and ecological advantages for biogas plant operators:

- Particle size reduction, cell wall alteration and increase of particle surface area
- Increased specific methane yield (SMY) of more than 30%
- Low specific energy demand of ball mill with only 5 kWh t_{FM}
- Higher proportion of low-cost substrates in the feed
- Ensure process reliability by reducing floating layers

→ Faster kinetics of biomass degradation and gas production process for on-demand biogas plant operation (flexibilisation)



Comparison of methane yield curves of digester 1 and 2 at shock feeding

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FNR Fachagentur Nachwachsende Rohstoffe e.V.

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Frederik Bade, Helmholtz-Centre for Environmental Research

Foam formation during anaerobic digestion of sugar beet - Antifoaming strategies

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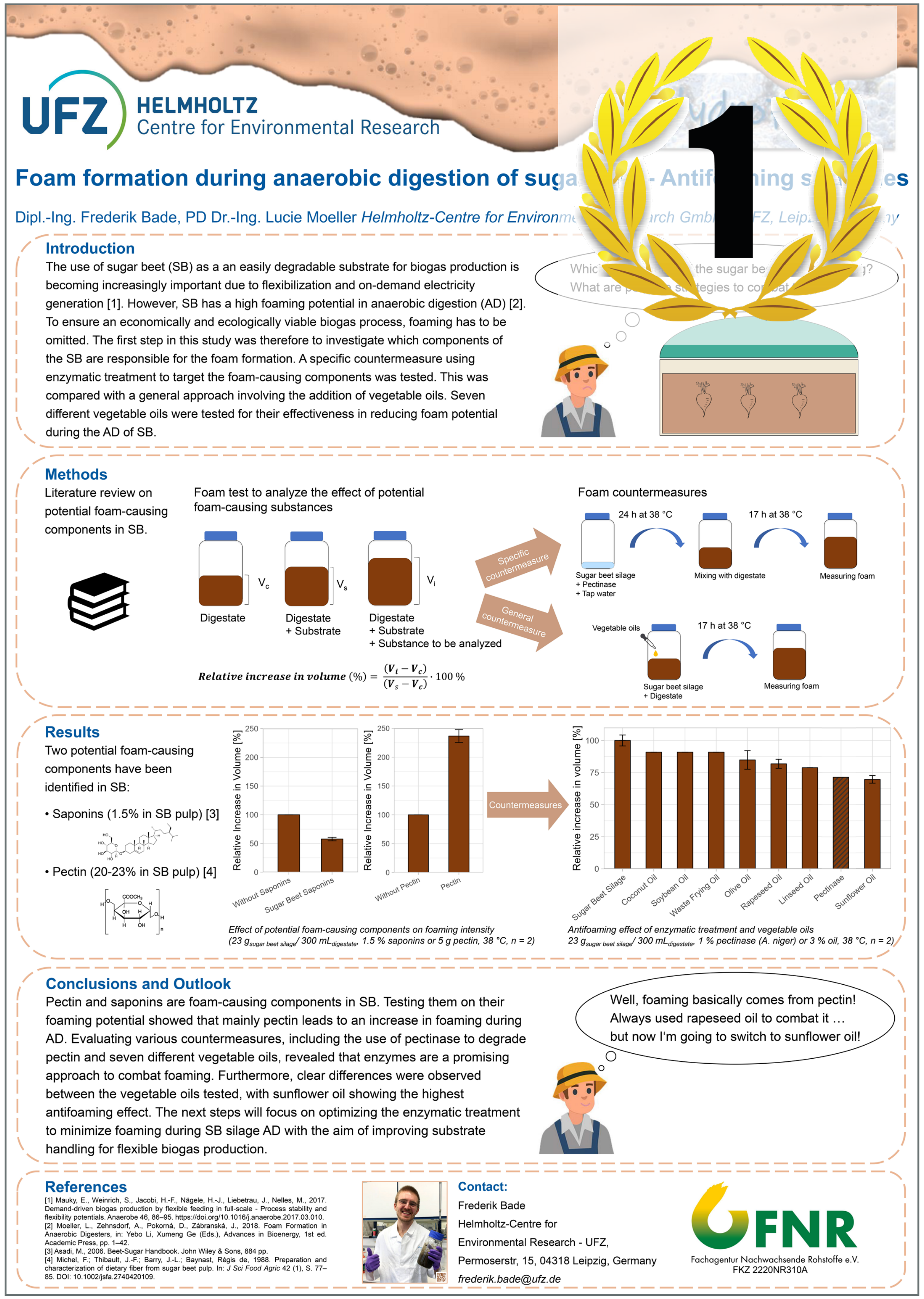
Keywords: Sugar Beet, Foaming, Antifoaming, Vegetable Oils, Hydrolytic Enzymes

Flexible electricity generation from biogas plants can be achieved by short-term enhancing biogas production through feeding with easily degradable substrates [1]. However, this approach carries the risks of process disturbances, such as foam formation, which may have wide-ranging consequences.

This study focuses on the foam formation during the anaerobic digestion (AD) of sugar beet (SB), an interesting easily degradable substrate for a flexible feeding regime. However, the AD of SB has the drawback of its strong foam propensity. The approach of this study was to analyze the components of SB that have major impact on its foaming tendency. Based on this analysis, (pre)treatments of SB were examined to decrease its foaming intensity. This study focused on two main components of SB: saponins and pectins. Saponins are naturally occurring surfactants associated with foaming problems in the sugar refining process of SB and pectins are known to enhance viscosity in mediums.

One commonly applied antifoaming treatment is the application of different vegetable oils. However, biogas operators often apply vegetable oils based on availability rather than their effectiveness. For this reason, different vegetable oils were compared for their defoaming effect. On the other hand, the application of hydrolytic enzymes was tested. This approach aims to degrade the foam-causing components, leading less foaming. Foam formation was analyzed through foaming tests, where substrates and digestates are mixed and incubated to determine the extent of foaming. The tests are carried out at high OLR's to enhance the visibility of foaming behavior. This method enables the examination of the effects of SB-components on foam formation and the effects of the (pre-)treatments.

Results of the foaming test were: First, they revealed pectin as a significant contributor to foaming during AD of SB, while saponins exhibit a negligible impact. Moreover, the tested (pre-)treatments showed significant decrease in foam formation. Differences in vegetable oils were observed, with sunflower oil being the most effective. The addition of hydrolytic enzymes resulted in reduced foaming, albeit requiring substrate pre-treatment. This research contributes valuable insights to the challenge of foaming in AD and supports ongoing efforts to enhance the flexibility and efficiency of biogas production.



Bomin Yuan, Deutsches Biomasseforschungszentrum

Investigation and modeling of the influence of partially treated digestate recirculation on methane yield and process efficiency

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Keywords: Digestate treatment, Biogas, Modelling

Digestate treatment can reduce the costs of transport, spreading, and storage by recovering the water and processing the nutrients into fertilizer products. However, the treatment process is costly and highly energy-intensive due to the many steps required to purify a large amount of digestate. Therefore, liquid digestate recirculation (LDR) is being investigated as a more economical and efficient method of digestate treatment. The aim of this study is to enhance biogas production by recirculating digestate into fermenters and to simplify the digestate treatment process by developing a model that determines the LDR strategy based on process variables. To achieve this, it is crucial to identify the substances that affect the fermentation process and selectively promote positive impacts while avoiding negative ones through digestate treatment and recirculation.

Different recirculation scenarios, including full and partial recirculation of the liquid fraction from solid-liquid separation and further treatment, will be tested in long-term fermentation experiments. The productivity of biomethane will be analyzed and correlated with process variables. Based on the data obtained from the experiments, a model will be established to determine a suitable digestate recirculation option depending on process variables. In the final step, the model will be validated in the pilot-scale plant while maintaining system stability. The appropriate digestate recirculation option, as determined by the model, will be tested in the pilot plant and the results will be compared with the expected outcomes and the model will be adapted accordingly. Finally, a model for the LDR strategy will be developed.

The fermentation experiments are still in the early stages and have not yet reached steady-state. Currently, literature review and initial modeling are being conducted. The first digestate recirculation experiments will begin once the fermentation process has stabilized. The results, including biogas and methane production, as well as the results of the component analysis, and the initial model attempt, will be presented at the colloquium.

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Leander Lerch, Deutsches Biomasseforschungszentrum

Multirate State Estimation and Parameter Identification of Agricultural Biogas Plants

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Keywords: Parameter identification, state estimation, anerobic digestion, ADM1

Demand-oriented control of agricultural biogas plants is essential for a renewable electricity grid, and relies on model-based online monitoring. Weinrich and Nelles have proposed systematic simplifications of the established Anaerobic Digestion Model No. 1 (ADM1) [1]. The simplified AD model investigated in this study is the ADM1-R3 model, which is applied to measurement data from DBFZ, using state of the art methods of parameter identification and state estimation.

Based on the recommendation from Villaverde et al. [2] the following methods are used for the parameter identification (PI): 1. Maximum Likelihood Estimation - the model errors are weighted by the measurement uncertainty. 2. Logarithmized parameters - transformation on the parameter search space to increase numerical stability. 3. Enhanced scatter search - a metaheuristic for global optimization. 4. Gradient evaluation - gradients are calculated with adjoint and direct sensitivities to improve convergence.

Optimized model parameters enable reliable state estimation. The challenge is to include both online data from sensors and offline data from lab analyses, which entails a significant delay that is unknow a-priori. For this task a multirate extended Kalman filter (MR-EKF) is being investigated [3]. The current PI leads to good results, and thereby validates the implementation (see Figure 1). The next step is to use the framework for large-scale simulations in order to find cross-validated parameter sets. With the parameter sets the MR-EKF will be tested on available data and the influence of delays of measurements will be investigated. The overall goal is to use the MR-EKF and an MPC controller to operate a lab-scale digester at optimized feeding regimes.

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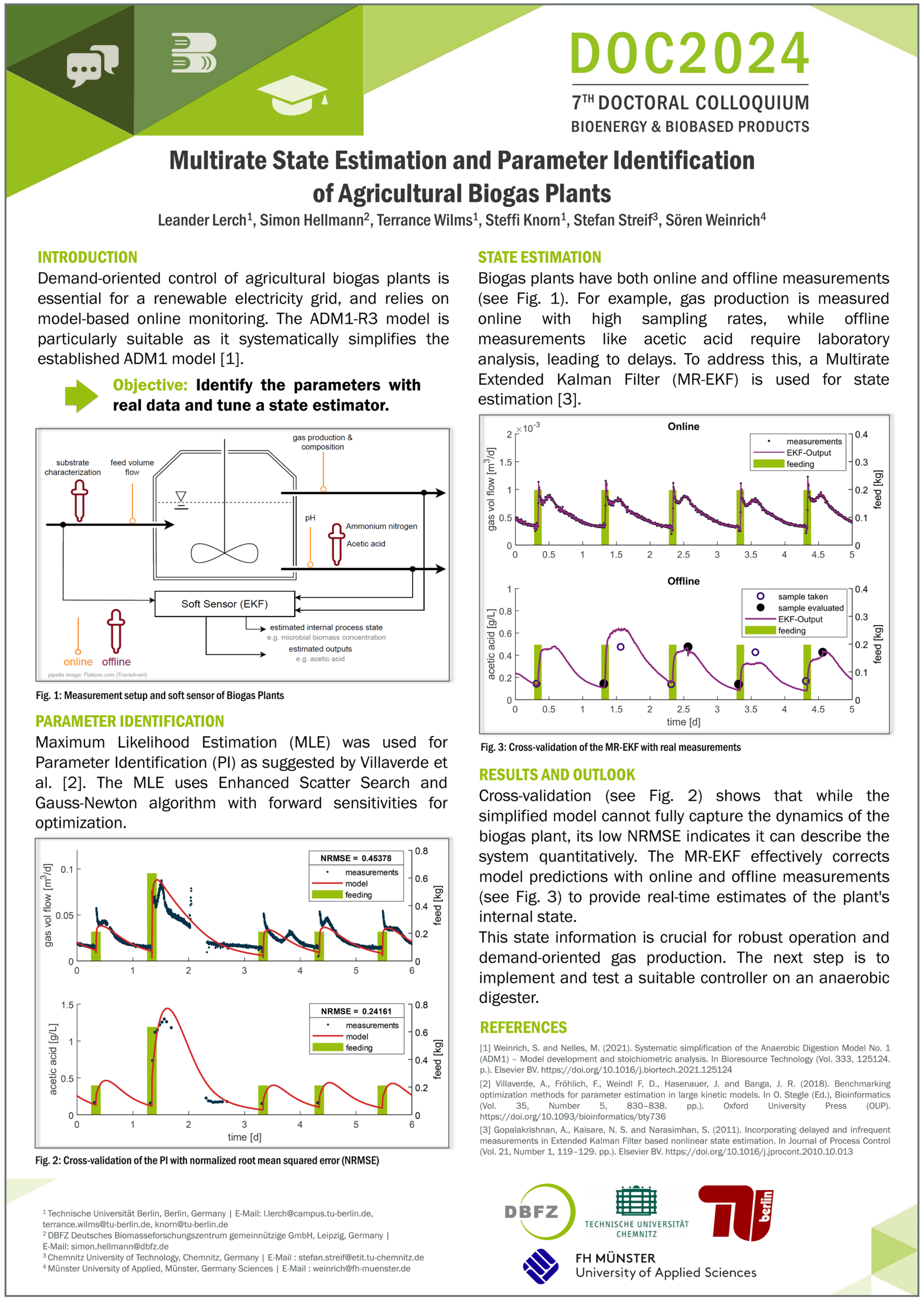

Annalena Koch, Deutsches Biomasseforschungszentrum

CCGAN-based Imputation method for anaerobic digestion processes

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Keywords: biogas technology, artificial intelligence, neural networks, process stability, machine learning

Models such as the ADM1 and Recurrent Neural Networks (RNNs) are often used for modelling the Anaerobic Digestion (AD) process, but they require high measurement frequency for several input parameters for successful process modelling. While the measurement of Volatile Fatty Acids (VFAs) is crucial for an accurate prediction of the AD process especially at high OLRs, VFAs are rarely measured due to high costs. Usually, missing data is imputed with simple methods, providing inexact values that do not allow models to perform well. Thus, more advanced imputation methods could improve results for all currently applied models. Generative Adversarial Networks (GANs) show potential due to their ability to generate realistic output values (images) from the input data (prompts). This study evaluates the usage of GANs as soft sensors for imputing missing values of time series of VFAs digestate's concentration.

Generative adversarial networks (GANs) consist of an NN attempting to generate realistic data (generator), and another NN attempting to distinguish implausible data from real data (discriminator). For generating images with a specific content, Conditional-GANs are applied, which accept additional label input. Context-Conditional GANs (CC-GANs), instead, get such labels directly from the context of the input data. When applied to VFAs time series, the generator of the CC-GAN can learn to generate realistic VFAs values at each timestep, considering other features that were measured at the same time. VFAs were modelled within a 165 days experiment carried on in a 188 m^3 biogas reactor fed with cow manure and several solid substrates, with a maximum OLR of 9 kg VS m^{-3} d^{-1}.

Since CC-GANs are a framework rather than a specific NN, several types of configurations were tested. Results show that simple multi-layer perceptrons applied to generator and discriminator are already able to provide plausible values, while Convolutional Neural Networks (CNNs) do not converge due to their complexity. This study demonstrates the possible usage of GANs as soft sensor in the AD process, more specifically for imputing VFAs values. GANs can support AD models when simulating typical process parameters. The usage of a time dimension applying long short-term memory NNs might further increase performances and model reliability.

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CCGAN-BASED IMPUTATION METHOD FOR ANAEROBIC DIGESTION PROCESSES

Annalena Koch[1, 2], Alberto Meola[1, 2], Sören Weinrich[1, 3]

INTRODUCTION

- Volatile Fatty Acids (VFAs) concentration in digestate is a key indicator for measuring anaerobic digestion process stability and reactor acidification [1]
- Due to high cost and effort, in most biogas plants VFAs are not measured or are not consistently measured
- Missing values are usually imputed with simple methods (e.g. mean imputation), but such methods can be inadequate, especially at high process flexibility
- Neural networks (NNs) can picture complex correlations, but are not sensitive enough to outliers, possibly leading to hallucinations and insufficient performances [2]
- Generative Adversarial Networks (GANs) can impute missing data while reproducing the original given distribution [3], possibly improving model imputation capabilities.

METHODS

Context-conditional GANs (CCGANs) use additional external input to control the direction of the generation [4]. In this case further process measurements (context) are used to generate the target, the concentration of acetic acid in the digestate.
As shown in Figure 1, the generator's input consists of the context and the target columns, overwritten with random values.

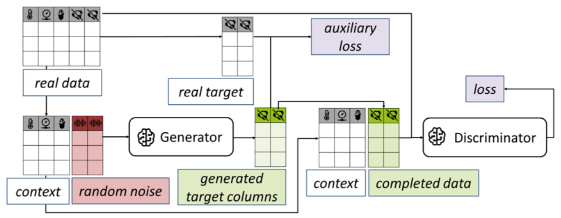

Figure 1: Architecture of the used neural network based on a CCGAN

The generated values are combined with their context and handed over to the discriminator. This data is then mixed at random with real samples, with the discriminator classifying the samples as real or fake. Besides the discriminator's loss, the generator uses MSE as an auxilliary loss which helps stabilizing the training. To our knowledge, this is the first-ever CC-GAN applied on time-series' data. A simple NN was further tested as comparison.

For model testing, data from a full-scale experiment (188 m^3 reactor) were used. The experiment was ran at an average OLR of 4, and an HRT between 23 and 66 days. The reactor was fed on average with 4 t of a mixture of solid and liquid substrate per day. In total, 70 data points were used as test data.

RESULTS

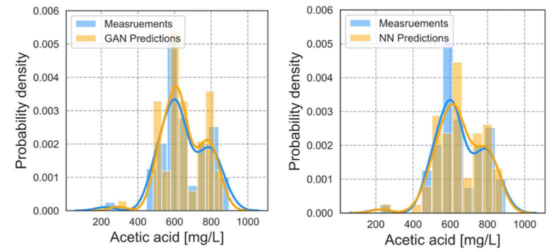

Figure 2: Distribution of GAN-generated data (left) and NN-generated data (right)

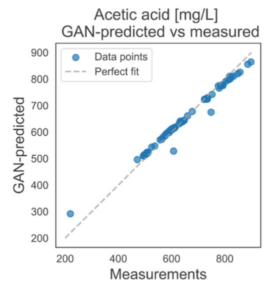

Figure 3: Preliminary results of the acetic acid concentration prediction from the developed CC-GAN,

As in Fig. 2, preliminary results demonstrate that both models can properly resemble the original distribution, with the CCGAN results displayed in Fig. 3 and the available error metrics in Table 1.

	RMSE	KS P-value
CCGAN	20.36	0.75
NN	29.33	0.61

Table 1: Preliminary results of both tested models. The KS (Kolmogorov-Smirnov) test verifies if two datasets have different distributions.

CONCLUSION

The developed CCGAN was succesfully applied as inputation method for the acetic acid concentration in the digestate of a full-scale reactor, slightly overperforming a simple NN. Further studies are required to fully evaluate the potential of CC-GANs.

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Consequences of commercial biochar heterogeneity on its application as cathode for hydrogen-driven bioelectrochemical systems

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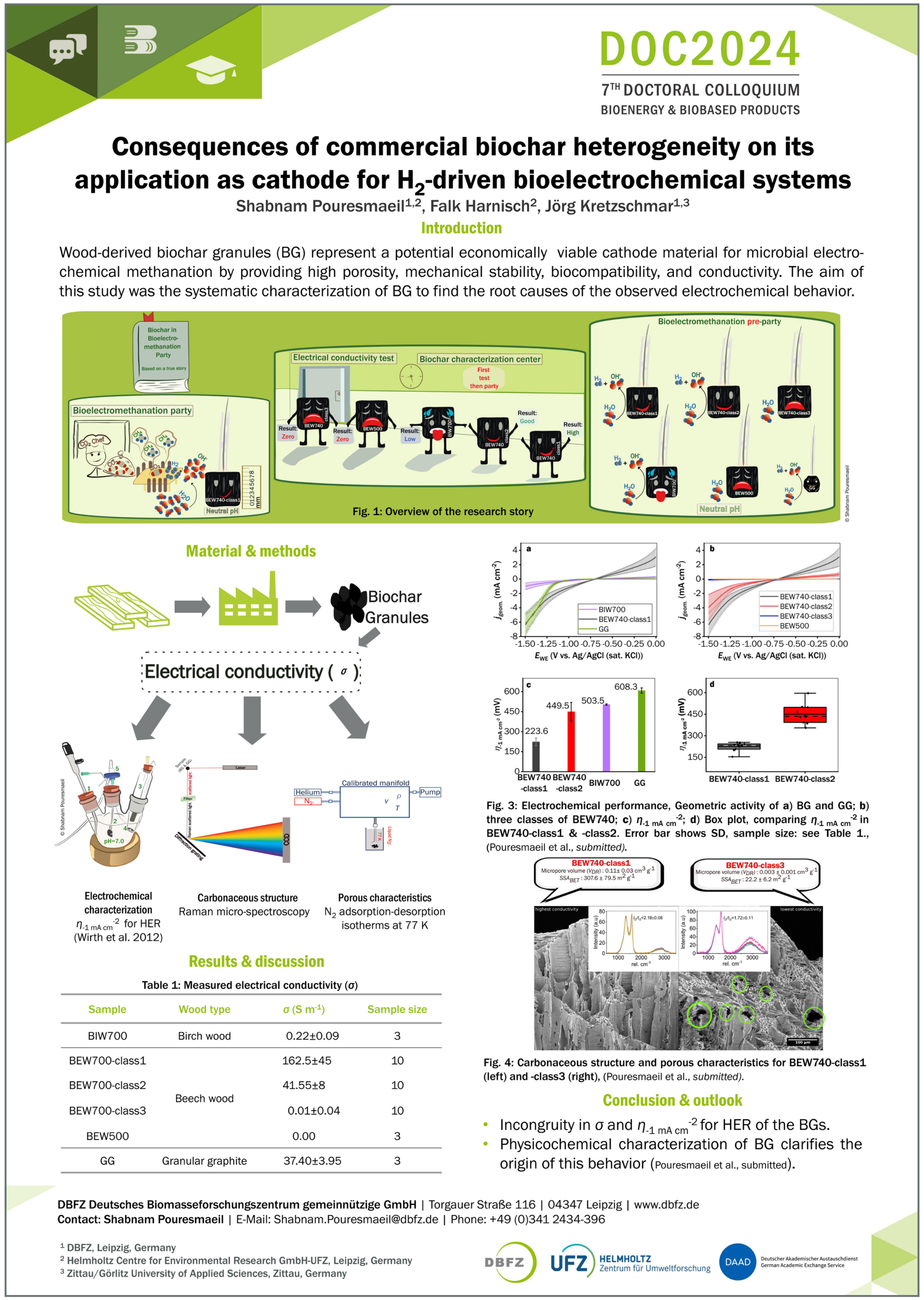
Keywords: Bioelectrochemical system, hydrogen evolution reaction, pyrolysis, heterogeneity, overpotential

Methane-producing bioelectrochemical systems (CH_4-BES) have become a promising technology to capture and convert CO_2. In a CH_4-BES, methanogens in cathode compartment metabolizes cathode-derived electrons either directly or indirectly via in-situ-produced molecular hydrogen. Hydrogen evolution at cathode in a close proximity to hydrogenotrophic methanogens mitigates H_2 low solubility and mass transfer limitations. 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 that high cost of electrode material is a major drawback of CH_4-BES and the identification of cheaper material is essential for the commercialization of this process. Biochar is an attractive biocompatible, costeffective, environmentally friendly, and electroconductive material, produced from various biomass feedstocks via reductive pyrolysis under anoxic atmosphere.

Pyrolysis process and the nature of wood affects produced biochar in terms of porosity, surface area, electrical conductivity, and degree of carbonization, as well as the carbonaceous structure which explains the electrochemical performance of the material. Granular biochar, produced via pyrolysis from beechwood at 740 °C (BEW740) showed highest electrical conductivity (σ); however, samples are utterly incongruous in σ.

This study unravels how physicochemical and electrochemical characteristics of BEW740 are influenced by product's heterogeneity. Cyclic voltammograms revealed that some of BEW740 cathodes have lowest overpotential for hydrogen evolution reaction, i.e., ~2.5 orders of magnitude less than granular graphite-based cathode. The knowledge achieved from this study will provide a scientific basis to select and/or produce high-performance granular biochar for applications in biocathodic reactions.



Sample	Wood type	σ (S m-1)	Sample size
BIW700	Birch wood	0.22±0.09	3
BEW700-class1	Beech wood	162.5±45	10
BEW700-class2		41.55±8	10
BEW700-class3		0.01±0.04	10
BEW500		0.00	3
GG	Granular graphite	37.40±3.95	3

Djangbadjoa Gbiete, University of Rostock

Enhancing Biohydrogen Production through Dark Fermentation of Food Waste: A Review of Substrates, Inoculums, and Pretreatment Strategies

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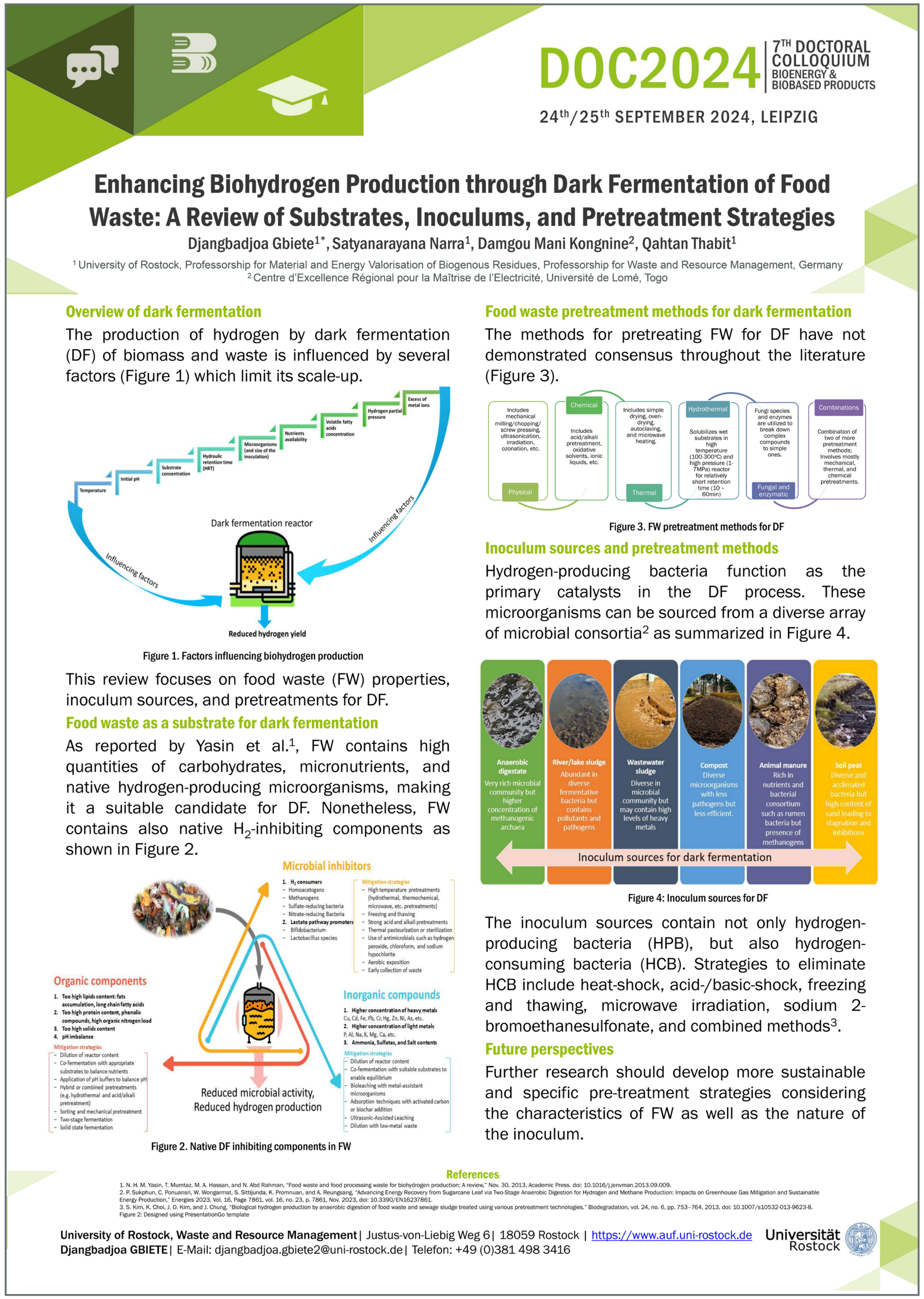
Keywords: Dark Fermentation; Biohydrogen; Food waste; Inoculum; Pre-treatment

The increasing population and economic growth result in heavy demand for energy amid climate change while waste generation and management become a complex equation. In the context of circular economy, waste management through bioenergy generation is gaining more interest leading to extensive research on waste bioconversion methods and strategies. Green hydrogen, considered a main future renewable energy supply can be also generated from food waste and food processing waste using dark fermentation. Dark fermentative hydrogen production from food waste and food processing waste as well as from organic residues at large is influenced by the pretreatment of the feedstock and the inoculum used in the process. This paper critically reviews food waste and food processing waste sources, their physical and chemical compositions, and their pretreatment methods as well as strategies for optimizing dark fermentative hydrogen production.

In this paper, the different inoculum types and innovations regarding the pre-treatment and enrichment applications of inoculums for dark fermentative hydrogen production are also highlighted and discussed critically. The literature discussed that food waste and food processing waste have complex physical and chemical compositions which include dark fermentation inhibitors. The main strategies employed across the literature to pre-treat food waste and food processing waste included thermal, chemical, thermochemical, ultrasound, enzymatic, bacterial, and physical pre-treatments. Some of the pre-treatment methods showed a positive impact on hydrogen production while the other methods resulted in a detrimental effect on hydrogen productivity. The reviewed scientific reports depicted that inoculums for dark fermentation of food waste and food processing waste were mostly sourced from anaerobic digestion plants, animal manure, wastewater treatment plants, river sludge, soil, compost material, etc.

The inoculums were mostly treated using heat and were enriched through acclimatization and cultural strategies. Ineffective inoculum treatment and handling strategies resulted in hydrogen consumption by H_2 consumers in the dark fermentation process. More sustainable and specific pre-treatment methods that consider food waste and food processing waste characteristics as well as the nature of the inoculum need to be researched in depth to prevent inhibitions and inefficiencies during the dark fermentation process.



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Agricultural Waste as a Sustainable Feedstock for the Production of Biobased Pots

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Keywords: Manure, plant pots, sustainable

In agriculture, managing waste, such as green waste, crop residues, and farm manure, is a significant challenge. Given the unique characteristics of various organic wastes, this study highlights the importance of exploring the combination of different substrates to evaluate their potential as a sustainable feedstock.

Recent trends have included bio-based materials like coconut fibers, sugarcane, and others, aligning with circular economy principles. However, residues such as the solid fraction of pig manure could offer additional benefits, due to the nutrient content, which may enhance plant growth. This study focuses on assessing the potential for plant pot production using the solid fraction of pig manure and wood chips, including the necessary pretreatment for material sanitization and odor elimination.

Initially, a characterization of the solid fraction of pig manure was conducted. The results revealed high levels of hemicellulose and lignin, at 16.5 % and 27.2 % respectively. In contrast, the cellulose content was relatively low, at only 2.8 %. To address this, incorporating another agricultural residue with a higher cellulose content, such as wood chips, which literature reports to contain about 32 % [1], could create a mixture that enhances the structure of biobased pots.

The material must undergo pretreatment to ensure sanitization. Additionally, different concentrations of citric acid were tested to control odors effectively. Various combinations of the two materials were tested to determine the optimal structure and composition for the plant pots.

This research could contribute to the utilization of a material that has so far been overlooked due to its odorous properties. Not only does this approach offer a solution for the management of agricultural waste, but the use of these bio-based pots could indicate a potential for the gradual release of fertilizers into the soil, presenting a possibility aligned with the principles of the circular economy.

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AGRICULTURAL WASTE AS A SUSTAINABLE FEEDSTOCK FOR THE PRODUCTION OF BIOBASED POTS

Cinthya Lara[1], Michael Nelles[1], and Jan Sprafke[1]

INTRODUCTION

- Managing agricultural waste presents a significant challenge due to the large volumes generated.
- Recently, there has been growing interest in developing bio-based materials derived from agro-food residues, which offer great potential as sustainable feedstocks for high-value products.
- One promising feedstock is the solid fraction of pig slurry, rich in keratin- a compound known for its excellent mechanical properties. In addition, it contains valuable nutrients, making it an ideal candidate for applications such as biodegradable plant pots.
- By integrating other organic waste materials, such as coffee grounds and wood chips, this approach can help mitigate odour-related problems. Moreover, recent research has explored the potential of eggshells as a natural binder, further advancing the development of sustainable composite materials.

METHODOLOGY AND PRELIMINARY RESULTS

Step 1: Material preparation

Figure 1: Feedstock for the production of biobased plant pots (from left to right: solid fraction of pig slurry, wood chips, coffee grounds, and eggshells)

Step 2: Characterisation

Biomass type	Cellulose [%dm]	Hemicellulose [%dm]	Lignin [%dm]
Eggshell	0,3	3,04	2,94
Coffee grounds	27,96	24,84	14,06
Wood chips	32,09	14,22	-
Solid fraction pig slurry	34,28	30,36	14,36

Table 1: Characterisation of the feedstocks

Step 3: Pre-treatment

- Thermal treatment
- Treatment with acids: The first trial involved the pre-treatment of the solid fraction with three different concentrations of citric acid M1 (0,04 M), M2(0,22M), M3 (0,44M).

Step 4: Molding

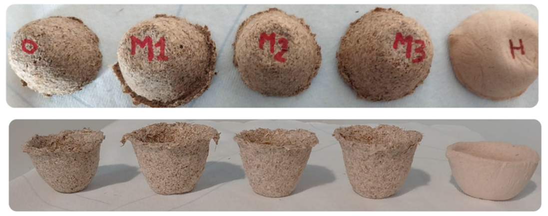

Figure 2: Production of Biobased Plant pots using the solid fraction from pig slurry, wood chips, and corn starch as feedstock.

Step 5: Testing

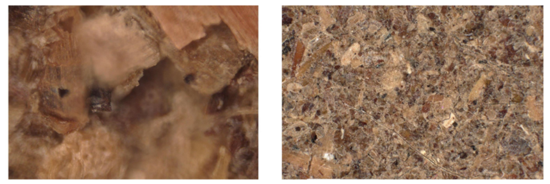

Figure 3: Analysis of the solid fraction of pig slurry with digital microscope using LIBS (laser-induced plasma spectroscopy).

CONCLUSION

The transformation of agricultural biomass into bio-based plant pots not only addresses the challenge of managing agricultural waste but also generates high-value products that support circular economy principles. An initial plant pot prototype demonstrates the feasibility of converting agri-food waste into sustainable composite materials. Ongoing research focuses on optimizing material properties and understanding how nutrient dynamics evolve.

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Options for reducing GHG emissions from rotting processes for the production of soil improvers

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Keywords: On-site approach, GHG emissions, biowaste utilization, anaerobic digestion, composting

Depending on the recycling process, the biowaste treatment plants consist of fermentation and post-rotting or composting. There are several emission sources in biological waste treatment plants that can emit methane (CH_4), ammonia (NH_3) and nitrous oxide (N_2O). One of these is composting or downstream rotting.

Unsuitable operating conditions can result in GHG-emissions in the form of CH_4 and N_2O during the composting process. An anaerobic milieu in the compost material can lead to CH_4 hotspots and cause high CH_4 emissions. According to the 6th IPCC report, the GWP100 of CH_4 is 27 CO_2-eq and is therefore a climate-damaging gas that should be avoided [1]. N_2O, on the other hand, can form in the course of nitrification and denitrification in both aerobic and anaerobic conditions. N_2O has a GWP100 of 273 CO_2-eq [1]. The loss of nitrogen in the form of NH_3 and N_2O is also a loss of nutrients in the fertilizer and should therefore be prevented from a resource protection perspective [3].

What options What options are there for reducing greenhouse gas emissions from rotting processes? In order to find out which operating parameters have a major influence on the generation of emissions during the composting process, several emission measurements were carried out at twelve biowaste treatment plants. In the KlimaBioHum project, various operating parameters were investigated along the four measurement phases.

The GHG emissions were quantified using an open dynamic chamber measurement. For this purpose, a wind tunnel with the largest possible surface area was installed on the emission-active surface of the rotting material and flowed through with a defined volume flow. This results in a volume-specific emission factor that is related to the volume under the wind tunnel in order to obtain comparable data [2]. The highest greenhouse gas emissions in the rotting process were produced by the discontinuous dry fermentation plants (mean value = 250 kg CO_2/Mg-WM).

An active aeration as an operational parameter by pressurized ventilation at the bottom of the compost heap showed the largest influence on the GHG emission situation during the composting process. For some parameter variations, no conclusive trends can yet be identified and there is still a need for further research in this area.

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Options for reducing GHG emissions from rotting processes for the production of soil improvers

Julian Matlach

Introduction

The maintenance of nutrient cycles through the material and energetic use of biogenic residues is an important aspect of circular waste economy. Since 2015, the separate collection of biogenic materials has been legally anchored in the recycling law in Germany. In 2021, 16.1 million tons of organic waste were generated and treated in anaerobic digestion and composting plants [1]. Unsuitable environmental conditions during composting process can lead to high methane (CH_4) and nitrous oxide (N_2O) emissions in particular. Emission measurements were carried out at twelve German biowaste treatment plants between 2019 and 2022 in several measurement campaigns to find out which operating parameters favor this condition.

Material and methods

The GHG emissions of seven composting and five anaerobic digestion plants with a subsequent rotting stage were quantified using a open dynamic tunnel measurement. For this purpose, a wind tunnel with the largest possible surface area was installed on the emission-active surface of the rotting material and flowed through with a defined volume flow (see Fig.1).

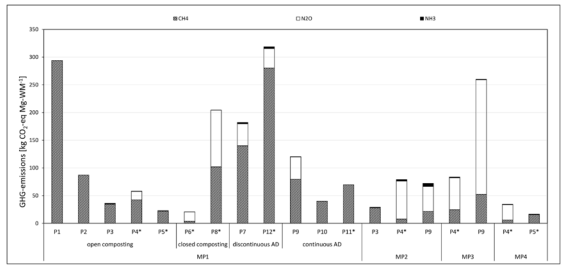
Figure 1: Open dynamic tunnel (left); pore gas measurement (right)

This results in a volume-specific emission factor that is related to the volume under the wind tunnel in order to obtain comparable data. In addition, a depth-differentiated temperature and pore gas measurement were carried out.

Results

The determined rotting process emissions show a high overall range, independent of the type of composting (see Fig. 2). Particularly high emissions were found at plants with:

- too high compost windrows (P1),
- not optimally working active ventilation of rotting processes (P8, P12) and
- discontinuous pre-treated materials (P7, P12)



AD = anaerobic digestion | * = active pressurized ventilation | MP = measurement phase

Figure 2: GHG emissions of investigated biowaste treatment plants

When considering the parameter variations, emission reductions were particularly apparent for active aeration of the composting processes (see Fig. 3).

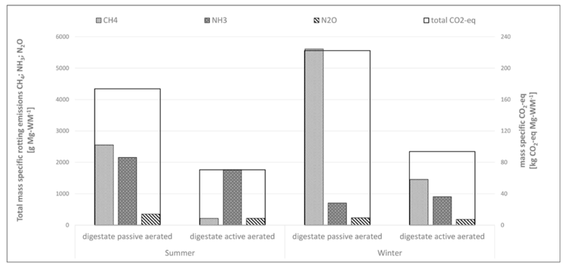


Figure 3: Total mass specific rotting emissions of active and passive aerated digestate windrows in summer and winter seasons

The comparison of different aeration types (active and passive) at a partly closed composting plant has shown that active aeration of the compost windrows produces up to 2.5 times less GHG regardless of the season.

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Doctoral Colloquium, Leipzig DBFZ, 24.09.2024

Holger Braun, HfWU

What is important? What is perceived? What is seen? – The interplay of different factors in consumer decision making on potting soils - an eye-tracking study

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Keywords: potting soil, visual attention, packaging cues, eye-tracking, peat-alternatives

The replacement of peat with more sustainable biomass alternative is a valuable action for climate protection, since peatlands are the most important natural carbon sink. On that account, the German government aims to eliminate the use of peat in hobby-gardening on a voluntary basis by 2026. Addressing this target, it is important to understand consumer behavior and decision-making when they purchase potting soils at the point of sale. To that end, we conducted a mixed-method study to investigate the purchasing behavior of 309 participants in a simulated purchasing environment in Germany. We captured consumer behavior at the simulated point of sale, using eye-tracking, followed by a qualitative exit interview and a quantitative survey using a questionnaire. Theoretically, our study is based on an approach that combines visual attention theory and cue utilization theory.

Our preliminary findings indicate that consumers pass through different behavioral stages when evaluating potting soils at the point of sale. Initially, they get a quick overview of the products and the surrounding environment, followed by a phase of a more detailed investigation of individual products. Although our findings indicate a correlation between consumers‘ stated importance of individual attributes and their perception of those attributes on the selected product, we also observe a discrepancy between consumers‘ stated importance and perception of certain product attributes and their actual visual inspection behavior with respect to packaging information. While participants may consider certain product attributes, such as application instructions, to be important, this may not always translate into action, like turning the packaging over or scanning QR codes. Variances in viewing frequency and intensity are also evident based on different cue types, such as price versus graphical. Our study provides valuable insights for marketers and policy makers on consumers‘ decision-making behavior regarding substrates at the point of sale. We show that not only the information content, such as peat-related details, but also the presentation on the packaging plays a decisive role in attracting consumers‘ attention and influencing their purchase decisions.

Beike Sumfleth, Deutsches Biomasseforschungszentrum

Bridging Gaps in Sustainability Certification of Low-ILUC-Risk Biomass - A Decision Support Scheme

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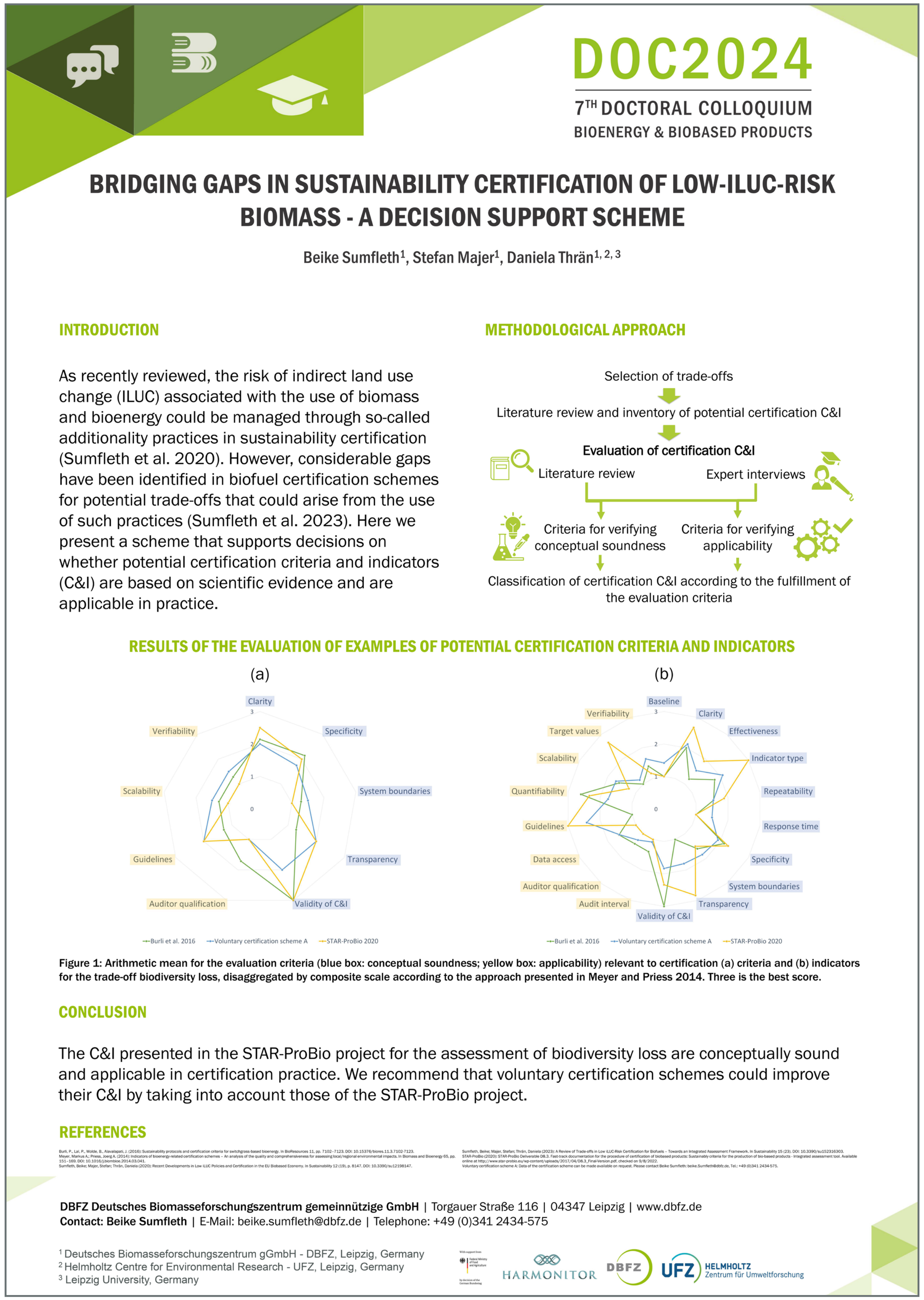
Keywords: Additionality, certification, low ILUC-risk, trade-off, assessment

Indirect land use change (ILUC) is considered a significant challenge for the sustainable production of biomass and bioenergy. In theory, sustainability certification of biofuels has the potential to support the management of this risk effectively. However, expanding biofuel certification schemes towards a credible and reliable approach to account for ILUC-risks is still an open challenge. As recently reviewed, low-ILUC-risk biomass production could be based on the use of so-called additionality practices. While this approach potentially reduces the risk for ILUC, potential trade-offs may arise from the use of such practices. As recently found, some of these trade-offs are addressed by biofuel certification schemes, while gaps in the schemes have been identified for others. The question remains whether the identified criteria and indicators (C&I) of the schemes that consider a particular trade-off are based on scientific evidence; and whether and how the identified gaps can be assessed in certification practice.

The aim of the study is to develop a decision support scheme to bridge gaps in the sustainability certification of low-ILUC-risk biomass.

First, based on a systematic literature review, we present an inventory of assessment approaches that are potentially suitable for the certification of a selection of trade-offs. Secondly, these approaches are evaluated on the basis of defined evaluation criteria to verify whether the identified assessment approaches are conceptually sound and applicable in certification practice. Finally, existing certification instruments that consider the trade-offs are compared with the evaluated assessment approaches. To illustrate how the decision support scheme works, we present the benefits and challenges for certification schemes through the examples of biodiversity loss and water pollution. Additionally, we show how the decision support scheme contributes to the improvement of existing certification C&I. With this study, we contribute to the need for implementing additionality practices in low-ILUC certification approaches without compromising sustainability by identifying trade-offs as required by the EU low-ILUC legislation for sustainable biofuels.

Furthermore, the presented decision support scheme could assist voluntary certification schemes in their decision to revise existing and include new certification instruments to assess the respective trade-offs.



Tom Karras, Deutsches Biomasseforschungszentrum / University of Leipzig

Economic evaluation of the straw supply chain: Influence of machine selection on logistics costs

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Keywords: logistic costs, straw transport, agricultural by-products, residual biomass

Straw is one of the most important biogenic by-product, residue and waste in Germany and Europe in terms of its technical potential. Logistics costs play an important role in the economic analysis of straw valorisation options. These logistical costs of straw depend on the design of the supply chain and the machinery used. Therefore, it is necessary to compare the different options in order to design an efficient logistics chain. The main purpose of this contribution is to analyse the economics of the main logistics processes, namely transport, handling.

As part of my PhD, I have already developed a model that determines the farmside supply costs for straw from the farmer‘s perspective. The next step is to analyse the logistics costs from the farmer to the biomass conversion plant. A data collection will be created that includes the costs of the individual process steps for different combinations of machines. These include, for example, trucks vs. tractors as haulers, as well as front loaders vs. telescopic handlers. The cost data is dependent on distance and mass. This allows each technology option to be compared. Subsequently, pre-defined supply chains can be employed to ascertain which of these chains is the most costeffective for given machines and distances.

The first preliminary results of the model indicate that, under the current assumptions, truck transport is more favourable than tractor transport. This economic advantage increases with distance. However, these results are strongly dependent on the assumptions made regarding, for example, investment costs, residual values, annual working hours and the loading capacities of the machines used. Consequently, the assumptions still need to be validated in order to generate reliable results.

In the longer term, these calculations will be used to map cost-supply curves together with regional straw potentials determined by the DBFZ and taking into account the available road network. This will enable the determination of the quantity of straw that can be made available in a defined radius with a specific supply chain and at what cost. Finally, hotspots for the supply of straw can be identified.

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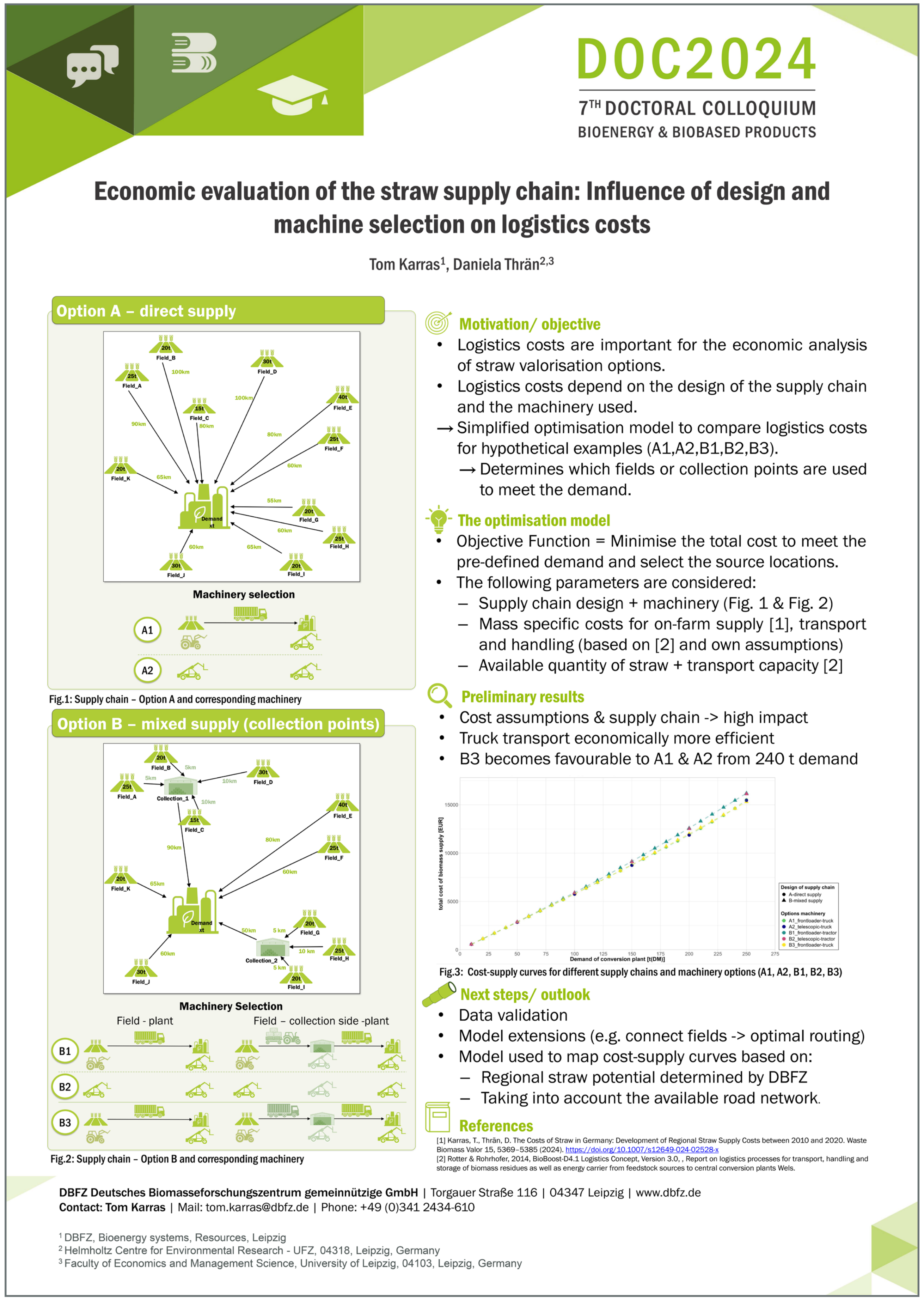

Elena Ferro, Universitá di Bologna

Enhancing Biomass Feedstocks for Sustainable Aviation Biofuel Production through Biostimulant

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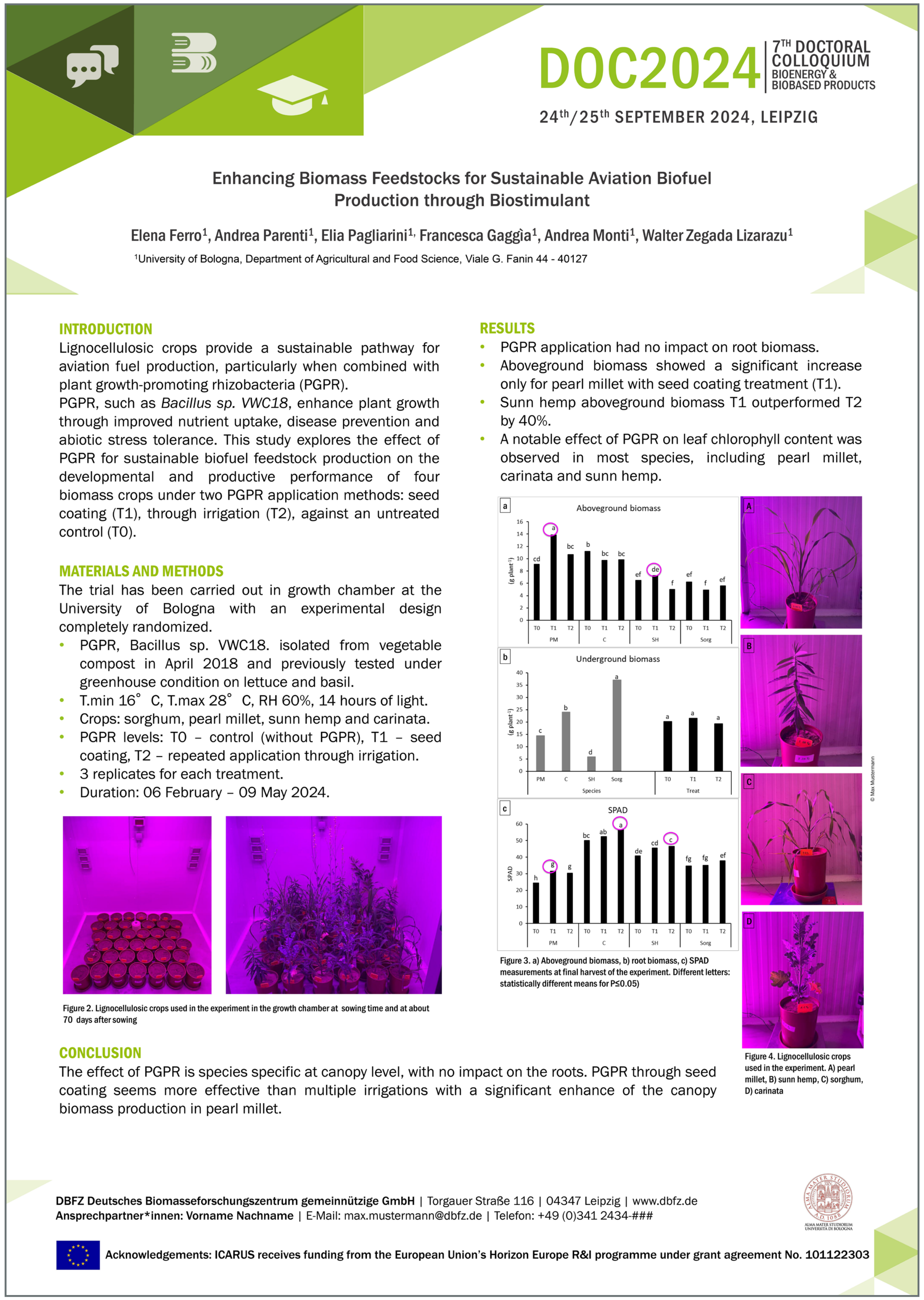
Keywords: Biomass feedstocks, sustainable aviation fuel, biostimulant

The global push to reduce greenhouse gas emission has made the production of renewable fuels as a critical component of sustainable strategies. The ReFuelEU Aviation Regulation aims to increase the utilization of Sustainable Aviation Fuels (SAF) from 2 % in 2025 to 70 % by 2050. According with this objective, the Euro-pean project ICARUS (International cooperation for sustainable aviation biofuels) aims to increase the sustainable production of aviation fuels. Consequently, novel concepts in biomass production, such as se-quential cropping and mixed cropping, are being explored to ensure a greater availability of sustainable bio-mass for SAF production.

A preliminary test has been conducted in the growth chamber at the University of Bologna to evaluate the interaction between 4 different crops and a PGPR (Bacillus sp. VWC18), isolated from vegetable compost in April 2018, with the aim to maximize biomass production for aviation fuel. The growth chamber was maintai-ned at a minimum temperature of 16 °C, maximum temperature of 28 °C, with a relative humidity of 60 % and 14 hours of light. For the experiment 4 crops (Sorghum, Pearl Millet, Sunn Hemp and Carinata) were chosen, alongside three treatments (PGPR levels) and three replicates for each treatment, totaling 36 pots. The three levels were: T0 – control (without PGPR), T1 – seed coating, T2 – repeated application through irrigation.

In a previous study (Pagliarini E. et al., 2023), the effect of Bacillus sp. VWC18 was examined under green-house conditions on lettuce (Lactuca sativa L.) and basil (Ocinum basilicum L.). Both the experiments affirmed that inoculating the substrate with Bacillus sp. VWC18 stimulated plant growth and mineral uptake. Root weight doubled or tripled compared to control plants, and chlorophyll concentrati-on increase even further (in a dose-dependendent manner). The visual findings obtained so far appear to be promising, highlighting a differential response to the treatment among the various industrial crops aimed at bioenergy production. The results of the ongoing study are currently under analysis.



Sebastian Foth, University of Rostock

Acquisition, treatment and utilization of alternative substrates in agricultural production processes

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Keywords: water care material (WCM), substrate properties, pre-treatment, recovery options, legal framework

There are ecological and economic interests in identifying new sources of biomass and developing 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 utilize and thus distribute them. In the context of the energy crisis, competition for land and the current state and ecological potential of our water bodies, economically and ecologically orientated water management is a basic prerequisite. The approach of harvesting highly productive, freely available biomass from water maintenance and utilizing it for material and energy recovery can therefore serve as a model for sustainable water management and a sustainable material flow economy.

Substrate acquisition concept and treatment
In order to prevent contaminants and other impurities (sand, etc.) from entering the substrate during water maintenance, the measures are adapted as appropriate. To ensure adequate further processing, the material is pre-cut to a particle size of 10-15 cm when it is picked up in the baling press. Utilization of biomass from water maintenance for the production of biogas

On the basis of the quantities determined to be available each year, and in view of the existing capacities of agricultural biogas plants, it seems feasible to substitute 10 % of the daily corn silage input with biomass from water maintenance. Utilization of biomass from water maintenance for nutrient recovery.

The fraction of the biomass that does not appear suitable for biogas conversion is used directly for the production of organic fertilizers. In a technically optimized composting process, it is possible to collect the leachate that escapes from the biomass and use it in plant cultivation as a supplement to the soil produced.

The evaluation of the experiments and field trials showed that the biomass acquired from water maintenance can be integrated into agricultural production processes using various methods and can be completely and economically utilized for both material and energy recovery. Own experiments and field trials supported by current research and relevant literature.

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Acquisition, treatment and utilization of alternative substrates in agricultural production processes

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Abstract

This study focuses on the acquisition, pre-treatment and utilization of alternative substrates in agricultural production processes using the example of biomass from water maintenance. The majority of second-order water bodies subject to maintenance are located in the direct environment of agricultural areas and operating sites. It therefore makes sense to consider the possibility of integrating water care material into agricultural production processes for material and energy recovery. Studies show that an estimated 36,000 tons of dry matter per year are available for this purpose in Mecklenburg-Western Pomerania alone as part of annual water maintenance [1]. The subject of the study was an approx. 1.8 km long section of a typical semi-urban second order water body in the North German Lowlands. The cooperation partner was the farm Gut Dummerstorf GmbH. A two-phase experimental complex was jointly designed. The aim of the investigations is to develop pilot concepts for energy production and nutrient recovery from free available biomass resources. From an agricultural perspective, it would make sense to utilize suitable water body associated biomass in a composting process or biogas plant [2]. The evaluation of the experiments and field trials provide information on whether the biomass obtained from water maintenance can be integrated into agricultural production processes using various methods and can be fully and practically utilized in terms of both material and energy recovery.

Acquisition

In order to implement this innovative utilization concept, it was necessary to network the relevant stakeholders from water management and agriculture as well as decision-makers. In a departure from standard practice, an adapted water maintenance concept was jointly developed in order to avoid the input of contaminants and other pollutants (sand, etc.) and to ensure the complete acquisition of biomass from the maintenance profile (Pic. 1). After the substrate was deposited on the maintenance trass, it was picked up by a compactor or baling press (Pic. 2). An economically viable area output was achieved.

Pic. 1 Water maintenance with a weed excavator

Pic. 2 Collection of biomass with a baling press

Treatment

The corresponding pre-treatment scenarios depend on the condition of the biomass after water maintenance and the respective recovery path. Under certain circumstances, drying of the substrate may be an option. This can be done, for example, by operating a Joskia silo vehicle developed for this purpose. An air stream is used to bring the substrate to a suitable dry matter content for storage and utilization. In this concept, the waste heat from the combined heat and power plant of the company's own biogas plant was used.

When using water care material as co-substrate in the production of biogas, it must be shredded in advance. In order to ensure adequate pumping ability of the biomass after mixing the substrates in the pre-fermentation pit, the material is cut to a particle size of 2-4 cm. This can be done when the substrate is picked up in the baling press or by treating it in a mobile shredder unit or the farm's own feed wagon. In this way, even very fibrous substrate can be used more effectively and without disturbing the biogas process.

Utilization - Concept 1 – Biogas production

In an initial trial phase between September and October 2023, the utilization of water care material as a co-substrate for the production of biogas was investigated. The daily input of corn silage was to be substituted by approx. 10 %. During the trial, a total of approx. 6,5 tons of fresh biomass from watercourse maintenance were used in the biogas plant. No significant changes in the quantity and quality of the biogas produced or disturbances in the process were recorded during the trial.

Utilization - Concept 2 – Nutrient recovery

In a second trial phase between April and August 2024, the utilization of water care material for nutrient recovery was tested. The fraction of the biomass that is not used for biogas production can be used for the production of valuable soils, organic fertilizers and phytosanitary products. This was realized in a technically optimized composting process (Pic. 3) in which the leachate from the biomass could be collected. During the period of fertilizer and phytosanitary product production (90 days), a total of 400 kg fresh matter compost substrate for field cultivation and 480 liters of leachate for irrigation were produced.

Pic. 3 Compost-leachate-reactor

Pic. 4 Organic cultivated potatoes

Pic. 5 Conventionally cultivated potatoes

These products were tested for their practical application in a trial for the cultivation of food potatoes. On an area of approx. 200 m^2, 16 plots were planted for the cultivation of food potatoes. The cultivation trial was carried out in several repetitions. Different variants of organic fertilization and crop care were compared with conventional cultivation and fertilization with mineral fertilizers.

The results show that the potato crops with organic fertilization have a higher yield compared to the conventionally fertilized potatoes. In addition, the replicates with the leachate treatment have significantly healthier surface plant parts (Pic. 4 and 5). They show significantly fewer traces of pests such as beetles or slugs. In addition, these plants were also vital for more than 2 weeks longer.

Conclusion

In the context of this study, various technical applications for the mechanical and thermal pre-treatment of the biomass recovered from water maintenance were tested and examined for their practicability. The results show that complete and practical utilization of biomass from water maintenance in agricultural production processes is feasible. By reducing the nutrient load in water bodies and increasing the biodiversity and structural diversity, the utilization of water care material represents an important addition to the implementation of the objectives of the EU WFD. The approach of harvesting highly productive, freely available biomass from water maintenance and recovery can therefore serve as a model for sustainable water management and a sustainable resource management. The necessary political organs and stakeholders for the innovation of a comprehensive value chain for the utilization of biomass from watercourse maintenance are existing and socially established or integrated in the market. The necessary instruments and technical applications are technically mature and practicable.

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Universität Rostock Traditio et Innovatio

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Microalgae cultivation in wastewater for subsequent biofuel production

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Keywords: Microalgae, Biomass, Biofuels, Carbon Fixation, Wastewater

Microalgae are photosynthetic organisms converting solar energy and CO_2 into valuable biomass. In contrast to higher plants, they can be cultivated in spaces not relevant for agricultural intense. Further advantages such as the ability to accumulate high lipid levels have made microalgae an interesting option for biofuel production. However, further development and final commercialisation is hindered by high costs and low productivity. Improved cultivation strategies are therefore requested in current research. Promising are combinatorial approaches as for example simultaneous usage or rather treatment of wastewaters. In this doctoral thesis, microalgae were cultivated in paper industry wastewater and subsequently submitted to a lipid production phase. Important research questions concerned 1) the reusability of residues in this wastewater type for microalgae growth and 2) finding new strategies to optimize the overall productivity.

Microalgae (Scenedesmus acuminatus) were cultivated in a purpose-made photobioreactor with membrane CO_2-aeration and appropriate illumination. Lipid production was investigated first by exposing the cultures to several stress conditions, which is known to effectively enhance product accumulation. Secondly, microalgae were incubated 16 days in a wastewater sample of a paper mill supplemented with nutrients. The cultivation was separated in two phases: Phase 1 took place under optimal conditions. In phase 2, microalgae were submitted to the previously selected stress condition. Biomass yield and lipid production were monitored as well as uptake of sulphate residues in the wastewater.

Among the examined stress conditions, sulphate starvation was most effective to stimulate lipid generation and chosen for the following experiments. Microalgae growth in wastewater was successful with a final biomass yield of 18 g/L, which is in fact higher than reported literature. Sulphate residues from the wastewater were completely consumed in nine days, after which the metabolism switched to phase 2. Lipid production was raised ~7fold, verifying the suitability of the stress condition.
In order to estimate the process feasibility, experiments are now scaled up to 6-liter-bioreactors.

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24th/25th SEPTEMBER 2024, LEIPZIG

Microalgae cultivation in wastewater for subsequent biofuel production

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Department of Bioprocess Engineering | Chemical and Biotechnology | University of Applied Sciences Darmstadt

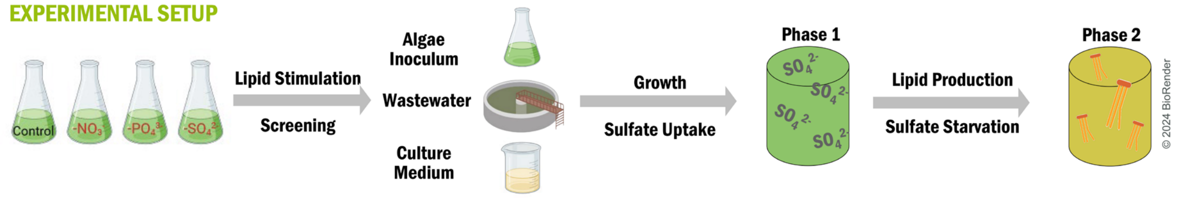
MOTIVATION

Microalgae are photosynthetic organisms converting solar energy and CO_2 into valuable biomass. Among applications in the food or pharmaceutical industries, they are considered as sustainable feedstock for biofuels. Particularly in terms of the European Green Deal and its claim for net-zero greenhouse gas emissions, algae oils are investigated in current research. Main advantage is the agricultural independence in contrast to first generation biofuels derived from edible crops. Although promising, high costs and low productivity still hinder commercialization [1,2].

OBJECTIVES

- Establishment of a combinatorial cultivation strategy with paper industry wastewater treatment to lower costs
- Selection of an efficient lipid stimulation tool and optimization of overall productivity using a high-density photobioreactor
- Searching new possibilities to further yield enhancements

EXPERIMENTAL SETUP



Microalgae (*Scenedesmus acuminatus*) were cultivated in an illuminated lab photobioreactor (CellDEG GmbH, Berlin) with CO_2-aeration. Lipid stimulation was investigated first by exposing the cultures to several stress conditions. Secondly, microalgae were incubated 16 days in clarified paper industry wastewater. The cultivation was separated in two phases: Phase 1 took place under optimal conditions. In phase 2, microalgae were submitted to the previously selected stress condition (sulfate starvation).

RESULTS

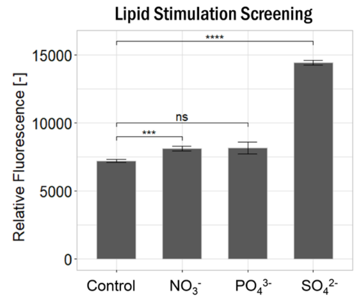


Fig 1: Microalgae lipid production under nitrate (NO_3^-), phosphate (PO_4^{3-}) or sulfate (SO_4^{2-}) starvation measured by Nile Red lipid staining. mean ± SD, N = 3, n = 4, $p < 0.05$.

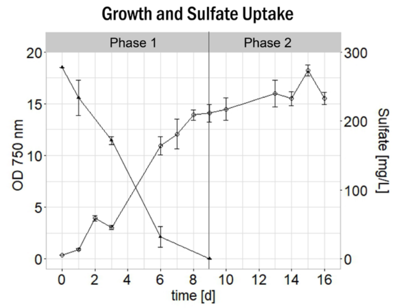


Fig 2: Microalgae growth (○) and sulfate consumption (▲) in wastewater using a high-density photobioreactor (100-400 µmol/m²s, 2-5 % CO_2). mean ± SD, N = 5, n = 1.

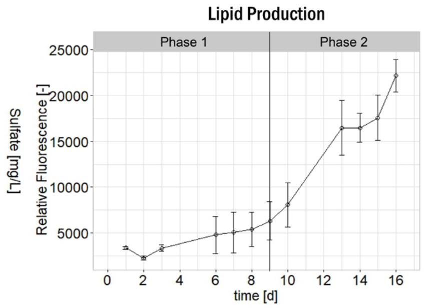


Fig 3: Microalgae lipid production in two phases measured by Nile Red lipid staining (result in diagram) and gravimetrically after solvent extraction (result in text). mean ± SD, N = 5, n = 3.

- In contrast to often applied nitrate stress, sulfate starvation was most effective in stimulating lipid production
- Using a high-cell-density photobioreactor, rapid growth was achieved with max. biomass of ~18 g/L on day 16
- Residual contents of sulfate in wastewater were assimilated in 9 days, after which the metabolism switched to phase 2
- In phase 2, lipid production was stimulated ~7fold with a max. lipid content of 40.5 mg/mg_{dw} %

CONCLUSION AND OUTLOOK

- Microalgae can convert wastewater components into valuable biomass, which is beneficial in terms of circular economy
- Combination with wastewater treatment is therefore definitely useful to increase process effectiveness
- Besides well-known nitrate and phosphate starvation, sulfate is an interesting lipid stimulation tool
- Next step in this doctoral thesis is the development of a scale-up process in semi-continuous mode to investigate the feasibility under more realistic conditions

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[2] Hoang, A.T., Sirohi, R., Pandey, A. *et al.* Biofuel production from microalgae: challenges and chances. *Phytochem Rev* **22**, 1089–1126 (2023).

Christian Klüpfel, Deutsches Biomasseforschungszentrum

Techno-economic assessment of a biorefinery concept consisting of AD and HTL

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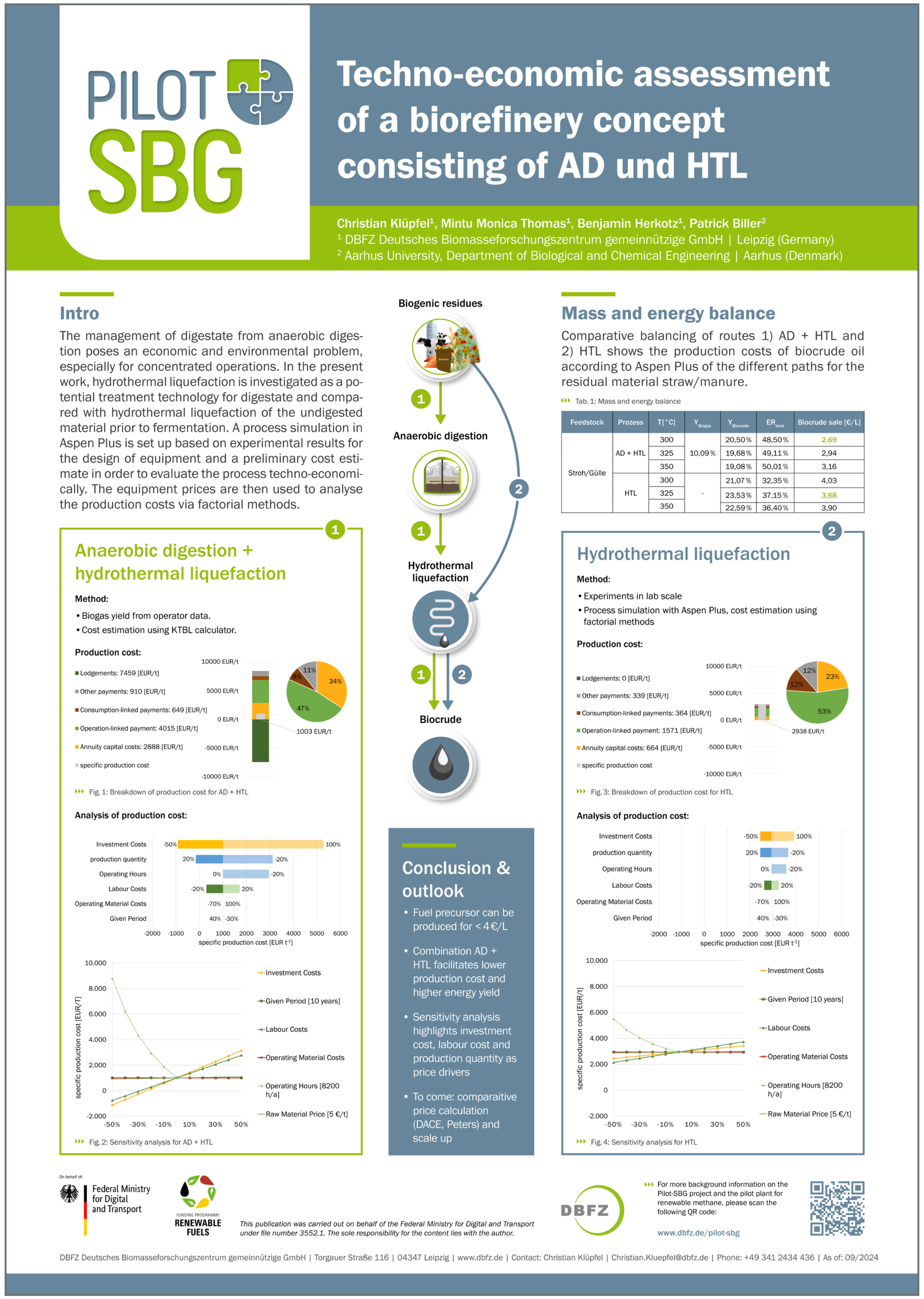
Keywords: hydrothermal liquefaction, waste valorization, digestate, biofuel, biorefinery

The increasing global energy demand combined with the growing global population requires technology to sustainably provide energy. Arguably the most established scheme to convert wet waste biomass to energy is anaerobic digestion (AD) to produce biogas. One of the process's main challenges is the side product, commonly termed digestate, which still contains vast amounts of digestate and carbon, around 50 % of the original biomass. State-of-the-art utilisation is the application to agricultural land, yet the amount which can be brought out to the fields is limited by law due to overfertilization and GHG emissions. This leads to storing and transportation, oftentimes rendering the process uneconomical. Innovative treatment methods are required to overcome these obstacles and improve both energy extraction and nutrient recycling while minimizing environmental impact.

Hydrothermal liquefaction (HTL) can be used as an alternative technology to treat and valorise digestate. At near-critical conditions (647 K, 22 MPa), biomass decomposes and recombines to form an energy-dense biocrude, an aqueous phase (AP) rich in small organic molecules and a nutrient- and carbon-rich hydrochar. This study compares the HTL behaviour by means of mass- and energy balances of three digestates: A digested sewage sludge, straw/manure digestate and digested biogenic waste as well as their respective undigested feedstocks. Generally, higher biocrude yield and thus energy recovery is found when using the undigested biomass, yet the overall energy recovery is higher when using the digestate, highlighting synergies of the two processes. High nutrient recovery in the solid residue suggests its utilisation as a carbon sink and soil amender. The experimental data was used to inform a process model using Aspen Plus ® software and a sensitivity analysis with regards to mass flow, input total solids (TS) and processing temperature was performed. Based on the equipment dimensioning, factorial methods were used to estimate CAPEX and OPEX of the two biorefining schemes 1) AD + HTL and 2) HTL plant to produce biocrude as the main energy product. The results highlight different paths for the investigated scenarios.

This presentation comparatively investigates the hydrothermal process for the utilisation of digestate and waste biomass. This process can help solve a disposal problem that is particularly urgent in regions with intensive livestock farming and at the same time create a renewable fuel, i.e., the biocrude. A process model is developed on the basis of experimental results and used to techno-economically assess the process and highlight, which added-value process is suitable and economical for which biomass. The economic efficiency of anaerobic fermentation can be increased with HTL.



Tommy Ender, University of Rostock

Characterization and anaerobic treatment of process water from hydrothermally carbonized sewage sludge

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Keywords: HTC, process water, anaerobic treatment

The growing demand for sustainable energy sources and effective waste management has driven interest in hydrothermal carbonization (HTC) as a method for processing wet biomass, such as sewage sludge, into valuable byproducts like hydrochar. Hydrothermal carbonization has developed considerably over the last 15 years and offers a viable alternative for the utilization of municipal and industrial organic waste such as sewage sludge. The process takes place in an aqueous environment without the need for pre-drying sewage sludge and thereby facilitating direct processing. However, the aqueous fraction generated during HTC, known as process water, poses challenges due to its high organic content and chemical oxygen demand. This study explores the potential of integrating HTC and anaerobic digestion (AD) to not only treat the process water by remove the organic pollution in the form of methane-rich biogas but also to assess nutrient recovery from the digestate.

Municipal sewage sludge from a WWTP in Mecklenburg Western Pomerania, Germany was hydrothermally treated in a 42 L batch reactor located in Stralsund (Germany). 10 kg of sewage sludge was fed into the reactor with 6 kg of water and treated at three reaction temperatures (180 °C, 200 °C and 220 °C), each with a holding time of 60 min. After completion and cooling, the HTC slurry produced was mechanically dewatered using a Büchner funnel. This produced approx. 11-12 kg of HTC process water per batch. The process water obtained was transferred to the Technical Scale Lab for Waste and Bioenergy at the University of Rostock, where it was stored in portions in 10 L barrels in a cooling cell at 7 °C.

The process water from each condition was then used as feedstock for AD, with methane production monitored over time to determine its methanogenic potential. By comparing the methane yields across the different HTC conditions, this study aims to identify the optimal temperature for maximizing energy recovery during AD. Additionally, the nutrient content in the resulting digestate was analyzed to evaluate the potential for nutrient recovery and reuse in agricultural applications. This aspect contributes to the broader goals of circular economy by promoting resource recovery from waste streams. The findings indicate that the HTC temperature significantly impacts the composition of the process water and, consequently, the efficiency of methane production during AD. Nutrient analysis of the digestate also provides insights into the potential recycling of valuable elements like nitrogen and phosphorus.


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Characterization and anaerobic treatment of process water from hydrothermally carbonized sewage sludge

Tommy Ender[1], Vicky Shettigondahalli Ekanthalu[1], Jan Sprafke[1], Michael Nelles[1, 2]

Hydrothermal carbonization (HTC) has developed considerably over the last 15 years and offers a viable alternative for the utilization of municipal waste such as sewage sludge. The process takes place in an aqueous environment without the need for pre-drying sewage sludge and thereby facilitating direct processing.

Material and methods

- **Hydrothermal carbonization (HTC) of municipal sewage sludge** from a WWTP in Mecklenburg Western Pomerania
- HTC trials with a **42 L batch reactor** for 10,00 kg sewage sludge and 6,00 kg water
- **HTC at three different reaction temperatures** (180 °C, 200 °C, 220 °C) and 1 h retention time
- Generation of process water after solid-/liquid-separation
- The following test series are carried out for this purpose:
  - Batch tests to determine anaerobic degradability and inhibition tests
  - Batch tests as long-term tests
  - Continuous and semi-continuous tests

Analysis of the process water (see also table 1)

- **GC-FID analysis** of organic components like acids and volatile substances (VFA and VOC)
- **Wastewater analysis** with UV/VIS-photometer
- **Organic pollution:** COD concentrations between 54,500 and 57,000 mg/l (higher values found in literature)
- **Organic acids** are mainly acetic acid and propionic acid as well as proportions of butyric acid and valeric acid
- **Nutrients in process water (PW):** nitrogen compounds – recovery potential?

Anaerobic treatment of HTC process water

- **Obligation to treat wastewater**: § 55 and § 56 WHG Discharge to public sewage treatment plant only possible after pre-treatment (indirect discharge according to § 58 para. 1 WHG)
- Anaerobic digestion is known for the treatment of highly polluted industrial wastewater → Transfer to HTC process water?
- **The organic load** of the process water (recorded as TOC or COD) can be reduced by anaerobic digestion. This produces biogas that can be utilized for energy

First results and outlook

- First experiences and findings of **anaerobic degradation** with mesophilic digested sludge as inoculum
- PW initially had a COD concentration of 19,000.00 mg/l and was initially diluted to 2,500.00 mg/l and successively increased to over 5,000.00 mg/l
- A **COD reduction of up to 60 %** could be achieved
- After this stable phase, however, there were repeated operational disturbances such as a **drop in the pH value or an excessive increase in organic acids**
- Presumption: **Inhibition** by persistent and toxic organic compounds such as phenols

180°C
200°C
220°C

Figure 1: Process water from HTC of sewage sludge (left: PW at 180 °C, mid: PW at 200 °C, right: PW at 220 °C)

Table 1: Analysis of the PW from the HTC of sewage sludge

Parameter	Unit	200°C, 60 min	220 °C, 60min	180°C, 60 min
pH-value		5,07	6,20	5,05
COD	mg/l	57.000,00	57.000,00	54.500,00
BOD5	mg/l	64,40	69,40	67,00
2-Hydroxypropanoic acid	mg/l	852,00	1.076,00	744,00
Ethanoic acid	mg/l	1.983,77	2.435,13	1.992,87
Propanoic acid	mg/l	343,68	473,66	412,02
Butanoic acid	mg/l	87,71	124,51	127,04
Isobutyric acid	mg/l	58,24	103,12	78,67
2-ethylbutanoic acid	mg/l	97,87	111,01	104,35
Pentanoic acid	mg/l	42,13	64,34	69,72
3-methylbutanoic acid	mg/l	120,72	174,51	127,04
Hexanoic acid	mg/l	108,06	114,72	101,32
Sum GC-FID-screening	mg/l	3.694,18	4.677,00	3.757,03
VOC	mg/l	6.088,00	5.146,00	5.401,00
Organic compounds calculated as acetic acid	mg/l	7.692,50	7.554,00	6.999,50
Nitrate	mg/l	123,50	120,00	114,50
Ammonium-N	mg/l	1.912,50	2.124,50	1.671,50
Ortho-phosphate	mg/l	375,50	308,50	382,50
Total Phosphorus	mg/l	418,50	322,50	418,50

Figure 2: Anaerobic digestion tests with process water from HTC of sewage sludge

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Kea Purwing, University Hohenheim

Optimization of the process chain for the separation of phosphorous and nitrogen from biogas digestate (Nitrophos 2)

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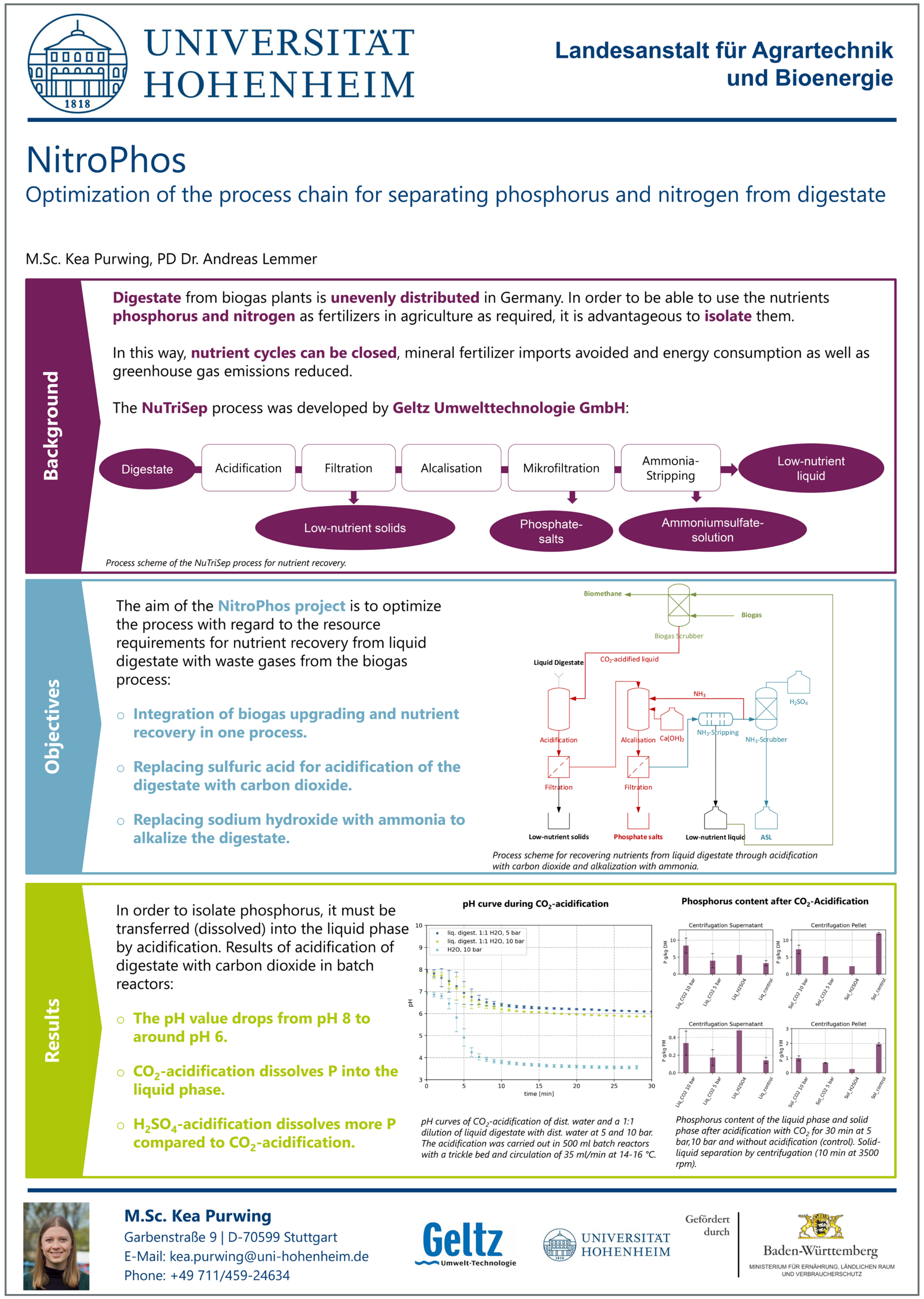
Keywords: Nutrient recovery, Biogas, Digestate, Phosphorus, Carbon dioxide

Mineral phosphorus (P) and nitrogen (N) fertilizers are used in agriculture to ensure food safety in Germany. Nowadays, P fertilizer is mainly extracted from phosphate rock, a finite and fossil resource with China, Morocco and Western Sahara as the main exporters.

The aim of the project is to optimize the NuTriSep process of the company Geltz Umwelttechnologie for the recovery of mineral P and N fertilizer from digestate. Nowadays, large quantities of sulphuric acid and sodium hydroxide solution are used in the NuTriSep process to dissolve the phosphate compounds, separation from organic particles and precipitation. As part of the NitroPhos 2 project, the sulphuric acid required for acidification will be replaced by CO_2 from a biogas scrubber. Phosphorus in the liquid phase can be recovered in a subsequent step in mineral fertilizer quality. It is therefore important to dissolve as much of the phosphorus bound to particles as possible by lowering the pH value.

Acidification with CO_2 takes place in pressure-stable reactors (500 ml). This allows the digestate to be acidified in a CO_2 atmosphere at different pressures. CO_2-acidification is conducted at 5 bar with 100 % CO_2 atmosphere for 30 min. Different dilutions with liquid digestate and distilled water have been acidified. After acidification, the pressure was released and the sample was prepared for centrifugation (3500 rpm, 5 min) within 10 min after pressure release. After centrifugation, the phosphorus content was measured both in the supernatant and in the pellet.

By acidifying liquid digestate with CO_2, the pH value can be lowered from around pH 8 to pH 6. Preliminary tests have shown that the pH value is stable after 30 minutes of acidification. Moreover, it can be observed that the phosphorus content of the solid phase is considerably lower after CO_2-acidification compared to the control. At the same time, the phosphorus content of the liquid phase increases as a result of CO_2-acidification compared to the control. From the results obtained, it can be concluded that lowering the pH value with CO_2 to pH 6 causes phosphates to dissolve and pass into the liquid phase. Phosphates that are present in the liquid phase in dissolved form and can be separated from organic particles and recovered as pure phosphate salts.



SESSION

THERMOCHEMICAL CONVERSION

Prof. Dr. Jürgen Karl
Dr. Kathrin Weber

7TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Carolin Eva Schuck, Aarhus University

Continuous Wet Oxidation of HTL aqueous phase derived from mixture of straw and cattle manure

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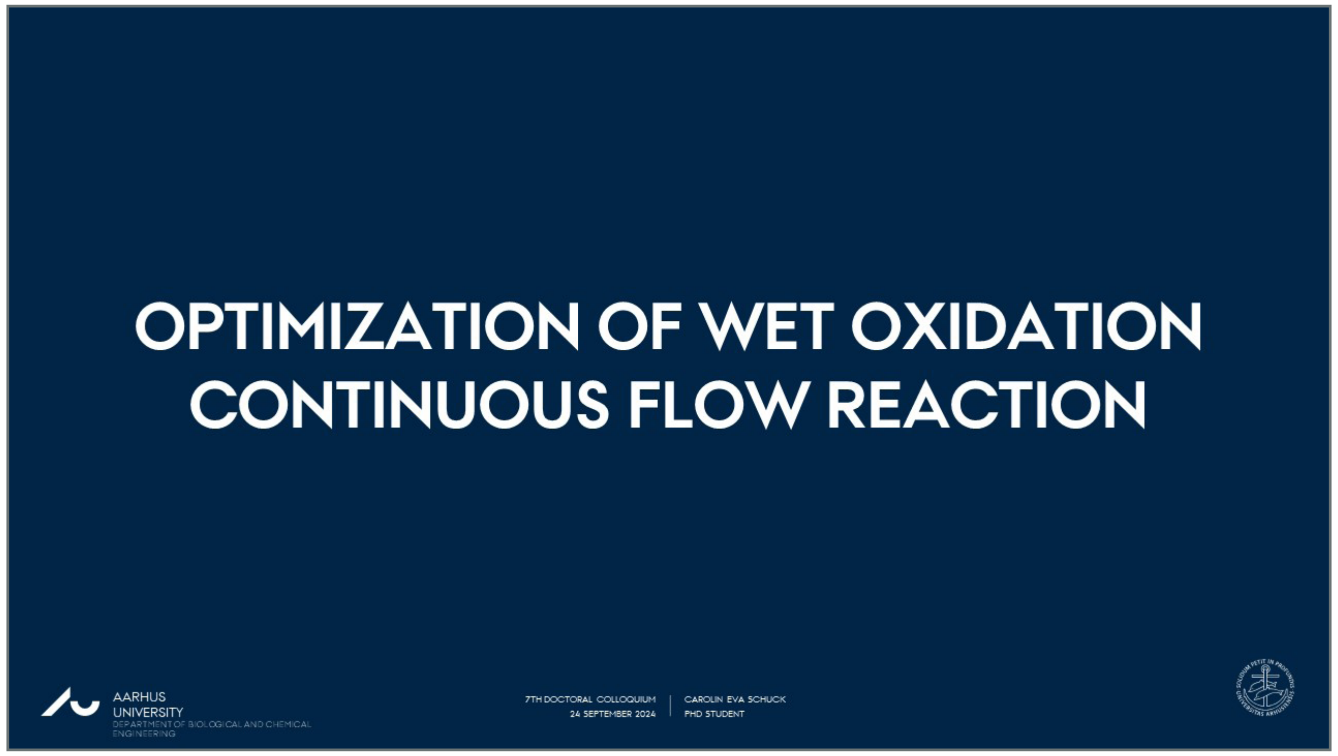
Keywords: Wet Oxidation, Hydrothermal Liquefaction, Process Integration

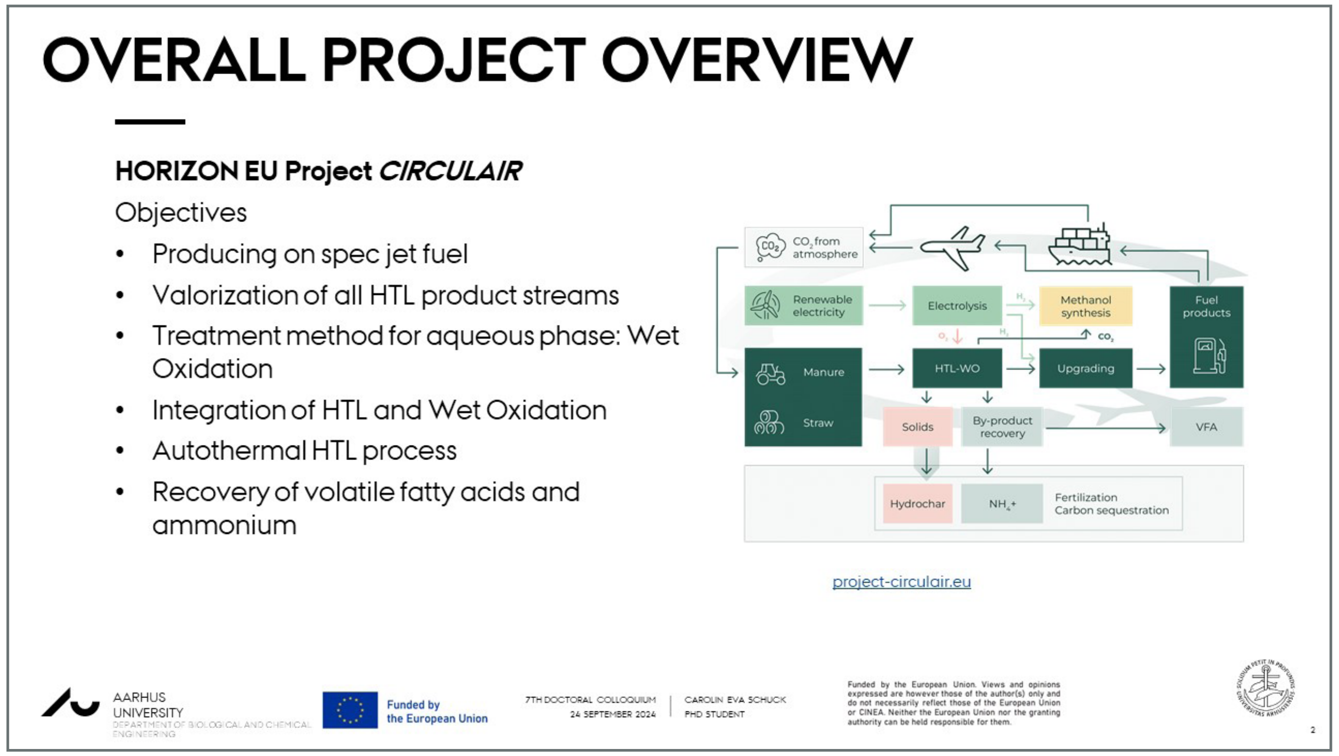
Hydrothermal Liquefaction (HTL) is a thermochemical processing technology that has been receiving increased interest for converting biomass into an organic phase, which can be further upgraded to fuels. However, treating the aqueous byproduct is necessary for further commercialization of this technology. A potential treatment method for HTL aqueous phase (AP) is subcritical non-catalytic Wet Oxidation (WO). Organic compounds are oxidized in the presence of O_2 to CO_2, H_2O, and small components (e. g. volatile fatty acids (VFA)) in an exothermic reaction.

The present study focuses on HTL-AP derived from a 50/50 % mixture of straw and cattle manure feedstock. The investigated WO process is conducted in a continuous flow reactor. The main goal is to evaluate the oxidation efficiency and heat generation to optimize process conditions. Furthermore, the production of high-value VFA and ammonium (NH_4+) in high concentration is favored to create upstream recovery possibilities.

The WO runs were carried out at temperatures and residence times similar to HTL process (350 °C, 11-43 min). Air was used as O_2 source in an equivalent of 0.5-2 times of Chemical Oxygen Demand (COD). In follow-up experiments, a 35 % hydrogen peroxide solution will be used to simulate pure O_2 as an alternative to air. Special attention is paid to temperature profiles of the reactor to observe energy released during WO.

Preliminary results show an increasing COD removal rate up to 84.5 % for a residence time of 45 min and stoichiometric air equivalent. Further increase in air equivalents did not result in any changes. Furthermore, the relative increase in VFA content of TOC up to 77.8 % and NH_4+ content of TN up to 80.0 % at 23 min is observed. Evaluating the results will give rise to determine optimal process conditions to treat the highly contaminated HTL-AP while creating possibilities to recover heat and value-added chemicals in an integrated HTL-WO system.

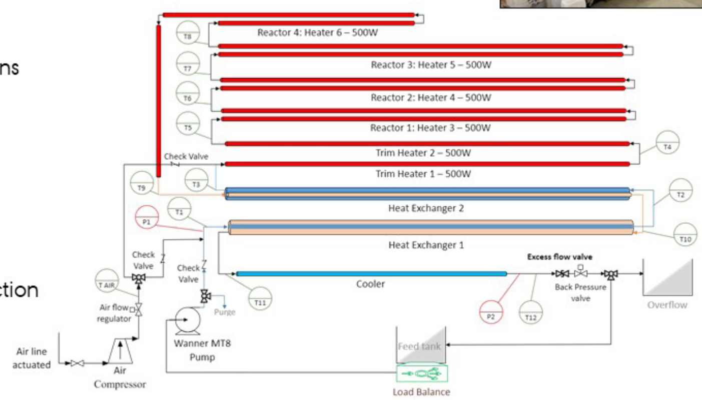




WET OXIDATION PLANT AT AU

Continuous flow bench-scale reactor

- Material: Sanicro35 pipes and 316 stainless steel fittings
- Reactor volume 880mL
- Tubular system divided into seven sections
  - AP feed system
  - Air compression system
  - Heat exchanger
  - Trim heater
  - Main reactor
  - Cooler
  - Take-off system with product collection



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EXPERIMENTAL CAMPAIGN

Feedstock: HTL aqueous phase derived from 1:1 cattle manure and straw mixture (325°C, 50kg/h, 14% DM)

Studied conditions

- Residence time 12 – 45 min
- Stoichiometric O_2 equivalent 0.5 – 2
- O_2 source: air, 35% H_2O_2
- Temperature 350 - 365°C

Analysis performed for HTL- and Wet Oxidation aqueous phase

- Chemical Oxygen Demand
- Total Carbon/ Total Nitrogen
- Ammonium content
- Volatile fatty acid content

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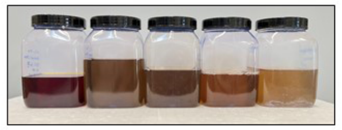
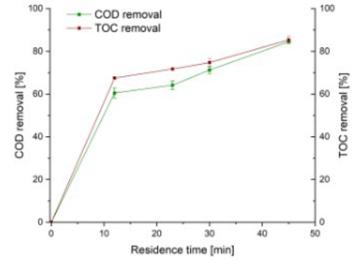
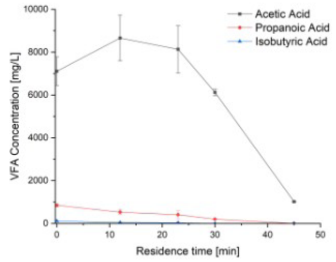
EFFECT OF RESIDENCE TIME

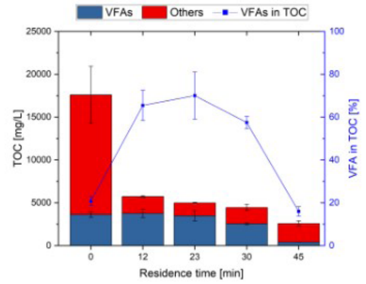
Studied conditions

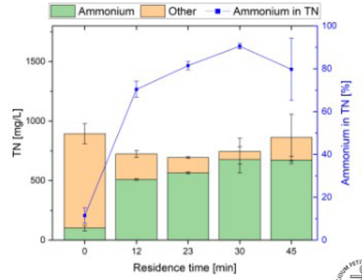
Varied residence times at 350°C and stoichiometric supply of air











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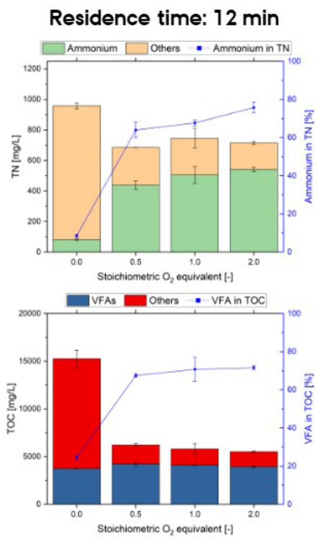
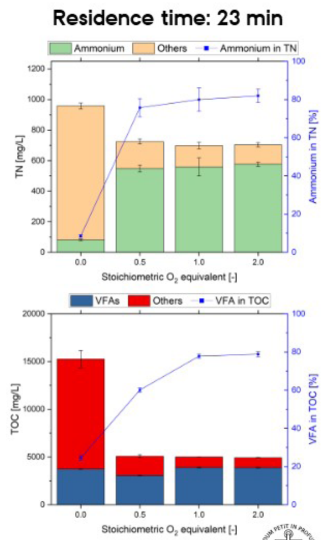
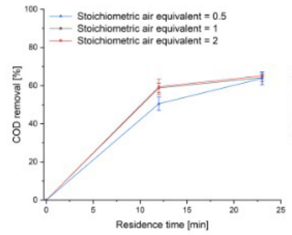
EFFECT OF SUPPLIED OXYGEN EQUIVALENT

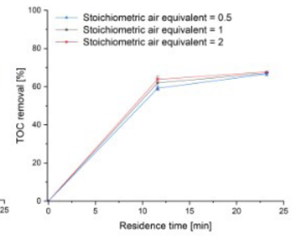
Studied conditions

Varied oxygen equivalents supplied by air at two different residence times and constant temperature of 350°C









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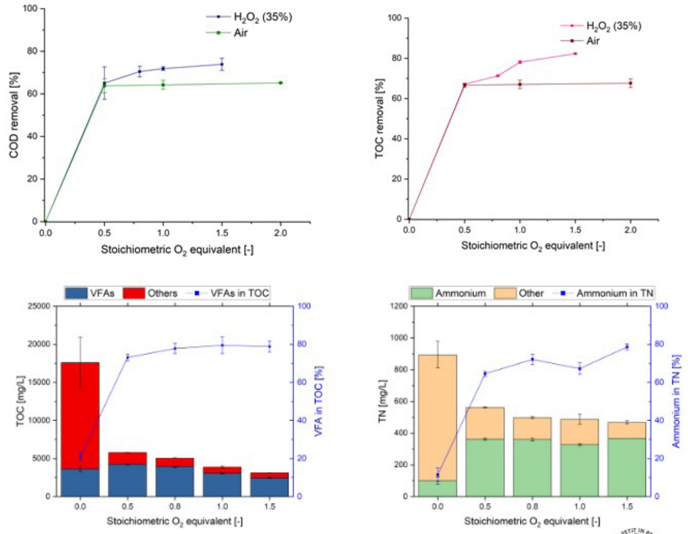
EFFECT OF OXYGEN SOURCE

Studied conditions

Varied stoichiometric equivalents supplied by 35% H_2O_2 at 23 min and 350°C



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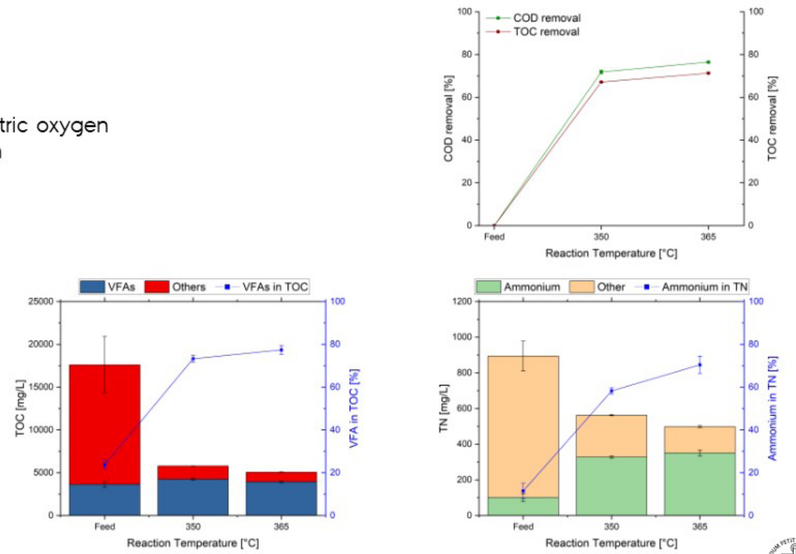
7

EFFECT OF REACTION TEMPERATURE

Studied conditions

Varied reaction temperature at stoichiometric oxygen equivalent supplied by 35% H_2O_2 at 23min



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CONCLUSION

- High COD and TOC removal achieved at residence times and temperatures similar to HTL
- Increase of COD removal with increasing residence time
- Intermediate product degradation at severe conditions
- Supply of increasing oxygen equivalent in form of air shows little effect to COD/TOC removal and increase of VFA and ammonium share
- Supply of 35% H_2O_2 shows higher oxidation efficiency compared to air
- Higher reaction temperature shows little improvement to COD and TOC removal and increase of VFA and ammonium share

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Mario König, Deutsches Biomasseforschungszentrum

Development and application of novel SCR catalysts for the low-temperature denitrification of exhaust gases from the thermo-chemical conversion of biogenic solid fuels

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Keywords: SCR, catalyst, NOx, Mn, SiO_2

Alongside particulate emissions and airborne hydrocarbons, nitrogen oxides (NO_x) are the most problematic group of pollutants in the thermal conversion of biomass. Due to the increasing material use of wood, non-woody biomass has to be utilized for energy production. Non-woody biomasses have an increased nitrogen content with correspondingly higher NO_x emissions during combustion. Existing reduction measures for NO_x do not have the technical and economic potential for an application in decentralized bioenergy plants. The aim of the PhD is to find a suitable low-temperature SCR-catalyst for biomass combustion. The approach of the presented PhD is a systematic screening on suitable active components, carriers and synthesis methods for the preparation of a low-temperature SCR catalyst. Based on a literature survey catalyst precursors and carrier materials has been selected. A synthesis route based on Excess Solution Impregnation was developed and several powder catalysts were synthesized.

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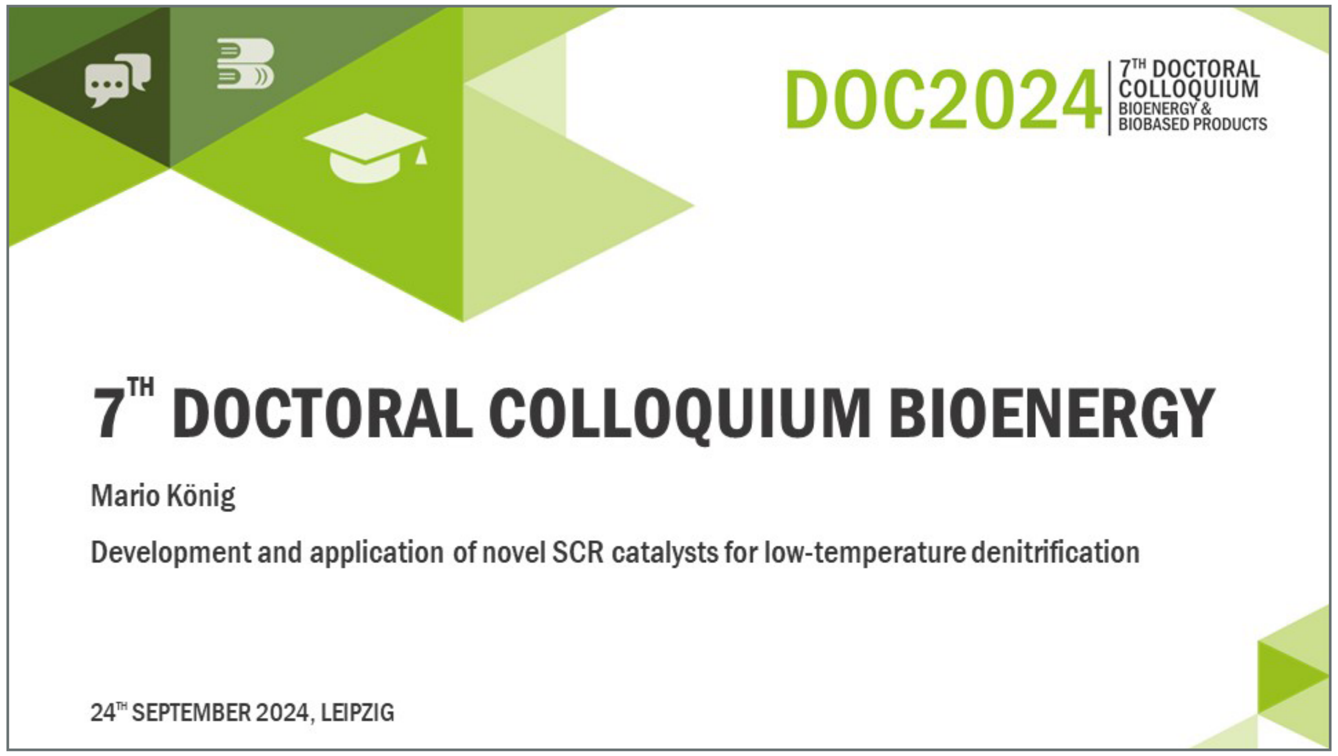
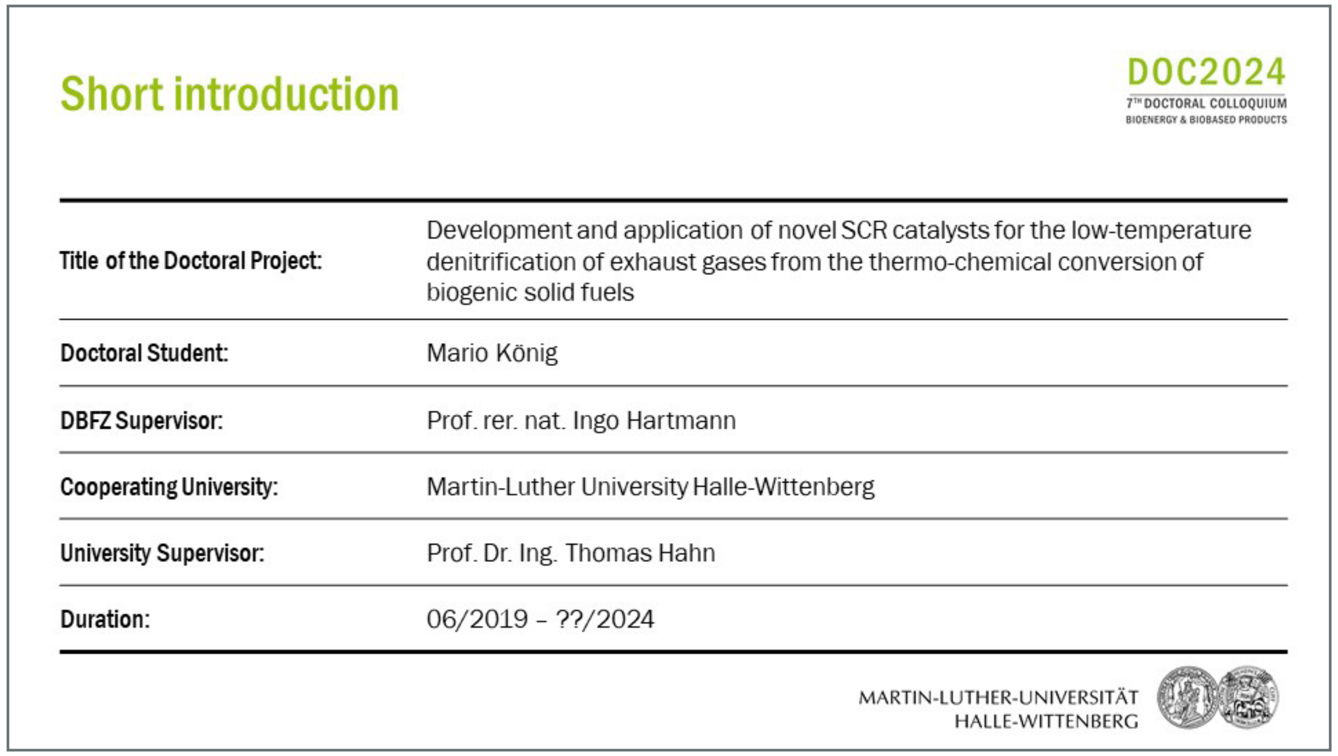
The catalyst screening took place on a laboratory scale reactor with a synthetic gas mixture in the low temperature range. Temperature-conversion charts were recorded in order to find out the most active catalyst. Beside the NO_x-conversion also the formation of N_2O was considered and the N_2-selectivity of the different catalysts were compared.

Results
- Simple synthesis route based on impregnation developed
- Temperature-conversion charts 120 up to 250 °C @ 22,000 $^{h-1}$ space velocity
- Manganese-Nitrate and SiO_2-powder with high pore volume show the best performance: highest NO_x-conversion @ 15 % Mn-loading, Decreasing conversion with higher loads
- BET surface and pore volume decreases with increasing Mn-loading
- XRD: MnO_2 is formed when using Mn-Nitrate, Mn_3O_4 is formed when using Mn-Acetat
- TGA shows stage @ 500 °C: conversion of MnO_2 into Mn_2O_3
- H_2-TPR: Mn-Nitrate shows a specific H_2-reduction twice as large as Mn-Acetate
- NH_3-TPD: Reason for good SCR-performance of 15 % Mn-Nitrate is good NH_3-Adsorption





Title of the Doctoral Project:	Development and application of novel SCR catalysts for the low-temperature denitrification of exhaust gases from the thermo-chemical conversion of biogenic solid fuels
Doctoral Student:	Mario König
DBFZ Supervisor:	Prof. rer. nat. Ingo Hartmann
Cooperating University:	Martin-Luther University Halle-Wittenberg
University Supervisor:	Prof. Dr. Ing. Thomas Hahn
Duration:	06/2019 – ??/2024

NO_x emissions from solid fuel combustion

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NO_x formation
- Biomass: mainly from the nitrogen bound in the fuel (hardly any thermal NO_x)
- Use of biogenic residues leads to comparatively high NO_x emissions due to higher N-content

NO_x are a problematic group of pollutants
- Formation of ground-level ozone and secondary aerosols
- Acute effects such as irritation of the respiratory tract
- Long-term effects such as respiratory and cardiovascular diseases

NO_x reduction commitment at EU level: Germany wants to reduce by 39 % until 2029 and by 65 % from 2030

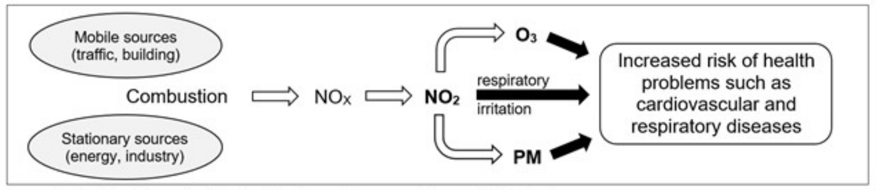

Figure 1: Simplified illustration of the health effects of nitrogen oxides and their derivatives

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NO_x abatement in solid fuel combustion

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Primary measures
- Only 20–50 % NO_x-reduction
- Only limited applicable for biomass fuels
- Poor cost/benefit ratio

Secondary measures NO_x abatement
- **SNCR: 50–75 %**, only works in a narrow temperature window of 850–950°C
- **SCR: up to 90 %**, temperatures > 300°C required for commercial catalysts)
- **SNCR+SCR: up to 95 %**, best result for solid fuels, disproportionately high costs)

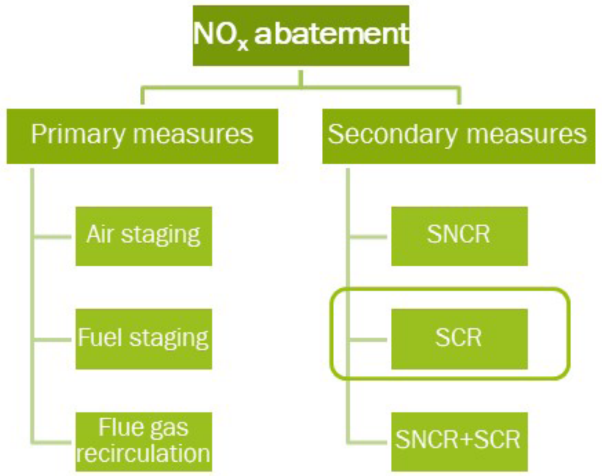

Figure 2: NO_x abatement measures

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Aim of the work / approach

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"Investigations on suitable low-temperature SCR catalysts that can be used in biomass plants in an economical and environmentally friendly manner."

Based on extensive literature study selection of:
- MnO_x as active phase
- SiO_2 as carrier
- Synthesis by wet impregnation
- Variation of:
  - Mn-precursor
  - SiO_2-powder
  - Mn mass ratio
  - Calcination temperature

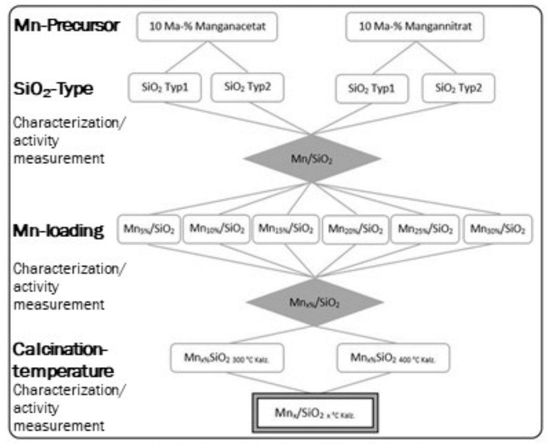

Figure 3: Catalyst screening procedure

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Methods

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Synthesis steps
- The precursor substance is dissolved
- SiO_2 powder completely covered with solution
- Stirring for 15 min at room temperature
- Vaporization at 70°C for 45 min
- Drying for two hours at 120 °C
- Calcination at 400 or 300 °C for 4 hours @ air

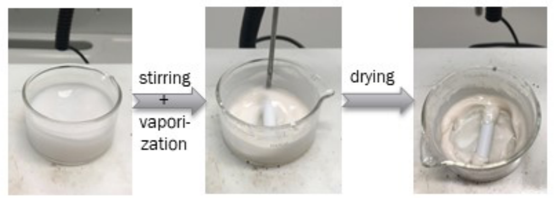

Figure 4: Preparation of the catalyst slurry

Figure 5: Magnetic stirrer with heating plate and contact thermometer (model: C-MAG HS 7)

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Methods

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Catalyst characterization

- ICP-OES (CETAC, ASX-520, Omaha, Nebraska, USA)
- XRD (D8 Advanced Diffractometer Company Bruker AXS; 0,013° step size) → RRUFF/COD
- N_2-Physisorption (BET-surface, pore volume, pore size distribution)
- TGA (STA 449 F3 Jupiter von NETZSCH)
- Chemisorption (H_2-TPR, NH_3-TPD)

Activity measurements

- laboratory flow reactor
- 12 mm inner diameter V4A
- Gas mix N_2, air, NO, NH_3 and H_2O
- NH_3 provided via evaporation of ammonia water

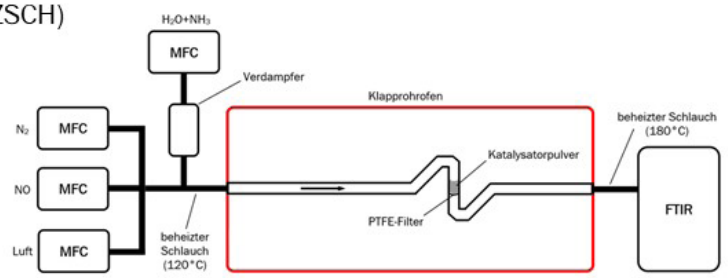

Figure 6: Laboratory-scale-reactor for activity measurements

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Results N_2-Physisorption

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2 different SiO_2 carrier types

- Type 1: BET = 316 m²/g; PV = 0,73 cm³/g; BJH-PS = 5,85 nm
- Type 2: BET = 228 m²/g; PV = 2,10 cm³/g; BJH-PS = 25,19 nm

Effect of Mn-loading

- BET and PV decreases with increasing Mn loading
- BJH-Pore size hardly changes due to Mn loading

Pore size distribution

- 10%MnO_x/SiO_2type 1: pore size = 6,3 nm - interconnected pores "poreblocking" (pores > 6 nm) and "cavitation" (pores < 6 nm)
- 10%MnO_x/SiO_2type 2: pore size = 19,5 nm - Independent cylindrical pores without "poreblocking" or "cavitation"

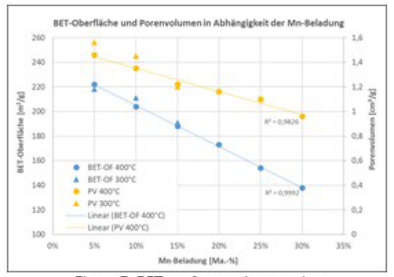

Figure 7: BET-surface and pore volume

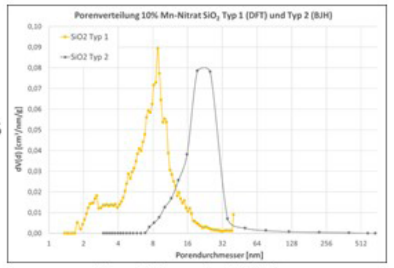

Figure 8: Pore size distribution

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Results XRD-measurements

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Main crystal phase on the catalyst surface depending on Mn-precursor

Mn-acetate tends to form Mn_3O_4

Mn-nitrate tends to form MnO_2

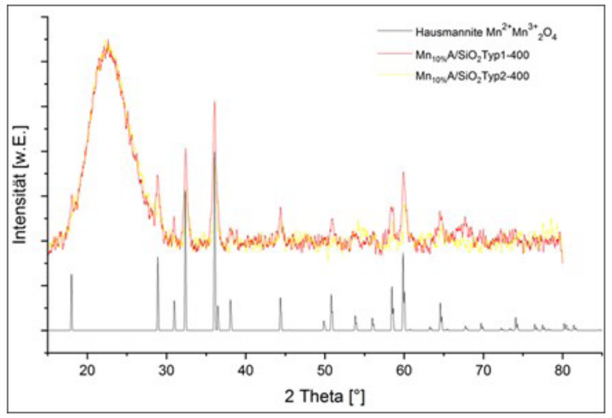

Figure 10: XRD pattern of Mn_3O_4

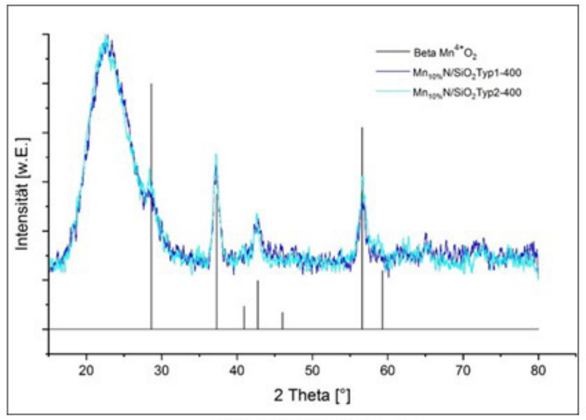

Figure 11: XRD pattern of MnO_2

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Results H_2-TPR

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3 reduction steps

1. MnO_2 → Mn_2O_3
2. Mn_2O_3 → Mn_3O_4
3. Mn_3O_4 → MnO

- Mn-nitrate shows better reducibility
- Increased Mn-loading leads to higher H_2-consumption until 25 % Mn-loading
- Low calcination temp. shows advantage for low Mn-loading (5 %)

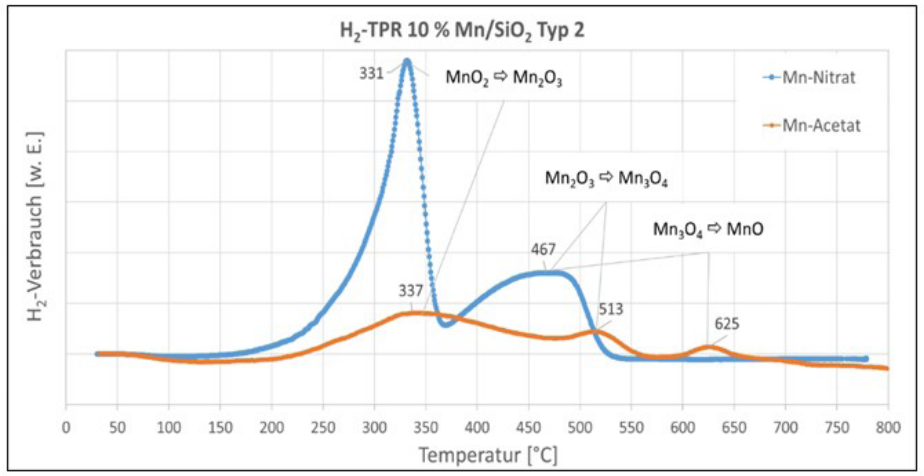

Figure 14: H_2 consumption for 10% MnO_x on SiO_2 type 2

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Results NH_3-TPD

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- Mn-nitrate shows higher NH_3-desorption for both SiO_2-carrier
- Increased Mn-loading leads to higher NH_3-desorption (over whole temperature range see figure 15)
- Consideration of relevant low temperature range: Peak 1 until 200˚C shows highest NH_3 sorption quantities at **15 % Mn** loading (400˚C Calc.)

Based on NH_3-TPD data, highest SCR activity expected for 15 % Mn (400˚C calcination temperature)

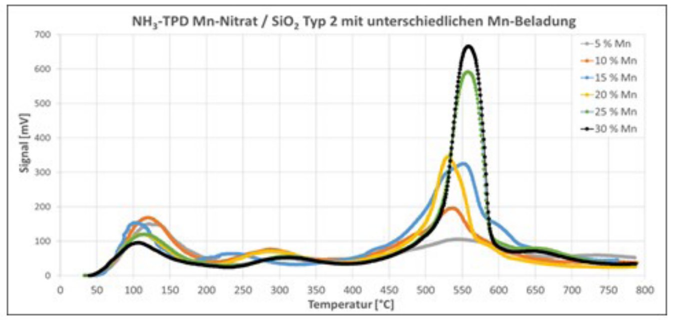

Figure 15: NH_3 desorption for 10% MnO_x on SiO_2 type 2

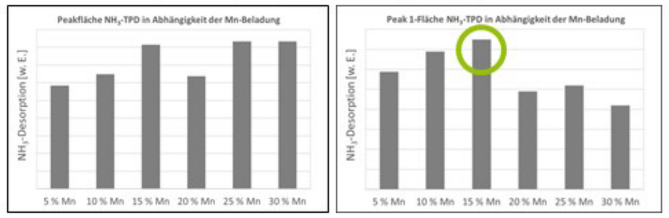

Figure 16: Peak area NH_3 TPD for different Mn-loading

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Results activity measurements

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Low vs. high pore volume

- Low PV performes better with Mn-acetate
- High PV performes better with Mn-nitrate

$$NO_x\ conversion = \left(1-\frac{NO_x(in)}{NO_x(out)}\right) * 100\%$$

Mn-acetate vs. Mn-nitrate

- Mn-nitrate shows higher NO_x conversion over whole temperature-range
- NO_x-conversion @ 200˚C:
  - 45 % Mn-acetate (SiO_2 1)
  - 80 % Mn-nitrate (SiO_2 2)

Best NO_x-conversion shows Mn-nitrate on SiO_2 type 2

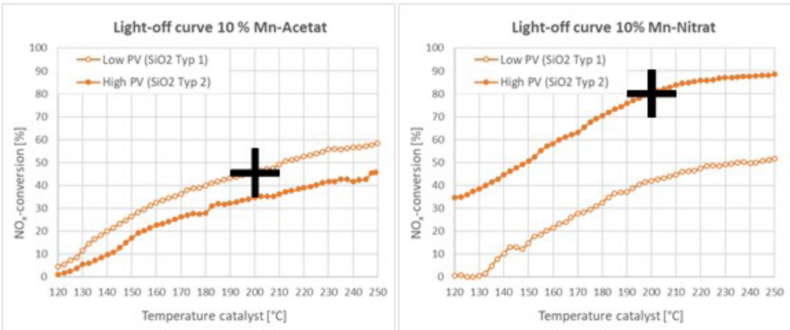

Figure 17: NO_x Light-off curves for 10% MnO_x/SiO_2

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Results activity measurements

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Mn-loading

- 15 % Mn shows highest NO_X-conversion
- 10 % Mn second best, but shows significant lower conv. in temp.-range 140 - 220˚C
- 30 % Mn shows comparable NO_X-conversion for 150 - 200˚C, but higher loading disadvantageous for economic reasons

15 % Mn best NO_X-conversion over whole temp. range

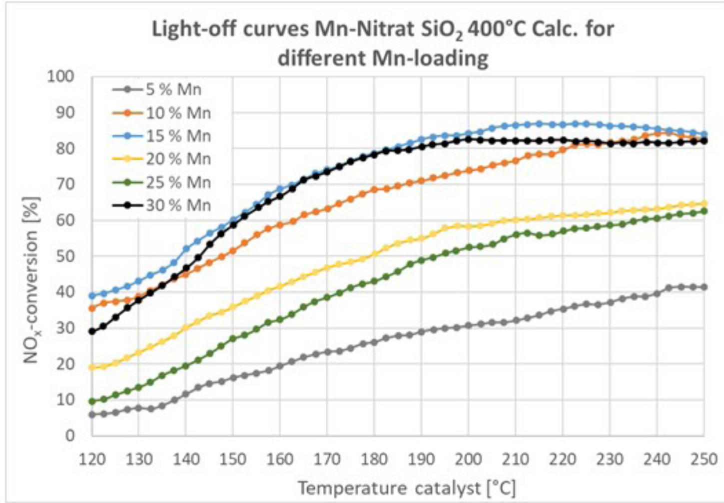

Figure 18: NO_x Light-off curves for different Mn-loading

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Calcination temperature 300 vs. 400˚C

- 5 % Mn shows higher NO_X-conversion with 300˚C calcination temperature
- 10 % and 15 % Mn loading superior with higher calcination temperature

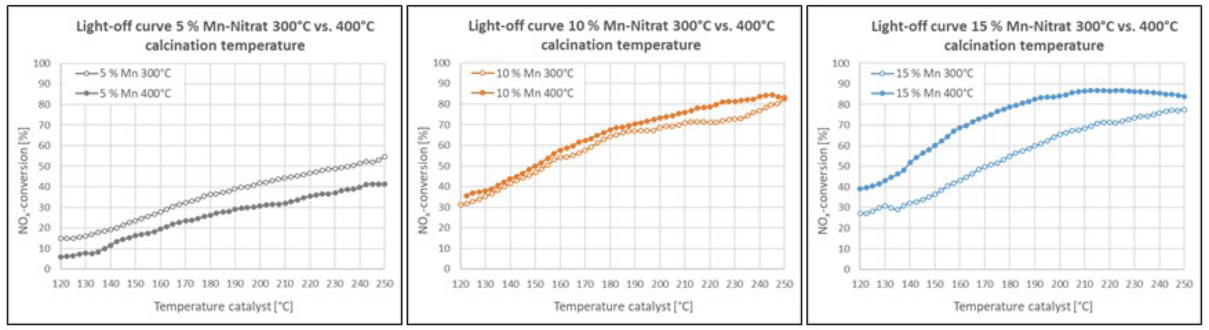

Figure 19: NO_x Light-off curves for different calcination temperatures and Mn-loadings

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$$N_2\ selectivity = \left(1 - \frac{N_2O(out)}{NO_X(in) - NO_X(out)}\right) * 100$$

$$N_2\ \text{yield} = \frac{N_2\ \text{selectivity} * NO_X\ conversion}{100}$$

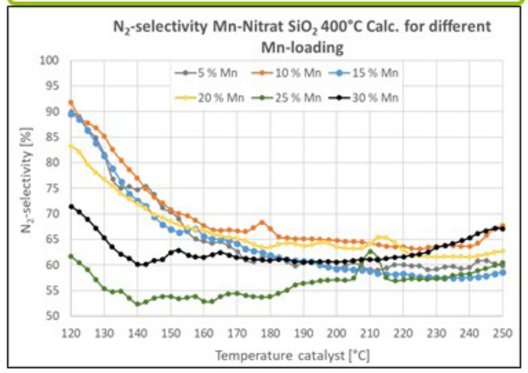

Figure 20: N_2-selectivity for different Mn-loading

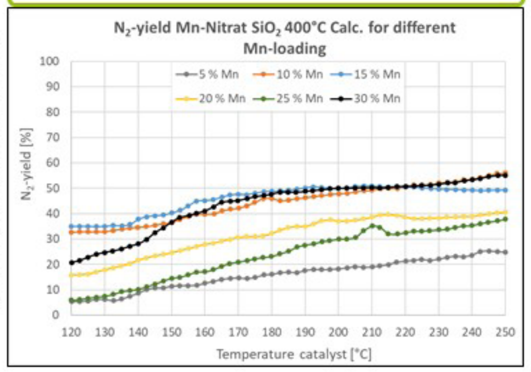

Figure 21: N_2-yield for different Mn-loading

- 10 % Mn shows best N_2 selectivity
- 15 % Mn shows lower N_2-selectivity, but higher NO_X-conversion → N_2-yield...

- 15 % Mn shows highest N_2 yield up to 200˚C
- 10 % and 30 % Mn only shows higher N_2 yield at temperatures > 220˚C

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Summary / Conclusion / Outlook

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Mn precursor

- Mn-nitrate superior to Mn-acetate, due to formation of MnO_2
- Mn-acetate results in the formation of Mn_3O_4

SiO_2 carrier

- SiO_2 with high pore volume shows advantages (> 10 nm)
- BET-surface alone is not decisive, pore volume and structure

Mn loading

- 15 % Mn loading highest N_2 yield, but 10 % Mn more selective
- Finer adjustment of optimum Mn loading range 10 to 15 % Mn

Calcination temperature

- 400˚C superior, lower temp. only better for low Mn loading (5 %)

Further optimization of low-temperature SCR catalyst by doping with metal oxides, testing various SiO_2 carriers or SiO_2-TiO_2 mixed carriers, Mn-loading between 10 % and 15 %, calcination temperature between 300°C and 400°C

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Thank you very much!

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Gasification of Biomass from Phytoremediation and Fate of Heavy Metal Contaminants

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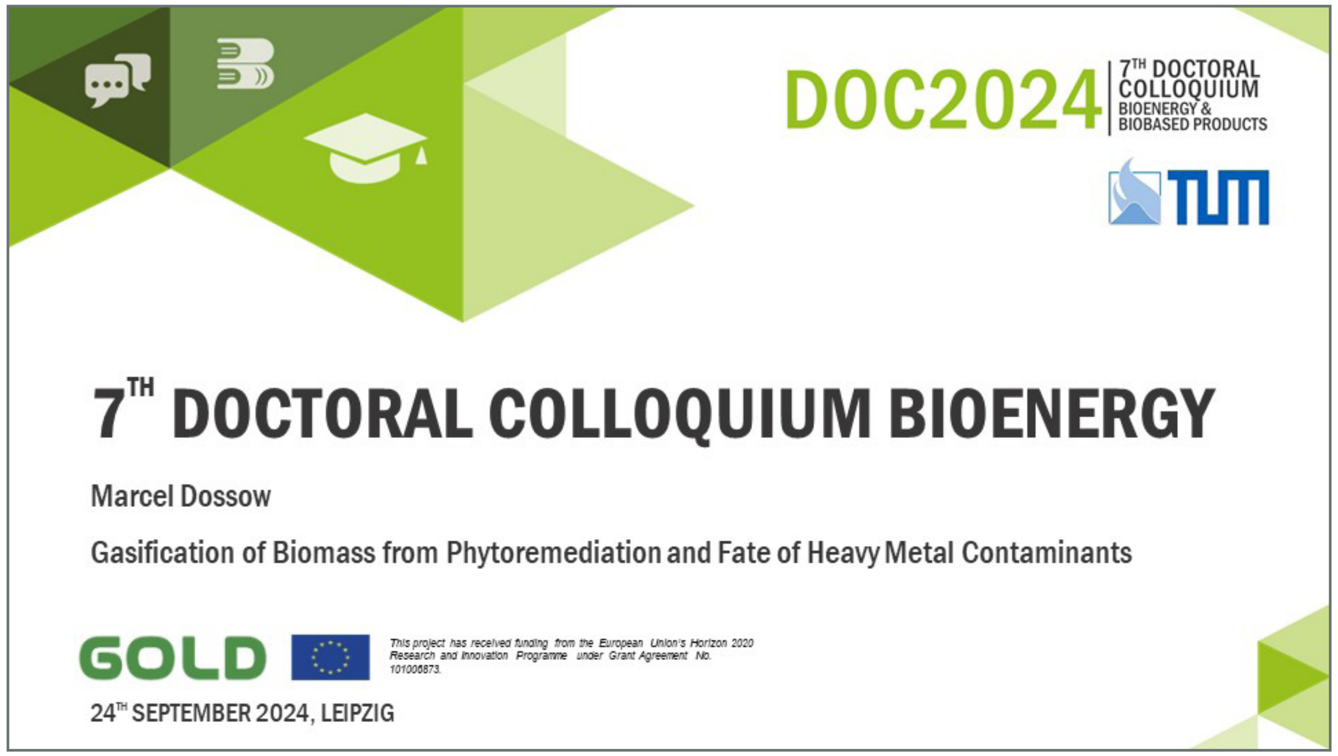
Keywords: Biomass-to-Liquid, Phytoremediation, heavy metals, entrained flow gasification, Electrification, Advanced Biofuels

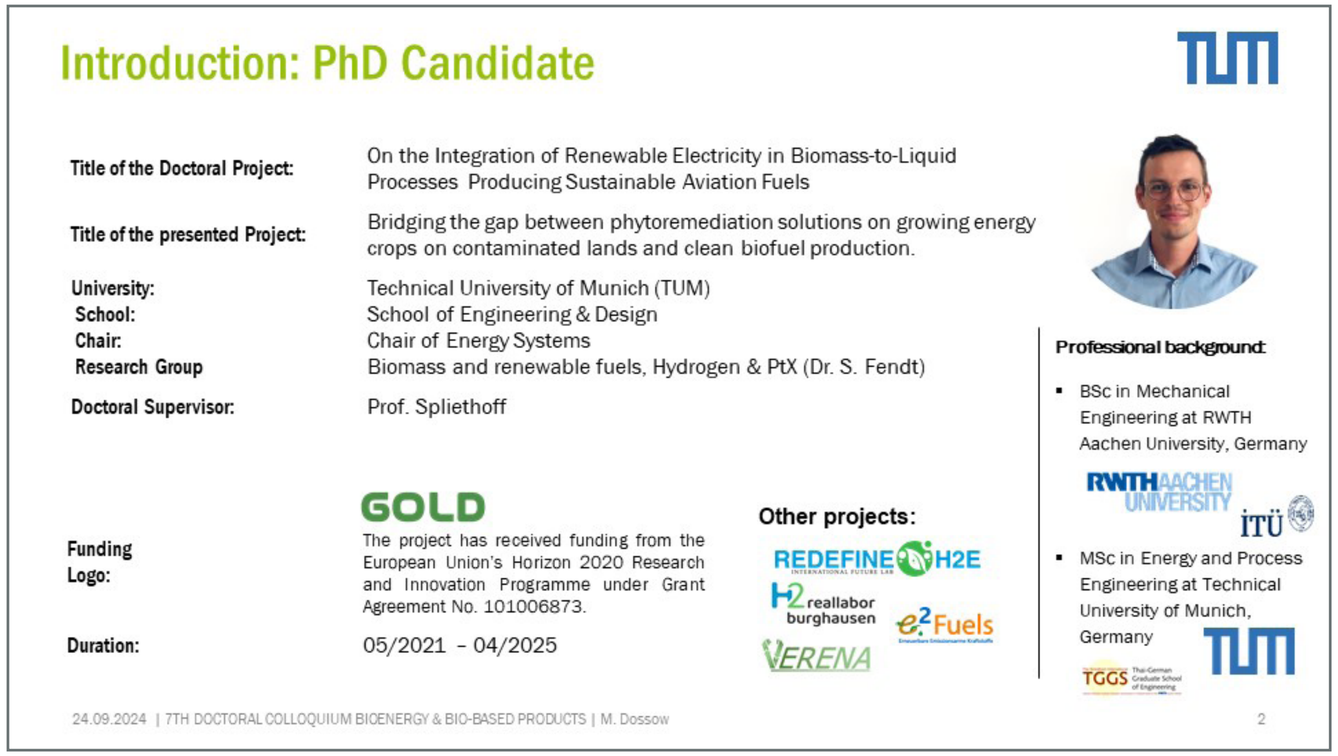
To return contaminated land to agricultural production in the long term, the GOLD project at the Chair of Energy Systems aims to produce clean and sustainable biofuels with low indirect land use change from selected high-yield lignocellulosic plants. These plants, which are optimized for phytoremediation purposes, will be efficiently decomposed into synthesis gas using entrained-flow gasification. In this process, the synthesis gas is converted into hydrogen and higher alcohols such as ethanol, acetic acid, butanol, and butyric acid by acetogenic microorganisms in a bioreactor after gas purification. The aim of this work is to predict the fate of heavy metal contaminants in the plants during gasification. This enables an assessment to where in the process chain heavy metals can be separated from the biomass, preferably in a non-leachable, vitrified form.

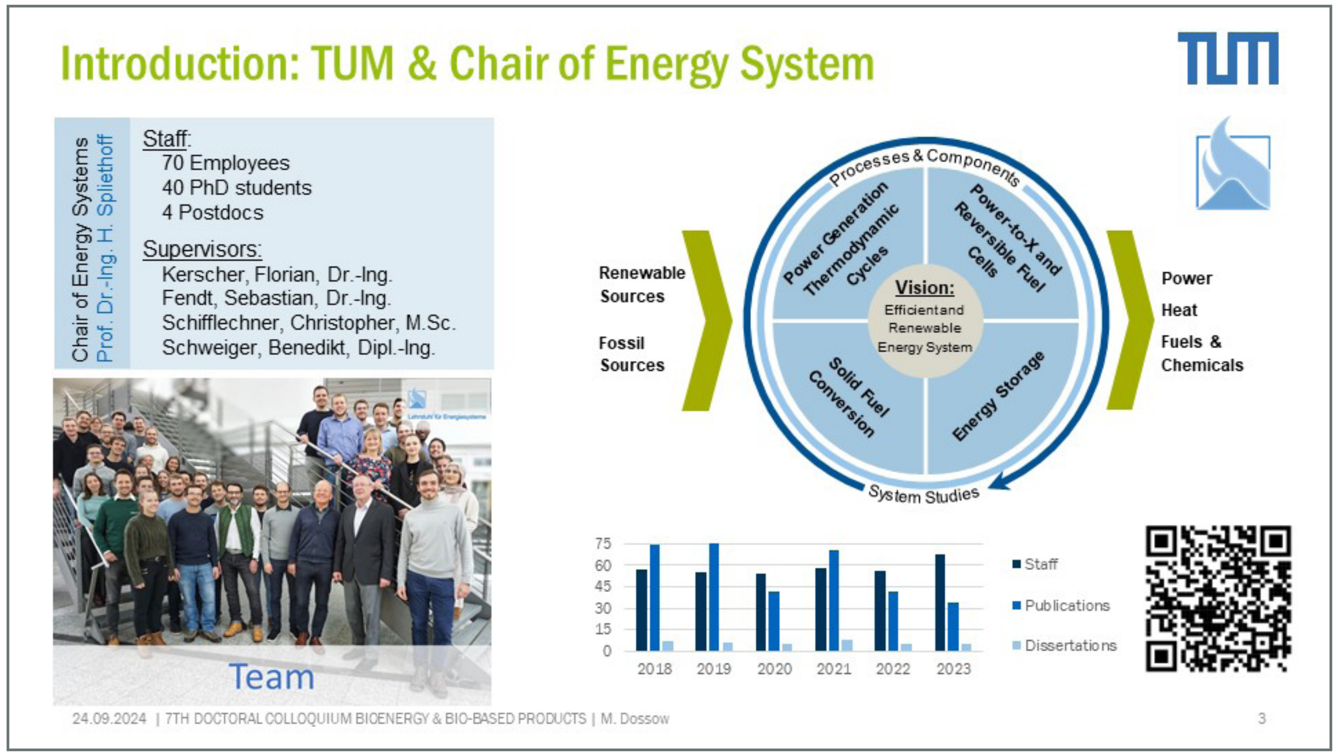
Contaminated biomass that was harvested from GOLD phytoremediation pilot sites is investigated experimentally. Using fuel analysis gasification test rigs, release kinetics are obtained. Using the contamination levels in the residue after gasification, the mass balance for heavy metals can be closed. The resulting temperature dependent release behavior of the contaminants is used to validate a previously developed model to predict the phase transitions of contaminants from solid phase to gas phase and back during entrained-flow gasification of contaminated biomass.

Experimental and simulation results show that cadmium, lead , and zinc show volatile behavior and are entirely volatilized during entrained-flow gasification. The other heavy metals are rather non-volatile and are only partially released during gasification. Non-volatile elements start to recondense in gasification and all heavy metals are entirely solidified in the water quench.

To understand the release behavior of heavy metals and metalloids during the gasification of contaminated biomass, this work allows to measure and predict their phase transition behavior under gasification conditions.



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Power-to-X and Reversible Fuel Cells
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Vision: Efficient and Renewable Energy System
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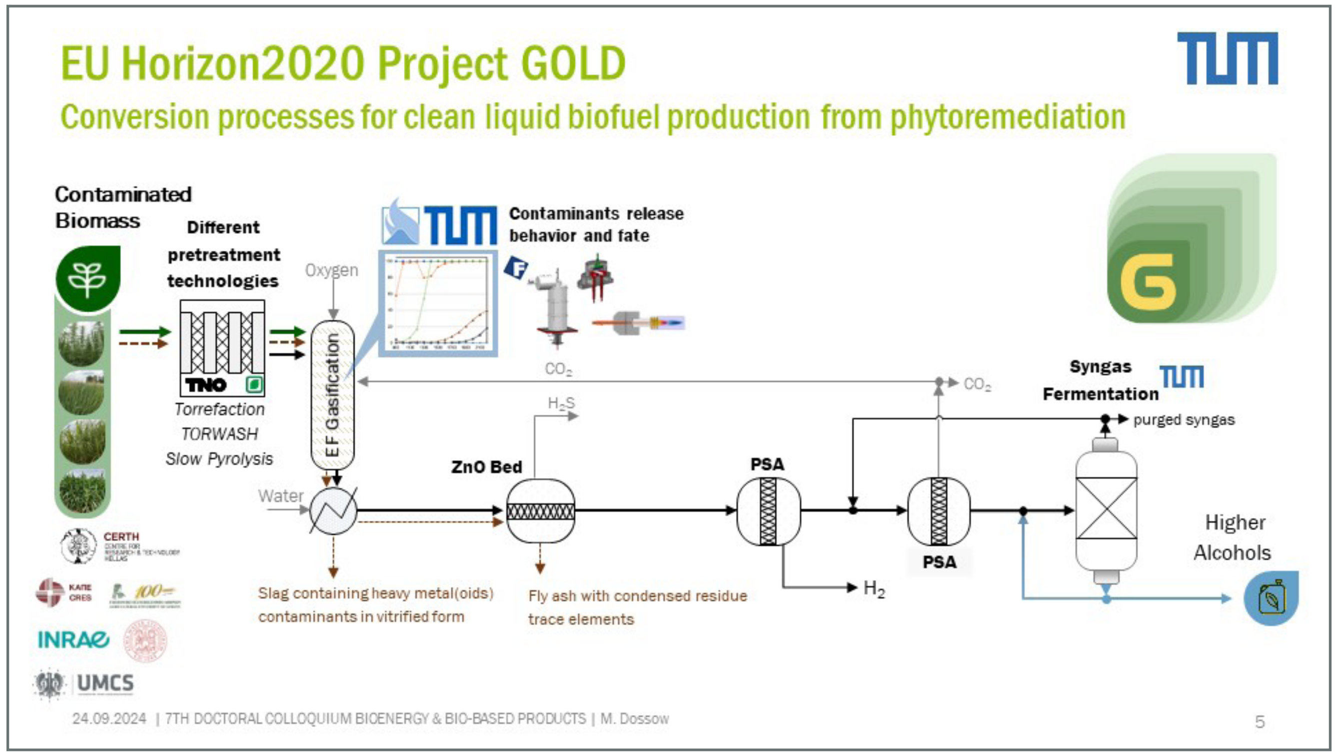
EU Horizon2020 Project GOLD
Conversion processes for clean liquid biofuel production from phytoremediation
Contaminated Biomass
Different pretreatment technologies
TNO
Torrefaction
TORWASH
Slow Pyrolysis
Oxygen
Water
EF Gasification
Contaminants release behavior and fate
CO_2
H_2S
ZnO Bed
PSA
PSA
H_2
Syngas Fermentation
purged syngas
Higher Alcohols
Slag containing heavy metal(oids) contaminants in vitrified form
Fly ash with condensed residue trace elements
CERTH
INRAE
UMCS
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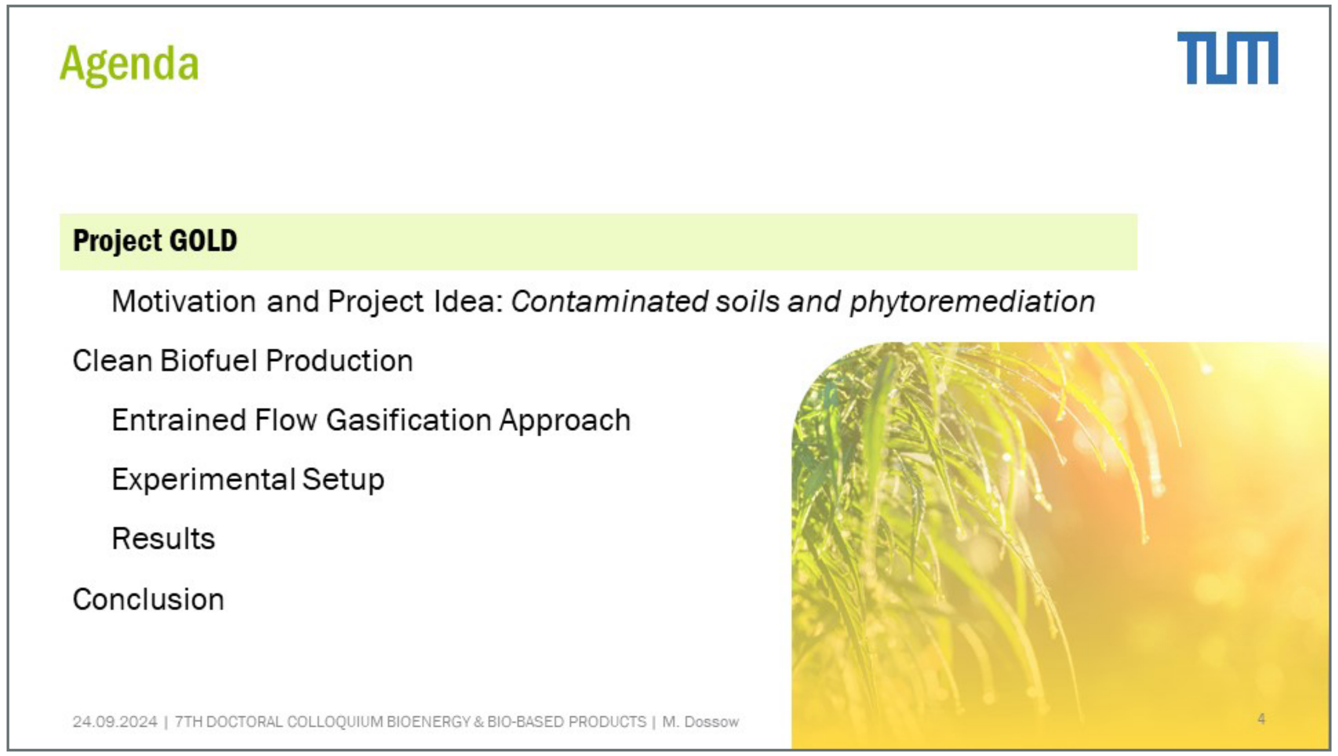
Agenda
Project GOLD
Motivation and Project Idea: *Contaminated soils and phytoremediation*
Clean Biofuel Production
Entrained Flow Gasification Approach
Experimental Setup
Results
Conclusion
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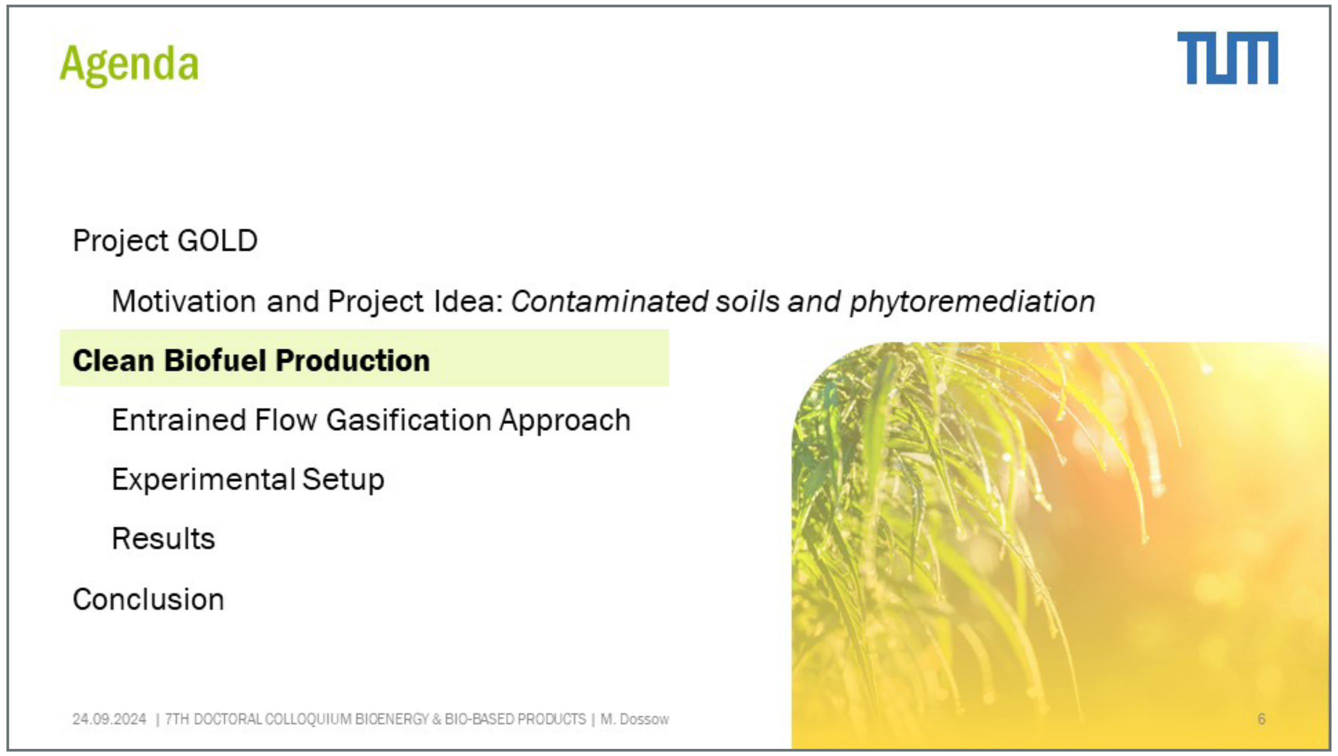
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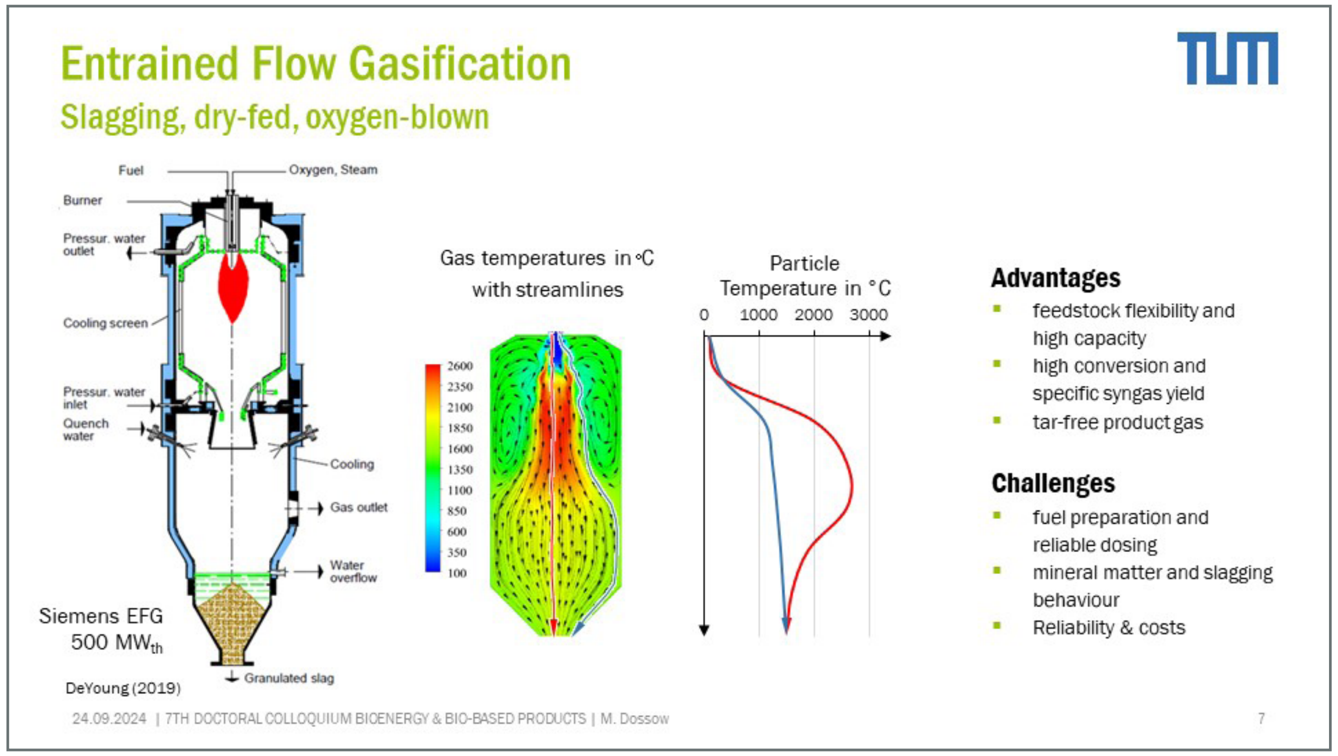

Entrained Flow Gasification
Slagging, dry-fed, oxygen-blown
Fuel
Oxygen, Steam
Burner
Pressur. water outlet
Cooling screen
Pressur. water inlet
Quench water
Cooling
Gas outlet
Water overflow
Granulated slag
Siemens EFG 500 MWth
DeYoung (2019)
Gas temperatures in °C with streamlines
Particle Temperature in °C
0 1000 2000 3000
Advantages
feedstock flexibility and high capacity
high conversion and specific syngas yield
tar-free product gas
Challenges
fuel preparation and reliable dosing
mineral matter and slagging behaviour
Reliability & costs
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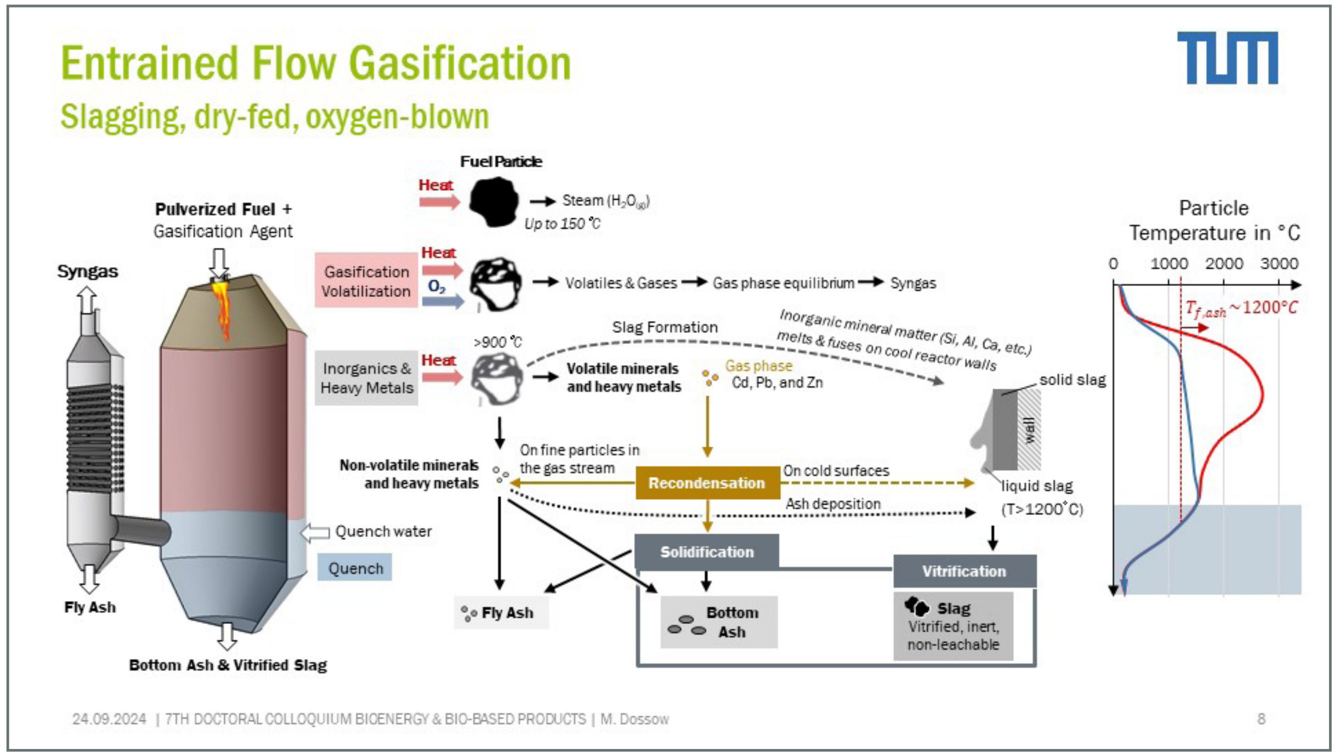

Entrained Flow Gasification
Slagging, dry-fed, oxygen-blown
Fuel Particle
Heat
Steam (H2O(g))
Up to 150 °C
Pulverized Fuel + Gasification Agent
Syngas
Gasification Volatilization
Volatiles & Gases
Gas phase equilibrium
Syngas
Slag Formation
Inorganic mineral matter (Si, Al, Ca, etc.) melts & fuses on cool reactor walls
>900 °C
Inorganics & Heavy Metals
Volatile minerals and heavy metals
Gas phase Cd, Pb, and Zn
solid slag
wall
On fine particles in the gas stream
Non-volatile minerals and heavy metals
Recondensation
On cold surfaces
Ash deposition
liquid slag (T>1200°C)
Quench water
Quench
Solidification
Vitrification
Fly Ash
Bottom Ash
Slag Vitrified, inert, non-leachable
Bottom Ash & Vitrified Slag
Particle Temperature in °C
0 1000 2000 3000
Tf,ash ~1200°C
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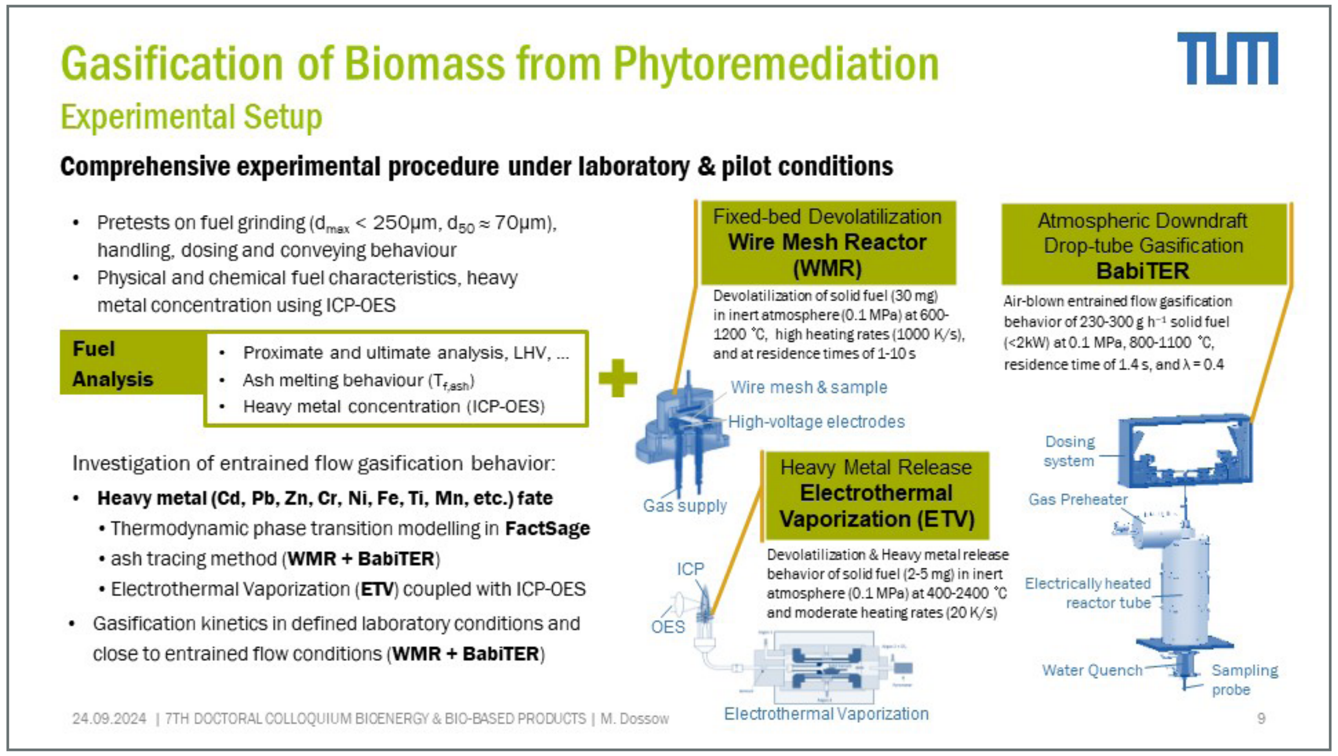

Gasification of Biomass from Phytoremediation
Experimental Setup
Comprehensive experimental procedure under laboratory & pilot conditions
Pretests on fuel grinding (dmax < 250µm, d50 ≈ 70µm), handling, dosing and conveying behaviour
Physical and chemical fuel characteristics, heavy metal concentration using ICP-OES
Fuel Analysis
Proximate and ultimate analysis, LHV, ...
Ash melting behaviour (Tf,ash)
Heavy metal concentration (ICP-OES)
Investigation of entrained flow gasification behavior:
Heavy metal (Cd, Pb, Zn, Cr, Ni, Fe, Ti, Mn, etc.) fate
Thermodynamic phase transition modelling in FactSage
ash tracing method (WMR + BabiTER)
Electrothermal Vaporization (ETV) coupled with ICP-OES
Gasification kinetics in defined laboratory conditions and close to entrained flow conditions (WMR + BabiTER)
Fixed-bed Devolatilization Wire Mesh Reactor (WMR)
Devolatilization of solid fuel (30 mg) in inert atmosphere (0.1 MPa) at 600-1200 °C, high heating rates (1000 K/s), and at residence times of 1-10 s
Wire mesh & sample
High-voltage electrodes
Gas supply
Heavy Metal Release Electrothermal Vaporization (ETV)
Devolatilization & Heavy metal release behavior of solid fuel (2-5 mg) in inert atmosphere (0.1 MPa) at 400-2400 °C and moderate heating rates (20 K/s)
ICP
OES
Electrothermal Vaporization
Atmospheric Downdraft Drop-tube Gasification BabiTER
Air-blown entrained flow gasification behavior of 230-300 g h⁻¹ solid fuel (<2kW) at 0.1 MPa, 800-1100 °C, residence time of 1.4 s, and λ = 0.4
Dosing system
Gas Preheater
Electrically heated reactor tube
Water Quench
Sampling probe
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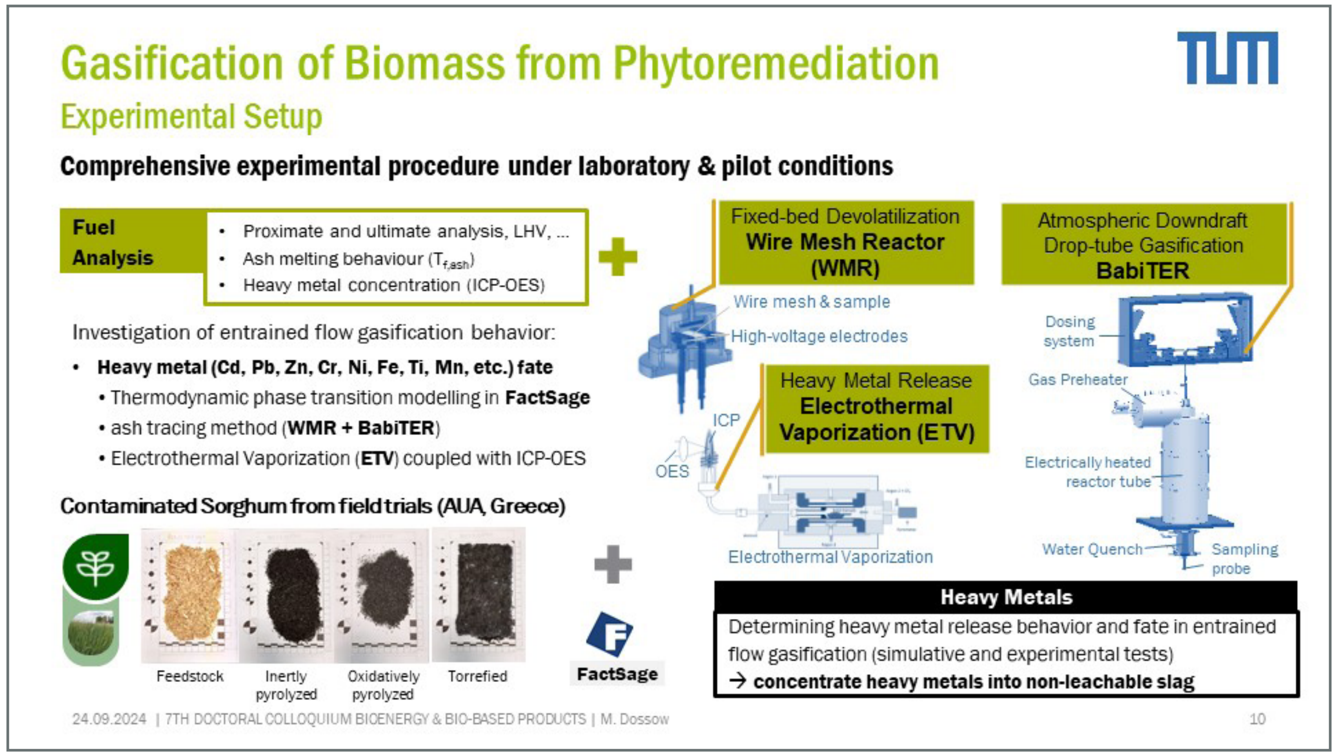

Gasification of Biomass from Phytoremediation
Experimental Setup
Comprehensive experimental procedure under laboratory & pilot conditions
Fuel Analysis
Proximate and ultimate analysis, LHV, ...
Ash melting behaviour (Tf,ash)
Heavy metal concentration (ICP-OES)
Investigation of entrained flow gasification behavior:
Heavy metal (Cd, Pb, Zn, Cr, Ni, Fe, Ti, Mn, etc.) fate
Thermodynamic phase transition modelling in FactSage
ash tracing method (WMR + BabiTER)
Electrothermal Vaporization (ETV) coupled with ICP-OES
Contaminated Sorghum from field trials (AUA, Greece)
Feedstock
Inertly pyrolyzed
Oxidatively pyrolyzed
Torrefied
FactSage
Fixed-bed Devolatilization Wire Mesh Reactor (WMR)
Wire mesh & sample
High-voltage electrodes
Heavy Metal Release Electrothermal Vaporization (ETV)
ICP
OES
Electrothermal Vaporization
Atmospheric Downdraft Drop-tube Gasification BabiTER
Dosing system
Gas Preheater
Electrically heated reactor tube
Water Quench
Sampling probe
Heavy Metals
Determining heavy metal release behavior and fate in entrained flow gasification (simulative and experimental tests)
→ concentrate heavy metals into non-leachable slag
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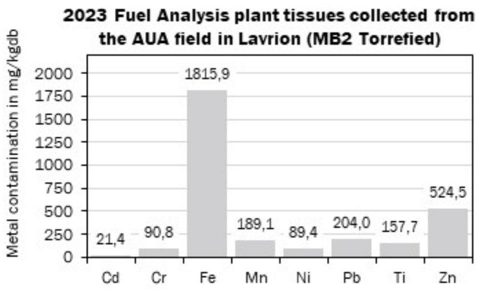
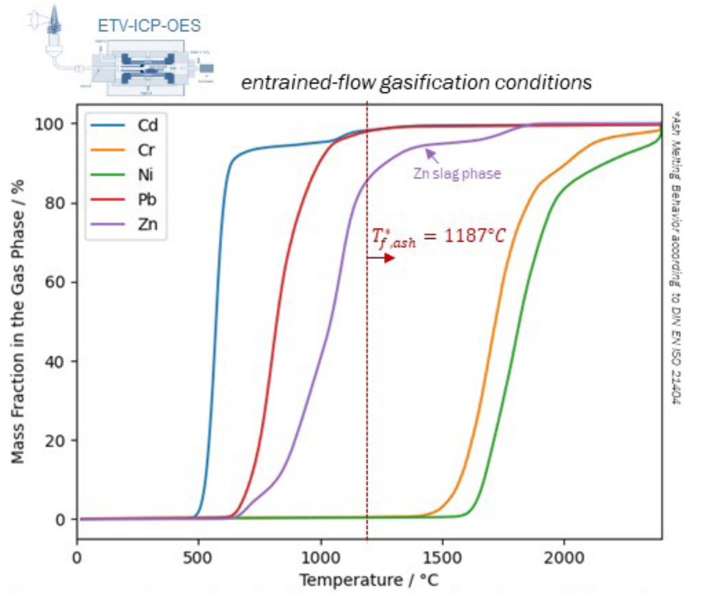
Gasification of Biomass from Phytoremediation

Experimental Results

Gasification of Torrefied Sorghum

- **Pb, Cd, Zn** are volatile and completely gasified at $1000°C < T < 1600\,°C$
- **Cr & Ni** show less volatile behavior
- **Fe, Mn, & Ti** are non-volatile and no substantial amounts are volatilized





Ritz and Dossow et al. (2024): Experimental investigation of heavy metal release in entrained-flow gasification. Submitted to Fuel

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Gasification of Biomass from Phytoremediation

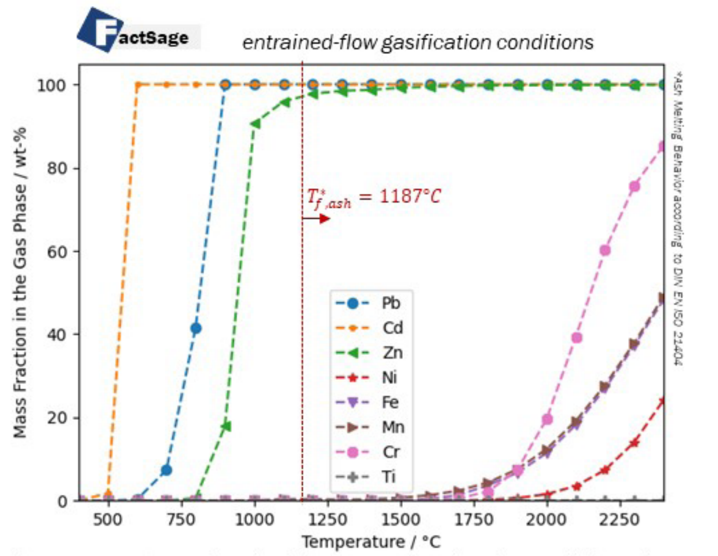
Simulation Results

Gasification of Torrefied Sorghum

- **Pb, Cd, Zn** are volatile and completely gasified at $T < 1200\,°C$
- **Ni, Fe, Mn, Cr, & Ti** are non-volatile and no substantial amounts are volatilized in entrained-flow gasification conditions.

- Cr & Ni modeling results are in good agreement with the experimental results
- Delayed volatilization of volatile elements in reality compared to the model

➡ Model can be used to predict: min. release temperature of Pb, Cd, Zn Max. release temperature of Cr, Ni



Ritz and Dossow et al. (2024): Experimental investigation of heavy metal release in entrained-flow gasification. Submitted to Fuel

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Gasification of Biomass from Phytoremediation

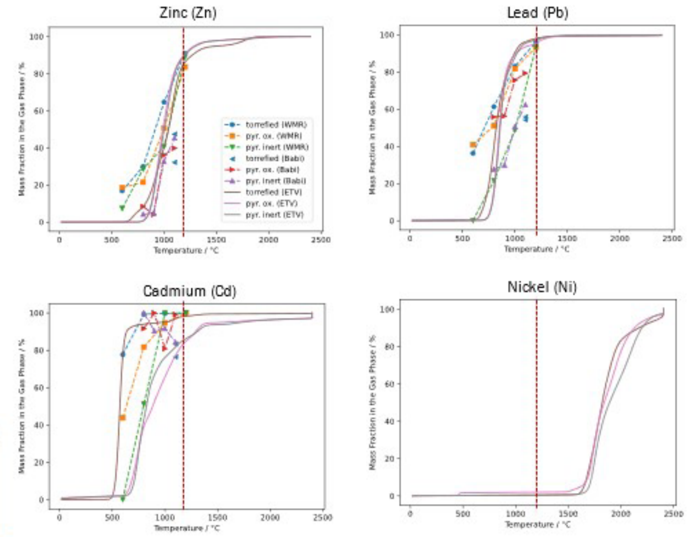
Experimental Results

Heavy Metal Release in ETV, WMR, and BabiTER

Experimental Results show good agreement and cross-verify each other

- pretreatment method does not influence the release of Pb and Zn, but for Cd (pyrolysis shift towards higher T)
- General release behavior of heavy metals in good agreement within the methods, but the volatilization is completed faster in the ETV compared to the other methods

➡ ETV as standard method for analysis of the release behavior of heavy metals from contaminated biomasses



Ritz and Dossow et al. (2024): Experimental investigation of heavy metal release in entrained-flow gasification. Submitted to Fuel

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Gasification of Biomass from Phytoremediation

Simulation Results

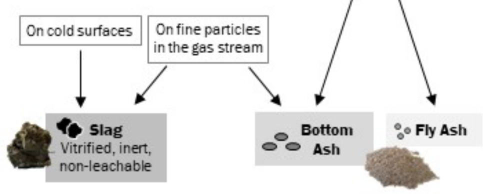
Water Quench of Torrefied Sorghum

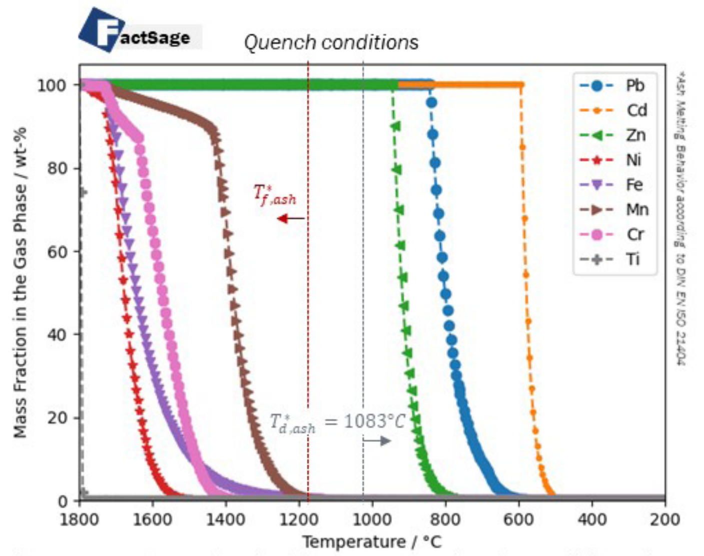
- All metals are entirely solidified in the quench
- The formation of metal complexes and slag phases can delay the solidification

Non-volatile elements **(Ni, Fe, Mn, Cr, & Ti)** solidify at temperatures > $T^*_{flow,ash}$

→ Recondensation starts in the gasification chamber

Pb, Cd, Zn only solidify close to the quench entry section





Ritz and Dossow et al. (2024): Experimental investigation of heavy metal release in entrained-flow gasification. Submitted to Fuel

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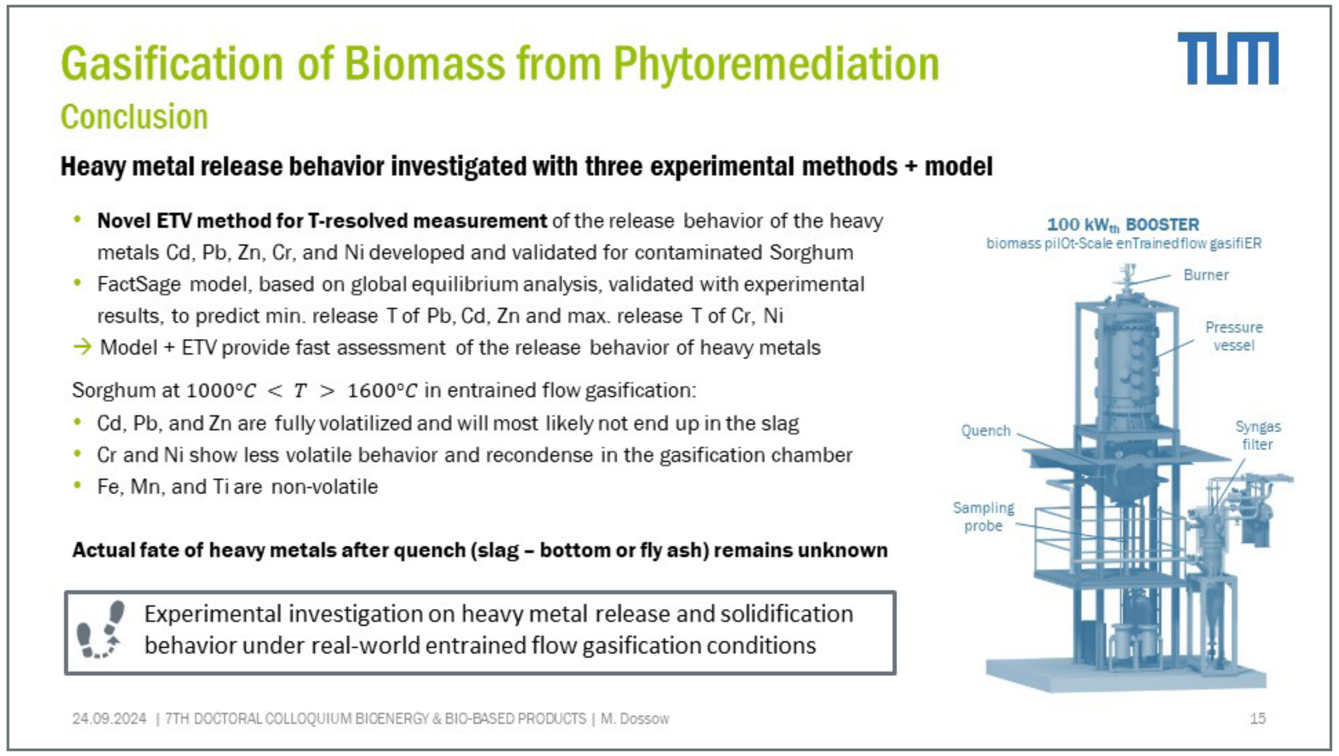
Gasification of Biomass from Phytoremediation
Conclusion
Heavy metal release behavior investigated with three experimental methods + model
• Novel ETV method for T-resolved measurement of the release behavior of the heavy metals Cd, Pb, Zn, Cr, and Ni developed and validated for contaminated Sorghum
• FactSage model, based on global equilibrium analysis, validated with experimental results, to predict min. release T of Pb, Cd, Zn and max. release T of Cr, Ni
→ Model + ETV provide fast assessment of the release behavior of heavy metals
Sorghum at 1000°C < T > 1600°C in entrained flow gasification:
• Cd, Pb, and Zn are fully volatilized and will most likely not end up in the slag
• Cr and Ni show less volatile behavior and recondense in the gasification chamber
• Fe, Mn, and Ti are non-volatile
Actual fate of heavy metals after quench (slag – bottom or fly ash) remains unknown
Experimental investigation on heavy metal release and solidification behavior under real-world entrained flow gasification conditions
100 kWth BOOSTER
biomass pilOt-Scale enTrained flow gasifiER
Burner
Pressure vessel
Quench
Syngas filter
Sampling probe
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Thank you for your attention
Any questions?
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Technical University of Munich
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Chair of Energy Systems
Leipzig, 24th September 2024
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[5]Technical University of Munich, Chair of Energy Systems, München, Germany

Arkya Sanyal, University of Erlangen-Nuremberg

Characterizing Fluidized Bed Bubbling Phenomena: Probing Dynamics with Dual-Sided Video and Pressure Analysis

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Keywords: fluidized beds, agglomeration behavior, image analysis, characteristic frequency, early detection

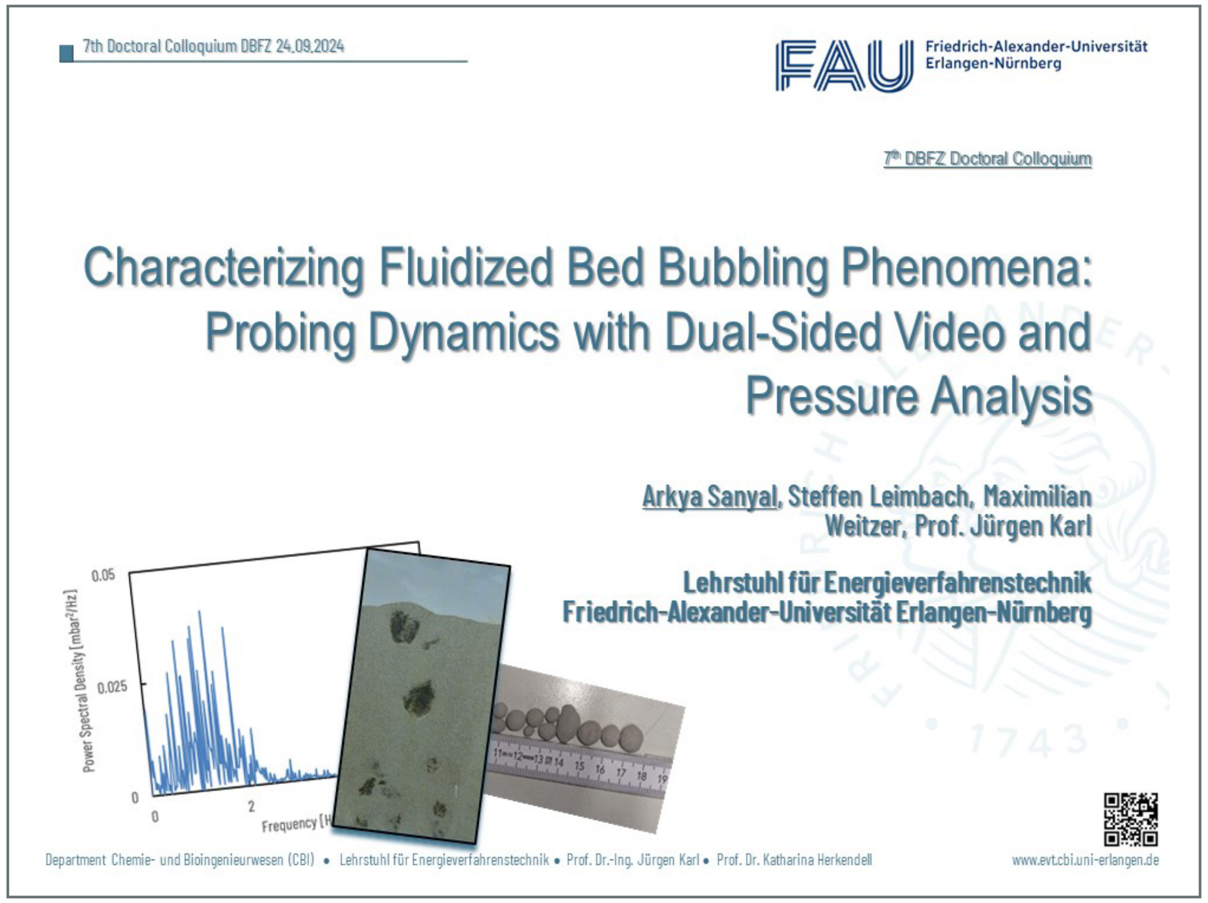
Incorporating biogenic fuels in fluidized beds presents distinct challenges such as heat exchanger fouling, high-temperature chloride corrosion, and agglomerate development. These effects can potentially disrupt fluidization dynamics, leading to bed defluidization and eventual plant failure, adversely affecting economic viability [1]. Understanding, controlling, and preferably avoiding agglomeration processes are crucial for efficient and cost-effective operations.

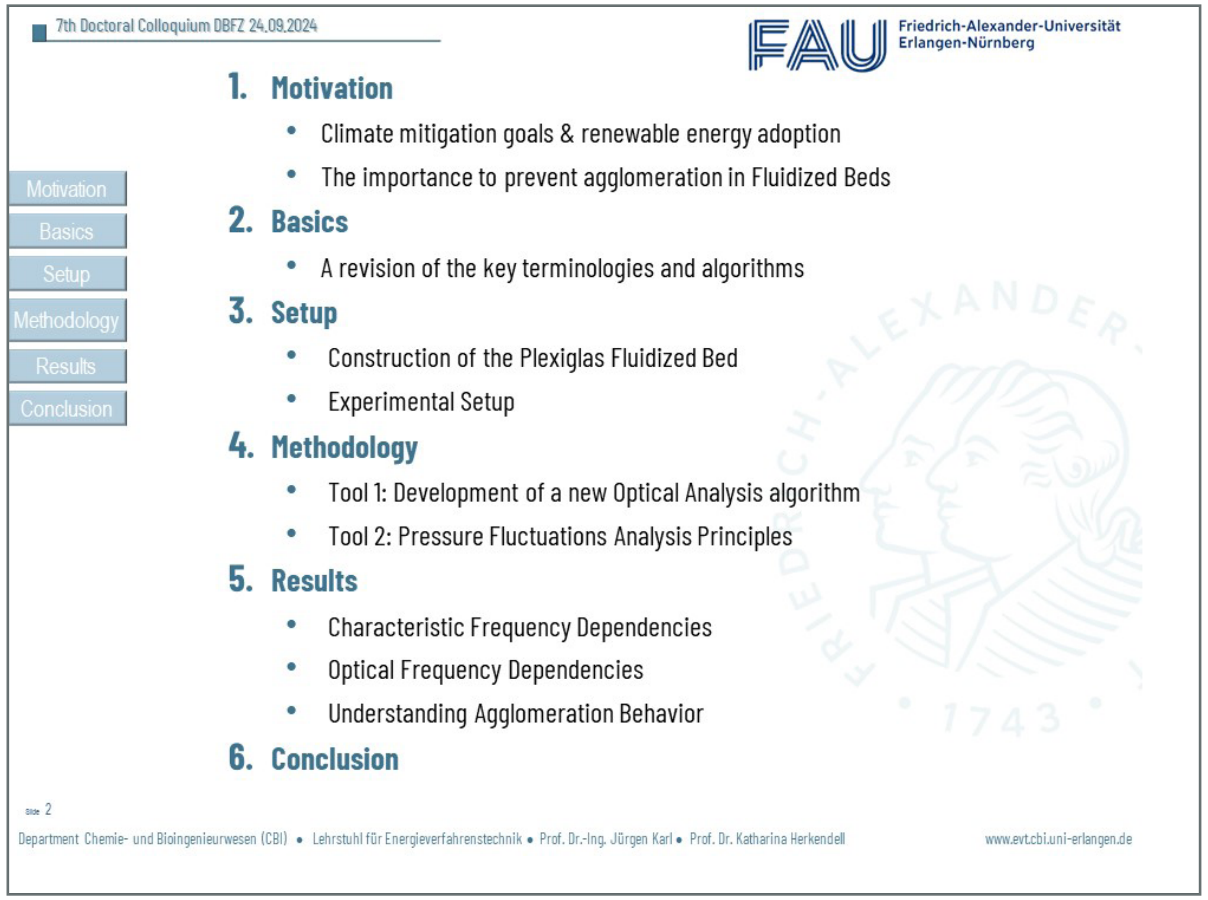
This study introduces two complementary methods for the early detection of agglomeration:
1. Novel Camera-based Image Analysis Tool: Inspired by Filipe and Rocha's work with transparent plexiglass fluidized beds, this tool was developed by the Chair of Energy Process Engineering (EVT) at the University of Erlangen-Nürnberg to detect changes in bubbling dynamics during fluidization allowing to determine the fluidization state. This method is based on image processing and thresholding and solely relies on visual detection of agglomeration processes, addressing challenges in direct observation inside fluidized beds.

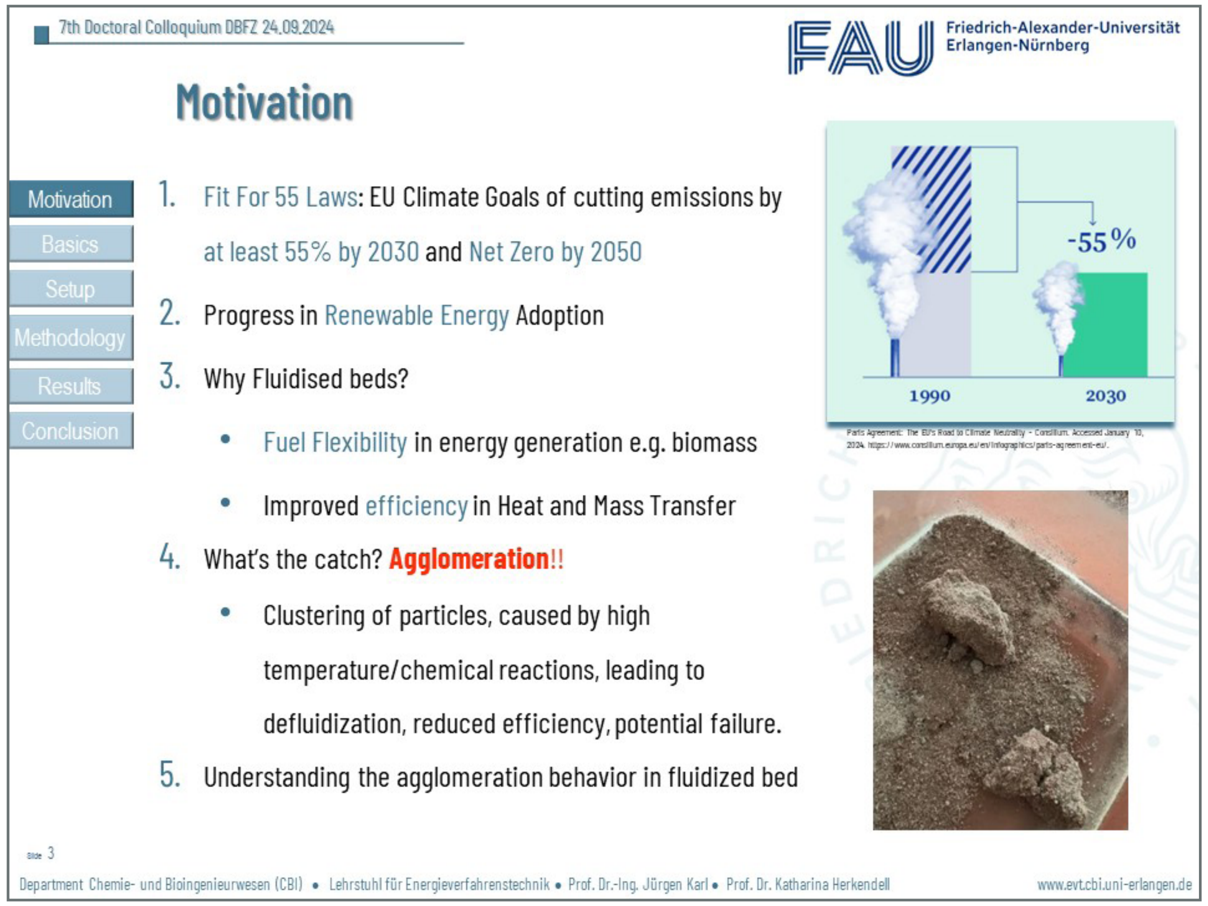
2. Characteristic Frequency (CF) Analysis: An existing methodology developed by the EVT, involves extracting a CF from the power spectral density of pressure signals obtained from different measurement points inside the fluidized beds using a fast Fourier transform.
To force agglomeration behavior in lab experiments, the stickiness of bed material particles in a prototype plexiglass fluidized bed was increased by manually spraying water after a defined operating time. This enhanced the attractive forces between particles, mimicking agglomeration behavior and thereby its early detection.

The Characteristic Frequency Analysis of the prototype revealed a significant decline in the CF after increasing the particle stickiness, signaling the onset of defluidization which is consistent with the findings of Leimbach et al. This decline is attributed to the heightened stickiness dampening higher-frequency collisions relative to lower-frequency bubble movements and bed vibrations induced by gas flow. Similarly, the Image Analysis tool successfully detected a notable change in bubble shape before and after defluidization. Combining these two methods, correlations between the CF and optical visualization were established, unveiling dependencies between the fluidized bed height, air inlet volume flow rate, material, and early detection of agglomeration.

The results of this study facilitate online agglomeration monitoring and process optimization in industrial applications with various fluidization parameters to early detect and prevent agglomeration.



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FAU Friedrich-Alexander-Universität Erlangen-Nürnberg
Motivation
Motivation
Basics
Setup
Methodology
Results
Conclusion
1. Fit For 55 Laws: EU Climate Goals of cutting emissions by at least 55% by 2030 and Net Zero by 2050
2. Progress in Renewable Energy Adoption
3. Why Fluidised beds?
• Fuel Flexibility in energy generation e.g. biomass
• Improved efficiency in Heat and Mass Transfer
4. What's the catch? Agglomeration!!
• Clustering of particles, caused by high temperature/chemical reactions, leading to defluidization, reduced efficiency, potential failure.
5. Understanding the agglomeration behavior in fluidized bed
-55 %
1990
2030
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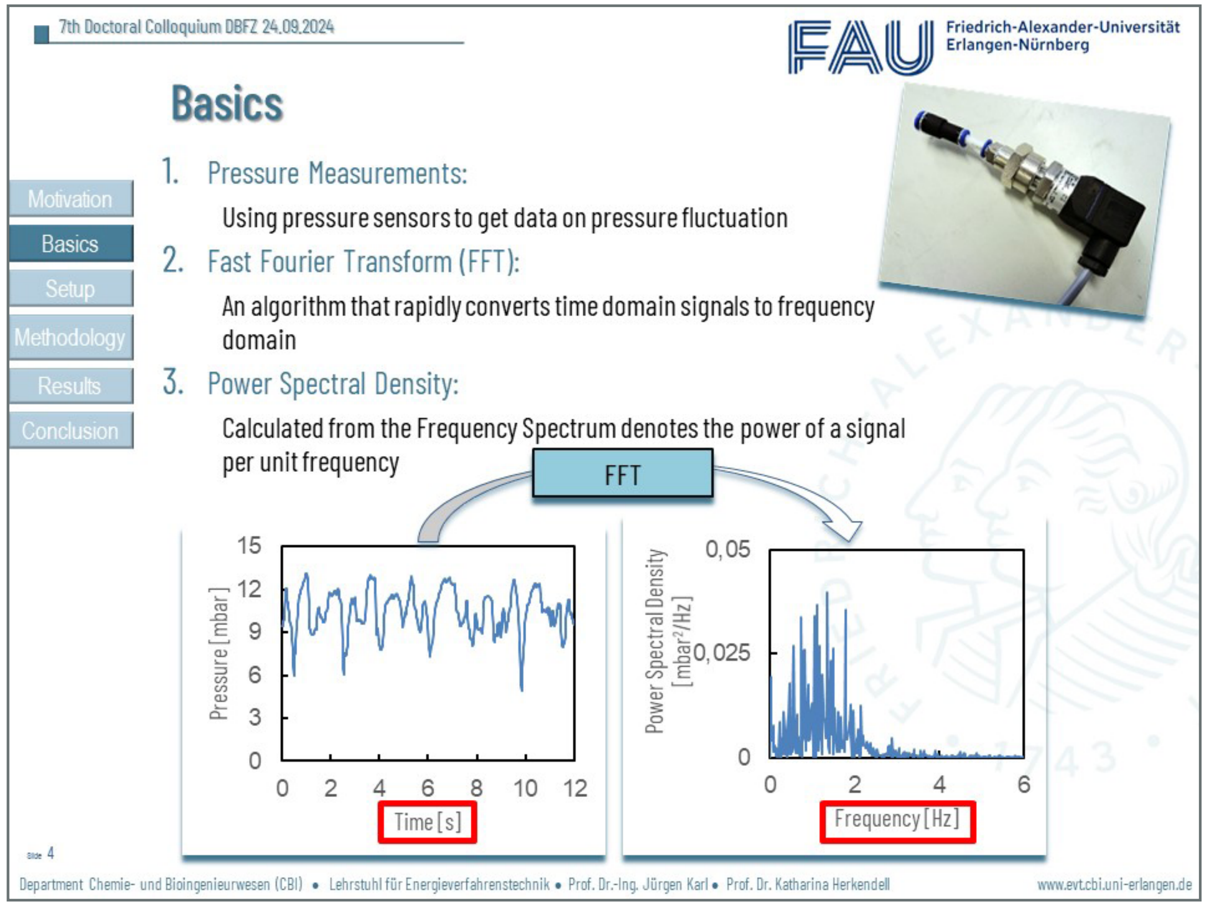
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FAU Friedrich-Alexander-Universität Erlangen-Nürnberg
Basics
Motivation
Basics
Setup
Methodology
Results
Conclusion
1. Pressure Measurements:
Using pressure sensors to get data on pressure fluctuation
2. Fast Fourier Transform (FFT):
An algorithm that rapidly converts time domain signals to frequency domain
3. Power Spectral Density:
Calculated from the Frequency Spectrum denotes the power of a signal per unit frequency
FFT
Pressure [mbar]
Time [s]
Power Spectral Density [mbar²/Hz]
Frequency [Hz]
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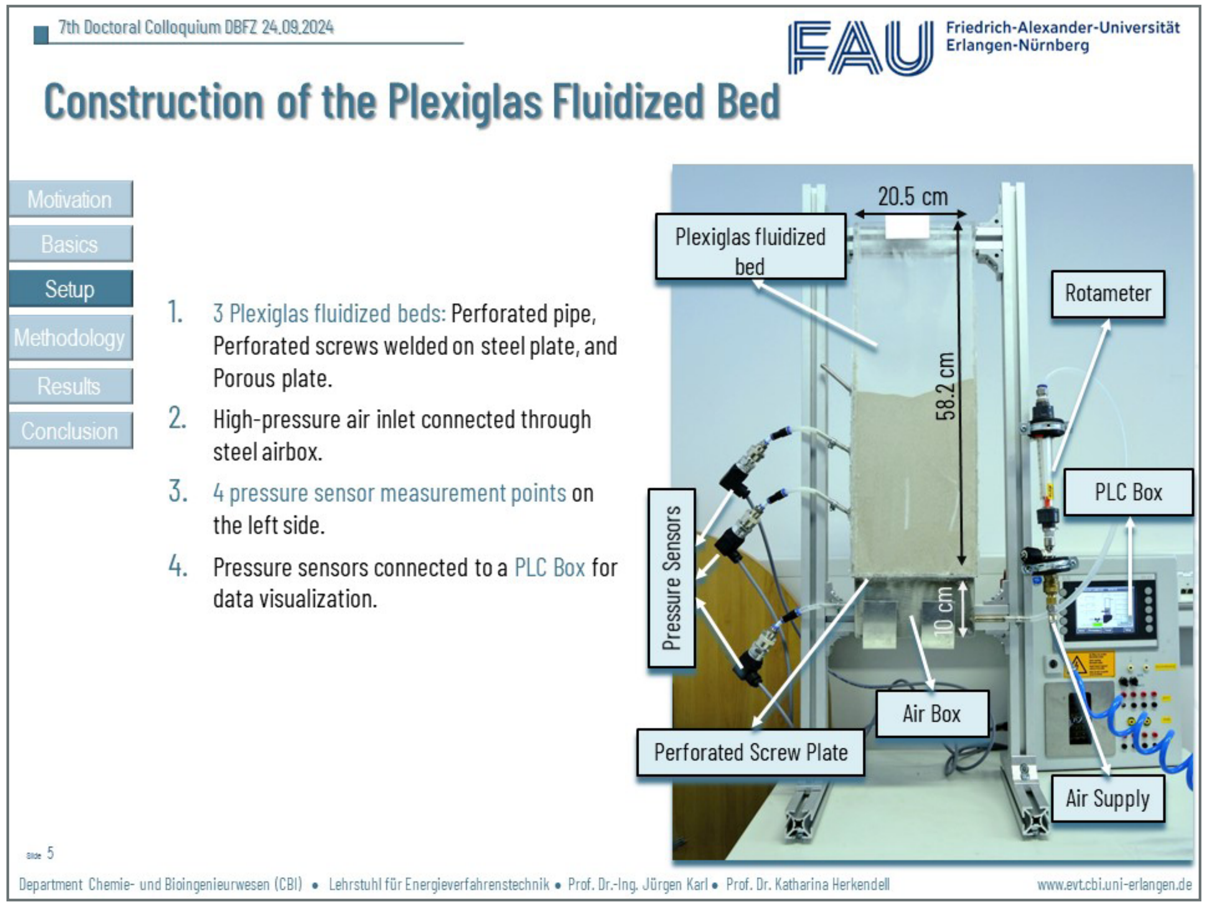
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Construction of the Plexiglas Fluidized Bed
Motivation
Basics
Setup
Methodology
Results
Conclusion
1. 3 Plexiglas fluidized beds: Perforated pipe, Perforated screws welded on steel plate, and Porous plate.
2. High-pressure air inlet connected through steel airbox.
3. 4 pressure sensor measurement points on the left side.
4. Pressure sensors connected to a PLC Box for data visualization.
20.5 cm
Plexiglas fluidized bed
Rotameter
58.2 cm
PLC Box
Pressure Sensors
10 cm
Air Box
Perforated Screw Plate
Air Supply
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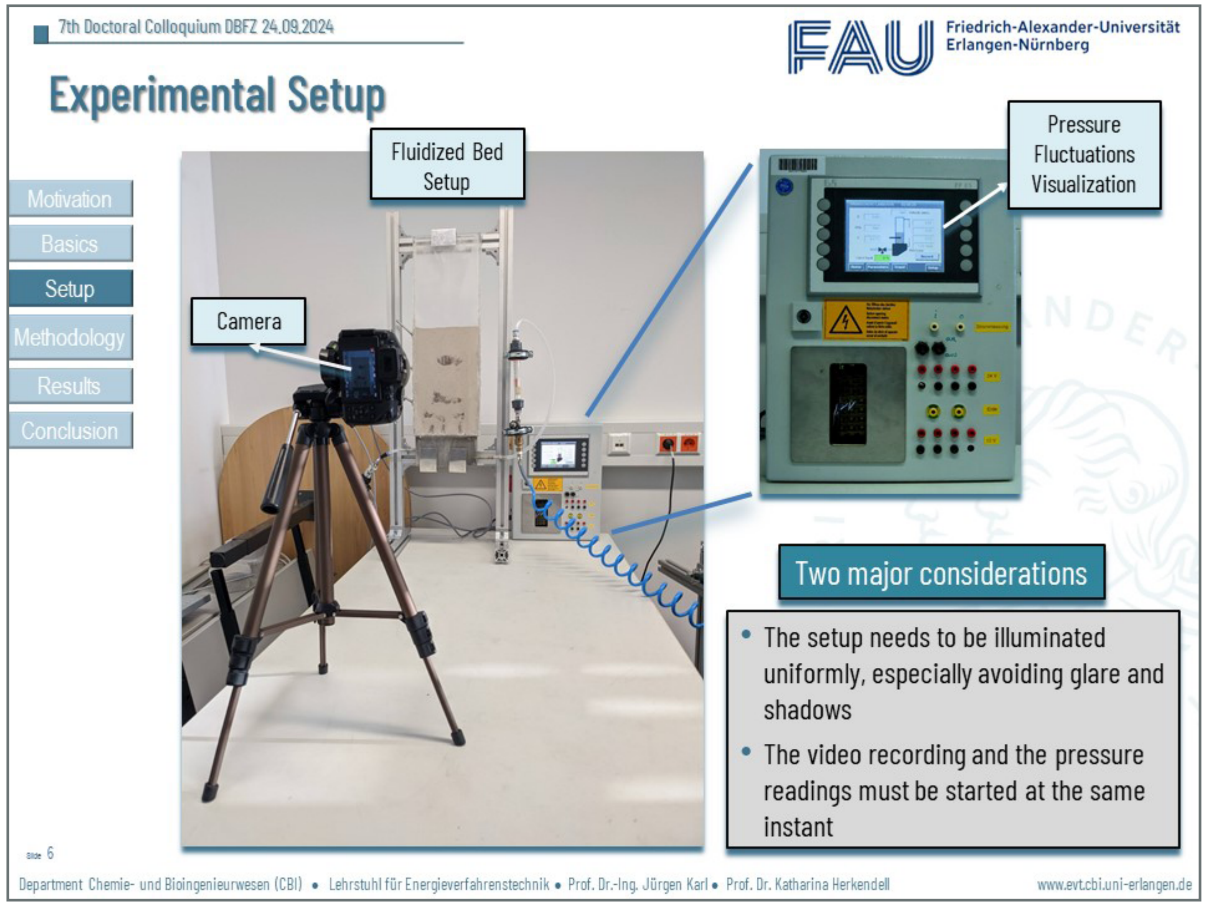
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Experimental Setup
Motivation
Basics
Setup
Methodology
Results
Conclusion
Fluidized Bed Setup
Pressure Fluctuations Visualization
Camera
Two major considerations
• The setup needs to be illuminated uniformly, especially avoiding glare and shadows
• The video recording and the pressure readings must be started at the same instant
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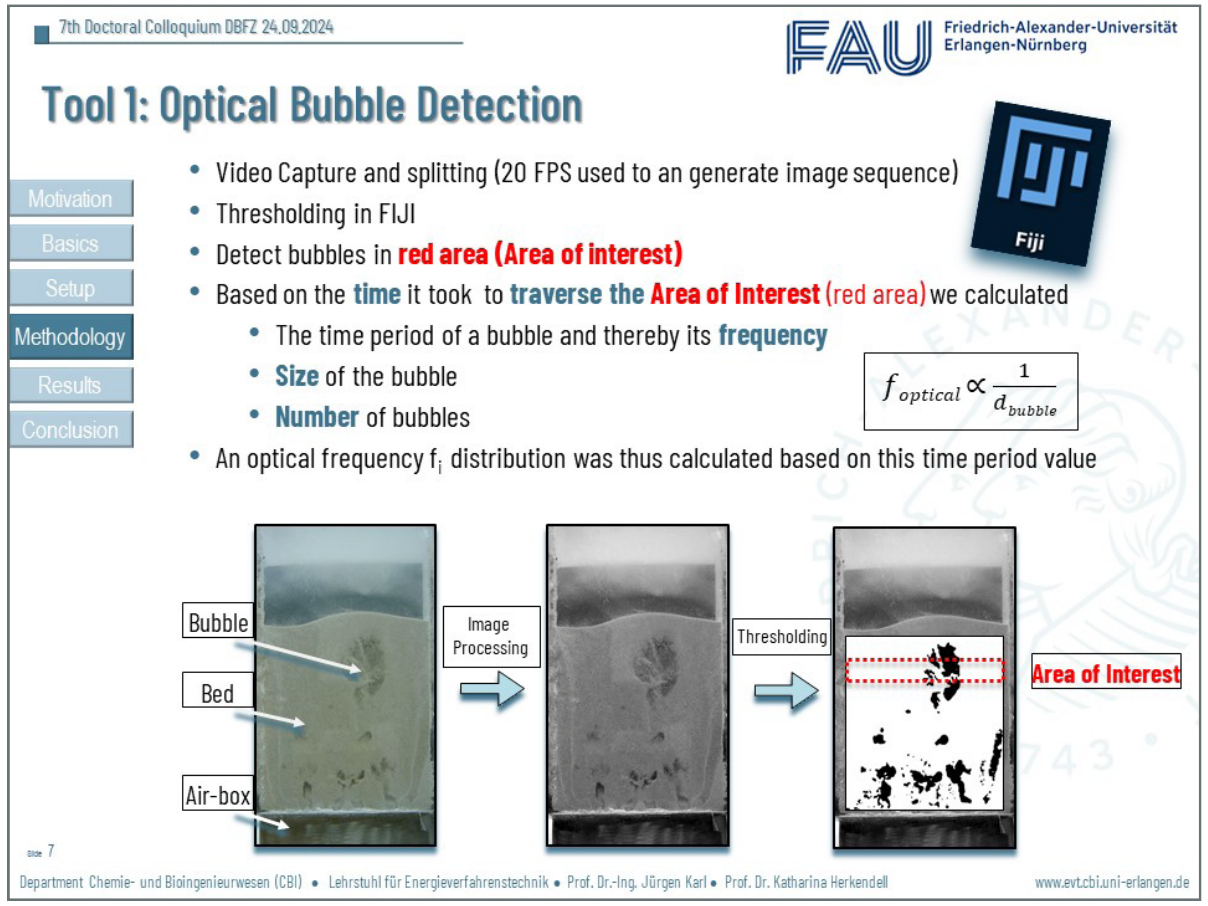
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Tool 1: Optical Bubble Detection
Motivation
Basics
Setup
Methodology
Results
Conclusion
Video Capture and splitting (20 FPS used to an generate image sequence)
Thresholding in FIJI
Detect bubbles in red area (Area of interest)
Based on the time it took to traverse the Area of Interest (red area) we calculated
The time period of a bubble and thereby its frequency
Size of the bubble
Number of bubbles
$f_{optical} \propto \frac{1}{d_{bubble}}$
An optical frequency f_i distribution was thus calculated based on this time period value
Fiji
Bubble
Bed
Air-box
Image Processing
Thresholding
Area of Interest
Slide 7
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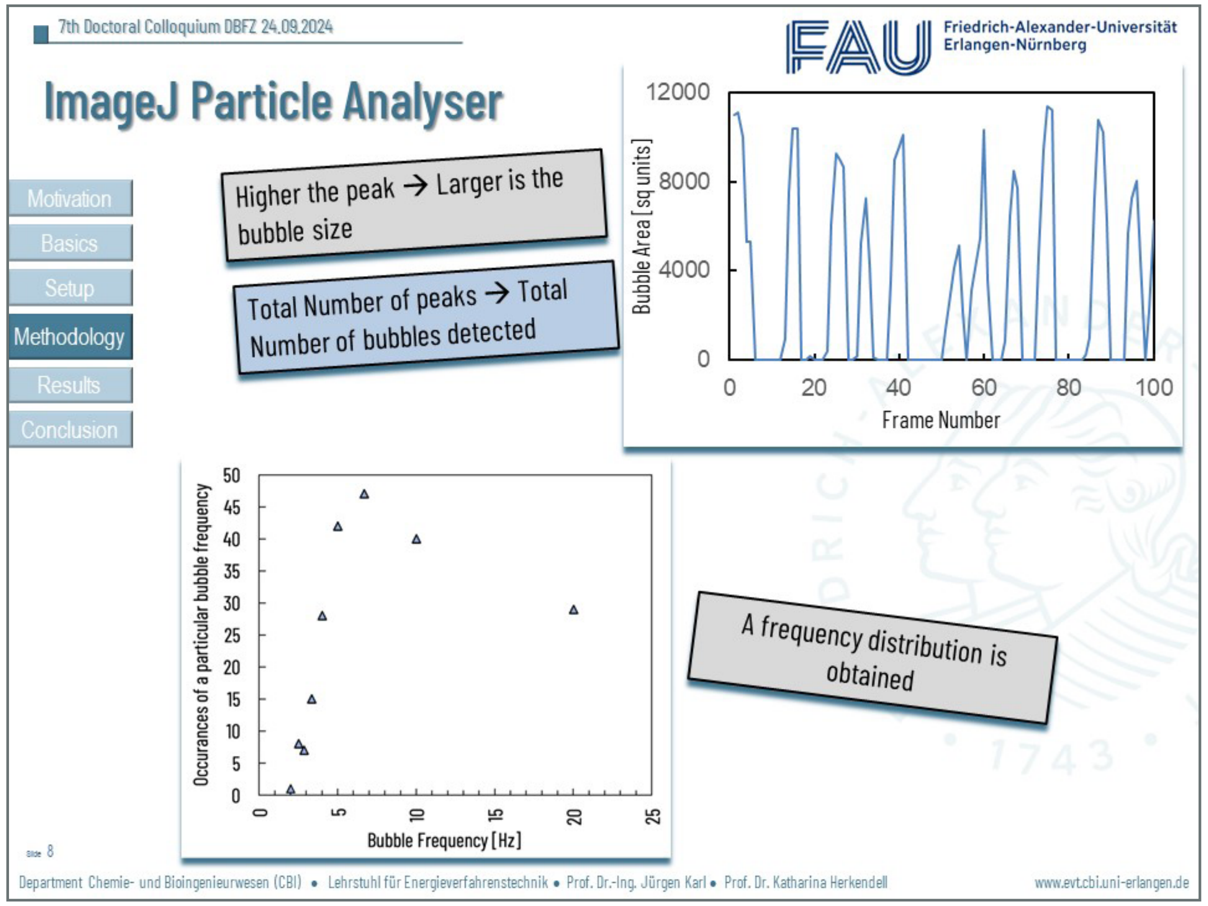
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ImageJ Particle Analyser
Motivation
Basics
Setup
Methodology
Results
Conclusion
Higher the peak → Larger is the bubble size
Total Number of peaks → Total Number of bubbles detected
Bubble Area [sq units]
12000
8000
4000
0
0 20 40 60 80 100
Frame Number
Occurances of a particular bubble frequency
50 45 40 35 30 25 20 15 10 5 0
0 5 10 15 20 25
Bubble Frequency [Hz]
A frequency distribution is obtained
Slide 8
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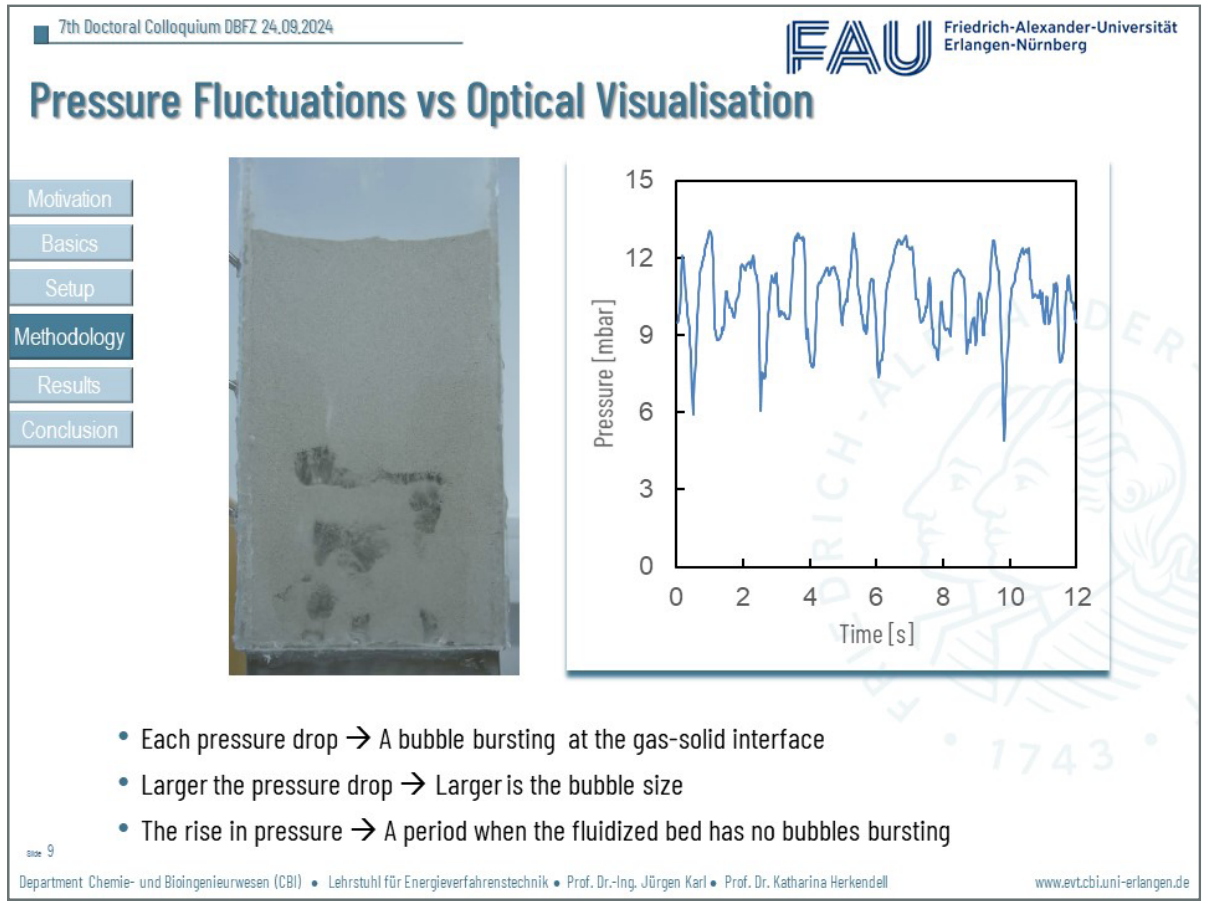
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Pressure Fluctuations vs Optical Visualisation
Motivation
Basics
Setup
Methodology
Results
Conclusion
Pressure [mbar]
15 12 9 6 3 0
0 2 4 6 8 10 12
Time [s]
Each pressure drop → A bubble bursting at the gas-solid interface
Larger the pressure drop → Larger is the bubble size
The rise in pressure → A period when the fluidized bed has no bubbles bursting
Slide 9
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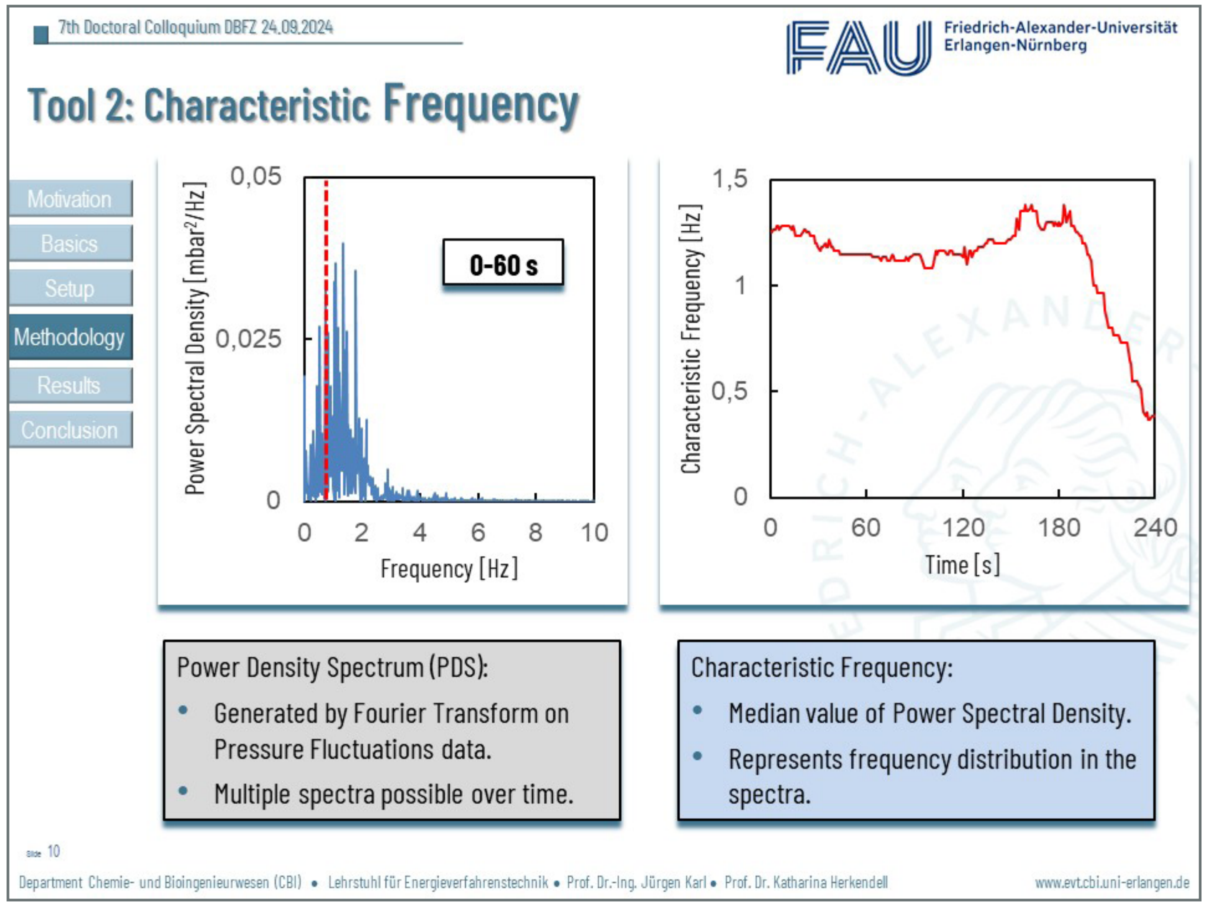
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Tool 2: Characteristic Frequency
Motivation
Basics
Setup
Methodology
Results
Conclusion
Power Spectral Density [mbar²/Hz]
0,05
0,025
0
0 2 4 6 8 10
Frequency [Hz]
0-60 s
Characteristic Frequency [Hz]
1,5
1
0,5
0
0 60 120 180 240
Time [s]
Power Density Spectrum (PDS):
Generated by Fourier Transform on Pressure Fluctuations data.
Multiple spectra possible over time.
Characteristic Frequency:
Median value of Power Spectral Density.
Represents frequency distribution in the spectra.
Slide 10
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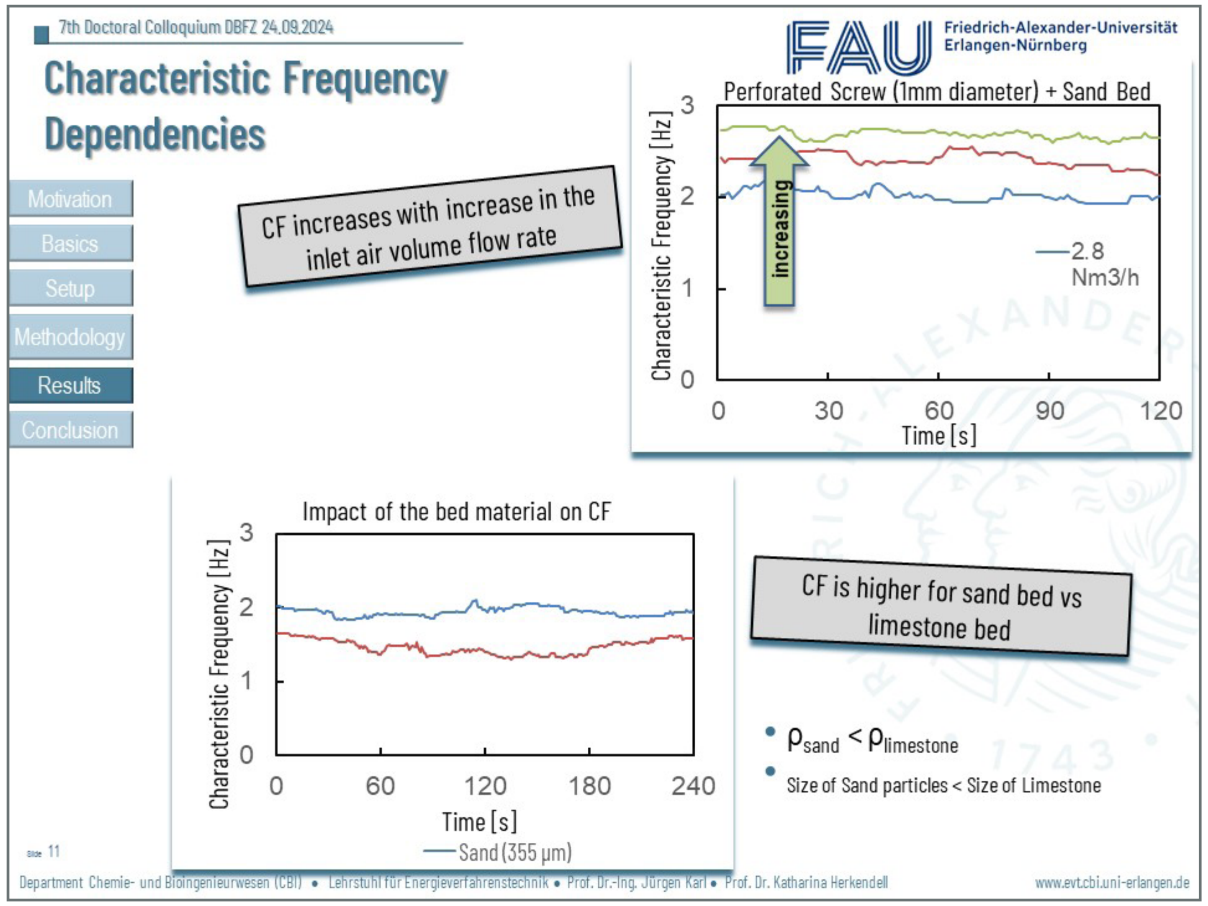
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Characteristic Frequency Dependencies
Motivation
Basics
Setup
Methodology
Results
Conclusion
CF increases with increase in the inlet air volume flow rate
Perforated Screw (1mm diameter) + Sand Bed
Characteristic Frequency [Hz]
increasing
2.8 Nm3/h
Time [s]
Impact of the bed material on CF
Characteristic Frequency [Hz]
Time [s]
Sand (355 µm)
CF is higher for sand bed vs limestone bed
ρsand < ρlimestone
Size of Sand particles < Size of Limestone
Slide 11
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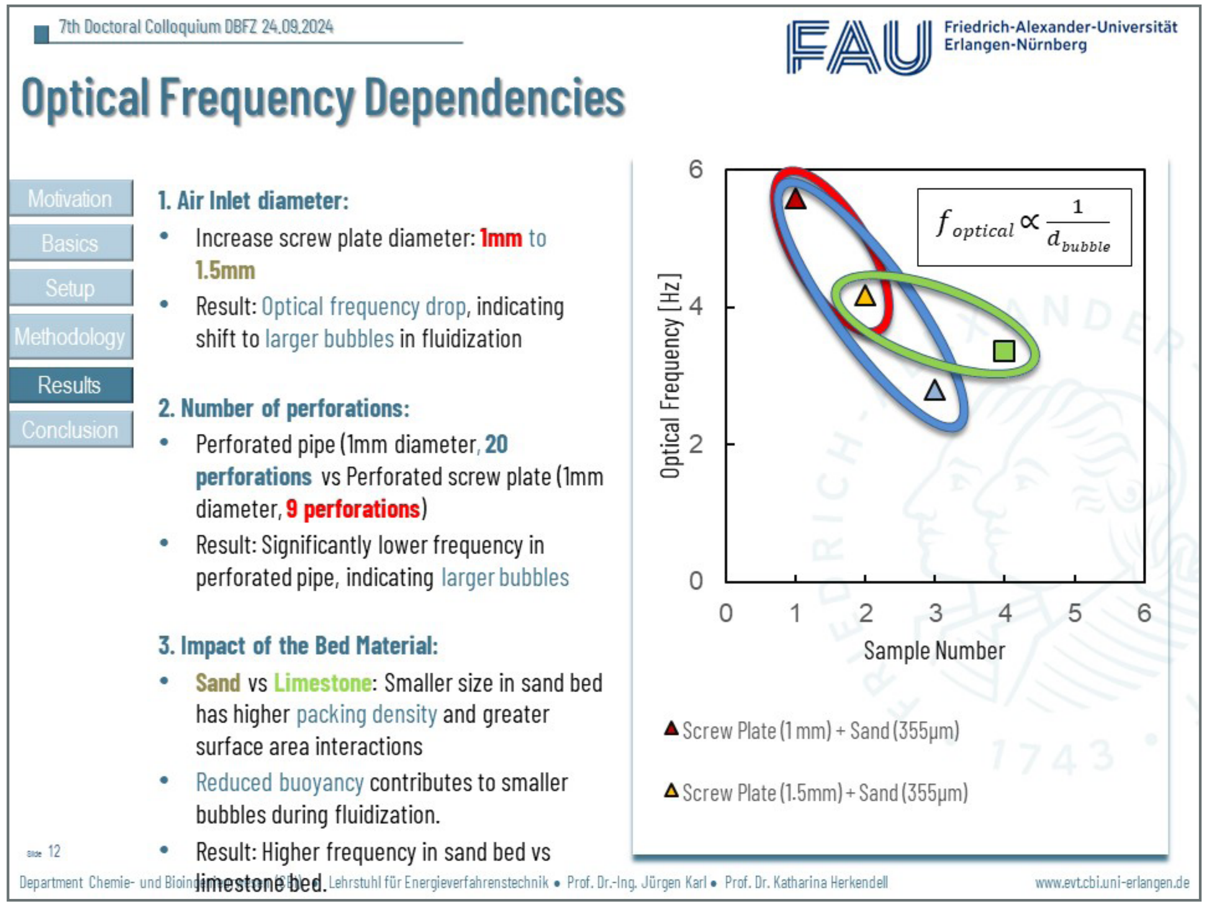
7th Doctoral Colloquium DBFZ 24.09.2024
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Optical Frequency Dependencies
Motivation
Basics
Setup
Methodology
Results
Conclusion
1. Air Inlet diameter:
Increase screw plate diameter: 1mm to 1.5mm
Result: Optical frequency drop, indicating shift to larger bubbles in fluidization
2. Number of perforations:
Perforated pipe (1mm diameter, 20 perforations vs Perforated screw plate (1mm diameter, 9 perforations)
Result: Significantly lower frequency in perforated pipe, indicating larger bubbles
3. Impact of the Bed Material:
Sand vs Limestone: Smaller size in sand bed has higher packing density and greater surface area interactions
Reduced buoyancy contributes to smaller bubbles during fluidization.
Result: Higher frequency in sand bed vs limestone bed.
f optical ∝ 1 / d bubble
Optical Frequency [Hz]
Sample Number
Screw Plate (1 mm) + Sand (355µm)
Screw Plate (1.5mm) + Sand (355µm)
Slide 12
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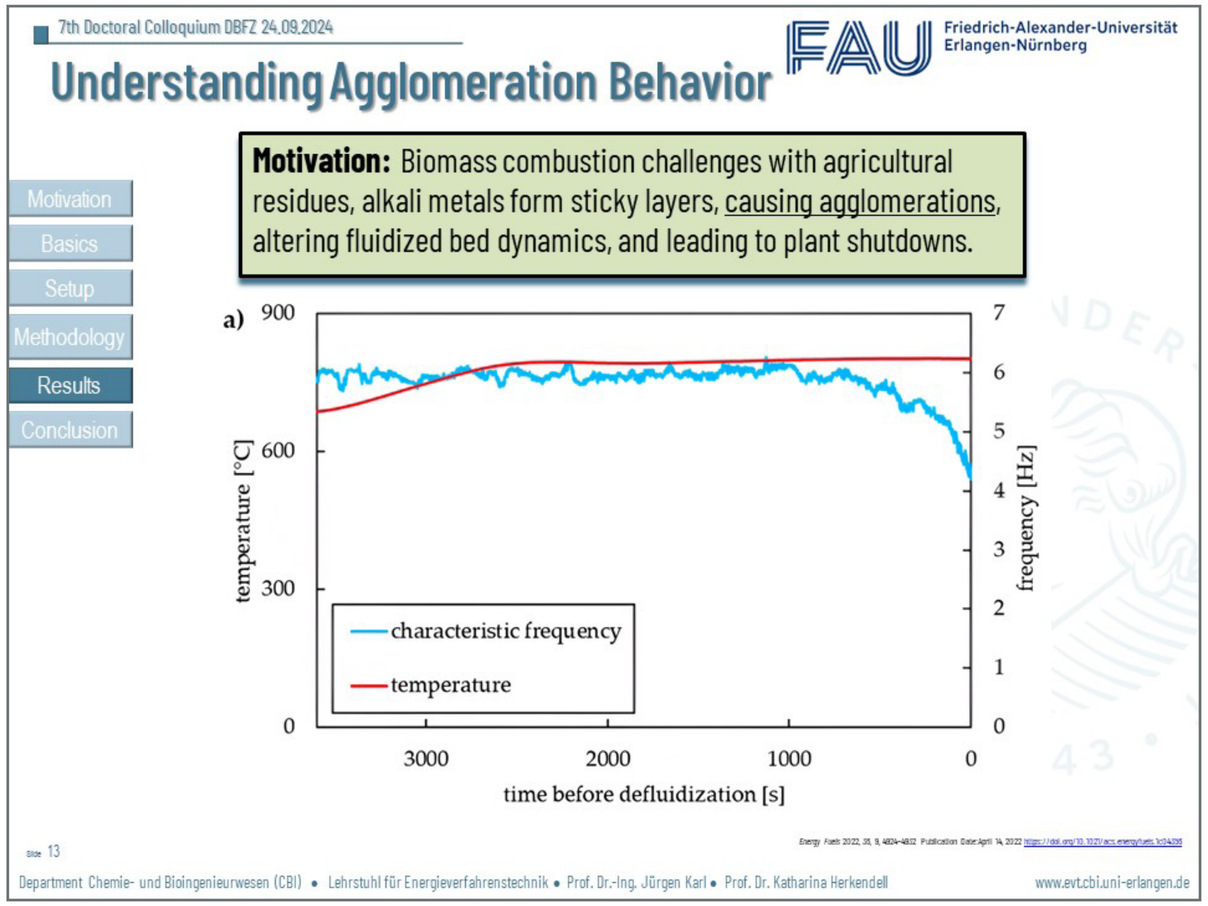
7th Doctoral Colloquium DBFZ 24.09.2024
FAU Friedrich-Alexander-Universität Erlangen-Nürnberg
Understanding Agglomeration Behavior
Motivation
Basics
Setup
Methodology
Results
Conclusion
Motivation: Biomass combustion challenges with agricultural residues, alkali metals form sticky layers, causing agglomerations, altering fluidized bed dynamics, and leading to plant shutdowns.
a)
temperature [°C]
frequency [Hz]
characteristic frequency
temperature
time before defluidization [s]
Slide 13
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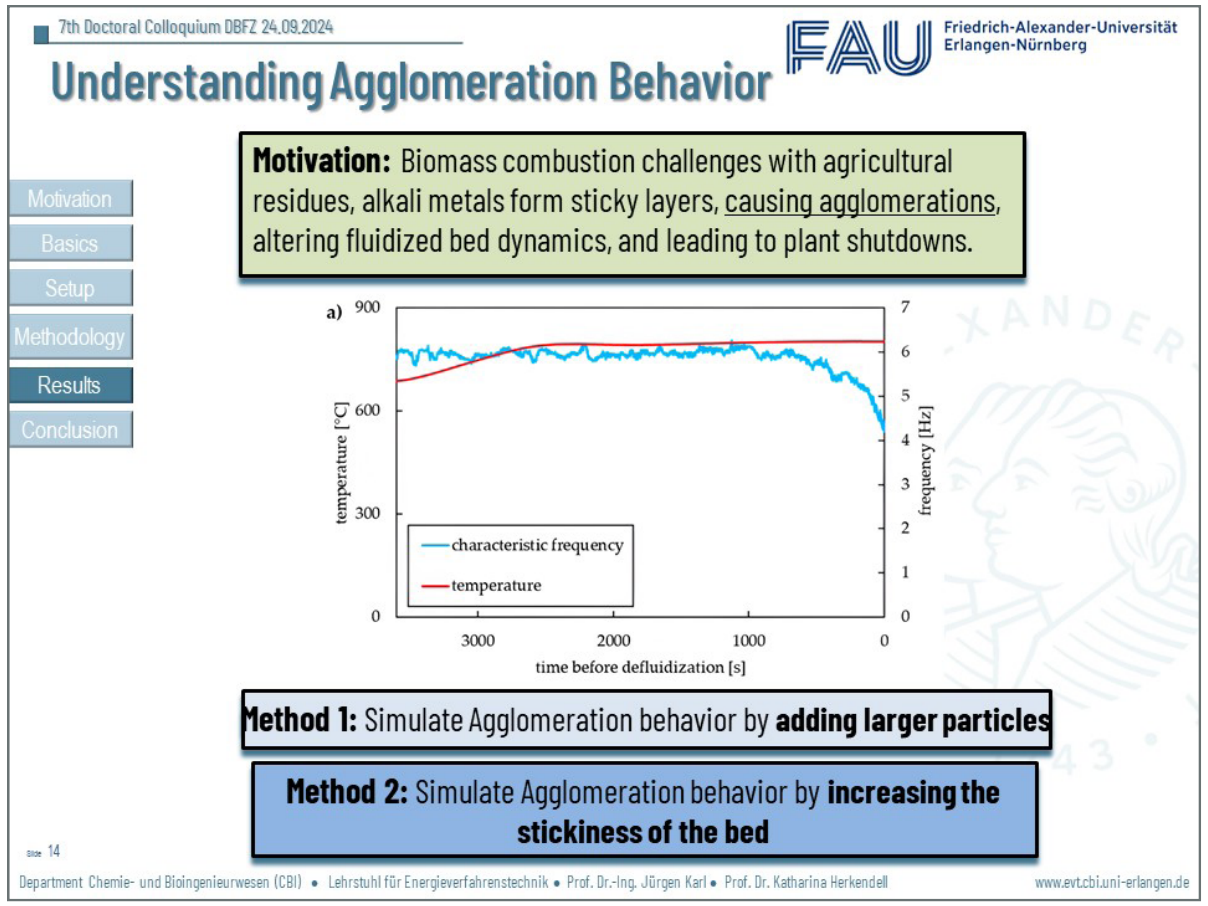
7th Doctoral Colloquium DBFZ 24.09.2024
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a)
temperature [°C]
frequency [Hz]
characteristic frequency
temperature
time before defluidization [s]
Method 1: Simulate Agglomeration behavior by adding larger particles
Method 2: Simulate Agglomeration behavior by increasing the stickiness of the bed
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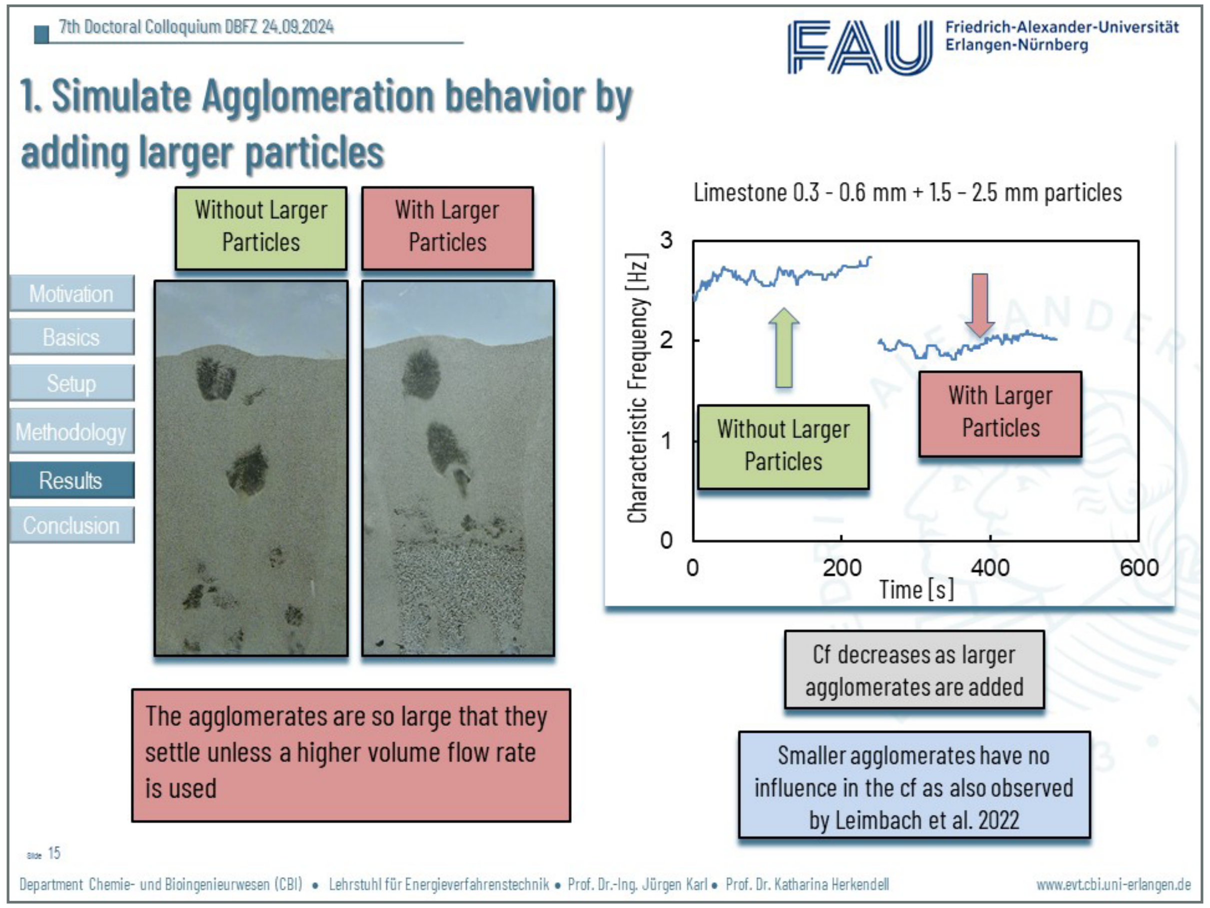
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1. Simulate Agglomeration behavior by adding larger particles
Without Larger Particles
With Larger Particles
Motivation
Basics
Setup
Methodology
Results
Conclusion
Limestone 0.3 - 0.6 mm + 1.5 - 2.5 mm particles
Characteristic Frequency [Hz]
Time [s]
Without Larger Particles
With Larger Particles
The agglomerates are so large that they settle unless a higher volume flow rate is used
Cf decreases as larger agglomerates are added
Smaller agglomerates have no influence in the cf as also observed by Leimbach et al. 2022
Slide 15
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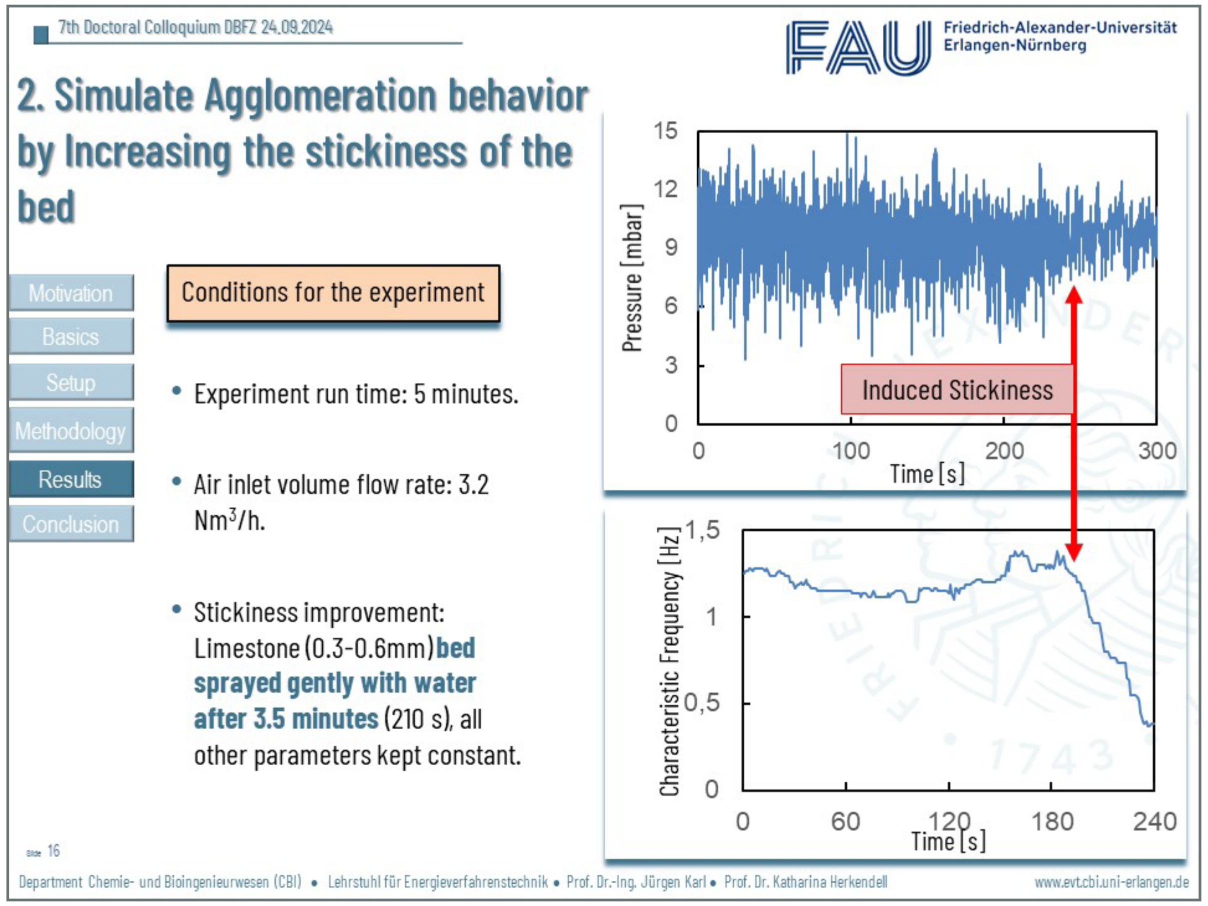
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2. Simulate Agglomeration behavior by Increasing the stickiness of the bed
Motivation
Basics
Setup
Methodology
Results
Conclusion
Conditions for the experiment
• Experiment run time: 5 minutes.
• Air inlet volume flow rate: 3.2 Nm³/h.
• Stickiness improvement: Limestone (0.3-0.6mm) bed sprayed gently with water after 3.5 minutes (210 s), all other parameters kept constant.
Pressure [mbar]
Time [s]
Induced Stickiness
Characteristic Frequency [Hz]
Time [s]
Slide 16
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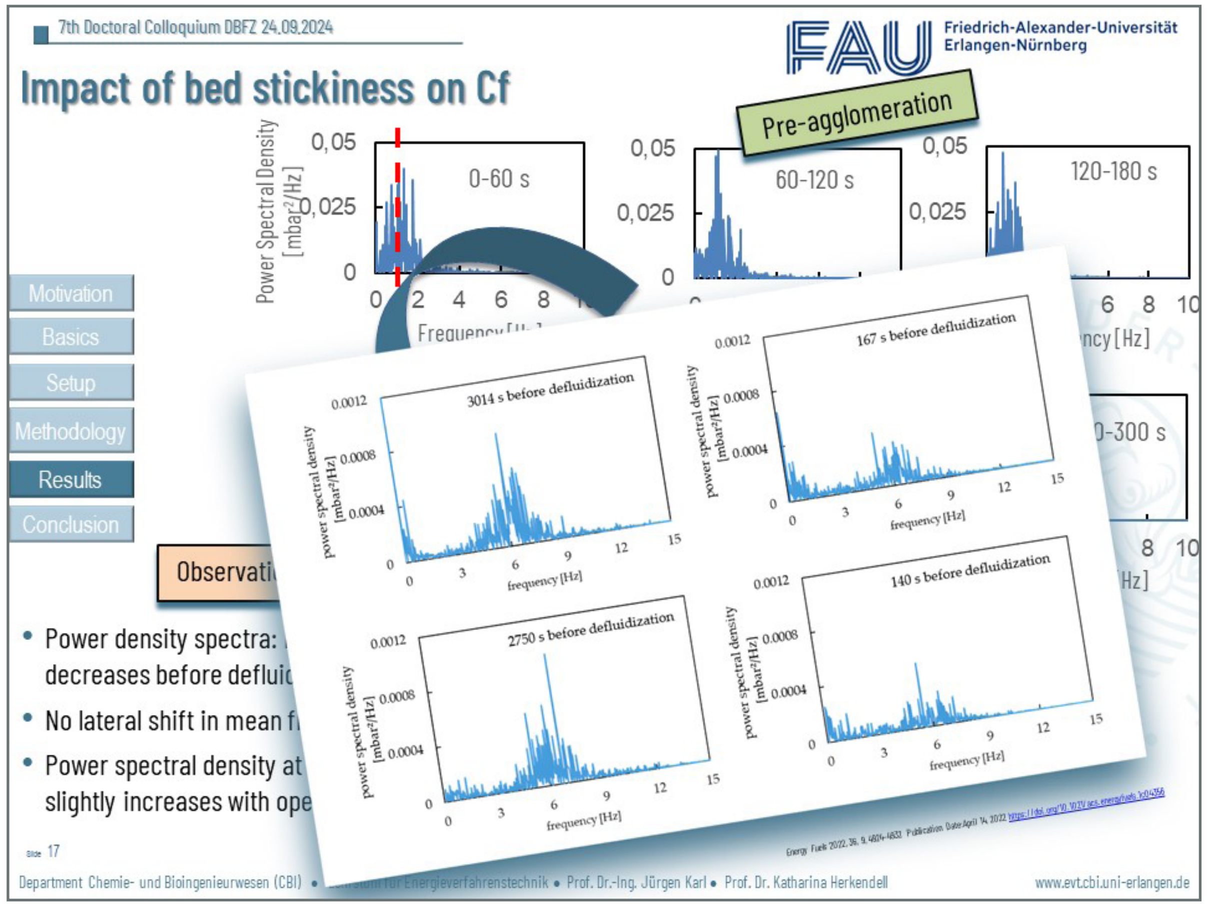
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Impact of bed stickiness on Cf
Pre-agglomeration
Power Spectral Density [mbar²/Hz]
0-60 s
60-120 s
120-180 s
Motivation
Basics
Setup
Methodology
Results
Conclusion
3014 s before defluidization
167 s before defluidization
2750 s before defluidization
140 s before defluidization
frequency [Hz]
power spectral density [mbar²/Hz]
• Power density spectra:
decreases before defluid
• No lateral shift in mean f
• Power spectral density at
slightly increases with ope
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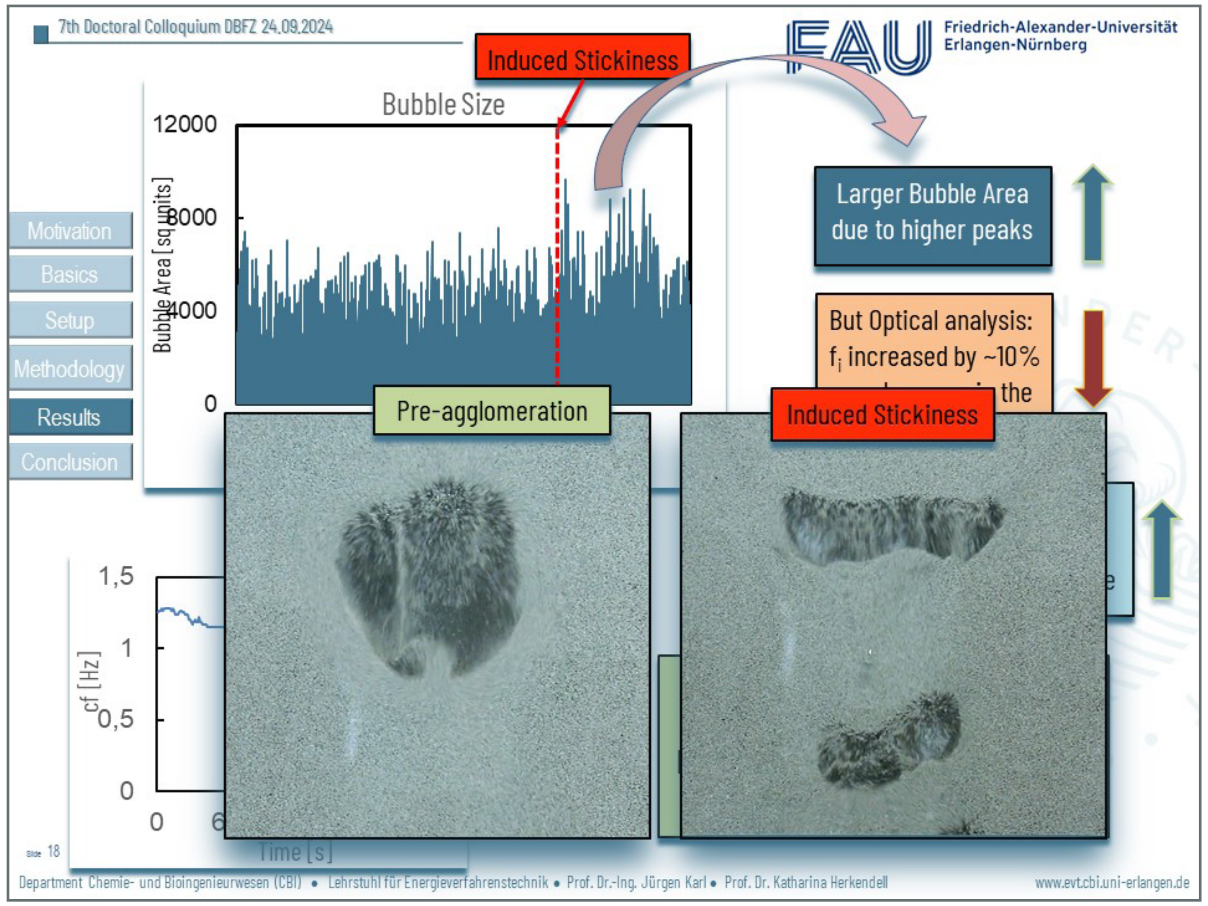
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Induced Stickiness
Bubble Size
Bubble Area [sq units]
Motivation
Basics
Setup
Methodology
Results
Conclusion
Larger Bubble Area due to higher peaks
But Optical analysis: fᵢ increased by ~10%
Pre-agglomeration
Induced Stickiness
cf [Hz]
Time [s]
Slide 18
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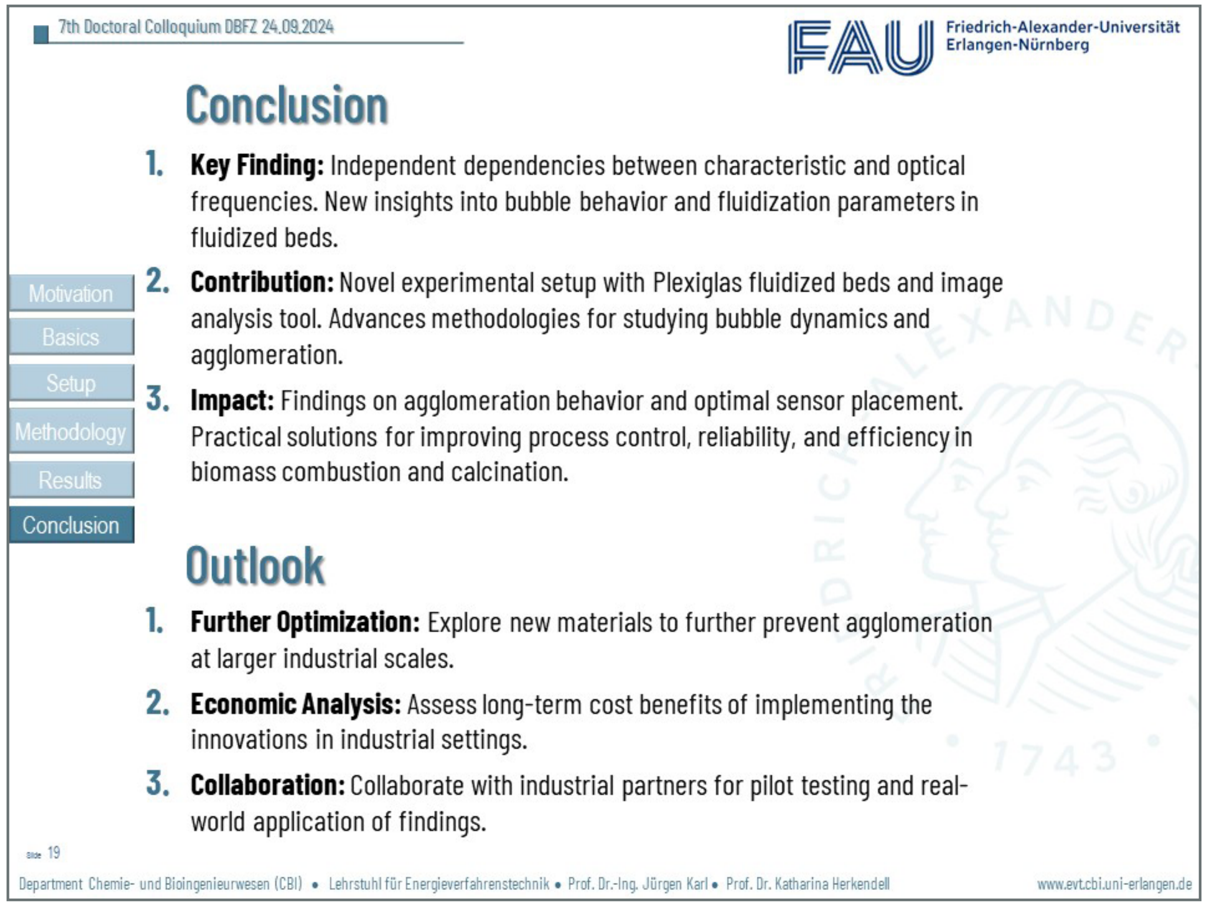
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Conclusion
1. Key Finding: Independent dependencies between characteristic and optical frequencies. New insights into bubble behavior and fluidization parameters in fluidized beds.
2. Contribution: Novel experimental setup with Plexiglas fluidized beds and image analysis tool. Advances methodologies for studying bubble dynamics and agglomeration.
3. Impact: Findings on agglomeration behavior and optimal sensor placement. Practical solutions for improving process control, reliability, and efficiency in biomass combustion and calcination.
Motivation
Basics
Setup
Methodology
Results
Conclusion
Outlook
1. Further Optimization: Explore new materials to further prevent agglomeration at larger industrial scales.
2. Economic Analysis: Assess long-term cost benefits of implementing the innovations in industrial settings.
3. Collaboration: Collaborate with industrial partners for pilot testing and real-world application of findings.
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SESSION

BIOENERGY SYSTEMS ANALYSIS

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

7TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Alfred Amin, University of Rostock

The influence of material flows on the resilience of bioenergy plants

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Keywords: resilience, energy supply, material flow

The topic of „resilience“ is becoming increasingly important in the fields of science, technology and society. The following definition is used: „Resilience describes the ability of a system to maintain its performance even under stress and under turbulent conditions“ [1]

In the scientific literature evaluated to date, resilience studies have been carried out on specific system constellations that only allow the system boundaries to be extended to a very limited extent. The aim is to develop a generally applicable method that will demonstrate the importance of material flows in particular for the resilience of energy supply systems.

The research questions are:

- Which properties that are important for resilience can be assigned to material flows?
- Which numerical methods should be used to enable comparability of the resilience values?
- How can the values obtained be interpreted with regard to the resilience of the overall system?

The relevant properties of the primary energy sources and conversion technologies that are important for the resilience of the energy supply systems under consideration are determined. In the evaluated literature, the components of resilience such as redundancy, diversity, loose couplings and subsidiarity were examined, but not the time behavior of the system components. The present work aims to combine the time behavior with the four components mentioned in order to determine a more precise resilience index.

By applying numerical methods, a resilience index can be determined for each combination of energy source and technology. The result of this work should be a methodology that makes it possible to determine a resilience index for energy generation plants and the associated material flows that is as accurate as possible. This allows comparisons to be made between existing energy supply systems and measures to increase resilience to be defined.

References:
[1] Gleich, Arnim von; Gößling-Reisemann, Stefan; Lutz-Kunisch, Birgitt; Stührmann, Sönke; Woizeschke, Peer (2010): Resilienz als Leitkonzept – Vulnerabilität als analytische Kategorie. In: Klaus Fichter, Arnim von Gleich, Reinhard Pfriem und Bernd Sieb

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7TH DOCTORAL COLLOQUIUM BIOENERGY

Name Alfred Amin

Title **"The influence of material flows on the resilience of bioenergy plants"**

24TH SEPTEMBER 2024, LEIPZIG

Short introduction

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Title of the Doctoral Project:	"The influence of material flows on the resilience of bioenergy plants"
Doctoral Student:	Alfred Amin M.Sc.
DBFZ Supervisor:	Prof. Dr. Michael Nelles
Cooperating University:	Universität Rostock/ Hochschule Merseburg
University Supervisor:	Prof. Dr. Michael Nelles/ Prof. Dr. Andreas Ortwein
Funding / Scholarship provider:	
Logo:	
Duration:	

1. Basics
1.1 Definition of resilience

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Various definitions, depending on the field of science, here in a ecological/engineering context

Resilience is the ability to

- *prepare and plan for actual or potential negative events*
- *to absorb them*
- *recover from them*
- *adapt to them more successfully.*

(Wink 2016)

3

1. Basics
1.2 Examples of resilience

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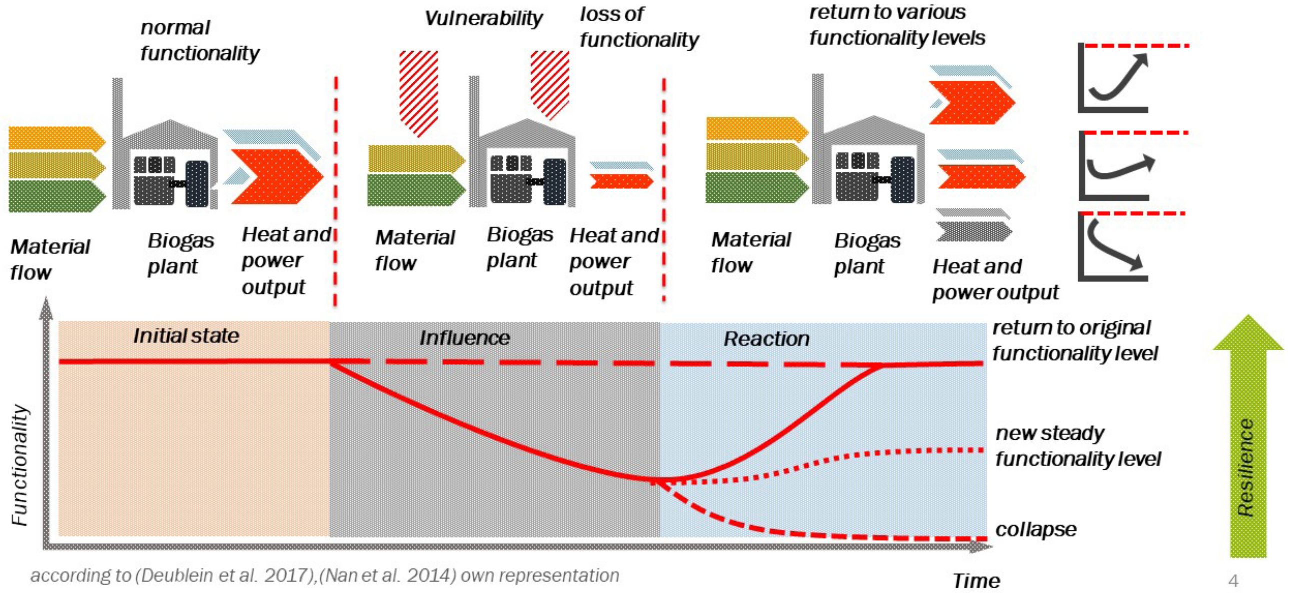

according to (Deublein et al. 2017),(Nan et al. 2014) own representation

4

2. Research objects
2.1 Research questions

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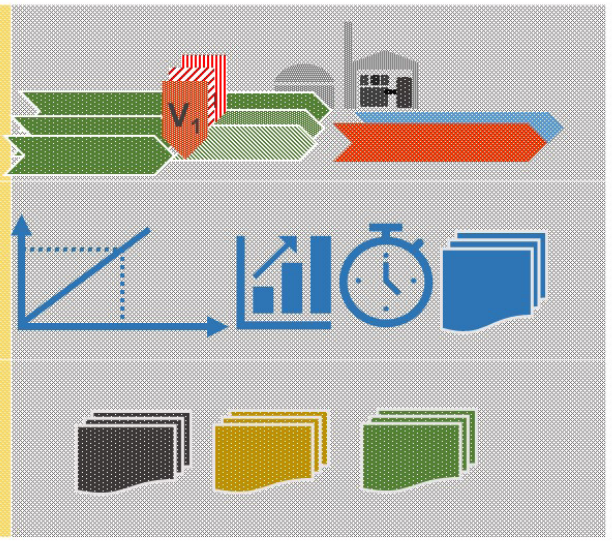
- *How do changes in the material flow properties affect the load capacity of the system?*
- *Which methods are best suited to determine the resilience of bioenergy plants?*
- *What data must be collected and what quality of data is required?*



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2. Research objects
2.2 System boundaries

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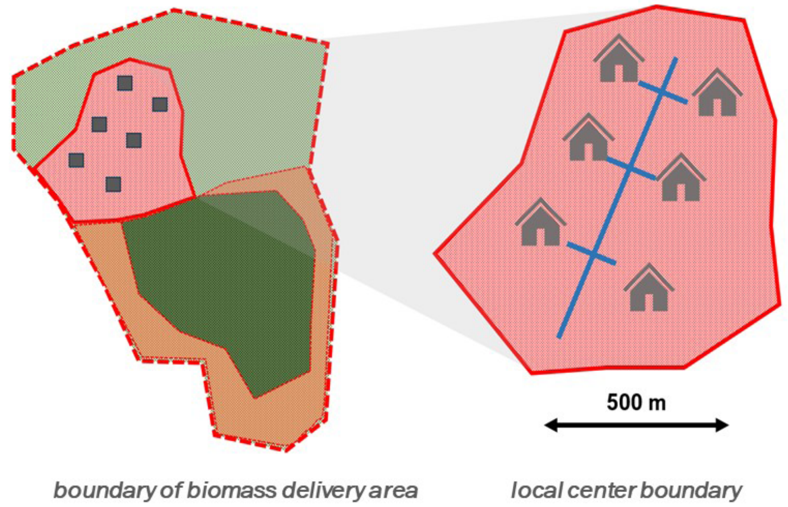

- *Real existing locality as an reference object*
- *Has the possibility of energy self-sufficiency*
- *All relevant data has been determined.*
- *Not yet realized*

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2. Research objects

2.3 Material flow and Technology

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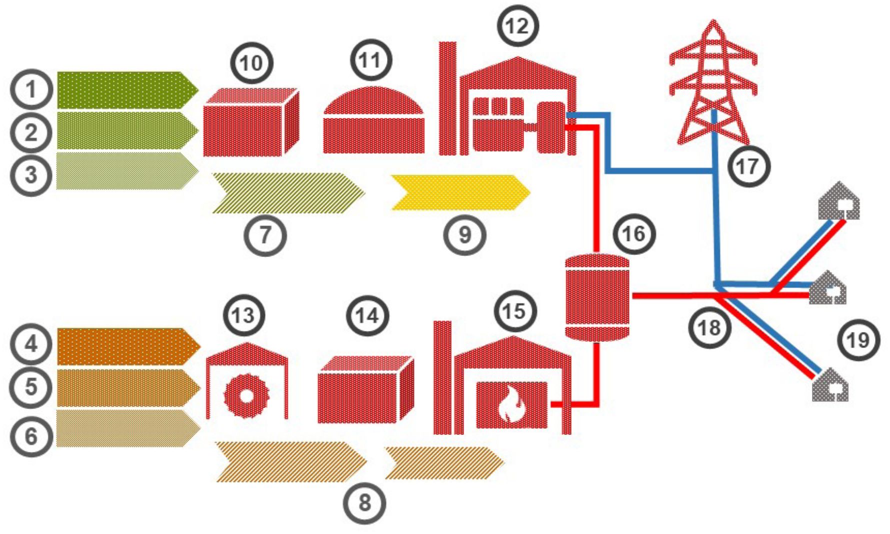

1	Green rye
2	Silage maize
3	Cattle manure
4	Poplar
5	Ash
6	Birch
7	Fermentation substrate
8	Wood chips
9	Biomethane
10	Storage of silage
11	Fermenter/gas storage
12	Combined heat and power plant
13	Wood shredder
14	Wood storage
15	Wood boiler
16	Heat storage
17	External power supply
18	Local heating and power grid
19	End consumer

3. Indicators

3.1 Resilience _ System performance

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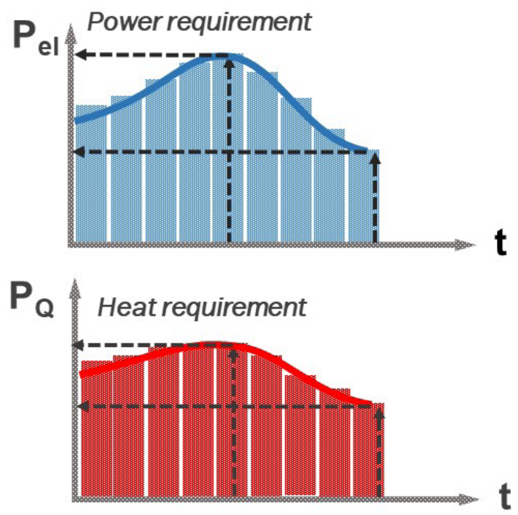

Electricity	Heat
Delivery of the desired service at any time and any place at the agreed price	
Compliance with legal regulations	
Compliance with the required voltage and frequency	Compliance with the parameters for pressure and temperature

according to (Brand et al. 2017), own representation

8

3. Indicators

3.2 Resilience _ Examples

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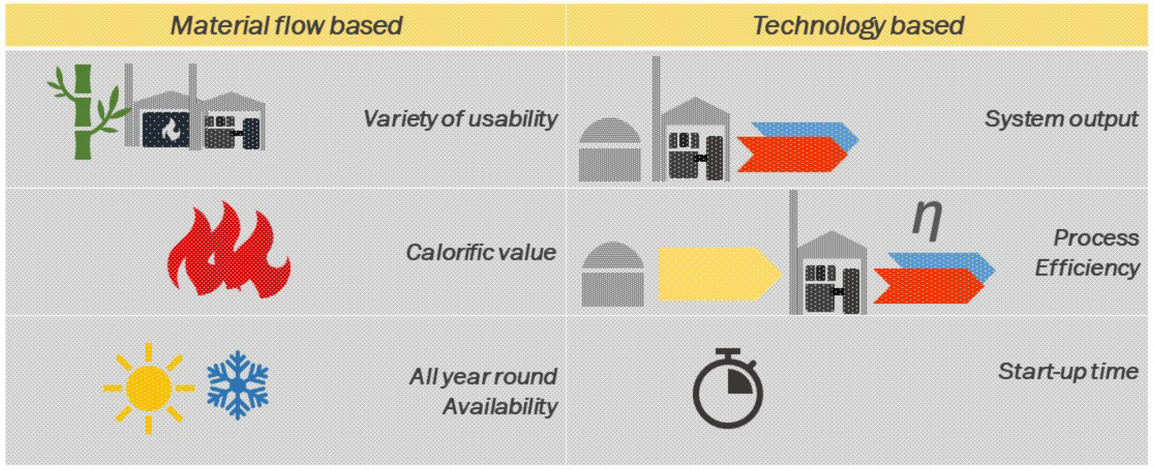

according to (Szarka 2021), own representation

9

3. Indicators

3.3 Resilience _ Diversity

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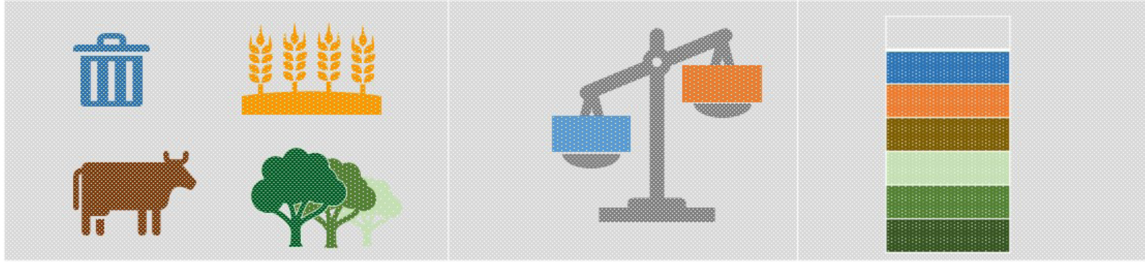
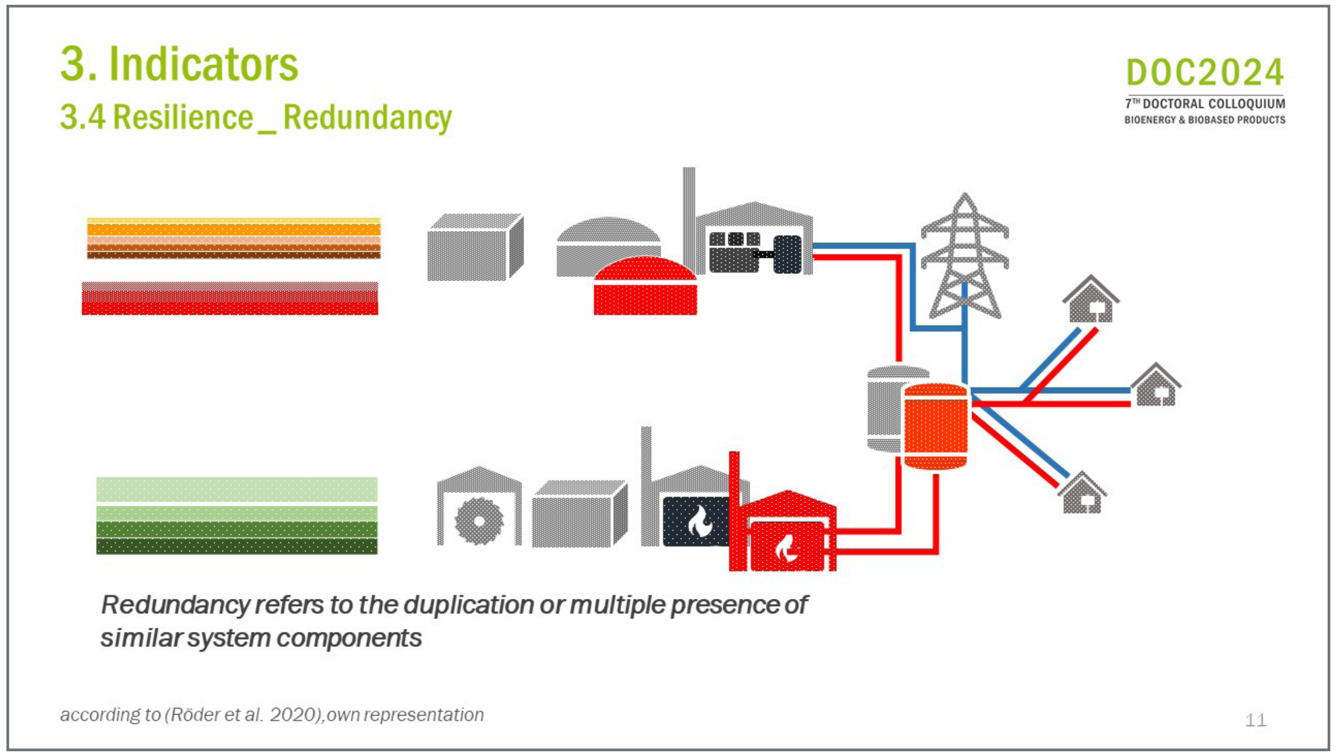
Variety	Balance	Disparity
Variety refers to the number of categories into which the system elements can be divided up.	Balance refers to the distribution patterns of elements across the different categories.	Disparity refers to the way in which and the degree to which elements can be qualitatively differentiated.



according to (Röder et al. 2020),own representation

10


3. Indicators
3.4 Resilience _ Redundancy
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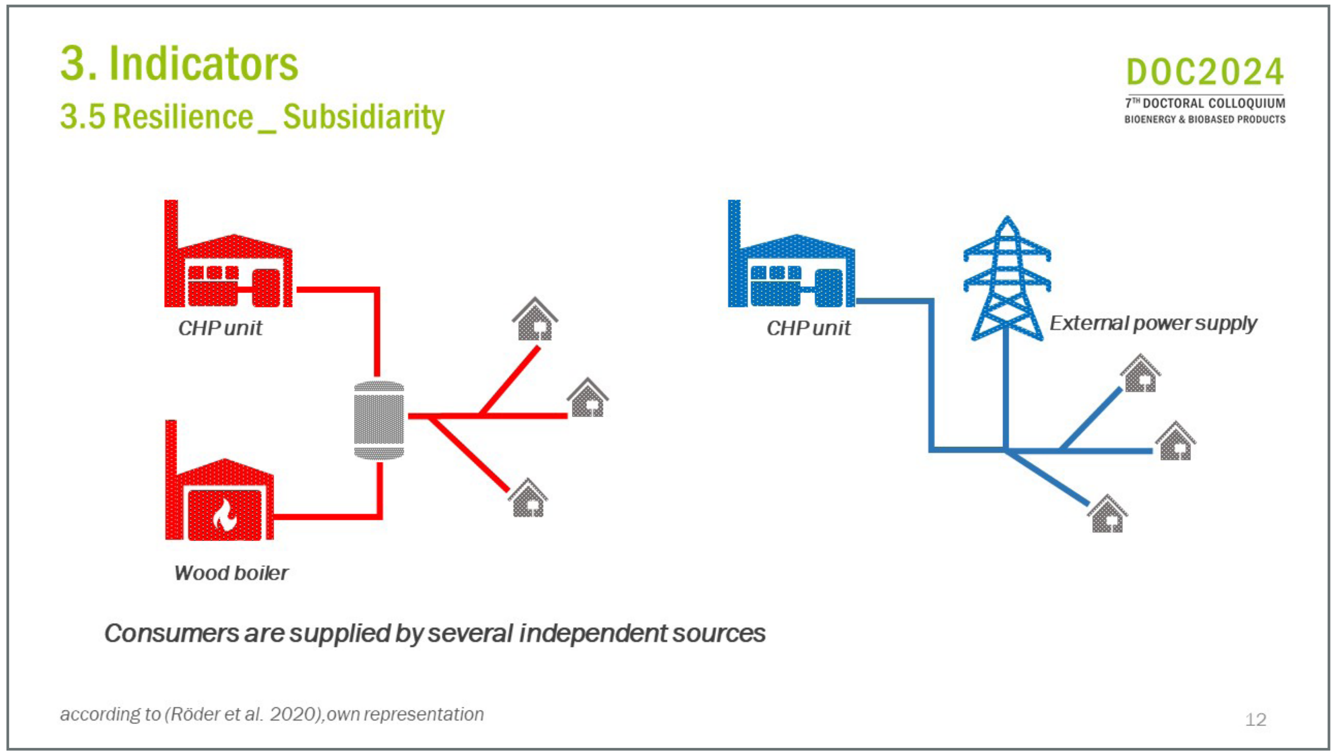
Redundancy refers to the duplication or multiple presence of similar system components
according to (Röder et al. 2020),own representation
11


3. Indicators
3.5 Resilience _ Subsidiarity
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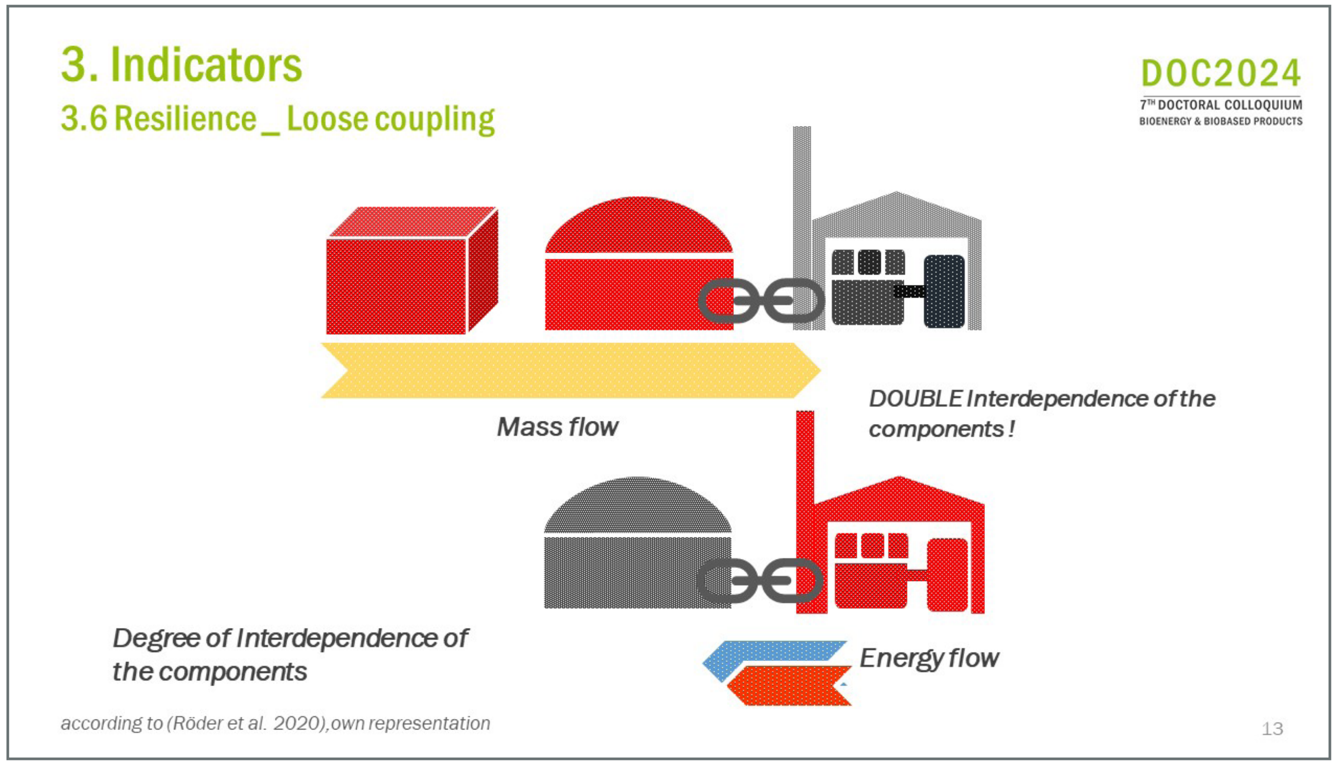
CHP unit
Wood boiler
CHP unit
External power supply
Consumers are supplied by several independent sources
according to (Röder et al. 2020),own representation
12


3. Indicators
3.6 Resilience _ Loose coupling
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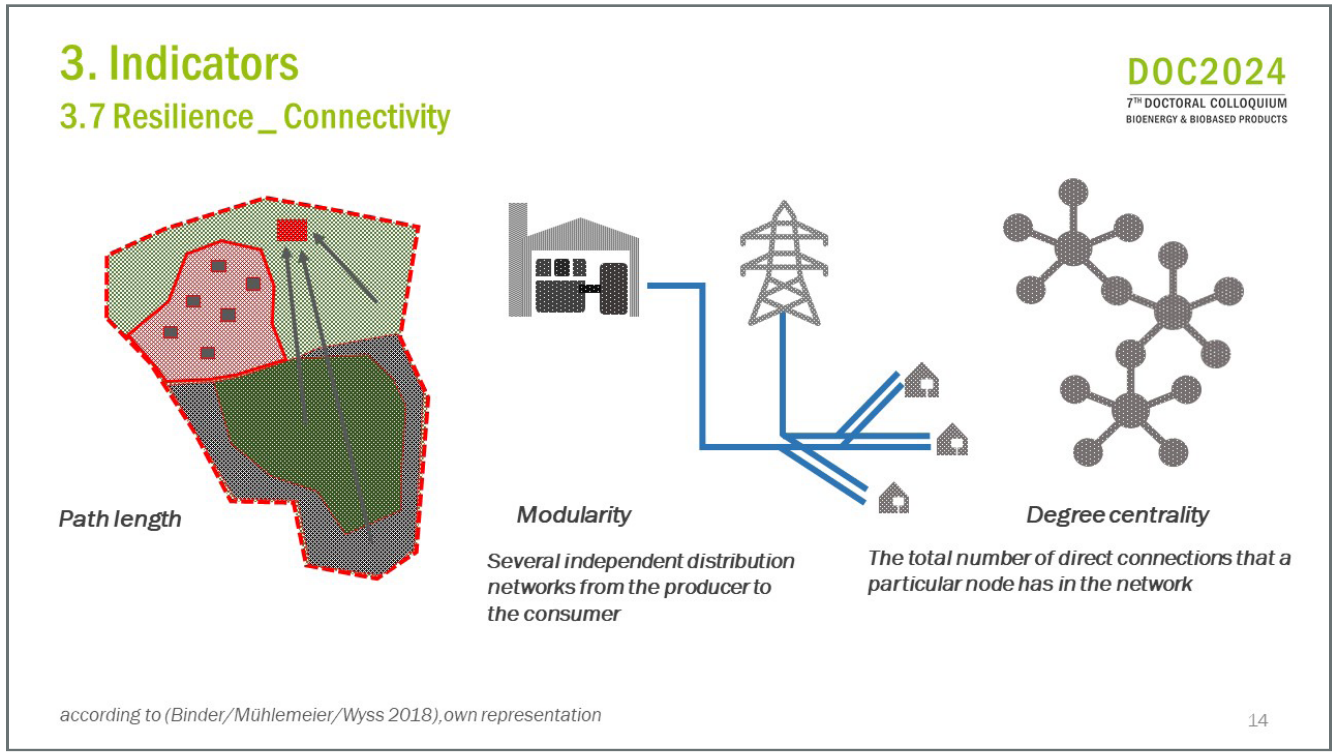
BIOENERGY & BIOBASED PRODUCTS
Mass flow
DOUBLE Interdependence of the components !
Degree of Interdependence of the components
Energy flow
according to (Röder et al. 2020),own representation
13


3. Indicators
3.7 Resilience _ Connectivity
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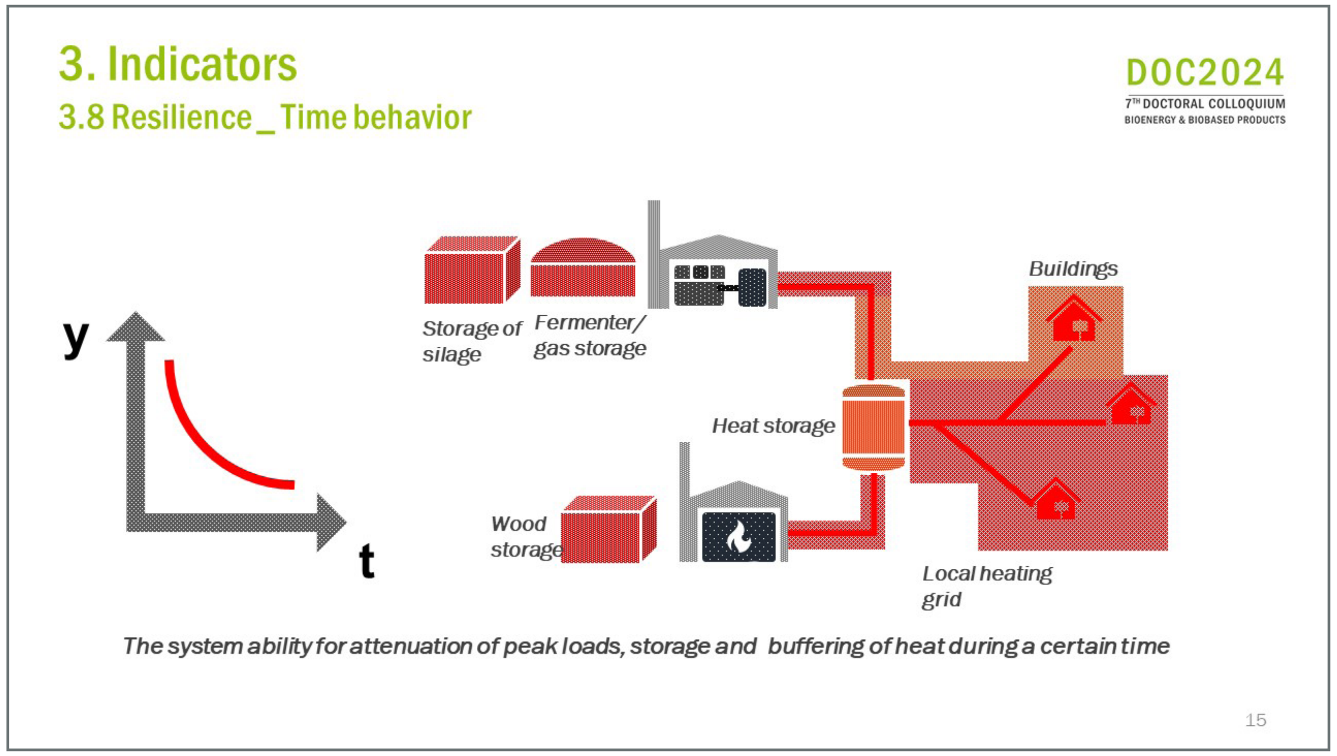
Path length
Modularity
Several independent distribution networks from the producer to the consumer
Degree centrality
The total number of direct connections that a particular node has in the network
according to (Binder/Mühlemeier/Wyss 2018),own representation
14


3. Indicators
3.8 Resilience _ Time behavior
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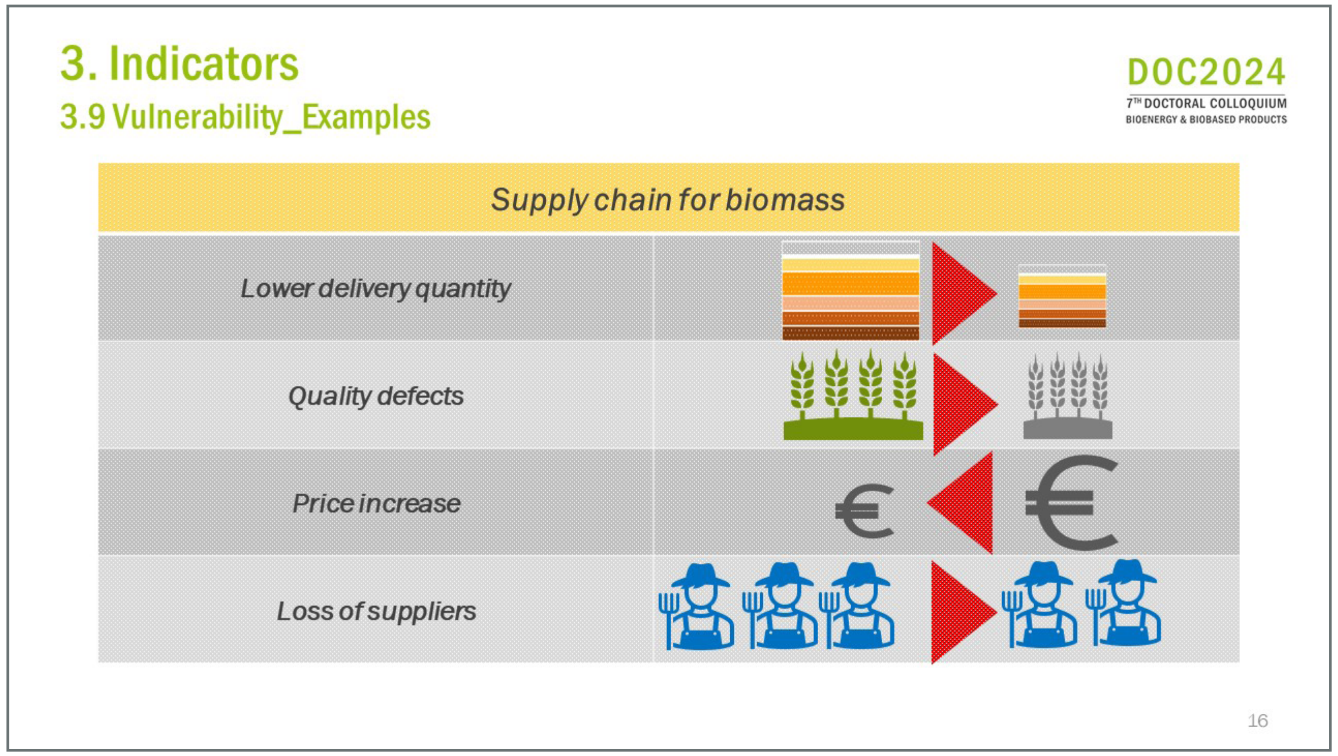
y
t
Storage of silage
Fermenter/ gas storage
Buildings
Heat storage
Wood storage
Local heating grid
The system ability for attenuation of peak loads, storage and buffering of heat during a certain time
15


3. Indicators
3.9 Vulnerability_Examples
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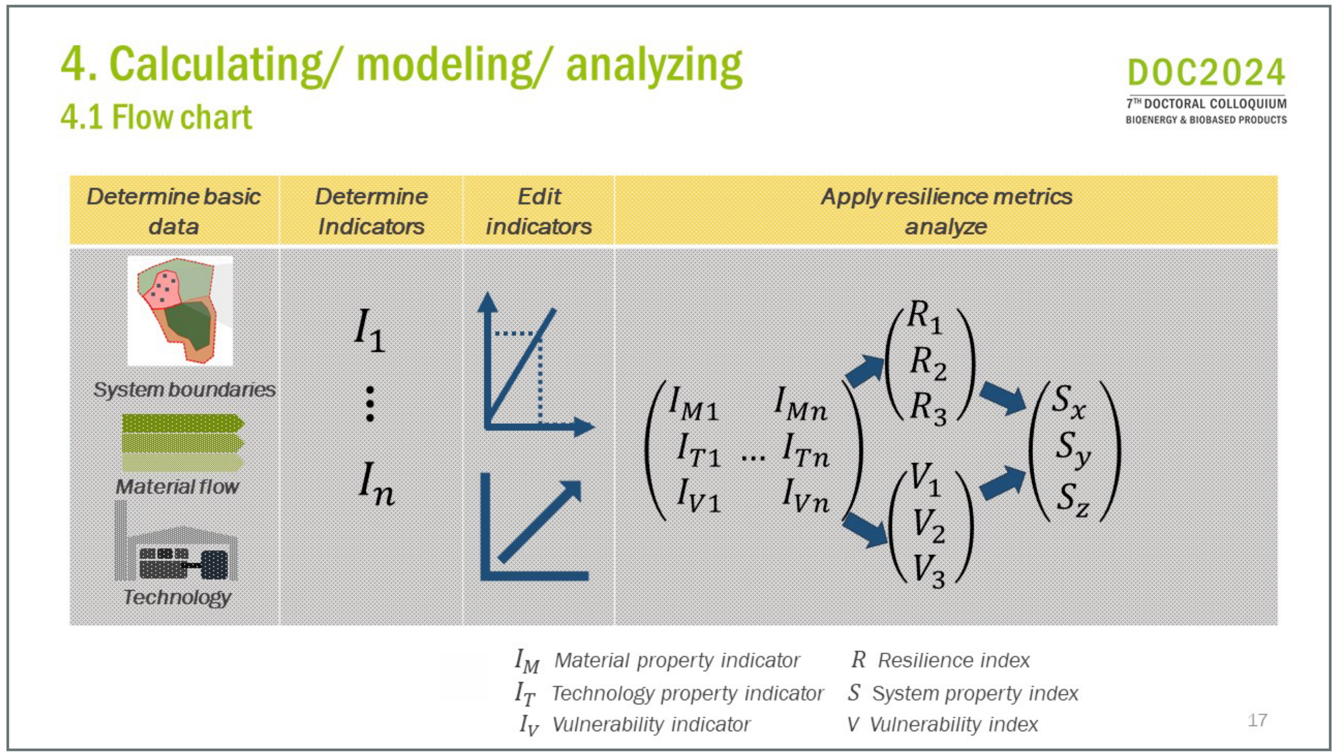
Supply chain for biomass
Lower delivery quantity
Quality defects
Price increase
Loss of suppliers
€
€
16


4. Calculating/ modeling/ analyzing
4.1 Flow chart
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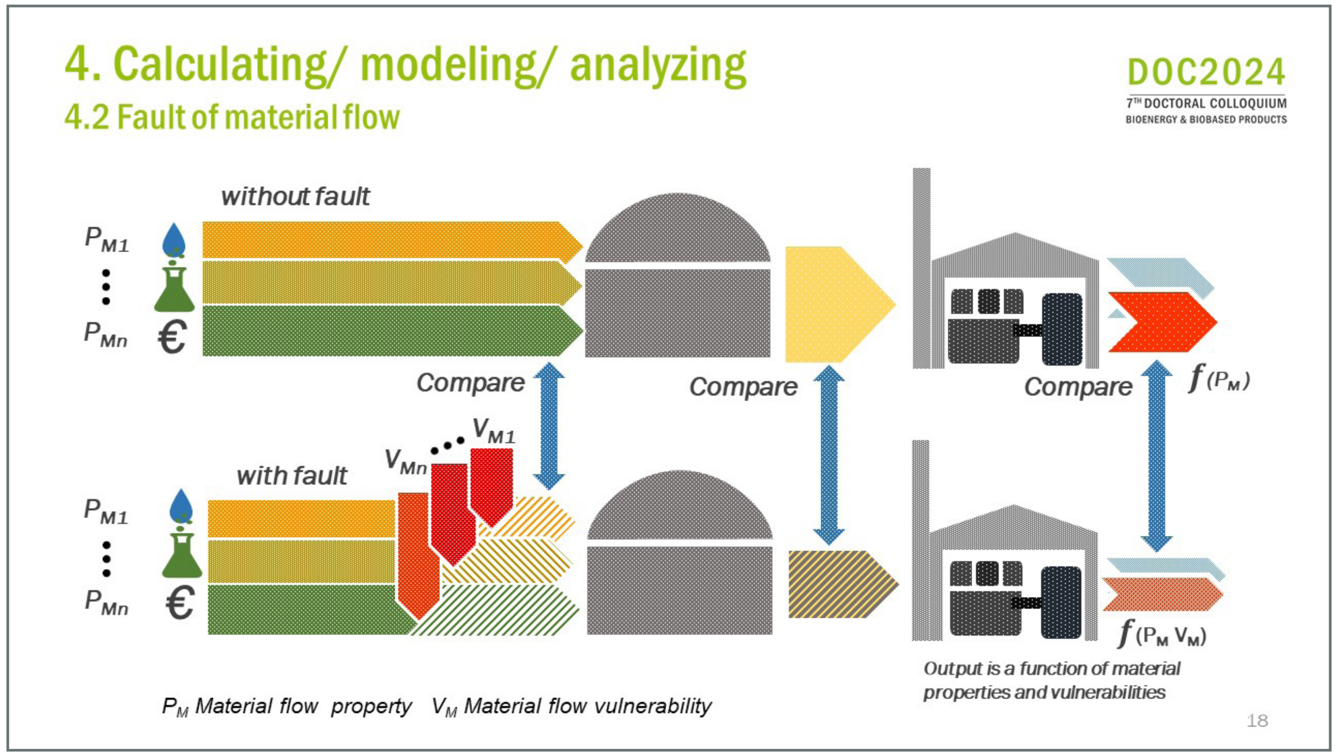
Determine basic data
Determine Indicators
Edit indicators
Apply resilience metrics analyze
System boundaries
Material flow
Technology
I_1 ⋮ I_n
$\begin{pmatrix} I_{M1} & \dots & I_{Mn} \\ I_{T1} & \dots & I_{Tn} \\ I_{V1} & & I_{Vn} \end{pmatrix}$
$\begin{pmatrix} R_1 \\ R_2 \\ R_3 \end{pmatrix}$
$\begin{pmatrix} V_1 \\ V_2 \\ V_3 \end{pmatrix}$
$\begin{pmatrix} S_x \\ S_y \\ S_z \end{pmatrix}$
I_M Material property indicator
I_T Technology property indicator
I_V Vulnerability indicator
R Resilience index
S System property index
V Vulnerability index
17


4. Calculating/ modeling/ analyzing
4.2 Fault of material flow
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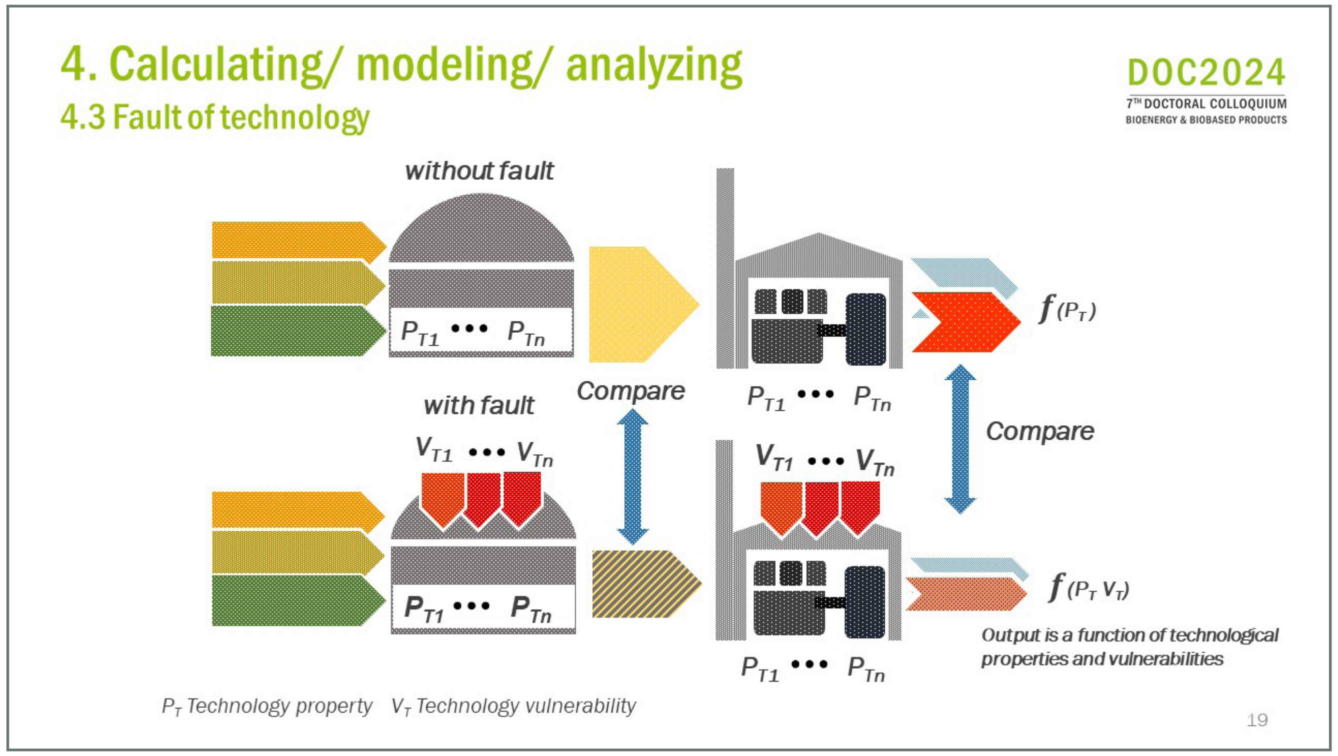
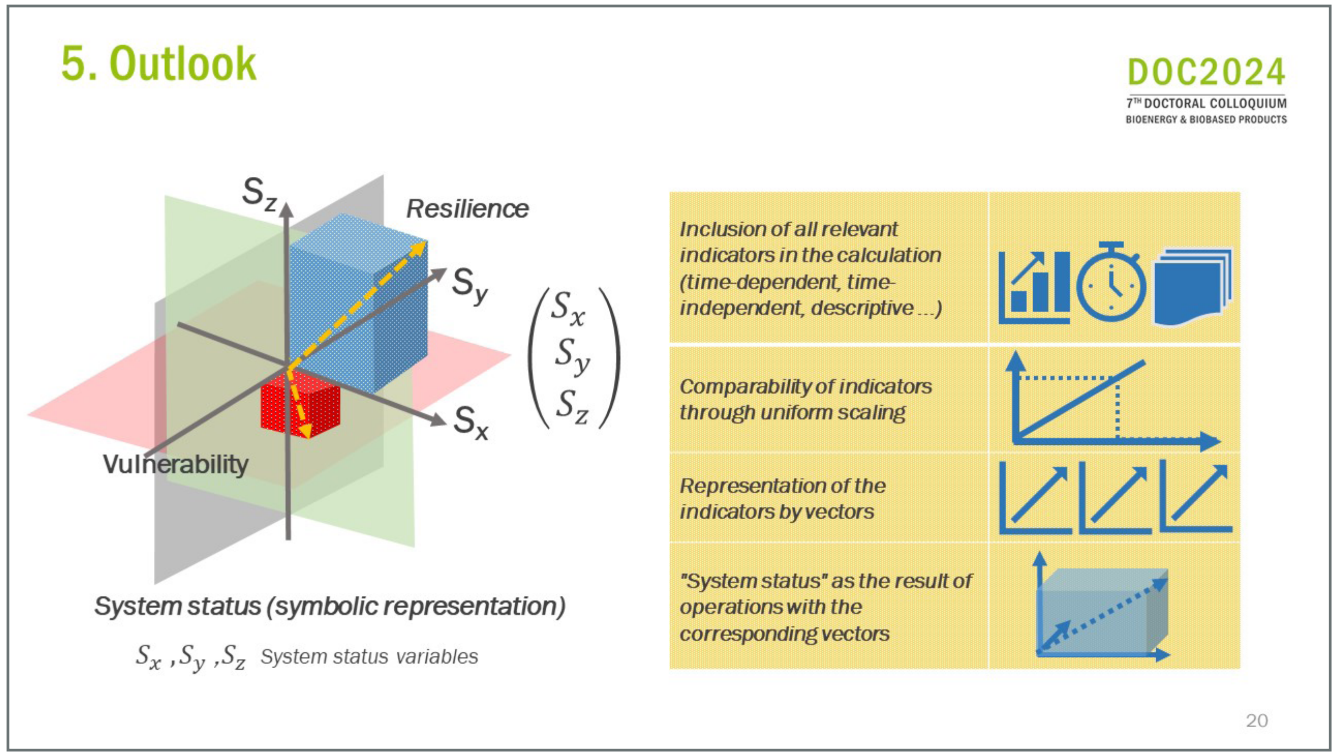
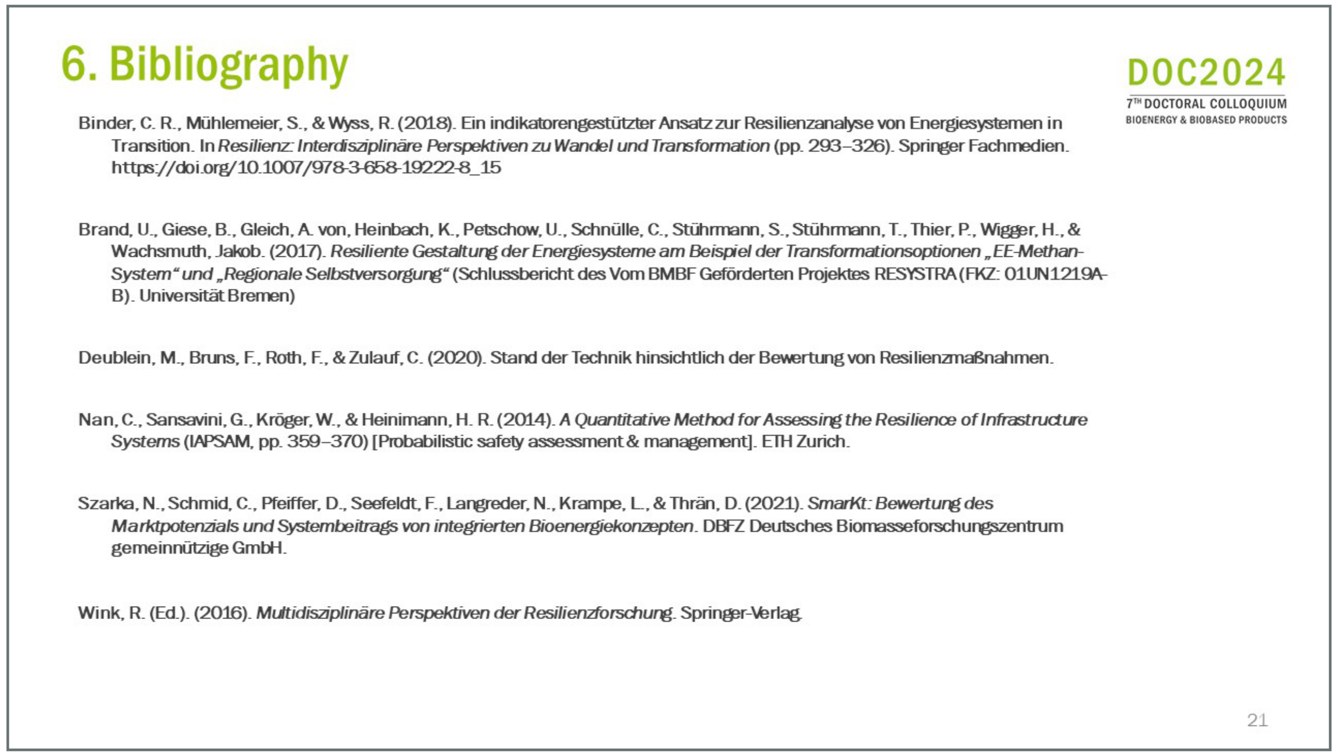
BIOENERGY & BIOBASED PRODUCTS
without fault
P_{M1} ⋮ P_{Mn} €
Compare
Compare
Compare
$f(P_M)$
with fault
V_{Mn} … V_{M1}
P_{M1} ⋮ P_{Mn} €
$f(P_M V_M)$
Output is a function of material properties and vulnerabilities
P_M Material flow property V_M Material flow vulnerability
18







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Martin Dotzauer, Deutsches Biomasseforschungszentrum

Scenarios for the future development of bioenergy plants in the German power sector to cover uncertainties and to evaluate different energy policy measures

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Keywords: Agent based modelling, bioenergy, power sector, EEG

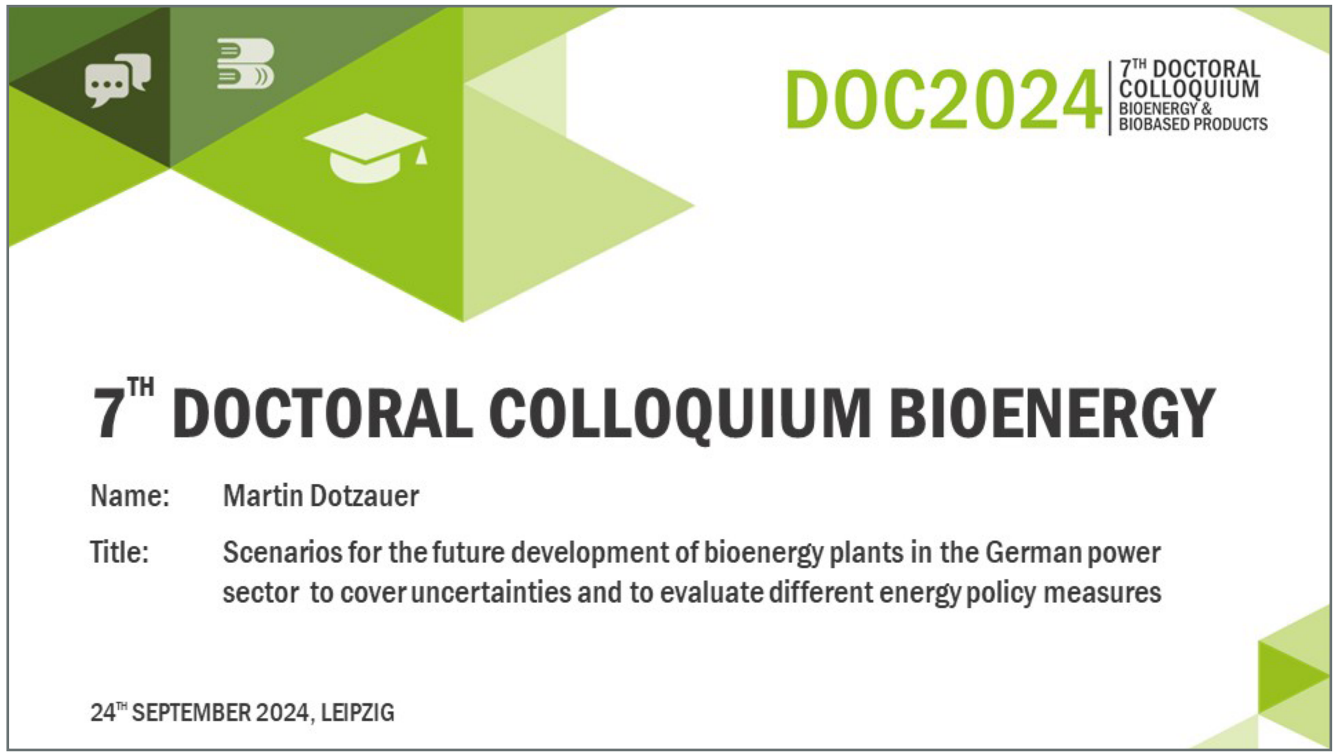
The German energy transition in the power sector is progressing towards a generation fleet, dominated by wind and solar power plants and with decreasing amounts of fossil power plants, which make assured capacity a scare source in the German power system. Bioenergy plants already serve assured capacity and could substitute the shrinking fossil fleet to some extent. Most of the capacity was built since the introduction of the EEG in the year 2000.

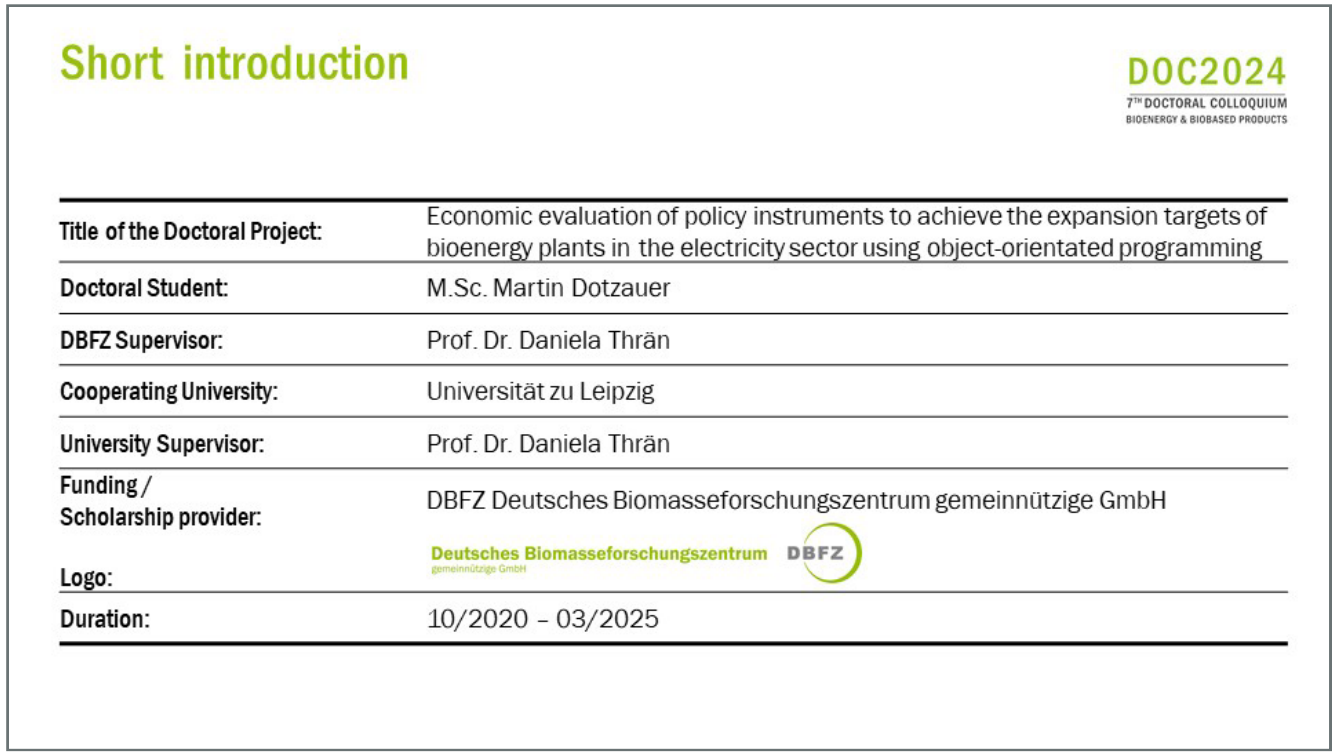
Until 2035 most for recent plants run out of the first remuneration period and need to look for new business opportunities. Basically, they can apply for a follow-up remuneration within the current tendering schema of the EEG, develop business new models outside funding mechanisms for example upgrading biogas to biomethane or should be finally decommissioned.

The current tendering scheme of the EEG is quite complex and its expression depends on several economic framework conditions as well as on future adjustments of the supporting scheme itself. To cover basic uncertainties in the general economic framework and to evaluate different adjustments on the national energy policy measures an agent based modelling approach was used to simulate eight scenarios for the future development of bioenergy plants in the German power sector.

The preparation of the final results are recently under construction and will be submitted as a manuscript to a scientific journal in the coming weeks.

The 7th DOC would give an ideal opportunity to present a selection of a very recent topic to a professional audience, especially interesting towards the expected discussion about the next EEG amendment starting after this summer. Will be given within the final presentation / poster.





Short introduction

Title of the Doctoral Project:	Economic evaluation of policy instruments to achieve the expansion targets of bioenergy plants in the electricity sector using object-orientated programming
Doctoral Student:	M.Sc. Martin Dotzauer
DBFZ Supervisor:	Prof. Dr. Daniela Thrän
Cooperating University:	Universität zu Leipzig
University Supervisor:	Prof. Dr. Daniela Thrän
Funding / Scholarship provider:	DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH
Logo:	Deutsches Biomasseforschungszentrum DBFZ
Duration:	10/2020 – 03/2025

Bioenergy plant portfolio stagnation and aging as a starting point

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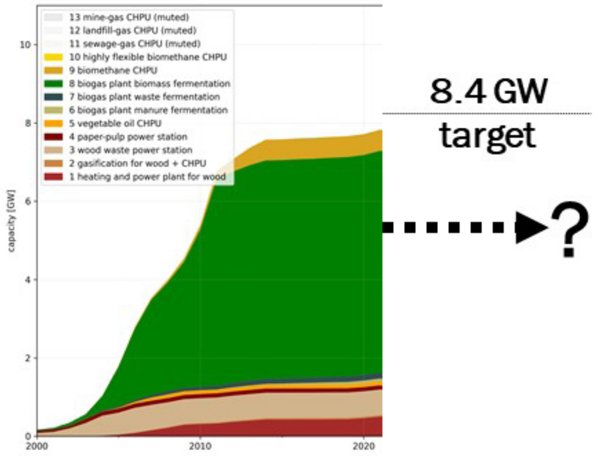
Historical development

Drivers for new installations:

- Regulation framework, EEG in particular, starting in 2000 and introduce special incentives for energy crops in 2004 & 2009

Reasons for stagnation and risk of shrinking:

- EEG amendments in 2014, 2017, 2021 and 2023, reduced remunerations and introduction of mandatory tendering
- Remuneration periods end after 20 years



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Aims for the study

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1. **Develop a method to model complex interaction of regulation and post-EEG opportunities for existing bioenergy plants in the German power sector.**
2. **Elucidate the future development of the plant fleet, covering a defined range of uncertainty.**
3. **Evaluate different policy measures for the most significant regulation of the EEG and additionally stronger pull effects from the GEG.**

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Methods: agent-based modelling to simulate the future tendering rounds for bioenergy plants

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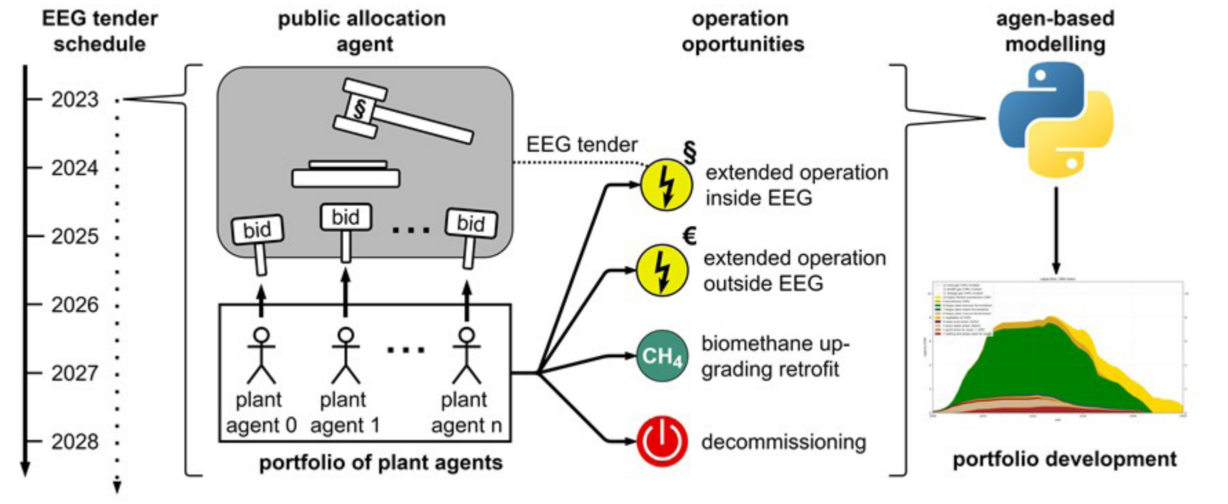

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Object-oriented programming for agent-based modelling

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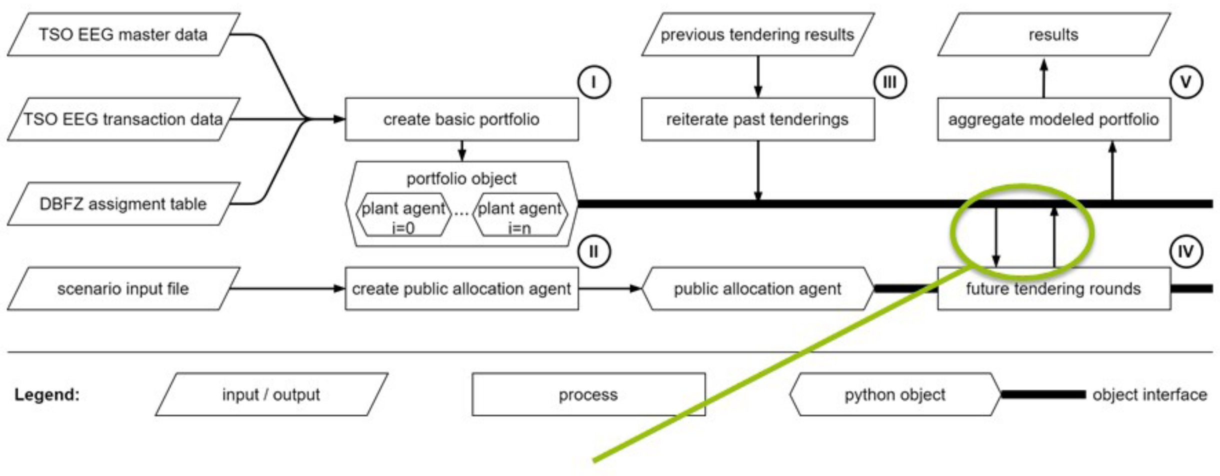

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Scenario setup for covering uncertainties and to evaluate different policy measures

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Uncertainties

Business as usual (BAU) scenarios

- BAU basic (BAU_b)
- BAU low (BAU_l)
- BAU high (BAU_h)
- BAU recently (BAU_r)

Policy measures

Policy measure scenarios for the EEG

- Increased vol. (VOL+)
- Incr. vol. & incr. flex. (V+F+)
- ex southern quota (ESQ)
- vol. transfer (VTF)

Policy measure scenarios for the GEG

- priority for biomethane (PBM)

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Results for BAU basic (BAU_b) – electrical capacity

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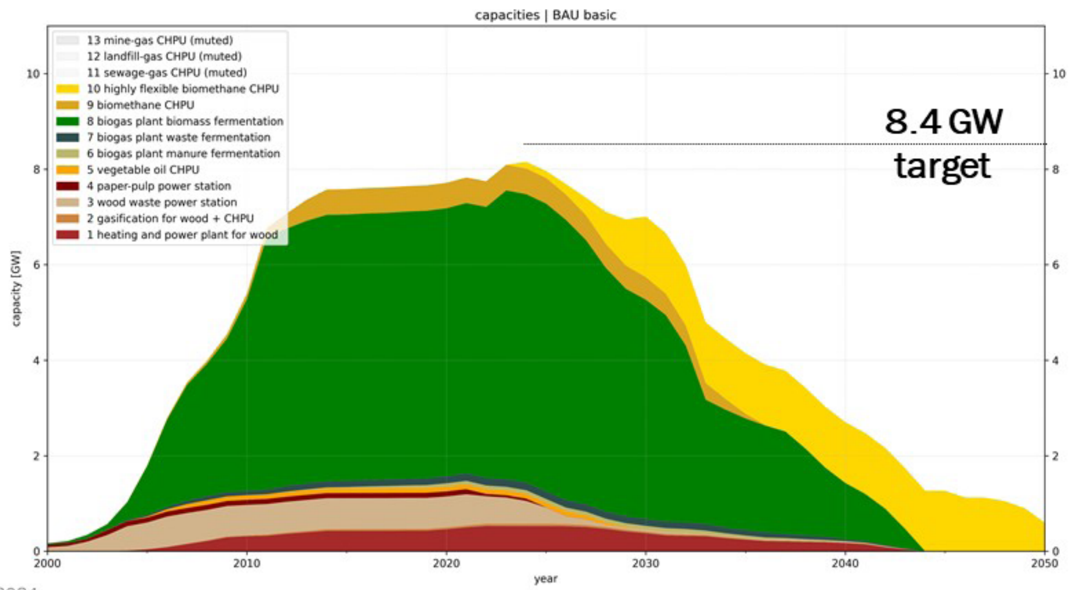

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Results for the basic BAU (BAU_b) used as a reference

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BAU_b results

Electricity sector:

- Decrease of installed capacity and generation, especially after 2030
- Considering the post-EEG options for the tender as well as direct marketing without EEG subsidies

Biomethane production:

- Increase (+ 42%) of upgrading capacity and biomethane production, until 2035

sector	electricity		biomethane	
dimension	capacity [GW]*1	generation [TWh]*1	upgr. cap. [GW]2	production [TWh]2
2020	8.1	38.2	1.5	11.3
2025	8.5	38.0	1.6	12.3
2030	8.0	29.6	2.0	15.2
2035	4.9	15.7	2.4	18.6
2040	3.0	8.0	2.4	18.7
2045	1.4	1.7	2.4	18.6

*1 refers to electrical capacity of all subclasses in the plant portfolio.
*2 refers to lower heating value of the biomethane production.

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Results for basic BAU (BAU_b) - biomethane

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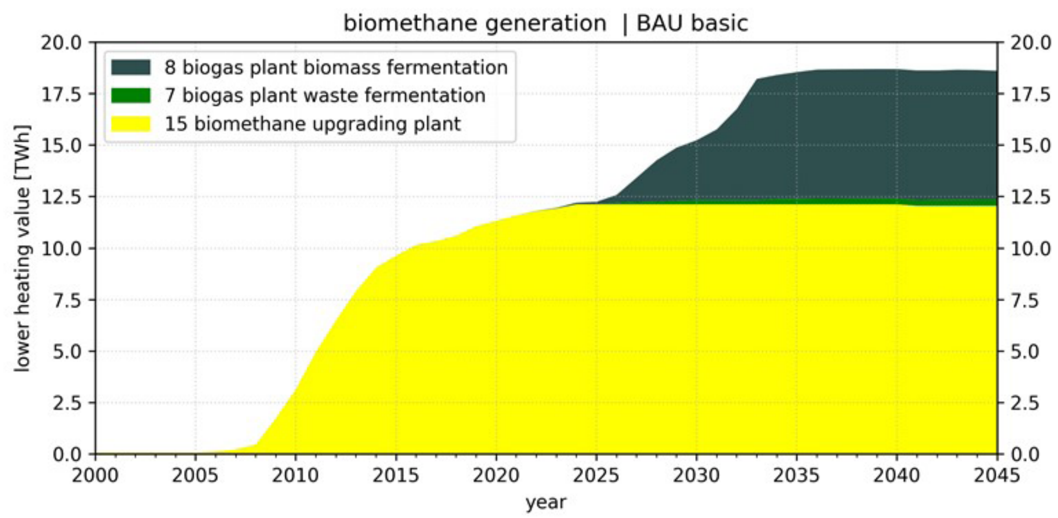

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Results for the basic BAU (BAU_b) used as a reference

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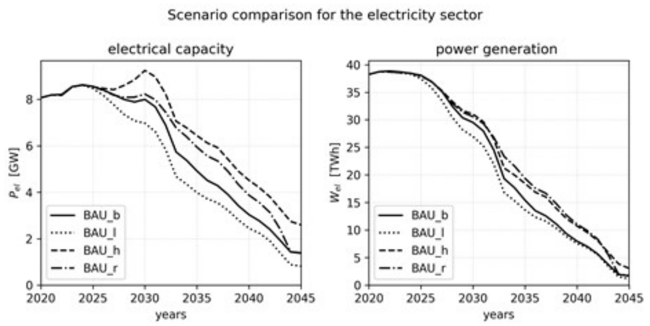
Comparison of BAU scenarios

Electrical capacity:

- BAU_h would increase the capacity until 2030
- The most recent amendments would result in moderate higher capacities especially after 2030

Electrical generation:

- Decrease constantly with lower variation than for the capacity



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Comparison of policy measures targeting the EEG

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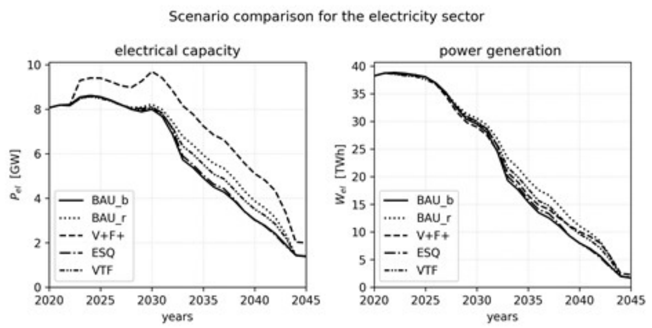
Comparison of EEG measures

Electrical capacity:

- V+F+ would result in sustaining higher capacities than for the reference BAU_b
- Other measures have also an increasing effect, but less stronger

Electrical generation:

- Effects on electrical generation is quantitively minor



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Comparison of policy measures targeting the GEG

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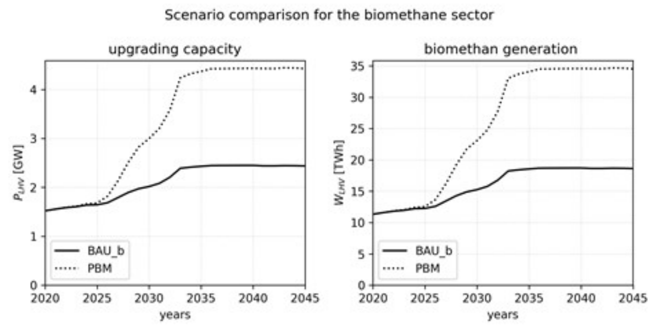
Comparison of GEG measures

upgrading capacity:

- Capacity could almost doubled comparing to BAU_b to 4.5 GW
- Generation is directly proportional to capacity since upgrading is inflexible

Biomethane generation:

- Todays generation is 11 TWh, PBM would result in nearly 35 TWh
- Todays natural gas consumption is 810 TWh, thus substitution could be increased from 1.3 % to 4.3 %



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Discussion & Conclusion

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Discussion

- Current regulation is not sufficient to achieve the target of 8.4 GW of bioenergy in the power sector
- The most recent regulation (BAU_r) improve the chances for more of existing plants to win in the tender
- Other or additional measure are required if the political targets for bioenergy should be met

Conclusions

- Strongest effects on portfolio development have tender volumes
- tender volumes are mostly consumed by existing plants, they generate only half of the effectiveness of new installations, with only 10 years operation
- Dynamic of tender rounds are non-linear and hard to predict without an appropriate approach like ABM

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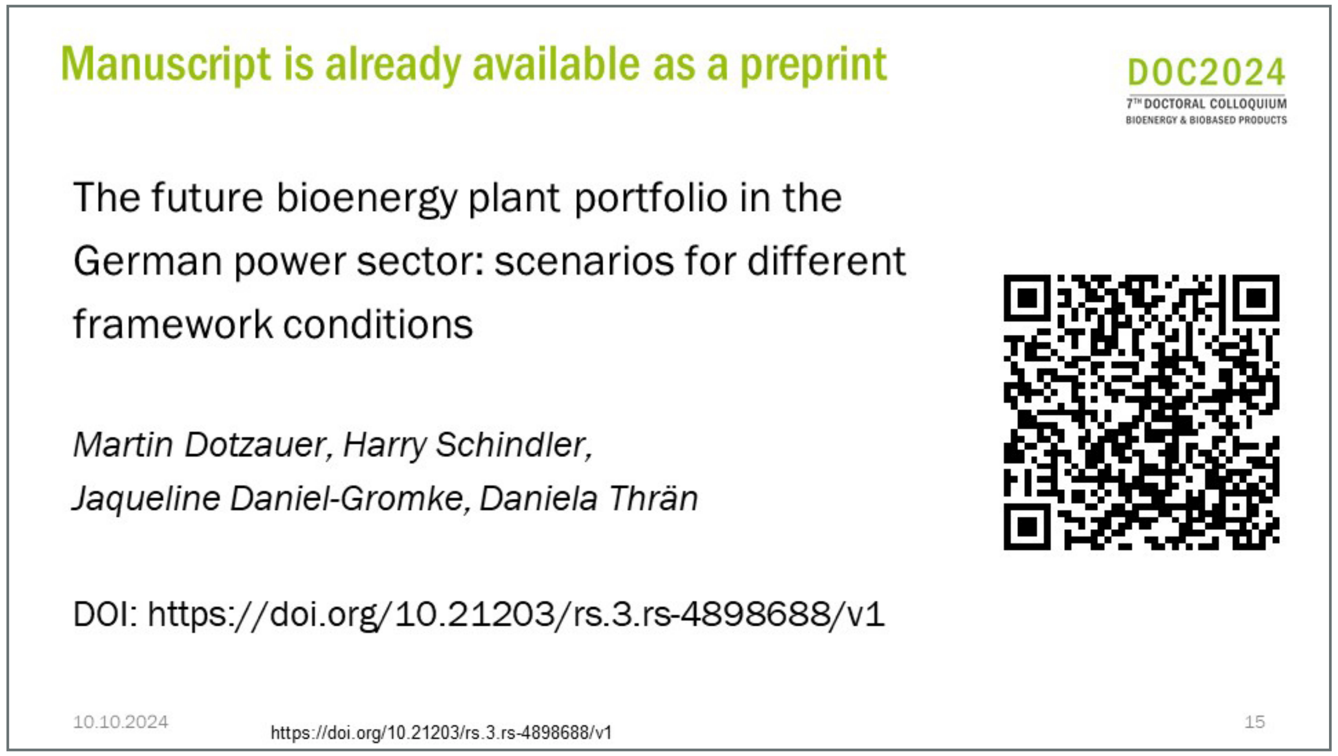
Manuscript is already available as a preprint
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BIOENERGY & BIOBASED PRODUCTS
The future bioenergy plant portfolio in the German power sector: scenarios for different framework conditions
Martin Dotzauer, Harry Schindler,
Jaqueline Daniel-Gromke, Daniela Thrän
DOI: https://doi.org/10.21203/rs.3.rs-4898688/v1
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Edgar Gamero, University of Stuttgart

Life cycle assessment of biorefinery concepts using biochemical conversion platforms for the production of hydrogen

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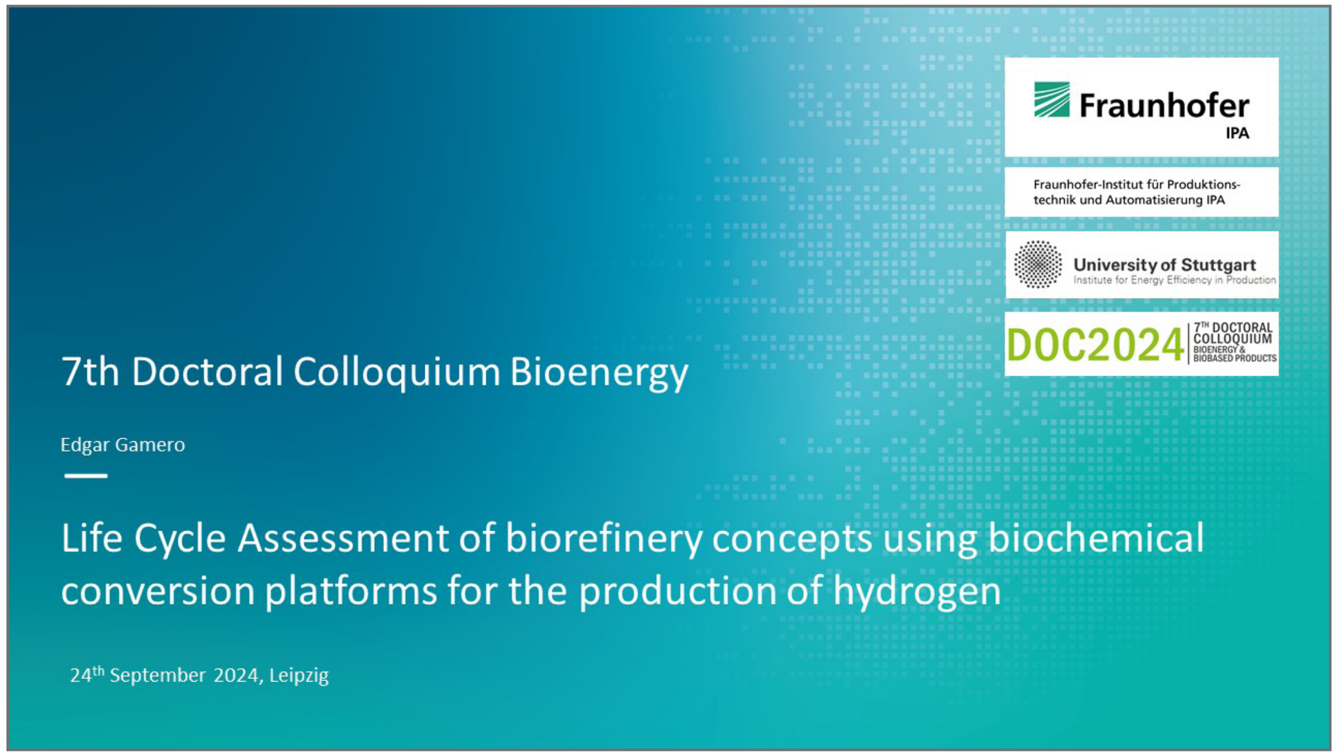
Keywords: Biohydrogen, biorefineries, LCA, green chemistry, biointelligence

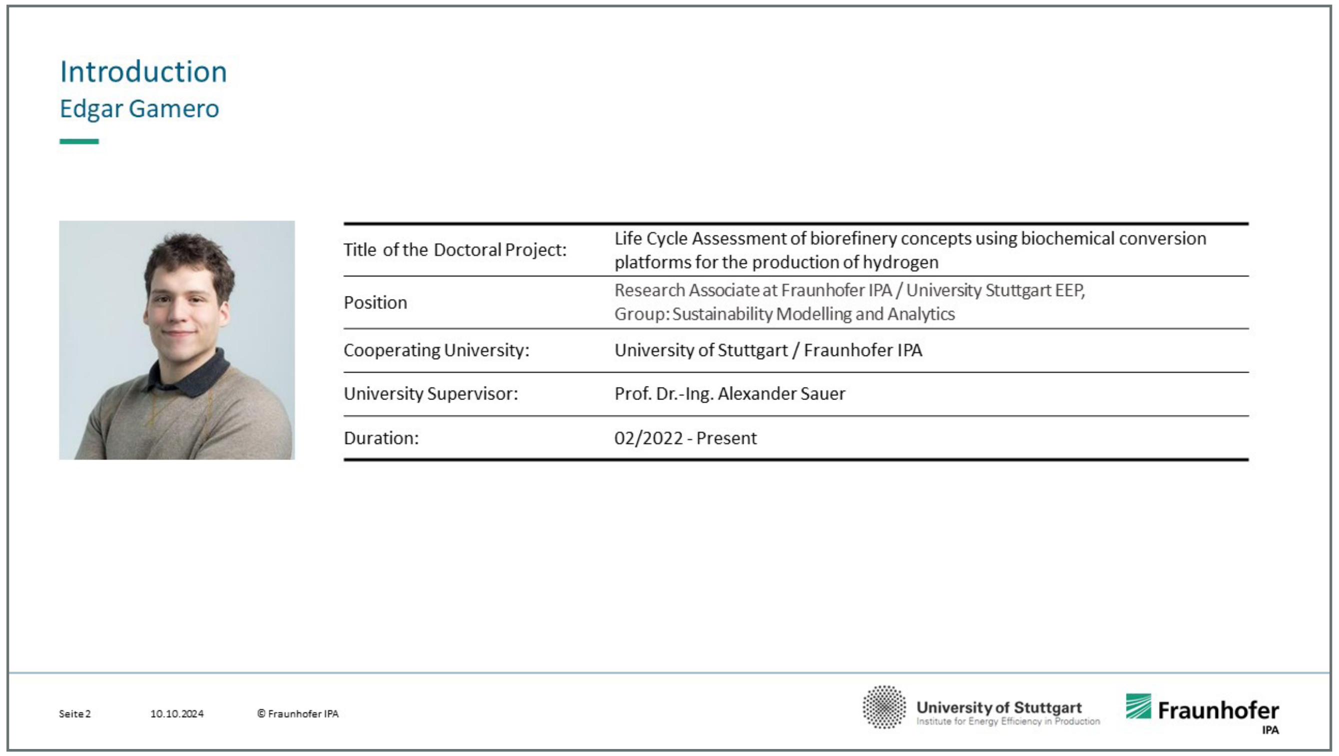
The threat of a warming planet has underlined the need to defossilize our economy. In this regard, hydrogen promises to play an important role in the transition to a more sustainable energy and chemical industry. Biochemical conversion platforms like dark fermentation have emerged as attractive approaches for producing hydrogen from organic waste. Their low energy requirements and relative technical simplicity are often cited as important factors contributing to their „greenness".

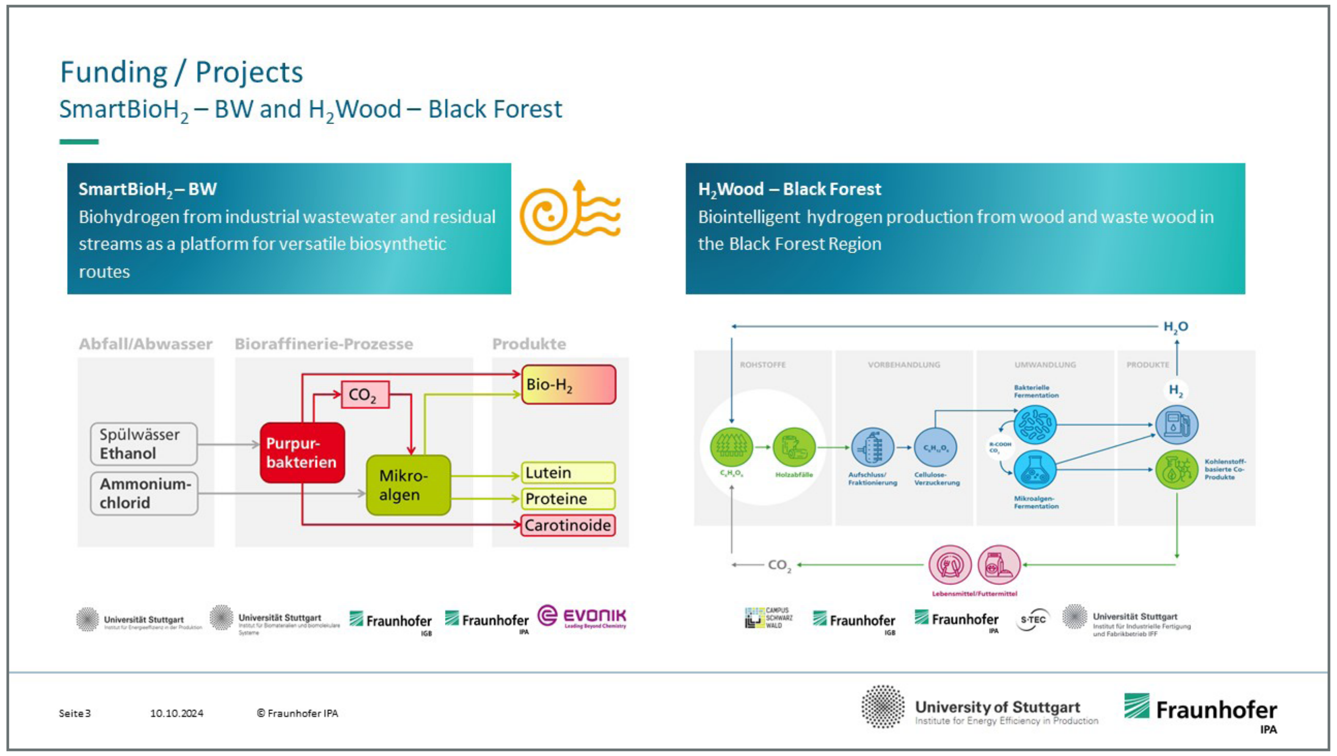
However, knowledge gaps exist regarding their environmental impacts and economic potential, especially when compared to thermochemical conversion platforms like gasification. This is aggravated by a lack of harmonized indicators and the use of different system boundaries in the published literature. As a result, uncertainties remain that hinder their widespread implementation. With our research, we seek to bridge some of these knowledge gaps by quantifying the performance of biochemical conversion platforms and comparing them to other hydrogen production routes. We hypothesize that the integration of these platforms into biorefinery concepts can help maximize their environmental and economic benefits. This, in turn, can help accelerate their deployment.

We develop various biorefinery concepts using selected biochemical conversion platforms to produce hydrogen. Literature and experimental data are then used in process models to crea¬te mass and energy balances for each concept. A Life Cycle Assessment is then carried out to estimate environmental impacts while input/ output models are used to calculate economic and green chemistry indicators. A scenario analysis is also carried out.

Results are compared to those from thermochemical platforms and conventional production routes for co-products. Concepts using sugar-rich wastes have been assessed. These show lower environmental impacts than thermochemical platforms for some impact categories. However, these impacts are highly dependent on factors like location, pretreatment method used, scale, and (co) product demand, among others. Further platforms and process options will be modelled, as well as other waste types. Future research will also focus on ensuring the comparability of the results.







Funding / Projects
SmartBioH2 – BW and H2Wood – Black Forest
SmartBioH2 – BW
Biohydrogen from industrial wastewater and residual streams as a platform for versatile biosynthetic routes
H2Wood – Black Forest
Biointelligent hydrogen production from wood and waste wood in the Black Forest Region
Abfall/Abwasser
Bioraffinerie-Prozesse
Produkte
Spülwässer Ethanol
Ammonium-chlorid
Purpur-bakterien
Mikro-algen
CO2
Bio-H2
Lutein
Proteine
Carotinoide
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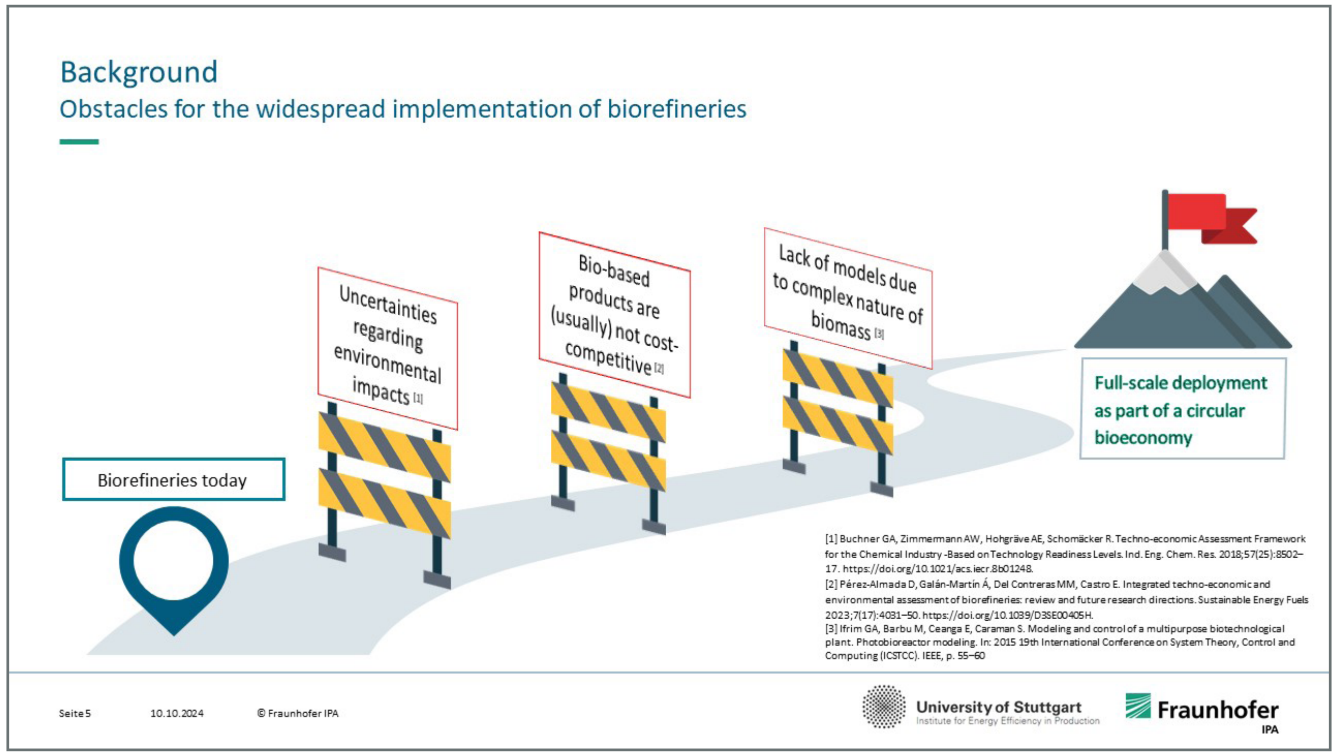

Background
Obstacles for the widespread implementation of biorefineries
Biorefineries today
Uncertainties regarding environmental impacts [1]
Bio-based products are (usually) not cost-competitive [2]
Lack of models due to complex nature of biomass [3]
Full-scale deployment as part of a circular bioeconomy
[1] Buchner GA, Zimmermann AW, Hohgräve AE, Schomäcker R. Techno-economic Assessment Framework for the Chemical Industry -Based on Technology Readiness Levels. Ind. Eng. Chem. Res. 2018;57(25):8502–17. https://doi.org/10.1021/acs.iecr.8b01248.
[2] Pérez-Almada D, Galán-Martín Á, Del Contreras MM, Castro E. Integrated techno-economic and environmental assessment of biorefineries: review and future research directions. Sustainable Energy Fuels 2023;7(17):4031–50. https://doi.org/10.1039/D3SE00405H.
[3] Ifrim GA, Barbu M, Ceanga E, Caraman S. Modeling and control of a multipurpose biotechnological plant. Photobioreactor modeling. In: 2015 19th International Conference on System Theory, Control and Computing (ICSTCC). IEEE, p. 55–60
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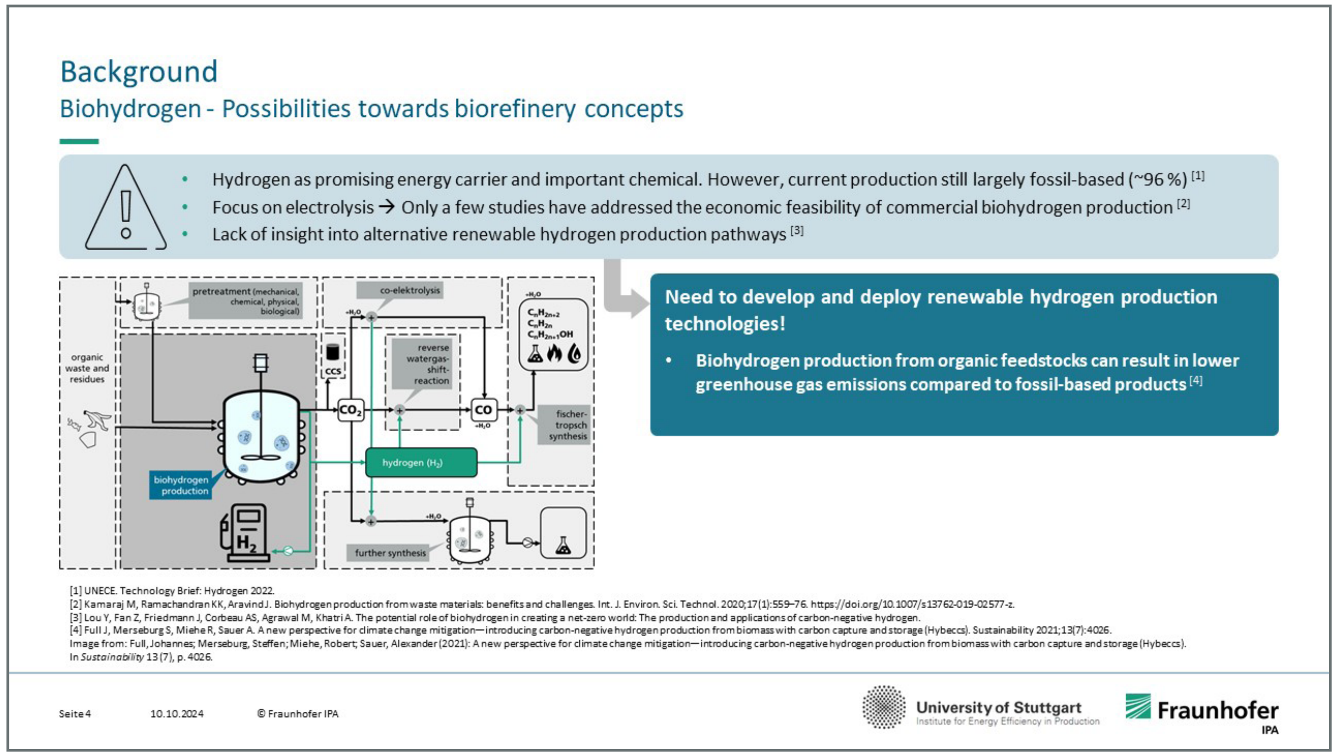

Background
Biohydrogen - Possibilities towards biorefinery concepts
Hydrogen as promising energy carrier and important chemical. However, current production still largely fossil-based (~96 %) [1]
Focus on electrolysis → Only a few studies have addressed the economic feasibility of commercial biohydrogen production [2]
Lack of insight into alternative renewable hydrogen production pathways [3]
Need to develop and deploy renewable hydrogen production technologies!
Biohydrogen production from organic feedstocks can result in lower greenhouse gas emissions compared to fossil-based products [4]
organic waste and residues
pretreatment (mechanical, chemical, physical, biological)
co-elektrolysis
reverse watergas-shift-reaction
fischer-tropsch synthesis
biohydrogen production
hydrogen (H2)
further synthesis
CCS
CO2
CO
H2
[1] UNECE. Technology Brief: Hydrogen 2022.
[2] Kamaraj M, Ramachandran KK, Aravind J. Biohydrogen production from waste materials: benefits and challenges. Int. J. Environ. Sci. Technol. 2020;17(1):559–76. https://doi.org/10.1007/s13762-019-02577-z.
[3] Lou Y, Fan Z, Friedmann J, Corbeau AS, Agrawal M, Khatri A. The potential role of biohydrogen in creating a net-zero world: The production and applications of carbon-negative hydrogen.
[4] Full J, Merseburg S, Miehe R, Sauer A. A new perspective for climate change mitigation—introducing carbon-negative hydrogen production from biomass with carbon capture and storage (Hybeccs). Sustainability 2021;13(7):4026.
Image from: Full, Johannes; Merseburg, Steffen; Miehe, Robert; Sauer, Alexander (2021): A new perspective for climate change mitigation—introducing carbon-negative hydrogen production from biomass with carbon capture and storage (Hybeccs). In Sustainability 13 (7), p. 4026.
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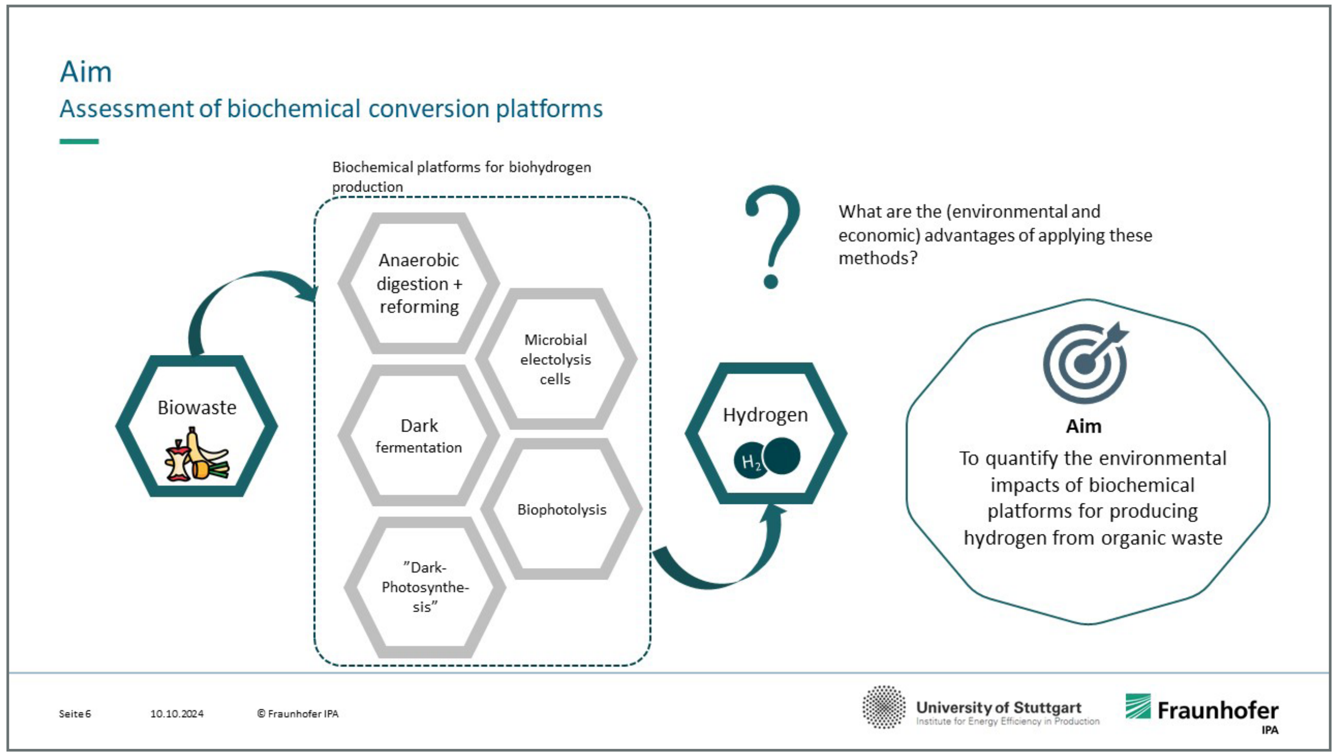

Aim
Assessment of biochemical conversion platforms
Biochemical platforms for biohydrogen production
Biowaste
Anaerobic digestion + reforming
Microbial electolysis cells
Dark fermentation
Biophotolysis
"Dark-Photosynthe-sis"
Hydrogen
H2
?
What are the (environmental and economic) advantages of applying these methods?
Aim
To quantify the environmental impacts of biochemical platforms for producing hydrogen from organic waste
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Motivation
Assessment of biochemical conversion platforms
The environmental and economic assessment of integrated biorefinery concepts can help identify the most sustainable and cost-effective ways to produce hydrogen from organic waste
Moussa, Rita Noelle; Moussa, Najah; Dionisi, Davide (2022): Hydrogen Production from Biomass and Organic Waste Using Dark Fermentation: An Analysis of Literature Data on the Effect of Operating Parameters on Process Performance. In: Processes 10 (1), S. 156. DOI: 10.3390/pr10010156.
Assessment of biohydrogen technologies, including supply chains, transformation processes, biomass sourcing, and utilization, is critical to ensure impacts do not exceed those of fossil-based hydrogen
Lou, Y.; Fan, Z.; Friedmann, J.; Corbeau, A. S.; Agrawal, M.; Khatri, A.: The potential role of biohydrogen in creating a net-zero world. The production and applications of carbon-negative hydrogen. Hg. v. Columbia SIPA Center on Global Energy Policy, zuletzt geprüft am 11.01.2023.
Application of an integrated TEA-LCA tool at low TRLs can provide robust and consistent information compared to separate TEA and LCA by considering consistent methodological choices and assumptions, and enhance decision making by enabling trade-off analysis between techno-economic and environmental performances of emerging technologies.
Pérez-Almada, Déborah; Galán-Martín, Ángel; Del Contreras, María Mar; Castro, Eulogio (2023): Integrated techno-economic and environmental assessment of biorefineries: review and future research directions. In: Sustainable Energy Fuels 7 (17), S. 4031-4050. DOI: 10.1039/D3SE00405H
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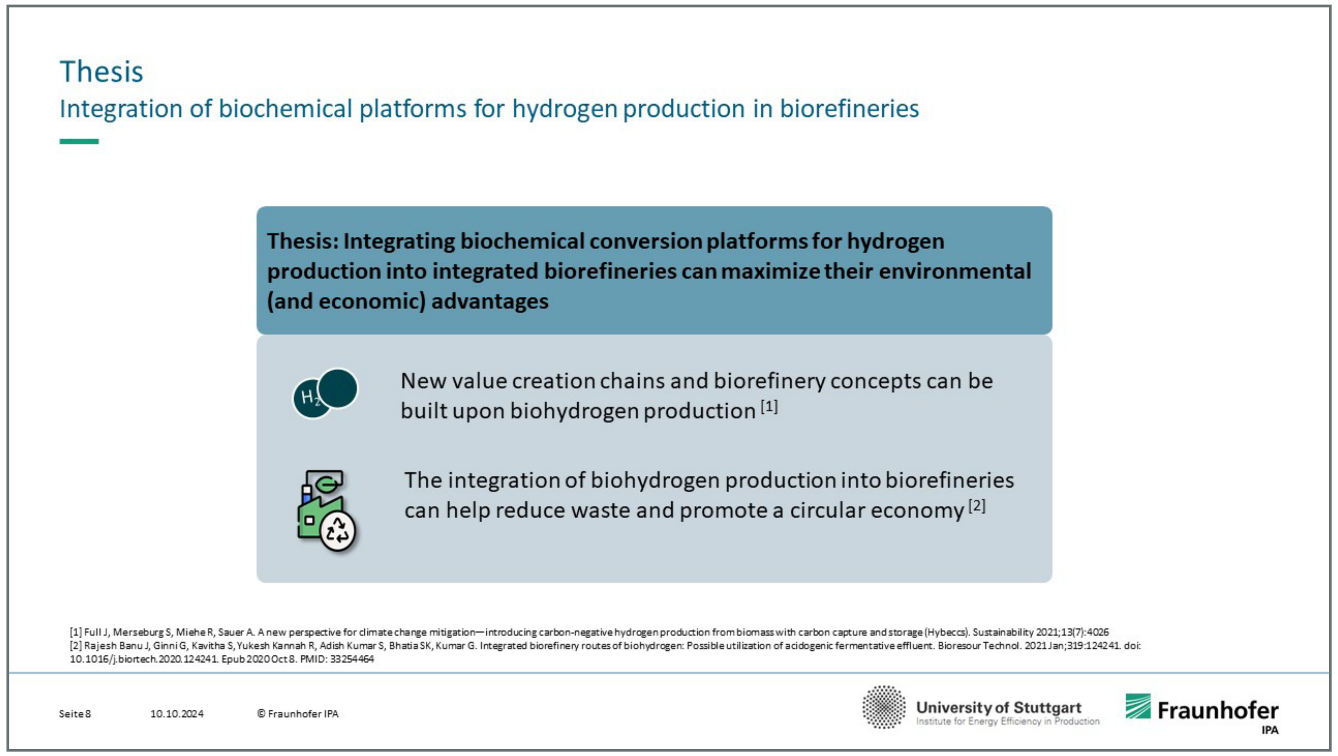
Thesis
Integration of biochemical platforms for hydrogen production in biorefineries
Thesis: Integrating biochemical conversion platforms for hydrogen production into integrated biorefineries can maximize their environmental (and economic) advantages
New value creation chains and biorefinery concepts can be built upon biohydrogen production [1]
The integration of biohydrogen production into biorefineries can help reduce waste and promote a circular economy [2]
[1] Full J, Merseburg S, Miehe R, Sauer A. A new perspective for climate change mitigation—introducing carbon-negative hydrogen production from biomass with carbon capture and storage (Hybeccs). Sustainability 2021;13(7):4026
[2] Rajesh Banu J, Ginni G, Kavitha S, Yukesh Kannah R, Adish Kumar S, Bhatia SK, Kumar G. Integrated biorefinery routes of biohydrogen: Possible utilization of acidogenic fermentative effluent. Bioresour Technol. 2021 Jan;319:124241. doi: 10.1016/j.biortech.2020.124241. Epub 2020 Oct 8. PMID: 33254464
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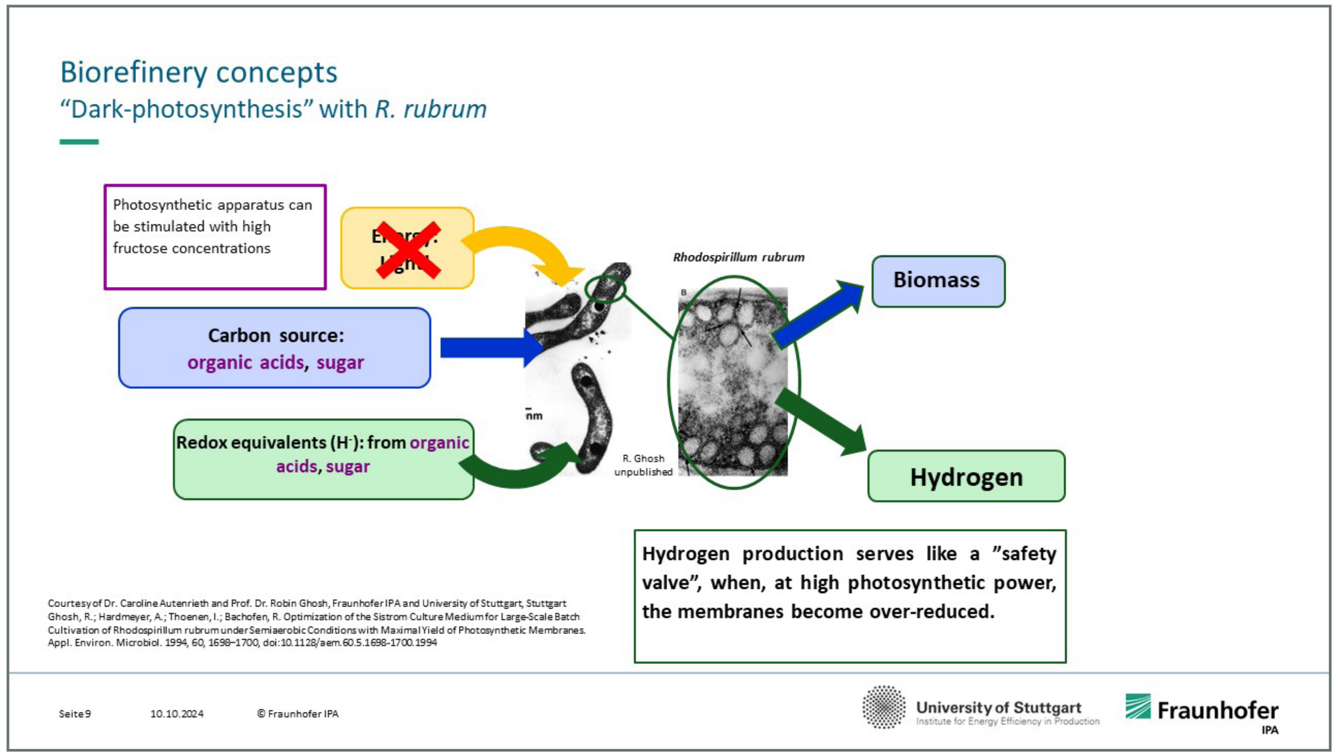
Biorefinery concepts
"Dark-photosynthesis" with R. rubrum
Photosynthetic apparatus can be stimulated with high fructose concentrations
Carbon source: organic acids, sugar
Redox equivalents (H⁻): from organic acids, sugar
Rhodospirillum rubrum
R. Ghosh unpublished
Biomass
Hydrogen
Hydrogen production serves like a "safety valve", when, at high photosynthetic power, the membranes become over-reduced.
Courtesy of Dr. Caroline Autenrieth and Prof. Dr. Robin Ghosh, Fraunhofer IPA and University of Stuttgart, Stuttgart
Ghosh, R.; Hardmeyer, A.; Thoenen, I.; Bachofen, R. Optimization of the Sistrom Culture Medium for Large-Scale Batch Cultivation of Rhodospirillum rubrum under Semiaerobic Conditions with Maximal Yield of Photosynthetic Membranes. Appl. Environ. Microbiol. 1994, 60, 1698–1700, doi:10.1128/aem.60.5.1698-1700.1994
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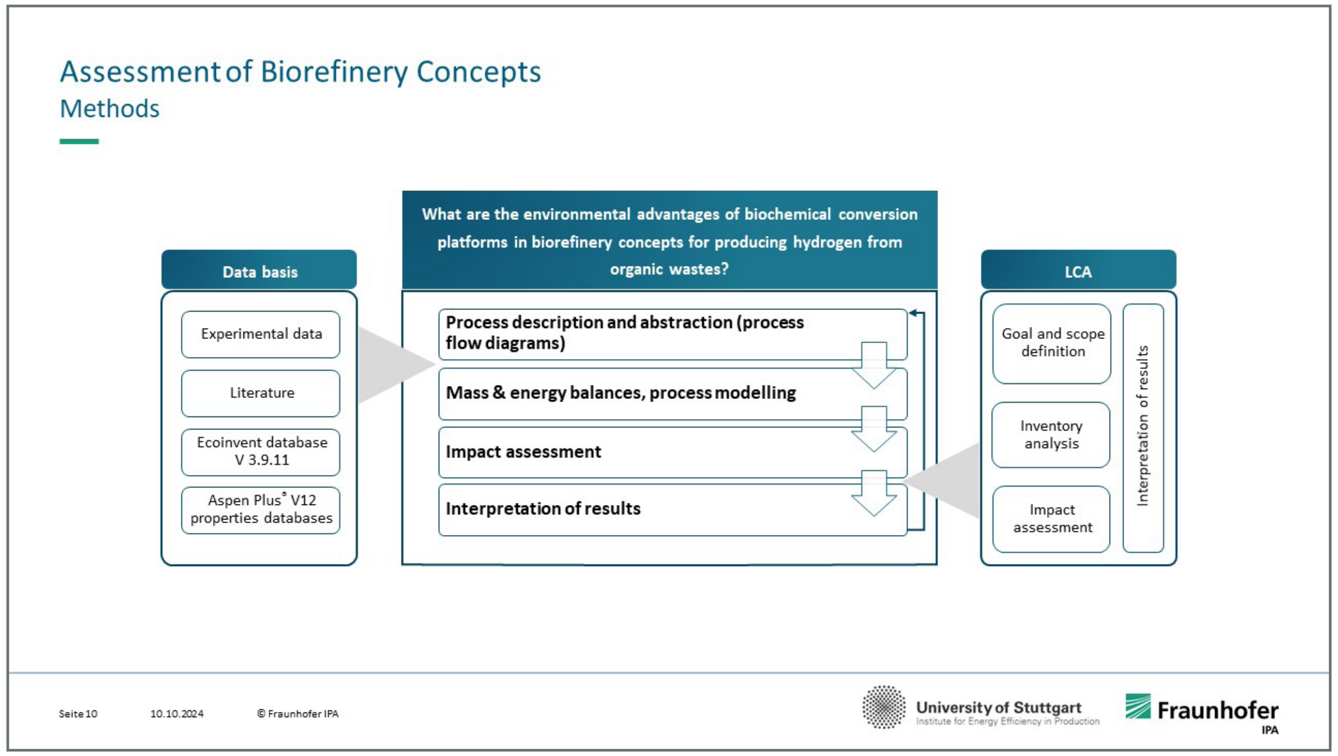
Assessment of Biorefinery Concepts
Methods
What are the environmental advantages of biochemical conversion platforms in biorefinery concepts for producing hydrogen from organic wastes?
Data basis
Experimental data
Literature
Ecoinvent database V 3.9.11
Aspen Plus® V12 properties databases
Process description and abstraction (process flow diagrams)
Mass & energy balances, process modelling
Impact assessment
Interpretation of results
LCA
Goal and scope definition
Inventory analysis
Impact assessment
Interpretation of results
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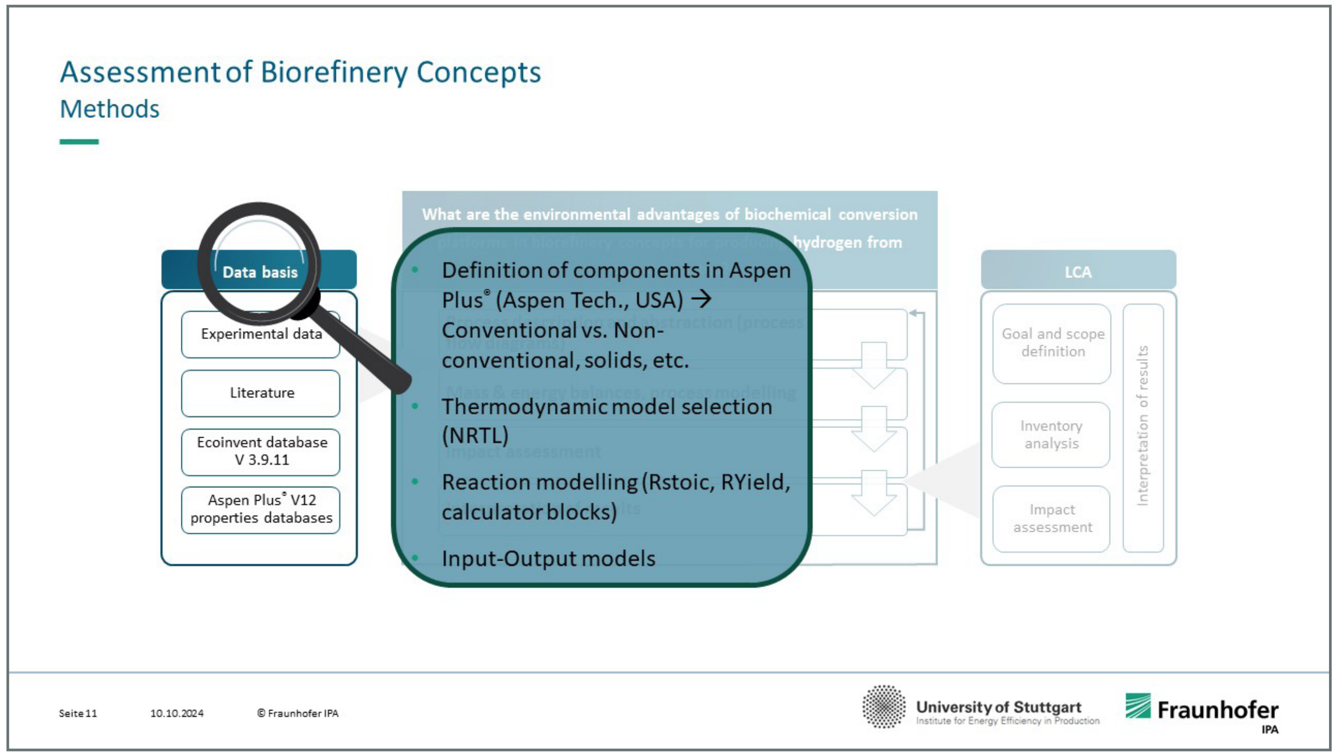

Assessment of Biorefinery Concepts
Methods
What are the environmental advantages of biochemical conversion
hydrogen from
Data basis
Experimental data
Literature
Ecoinvent database V 3.9.11
Aspen Plus® V12 properties databases
• Definition of components in Aspen Plus® (Aspen Tech., USA) → Conventional vs. Non-conventional, solids, etc.
• Thermodynamic model selection (NRTL)
• Reaction modelling (Rstoic, RYield, calculator blocks)
• Input-Output models
LCA
Goal and scope definition
Inventory analysis
Impact assessment
Interpretation of results
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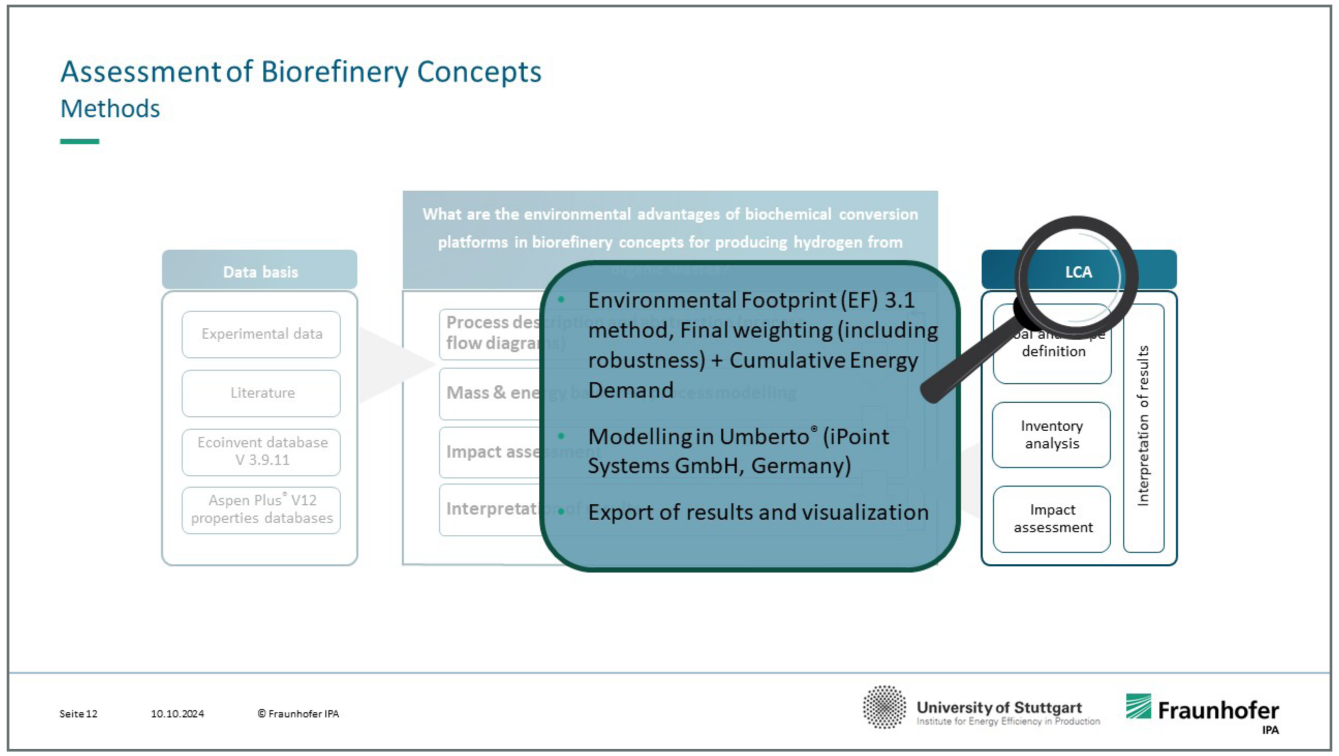

Assessment of Biorefinery Concepts
Methods
What are the environmental advantages of biochemical conversion platforms in biorefinery concepts for producing hydrogen from
Data basis
Experimental data
Literature
Ecoinvent database V 3.9.11
Aspen Plus® V12 properties databases
Process description flow diagram
Mass & energy balances
Impact assessment
Interpretation
• Environmental Footprint (EF) 3.1 method, Final weighting (including robustness) + Cumulative Energy Demand
• Modelling in Umberto® (iPoint Systems GmbH, Germany)
• Export of results and visualization
LCA
definition
Inventory analysis
Impact assessment
Interpretation of results
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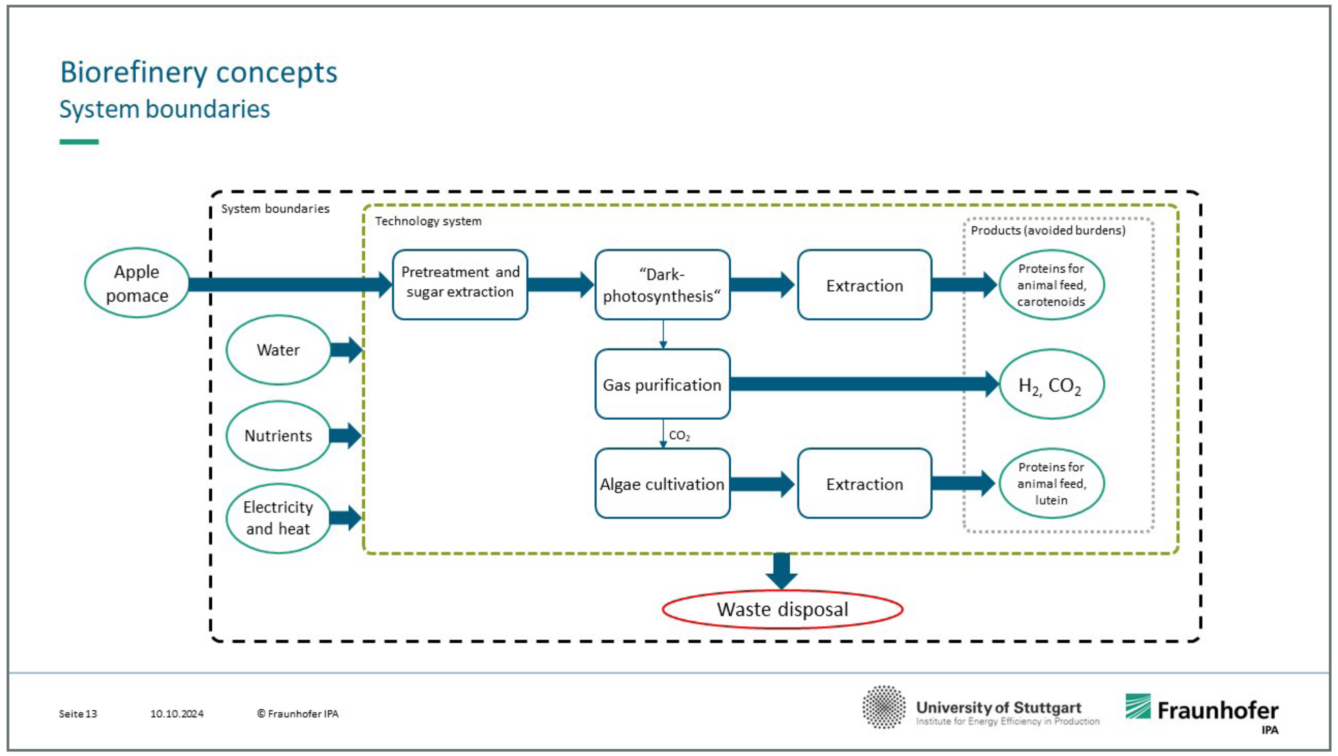

Biorefinery concepts
System boundaries
System boundaries
Technology system
Products (avoided burdens)
Apple pomace
Water
Nutrients
Electricity and heat
Pretreatment and sugar extraction
"Dark-photosynthesis"
Extraction
Proteins for animal feed, carotenoids
Gas purification
H2, CO2
CO2
Algae cultivation
Extraction
Proteins for animal feed, lutein
Waste disposal
Seite 13
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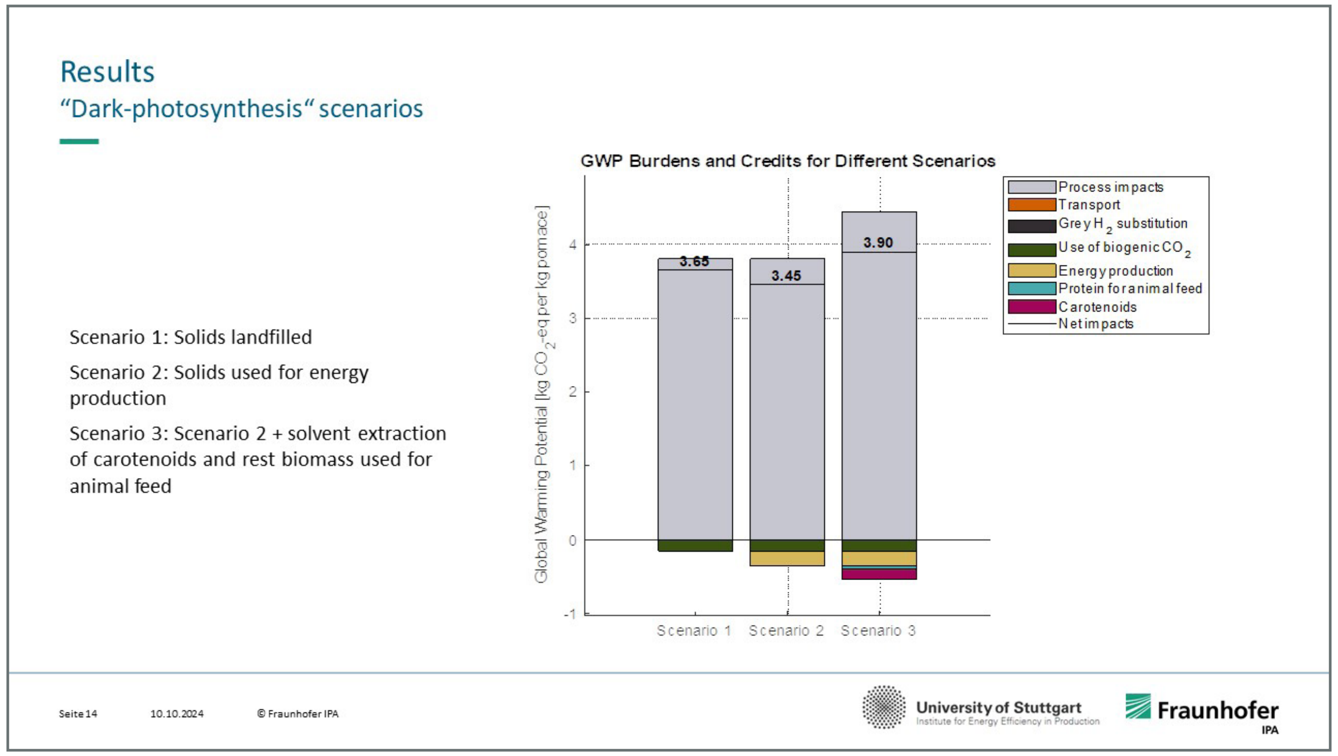

Results
"Dark-photosynthesis" scenarios
Scenario 1: Solids landfilled
Scenario 2: Solids used for energy production
Scenario 3: Scenario 2 + solvent extraction of carotenoids and rest biomass used for animal feed
GWP Burdens and Credits for Different Scenarios
Global Warming Potential [kg CO2-eq per kg pomace]
Process impacts
Transport
Grey H2 substitution
Use of biogenic CO2
Energy production
Protein for animal feed
Carotenoids
Net impacts
3.65
3.45
3.90
Scenario 1
Scenario 2
Scenario 3
Seite 14
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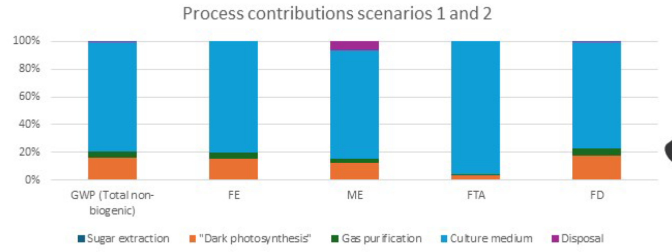
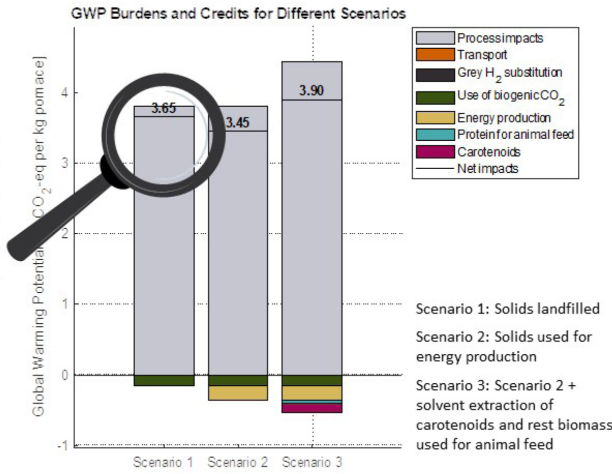
Results
“Dark photosynthesis“ scenarios





Scenario 1: Solids landfilled
Scenario 2: Solids used for energy production
Scenario 3: Scenario 2 + solvent extraction of carotenoids and rest biomass used for animal feed

(GWP = Global Warming Potential; FE = Freshwater Eutrophication; ME = Marine Eutrophication; FTA = Freshwater and Terrestrial Acidification; FD = Fossil Depletion).

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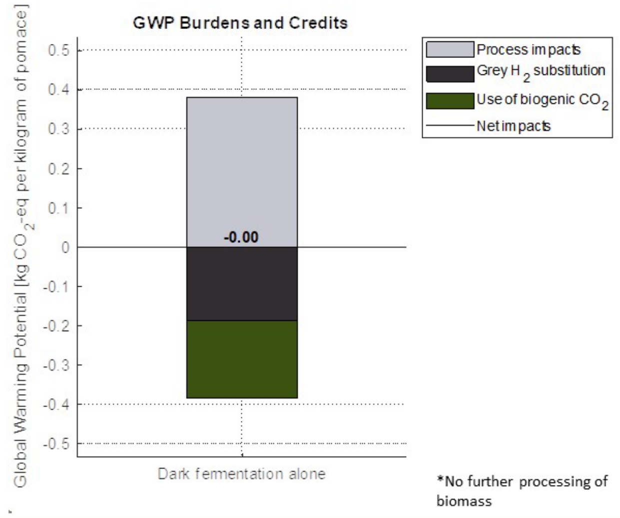
Results
Dark fermentation



*No further processing of biomass

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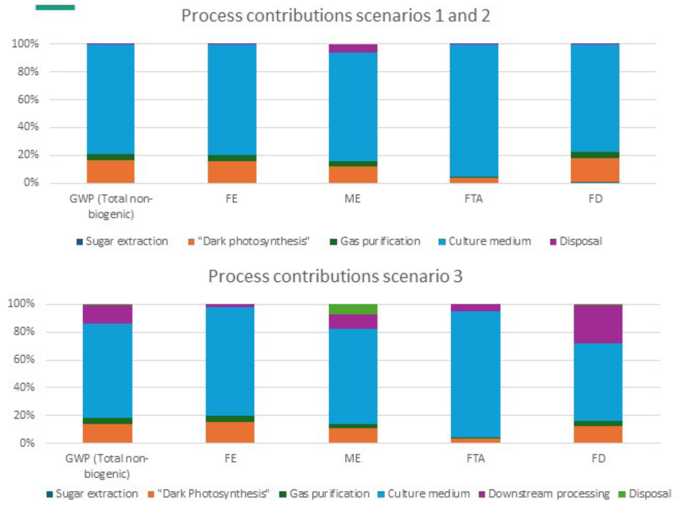
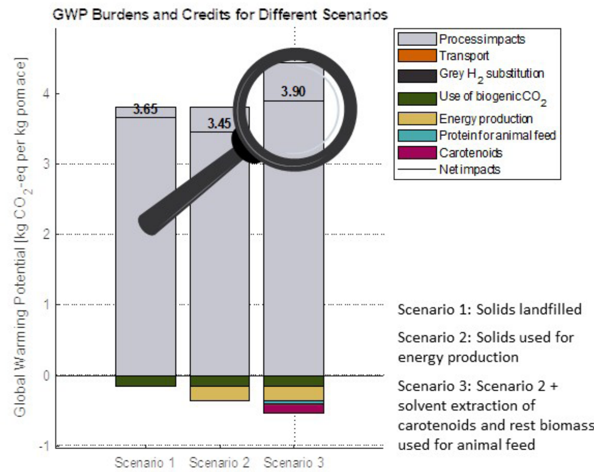
Results
“Dark photosynthesis“ scenarios





Scenario 1: Solids landfilled
Scenario 2: Solids used for energy production
Scenario 3: Scenario 2 + solvent extraction of carotenoids and rest biomass used for animal feed

(GWP = Global Warming Potential; FE = Freshwater Eutrophication; ME = Marine Eutrophication; FTA = Freshwater and Terrestrial Acidification; FD = Fossil Depletion).

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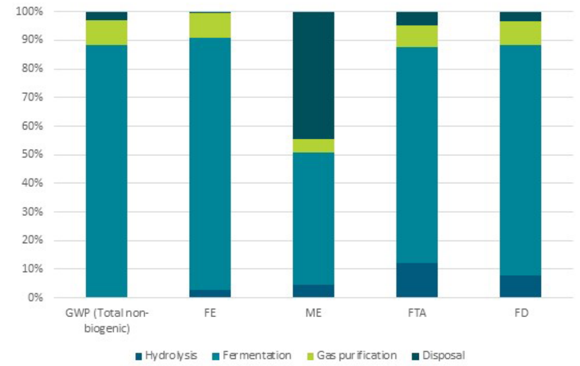
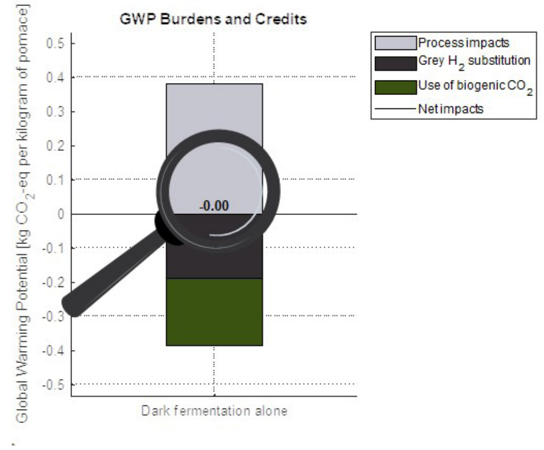
Results
Dark fermentation





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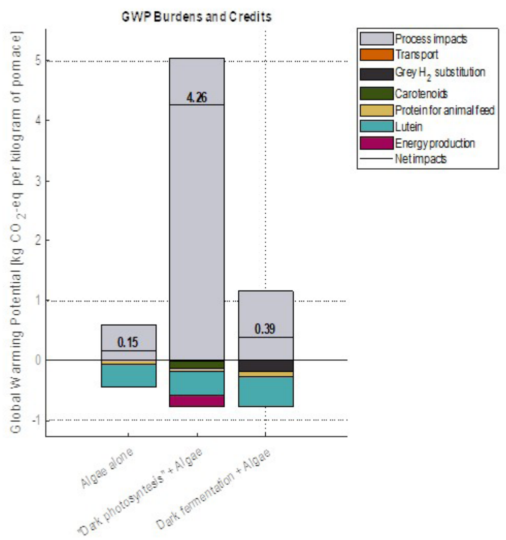
Results
Algae scenarios



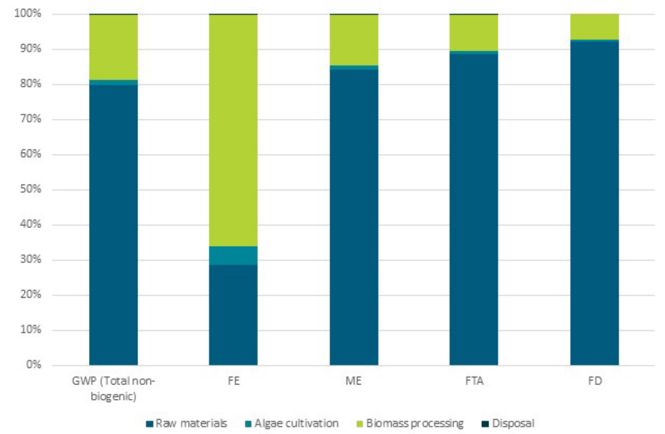
Interim results
Anaerobic digestion + steam methane reforming

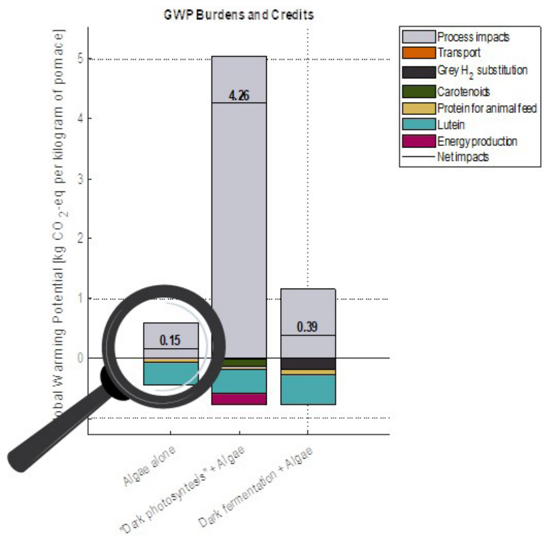
	GWP (Total non-biogenic) [kg CO_2-eq.]	FE [g P eq.]	ME [g N eq.]	FTA [mol H^+-eq.]	FD [kWh]
Purification and Conditioning	1,39	2,02	0,99	0,003	6,00
Biogas production	1,80	1,07	37,0	0,06	4,02
Steam methane reforming	3,50	0,43	1,71	0,01	13,28
Total	**6,69**	**3,5**	**39,7**	**0,08**	**23,31**

Assumptions:

- Functional unit: 1 kg of hydrogen gas
- No further products considered
- Manure and maize silage used for biogas production (50/50 by weight)

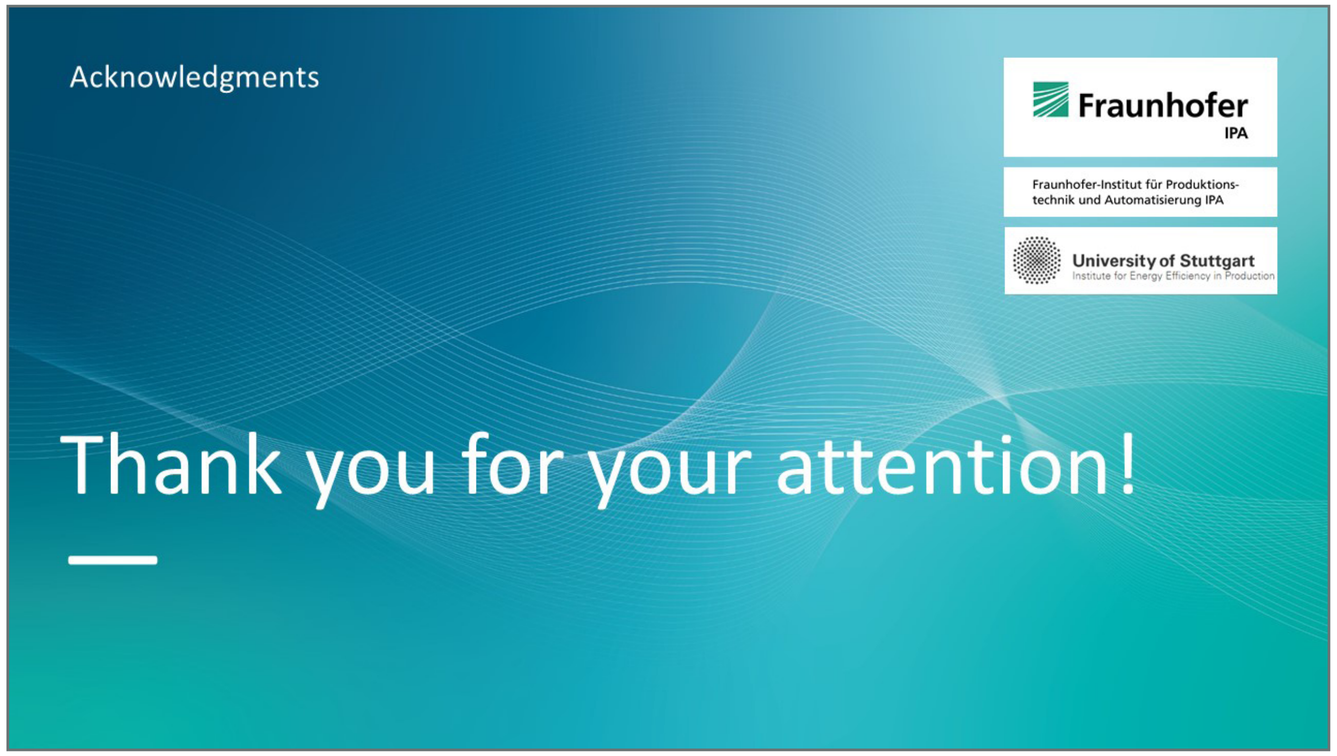
Results
Algae scenarios





Outlook

- ✓ Modelling and assessment of other extraction methods → super critical CO_2 extraction
- ✓ Update of "dark-photosynthesis" process with latest data
- ✓ Modelling and assessment of further dark fermentation scenarios
- ✓ Development of biorefinery scenarios for anaerobic digestion with steam methane reforming
- ✓ Modelling and assessment of biomass gasification to compare results (first model available)
- ✓ Basic economic assessment of all scenarios
- ✓ Interpretation and analysis of results


Acknowledgments
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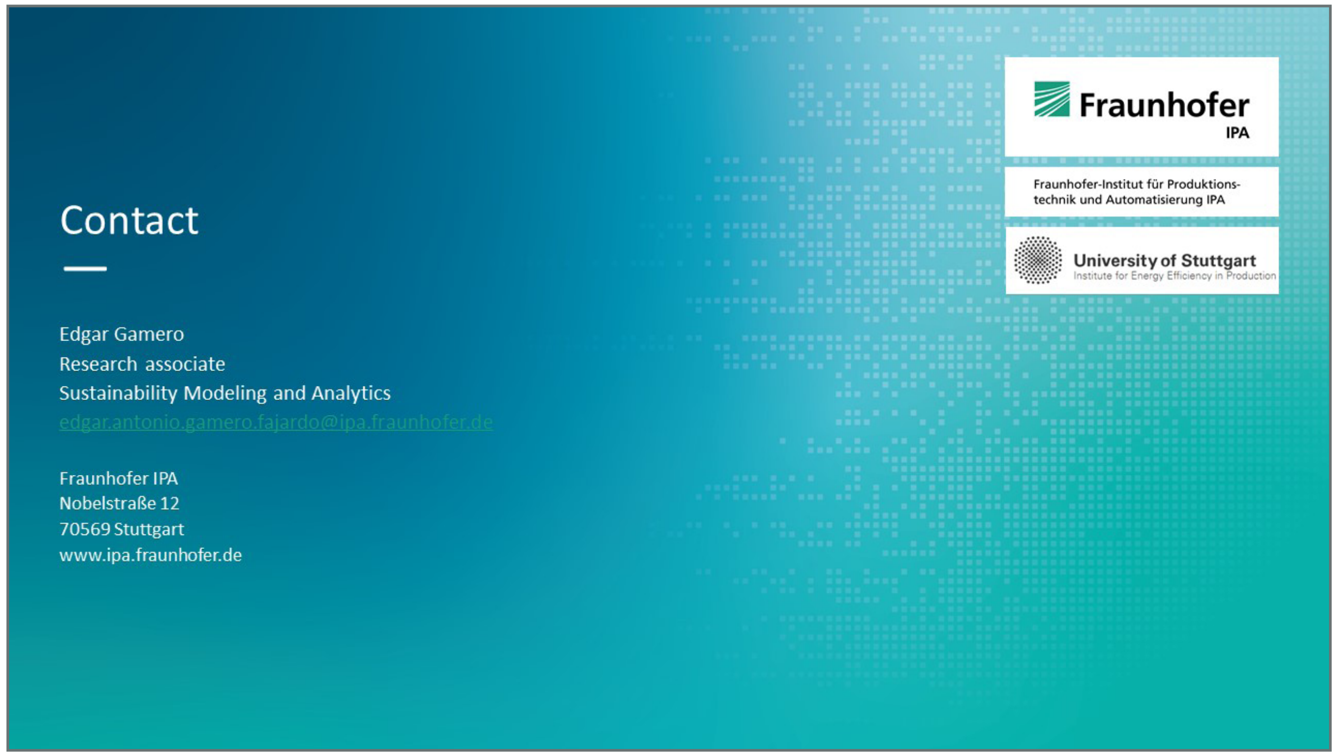
University of Stuttgart
Institute for Energy Efficiency in Production
Thank you for your attention!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Ronja Wollnik, Deutsches Biomasseforschungszentrum

Telling the tale of CDR - Scenarios for bio-based carbon dioxide removal to achieve net-zero in Germany

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Keywords: Carbon dioxide removal (CDR); Negative emissions technologies (NET); Biomass; Scenarios; Storylines

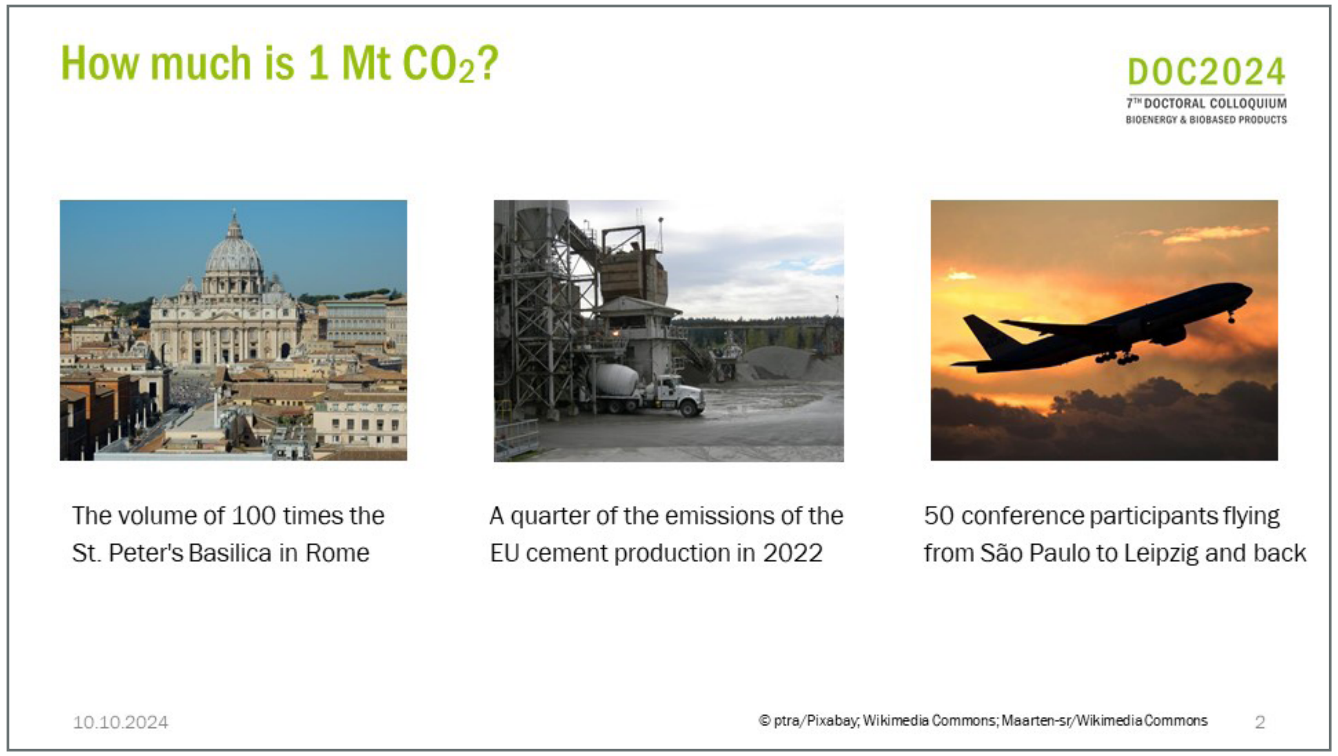
Carbon dioxide removal (CDR) is indispensable for climate neutrality, as a complementary strategy alongside reducing and avoiding greenhouse gas emissions. Its ramp-up is driven by a diverse set of factors, which are described in this work. Bio-based CDR is put into focus, i.e., natural sink enhancement, renewable long-lived building materials, and bioenergy with carbon capture and storage (BECCS). By focusing on bio-based solutions, actions can be streamlined to achieve both carbon removal and a range of co-benefits.

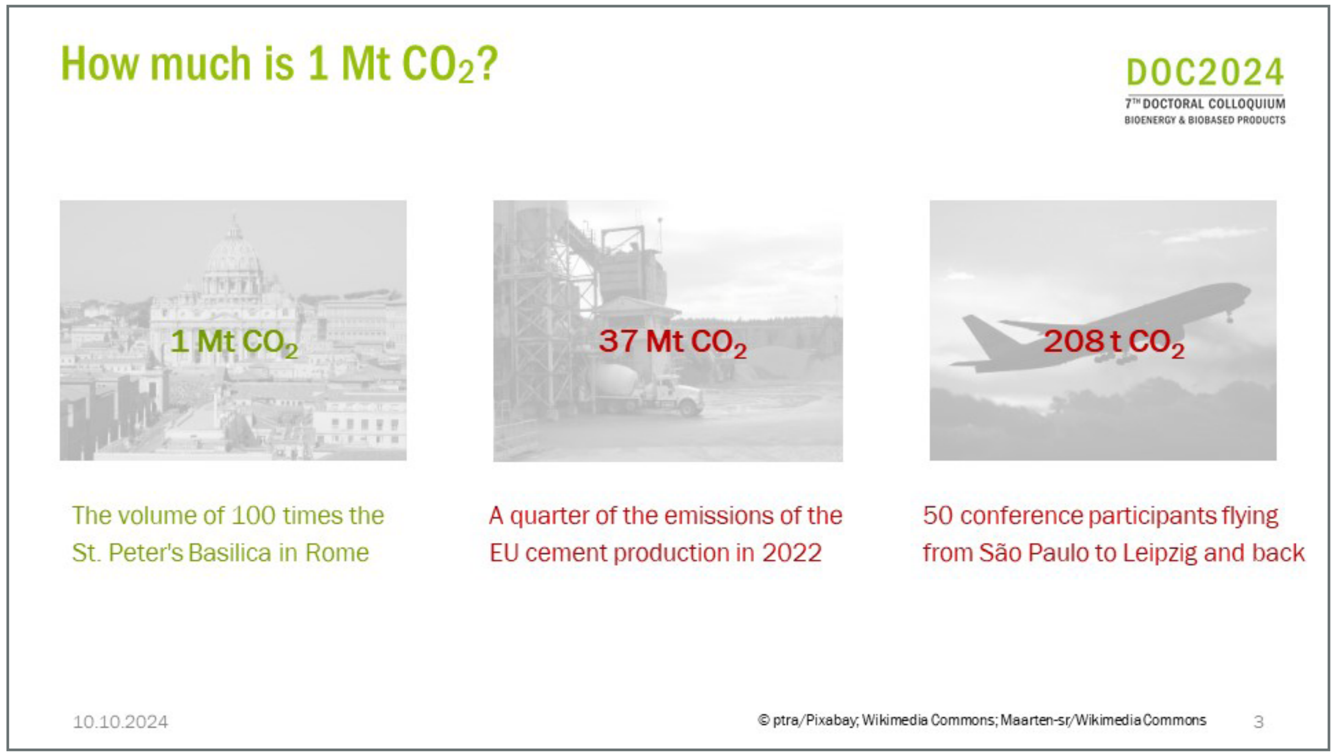
Scenarios were developed that allow us to explore biomass-specific drivers in a set of four narratives. The selection of key drivers followed the PESTEL approach (Policy, Environmental, Social, Technological, Economic, and Legal aspects), to which the Biomass category was added, to reflect the heterogeneity of challenges around deploying bio-based CDR. Desirable net-zero futures and drivers identified in stakeholder interviews and workshops were translated into consistent scenario storylines.

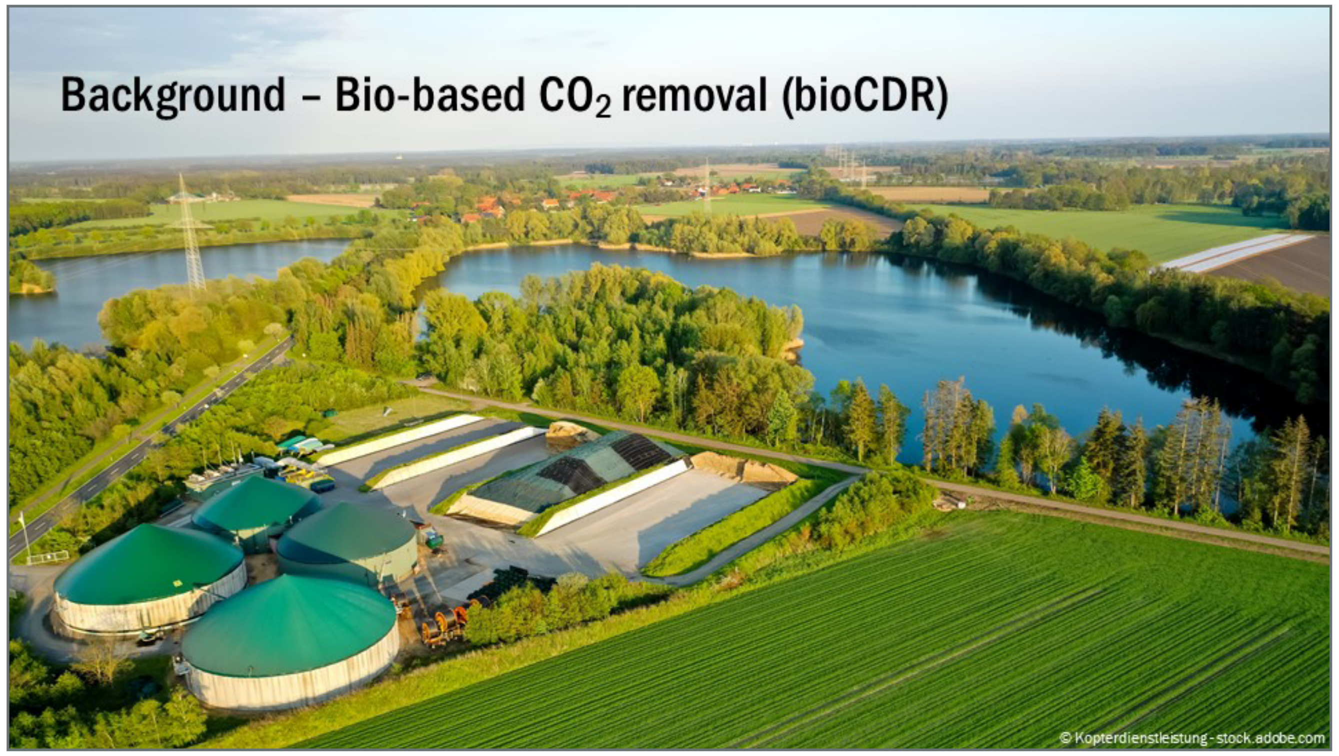
This resulted in distinct option portfolios, which feed into modelling for cost-optimized implementation using the BENOPTex model. System boundaries are geographical (Germany), temporal (2020-2045), and technology-specific (maximum capacities).

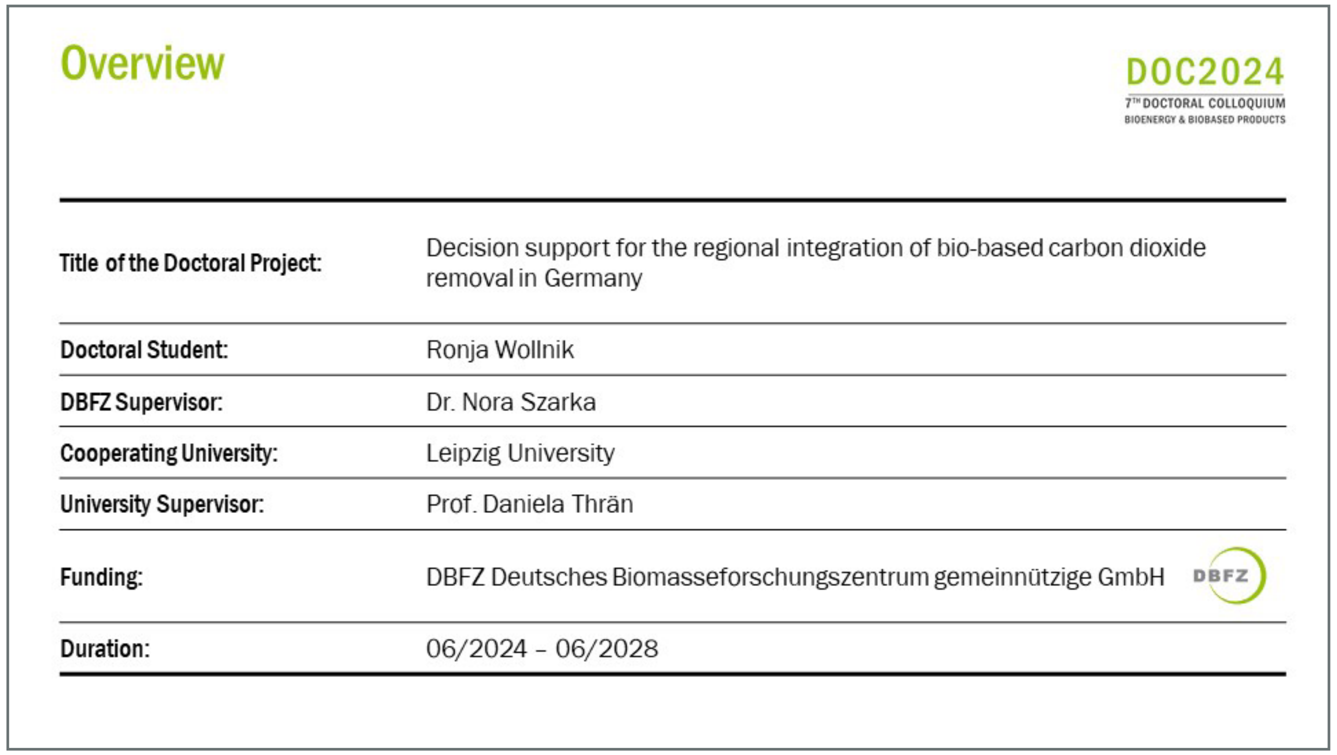
The four storylines encompass (1) cost-efficient deployment, (2) deployment restricted by a focus on decentralized options and natural sinks, (3) ambitious deployment, and (4) roadblock with a reliance on carbon offsetting. Each storyline is described by a set of key drivers, whose trends differ among scenarios.

The scenarios represent diverse bio-based CDR portfolios that differ in implementation level of single technologies, and in the overall contribution to negative emissions. The storylines and driver trends will inform the modelling, as well as painting a picture of potential developments for stakeholders. They serve as a basis for compiling bio-based value chains with maximum removal capacities which deliver a series of additional system benefits.

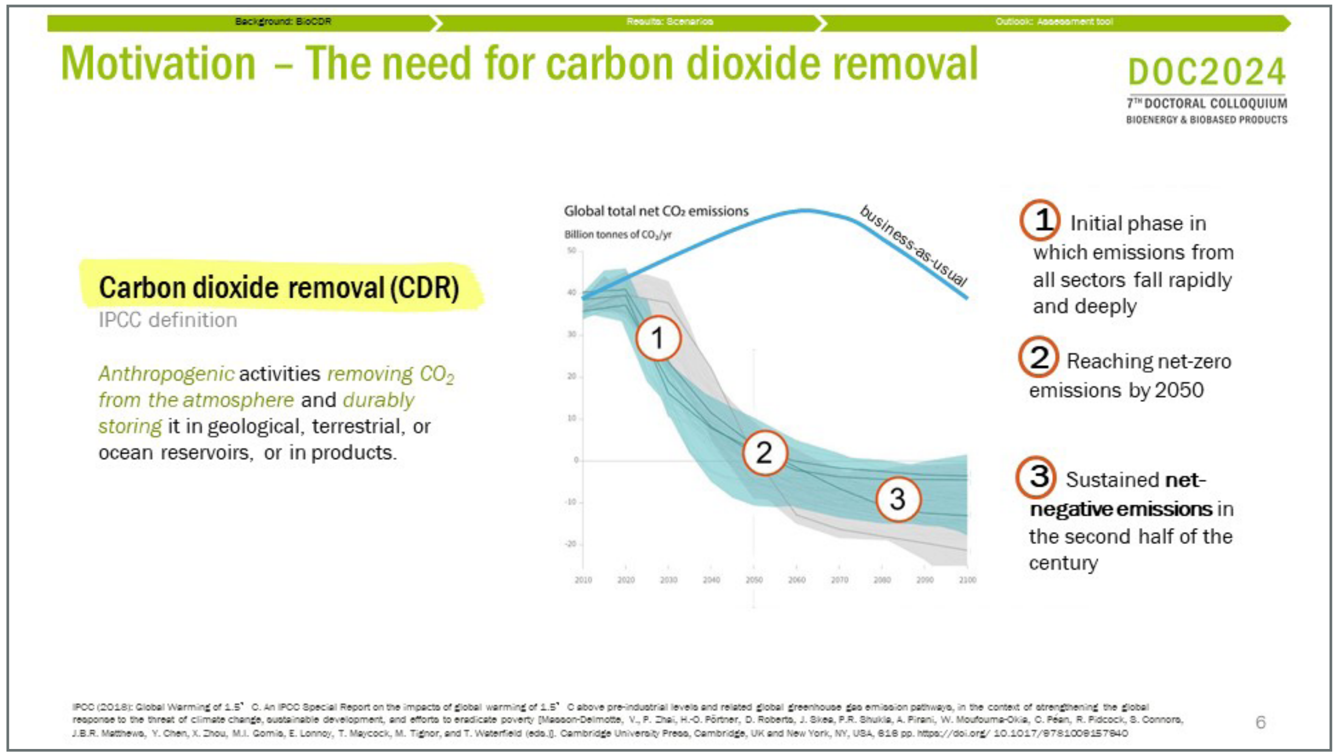


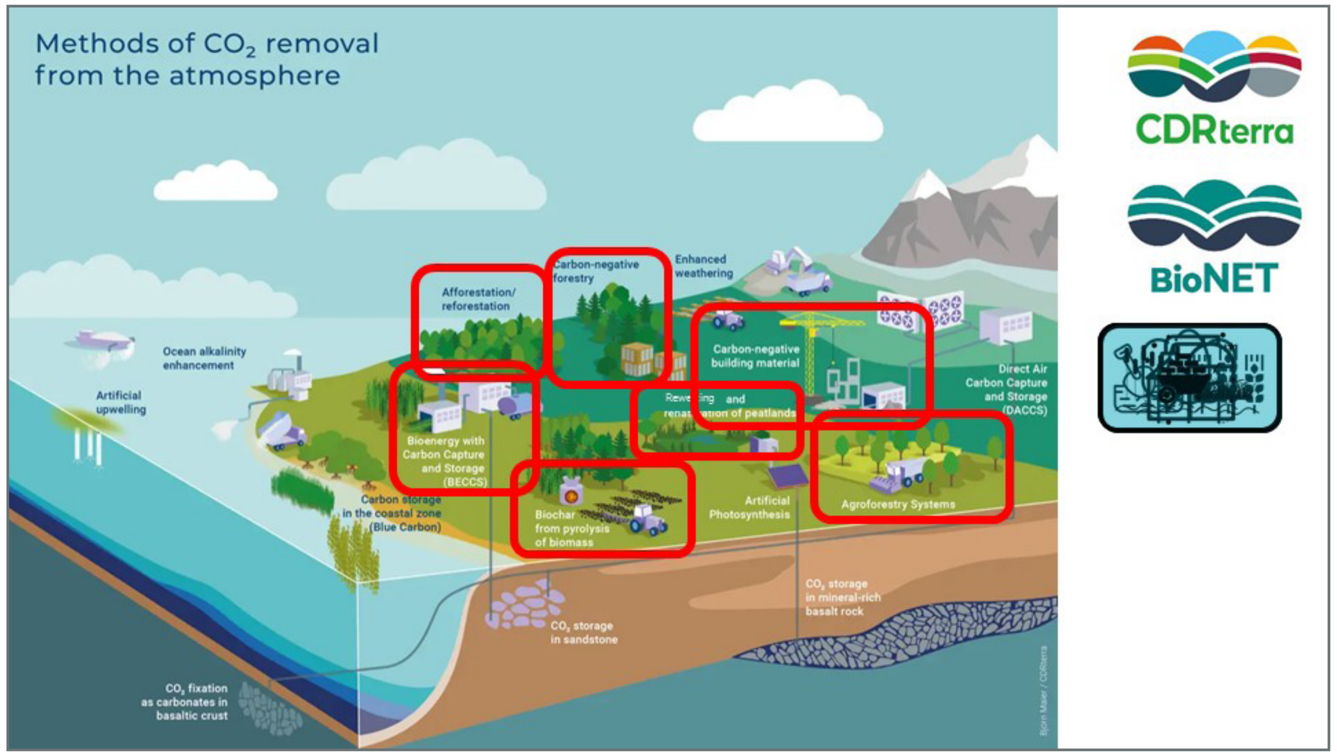




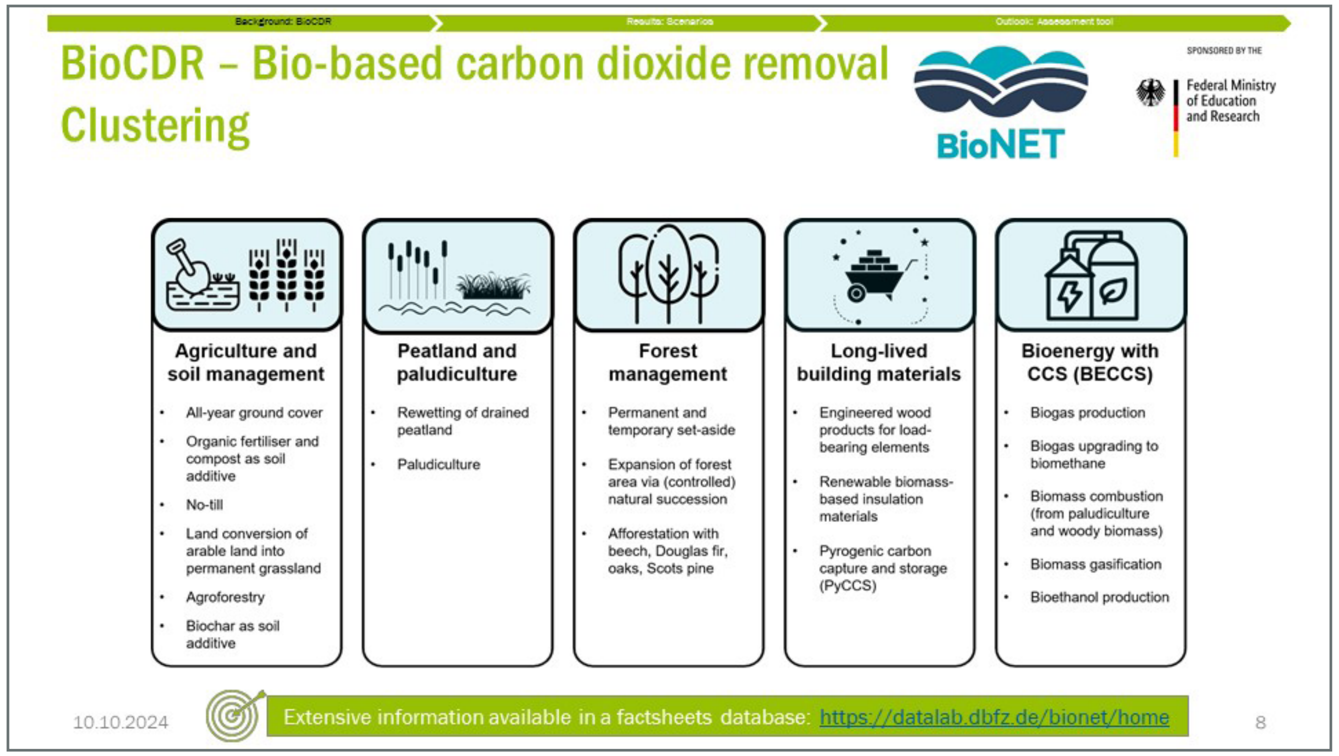


Title of the Doctoral Project:	Decision support for the regional integration of bio-based carbon dioxide removal in Germany
Doctoral Student:	Ronja Wollnik
DBFZ Supervisor:	Dr. Nora Szarka
Cooperating University:	Leipzig University
University Supervisor:	Prof. Daniela Thrän
Funding:	DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH
Duration:	06/2024 – 06/2028





Methods of CO_2 removal from the atmosphere
CDRterra
BioNET
Afforestation/ reforestation
Carbon-negative forestry
Enhanced weathering
Carbon-negative building material
Direct Air Carbon Capture and Storage (DACCS)
Ocean alkalinity enhancement
Artificial upwelling
Bioenergy with Carbon Capture and Storage (BECCS)
Carbon storage in the coastal zone (Blue Carbon)
Biochar from pyrolysis of biomass
Artificial Photosynthesis
Agroforestry Systems
CO_2 storage in mineral-rich basalt rock
CO_2 storage in sandstone
CO_2 fixation as carbonates in basaltic crust



Background: BioCDR
Results: Scenarios
Outlook: Assessment tool
BioCDR – Bio-based carbon dioxide removal
Clustering
BioNET
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Agriculture and soil management
All-year ground cover
Organic fertiliser and compost as soil additive
No-till
Land conversion of arable land into permanent grassland
Agroforestry
Biochar as soil additive
Peatland and paludiculture
Rewetting of drained peatland
Paludiculture
Forest management
Permanent and temporary set-aside
Expansion of forest area via (controlled) natural succession
Afforestation with beech, Douglas fir, oaks, Scots pine
Long-lived building materials
Engineered wood products for load-bearing elements
Renewable biomass-based insulation materials
Pyrogenic carbon capture and storage (PyCCS)
Bioenergy with CCS (BECCS)
Biogas production
Biogas upgrading to biomethane
Biomass combustion (from paludiculture and woody biomass)
Biomass gasification
Bioethanol production
10.10.2024
Extensive information available in a factsheets database: https://datalab.dbfz.de/bionet/home
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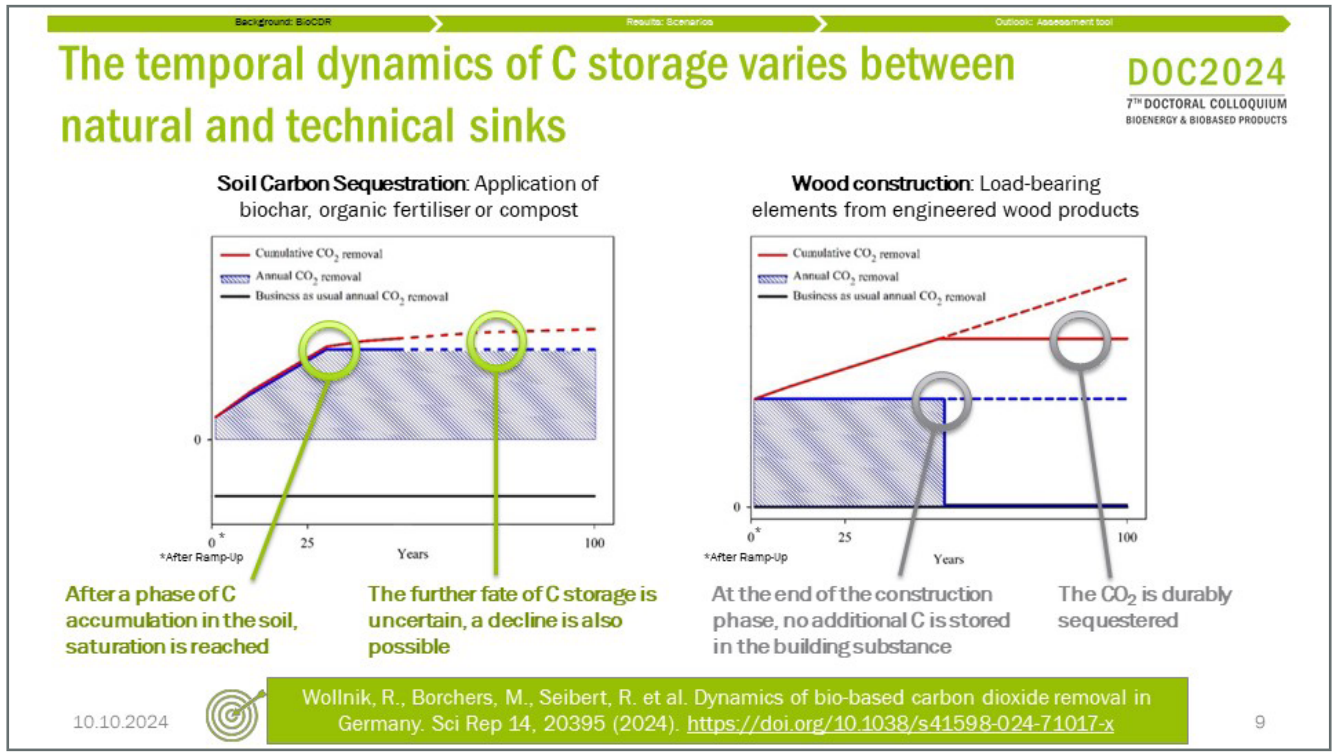

Background: BioCDR
Results: Scenarios
Outlook: Assessment tool
The temporal dynamics of C storage varies between natural and technical sinks
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Soil Carbon Sequestration: Application of biochar, organic fertiliser or compost
Wood construction: Load-bearing elements from engineered wood products
Cumulative CO_2 removal
Annual CO_2 removal
Business as usual annual CO_2 removal
0
0*
25
Years
100
*After Ramp-Up
After a phase of C accumulation in the soil, saturation is reached
The further fate of C storage is uncertain, a decline is also possible
At the end of the construction phase, no additional C is stored in the building substance
The CO_2 is durably sequestered
10.10.2024
Wollnik, R., Borchers, M., Seibert, R. et al. Dynamics of bio-based carbon dioxide removal in Germany. Sci Rep 14, 20395 (2024). https://doi.org/10.1038/s41598-024-71017-x
9

Results – Scenarios for bioCDR
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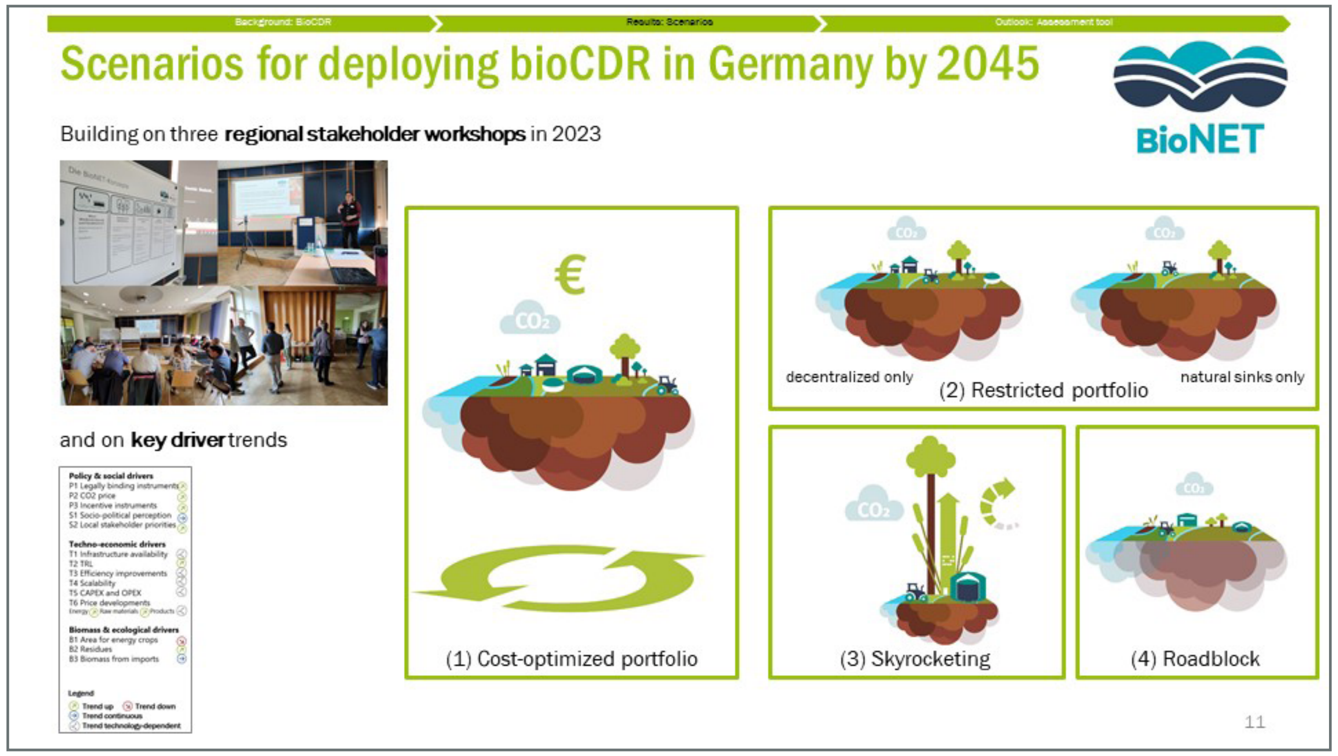
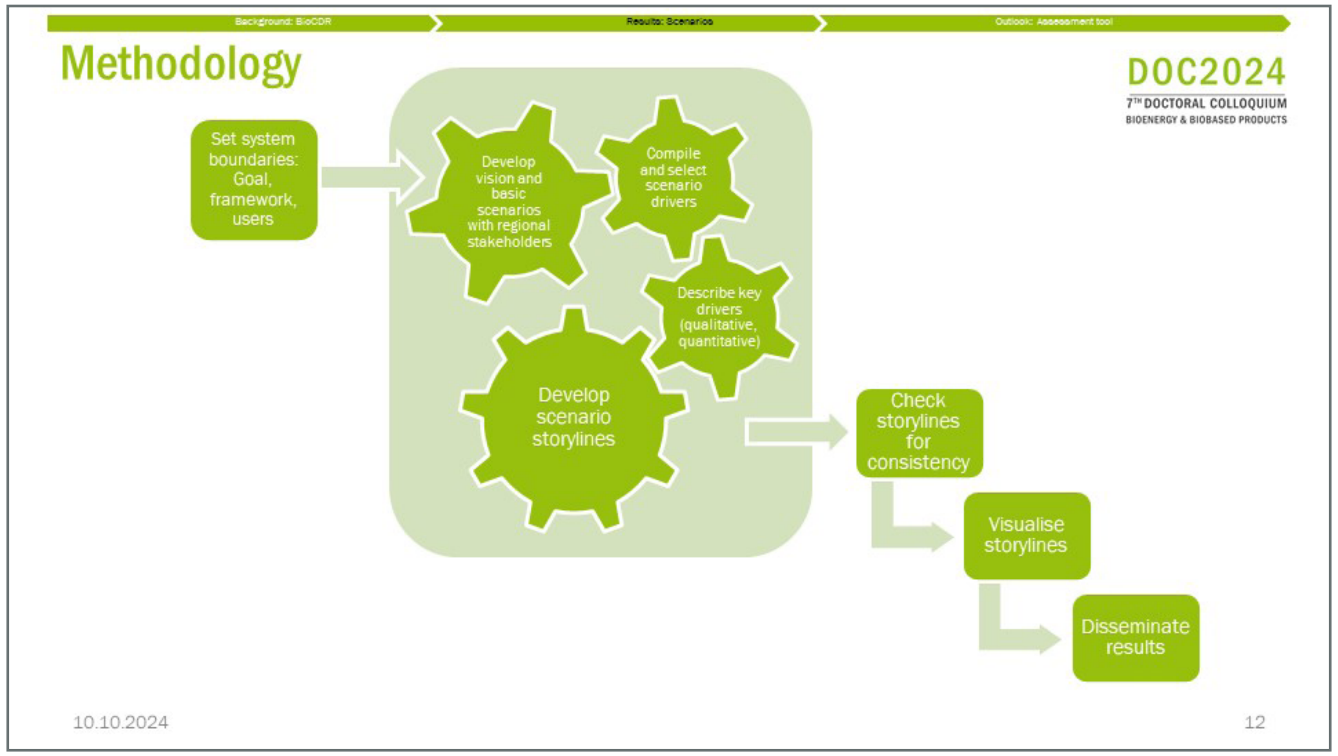
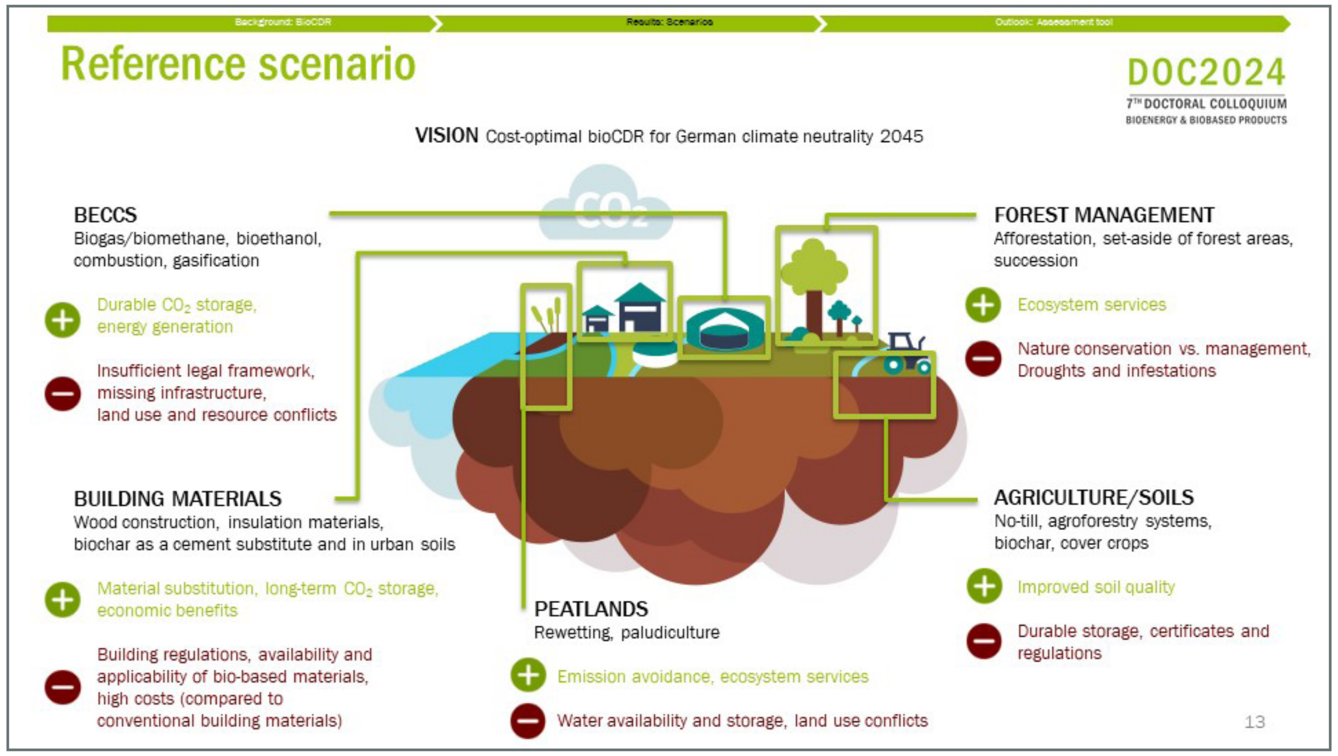
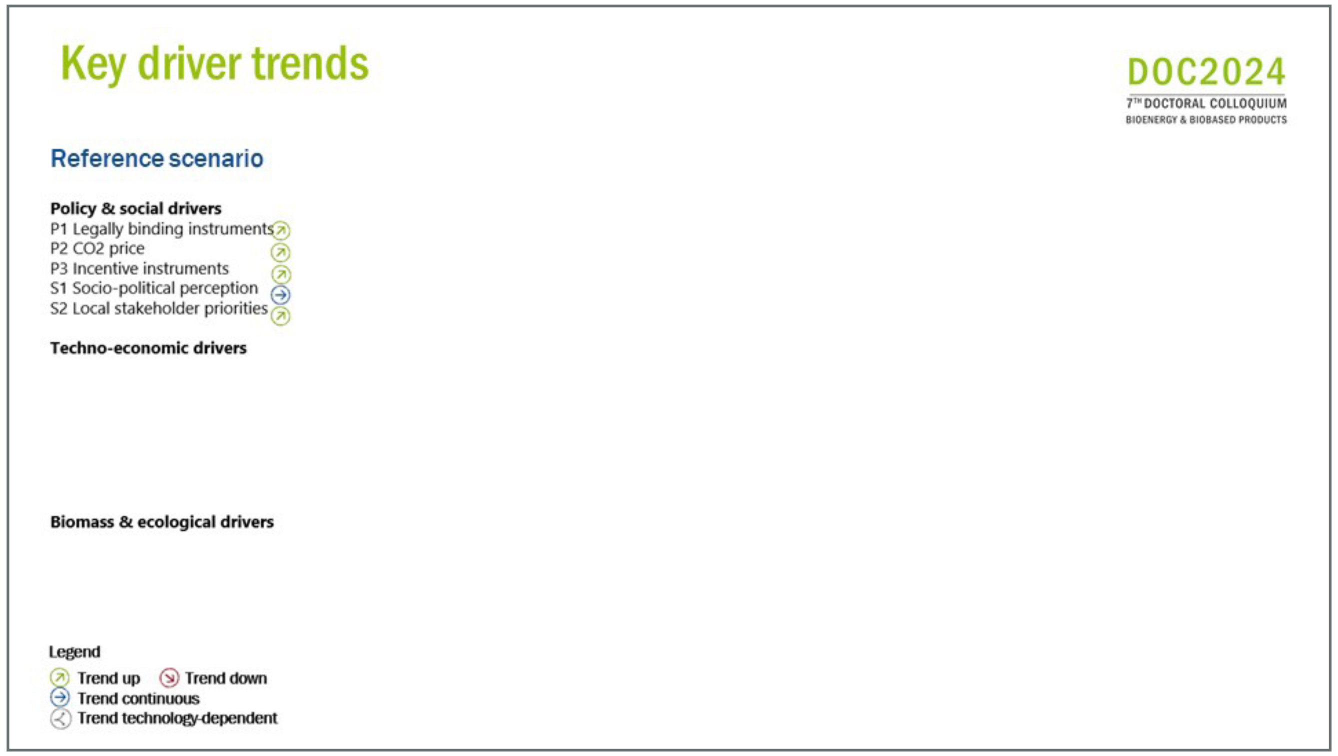

Background: BioCDR
Results: Scenarios
Outlook: Assessment tool
Scenarios for deploying bioCDR in Germany by 2045
BioNET
Building on three regional stakeholder workshops in 2023
and on key driver trends
€
CO_2
(1) Cost-optimized portfolio
decentralized only
(2) Restricted portfolio
natural sinks only
(3) Skyrocketing
(4) Roadblock
11


Background: BioCDR
Results: Scenarios
Outlook: Assessment tool
Methodology
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Set system boundaries: Goal, framework, users
Develop vision and basic scenarios with regional stakeholders
Compile and select scenario drivers
Describe key drivers (qualitative, quantitative)
Develop scenario storylines
Check storylines for consistency
Visualise storylines
Disseminate results
10.10.2024
12


Background: BioCDR
Results: Scenarios
Outlook: Assessment tool
Reference scenario
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
VISION Cost-optimal bioCDR for German climate neutrality 2045
BECCS
Biogas/biomethane, bioethanol, combustion, gasification
Durable CO_2 storage, energy generation
Insufficient legal framework, missing infrastructure, land use and resource conflicts
BUILDING MATERIALS
Wood construction, insulation materials, biochar as a cement substitute and in urban soils
Material substitution, long-term CO_2 storage, economic benefits
Building regulations, availability and applicability of bio-based materials, high costs (compared to conventional building materials)
PEATLANDS
Rewetting, paludiculture
Emission avoidance, ecosystem services
Water availability and storage, land use conflicts
FOREST MANAGEMENT
Afforestation, set-aside of forest areas, succession
Ecosystem services
Nature conservation vs. management, Droughts and infestations
AGRICULTURE/SOILS
No-till, agroforestry systems, biochar, cover crops
Improved soil quality
Durable storage, certificates and regulations
13


Key driver trends
DOC2024
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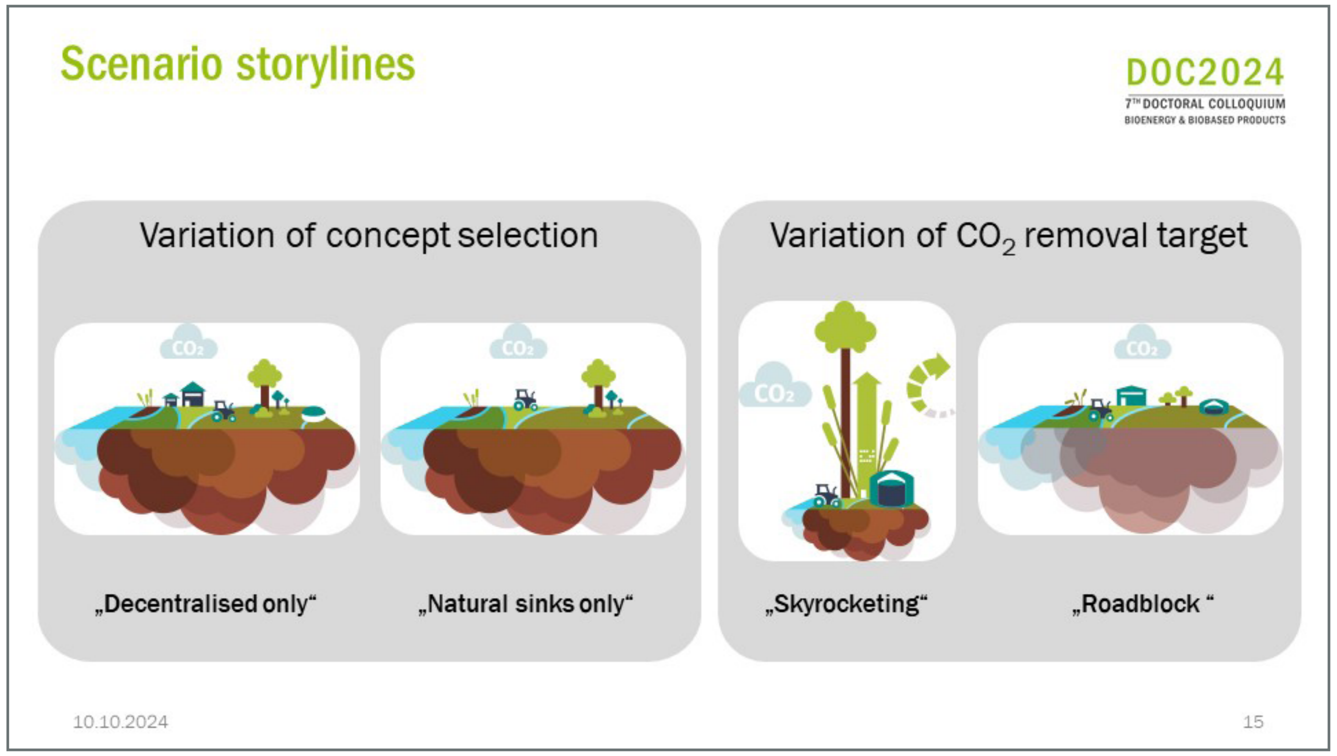
BIOENERGY & BIOBASED PRODUCTS
Reference scenario
Policy & social drivers
P1 Legally binding instruments
P2 CO2 price
P3 Incentive instruments
S1 Socio-political perception
S2 Local stakeholder priorities
Techno-economic drivers
Biomass & ecological drivers
Legend
Trend up
Trend down
Trend continuous
Trend technology-dependent


Scenario storylines
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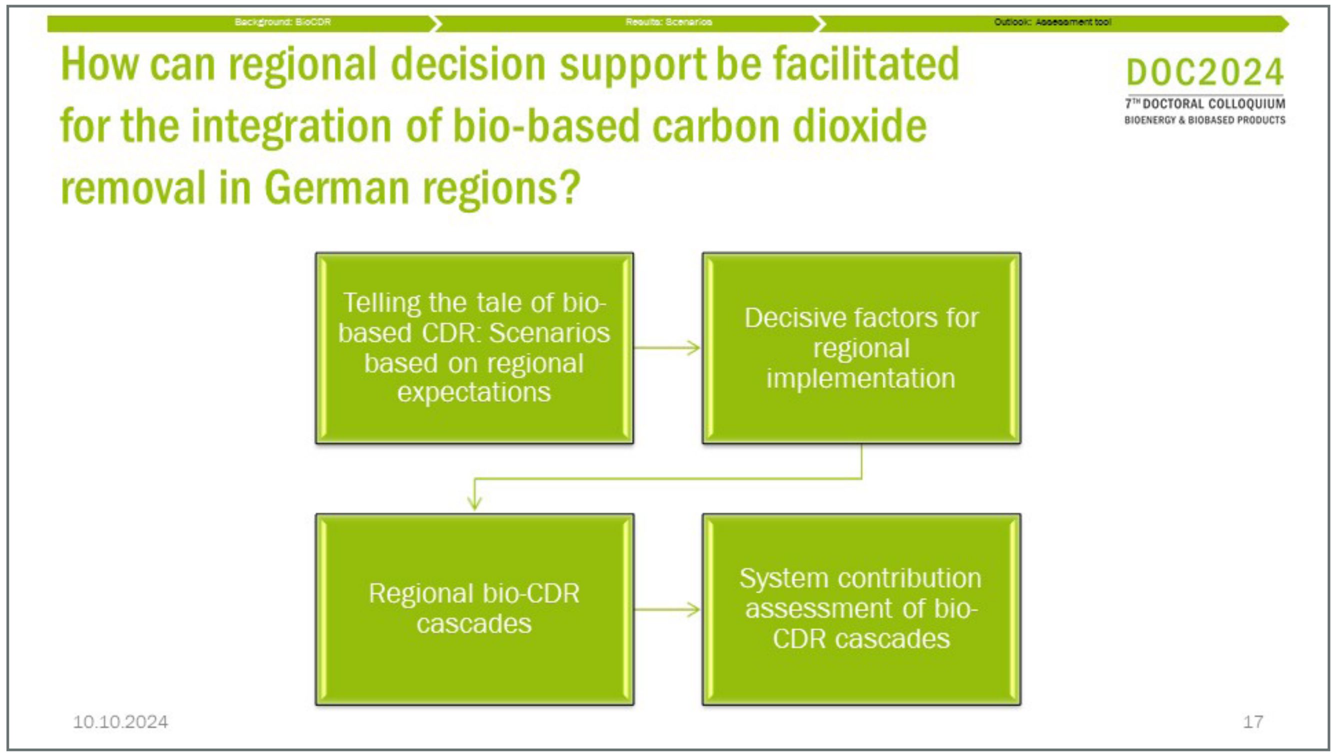
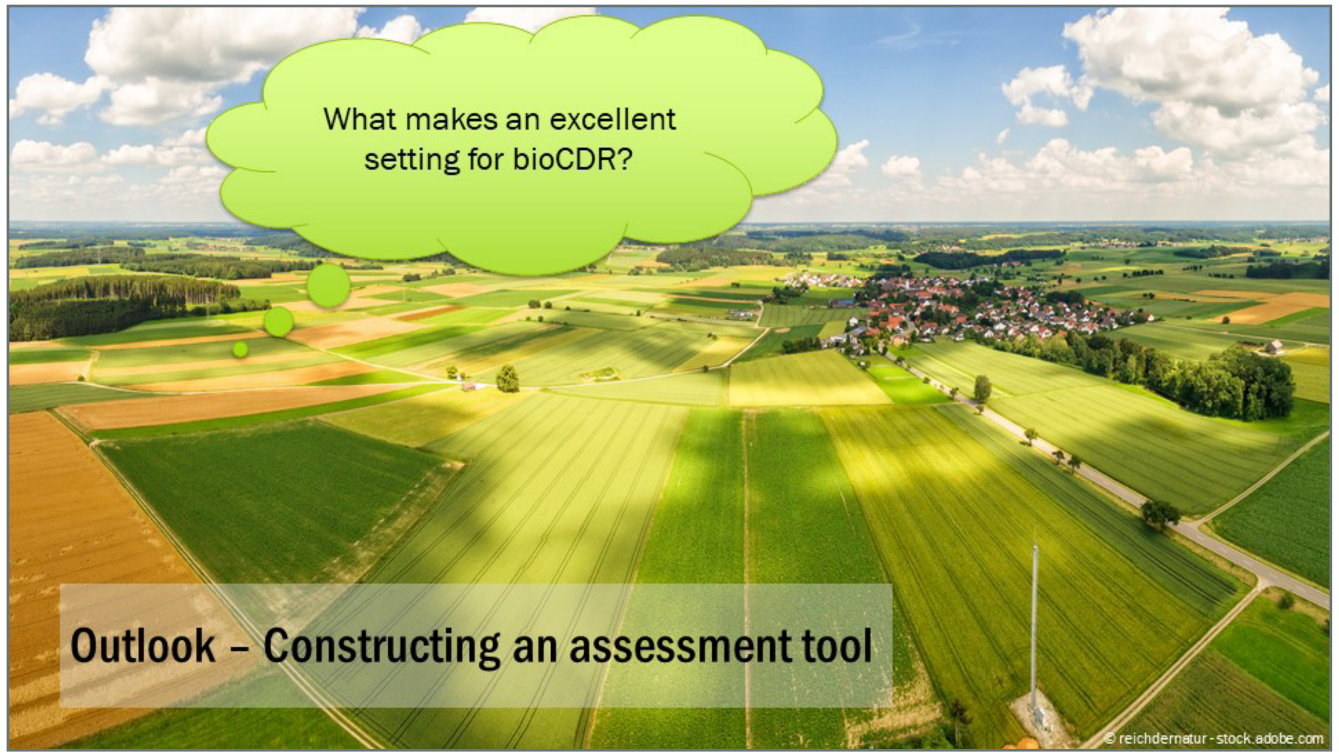
BIOENERGY & BIOBASED PRODUCTS
Variation of concept selection
Variation of CO2 removal target
„Decentralised only“
„Natural sinks only“
„Skyrocketing“
„Roadblock “
10.10.2024
15


How can regional decision support be facilitated for the integration of bio-based carbon dioxide removal in German regions?
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Telling the tale of bio-based CDR: Scenarios based on regional expectations
Decisive factors for regional implementation
Regional bio-CDR cascades
System contribution assessment of bio-CDR cascades
10.10.2024
17


What makes an excellent setting for bioCDR?
Outlook – Constructing an assessment tool
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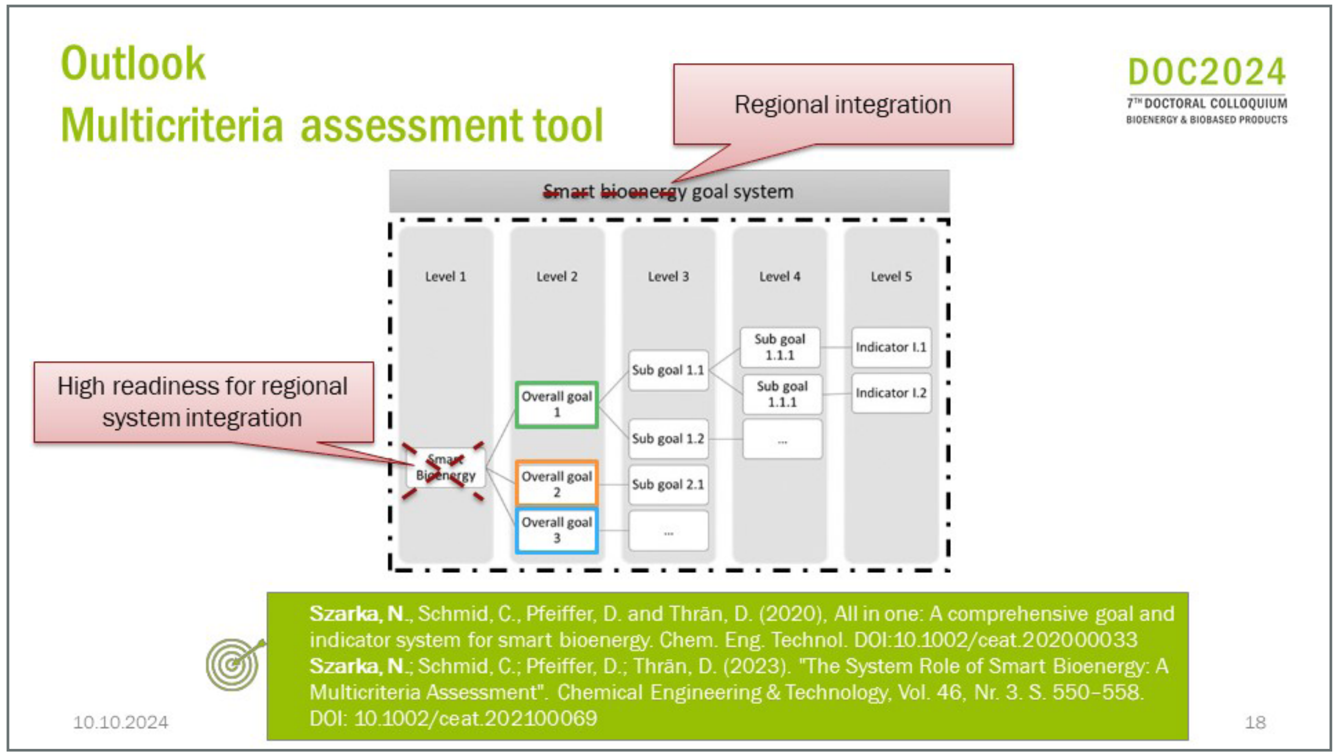
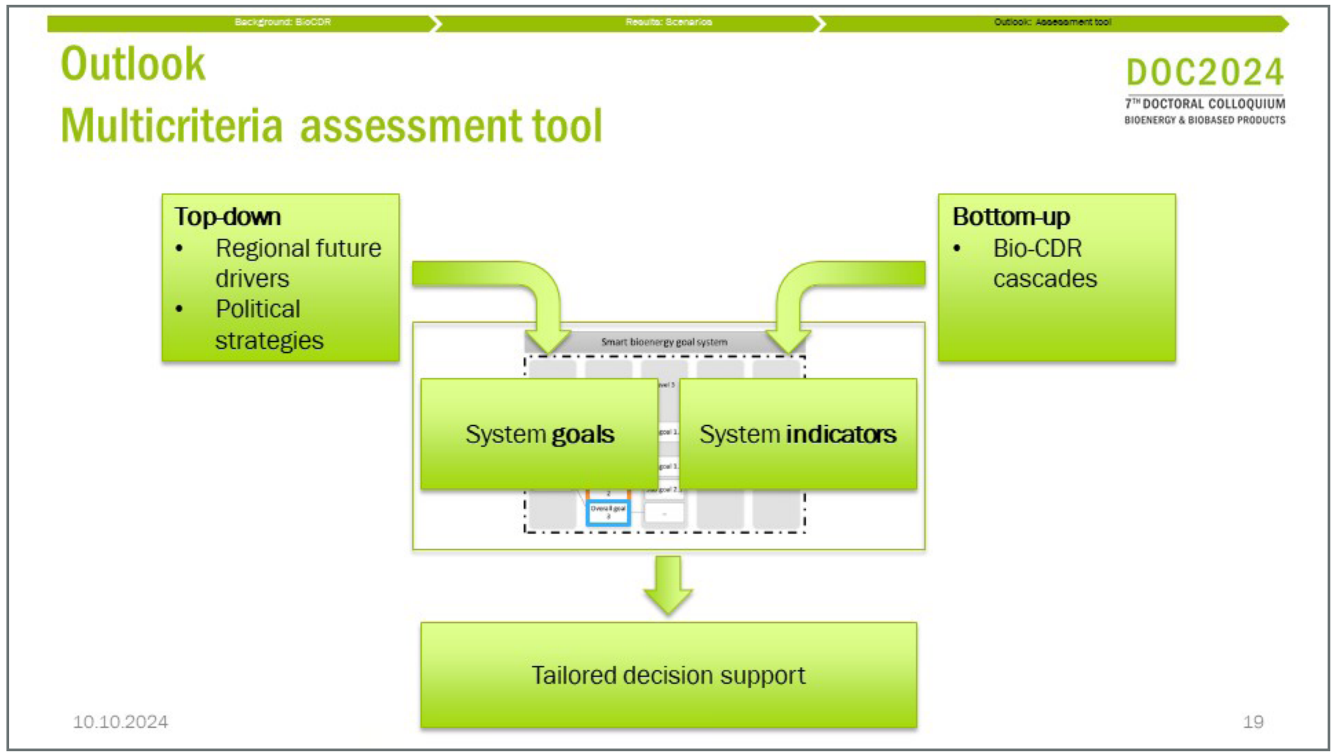
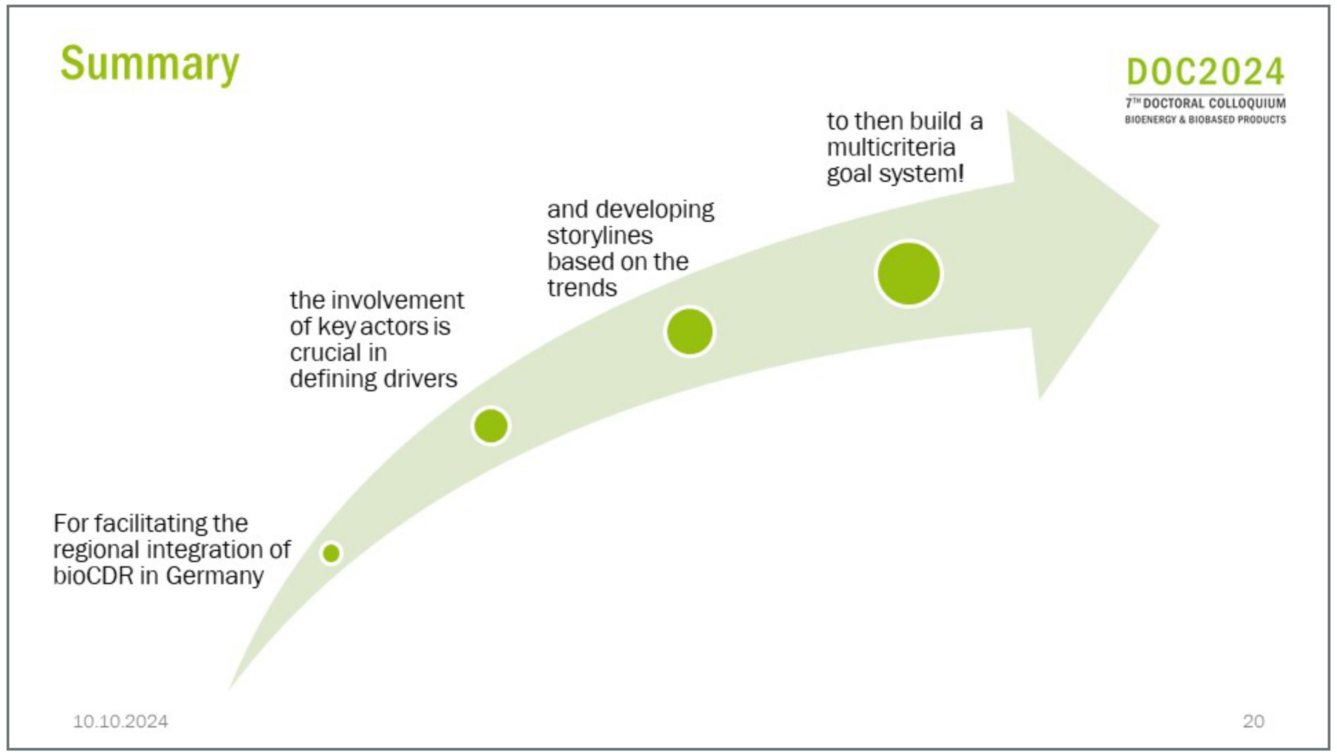

Outlook
Multicriteria assessment tool
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Regional integration
Smart bioenergy goal system
Level 1
Level 2
Level 3
Level 4
Level 5
High readiness for regional system integration
Overall goal 1
Overall goal 2
Overall goal 3
Sub goal 1.1
Sub goal 1.2
Sub goal 2.1
Sub goal 1.1.1
Indicator I.1
Indicator I.2
Szarka, N., Schmid, C., Pfeiffer, D. and Thrän, D. (2020), All in one: A comprehensive goal and indicator system for smart bioenergy. Chem. Eng. Technol. DOI:10.1002/ceat.202000033
Szarka, N.; Schmid, C.; Pfeiffer, D.; Thrän, D. (2023). "The System Role of Smart Bioenergy: A Multicriteria Assessment". Chemical Engineering & Technology, Vol. 46, Nr. 3. S. 550–558. DOI: 10.1002/ceat.202100069
10.10.2024
18


Background: BioCDR
Results: Scenarios
Outlook: Assessment tool
Outlook
Multicriteria assessment tool
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Top-down
• Regional future drivers
• Political strategies
Bottom-up
• Bio-CDR cascades
Smart bioenergy goal system
System goals
System indicators
Tailored decision support
10.10.2024
19


Summary
DOC2024
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BIOENERGY & BIOBASED PRODUCTS
For facilitating the regional integration of bioCDR in Germany
the involvement of key actors is crucial in defining drivers
and developing storylines based on the trends
to then build a multicriteria goal system!
10.10.2024
20


DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
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KEYNOTE DAY II

7TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Piero Venturi, European Commission

RTD policies and funding opportunities at EU level

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Directorate General for Research and Innovation
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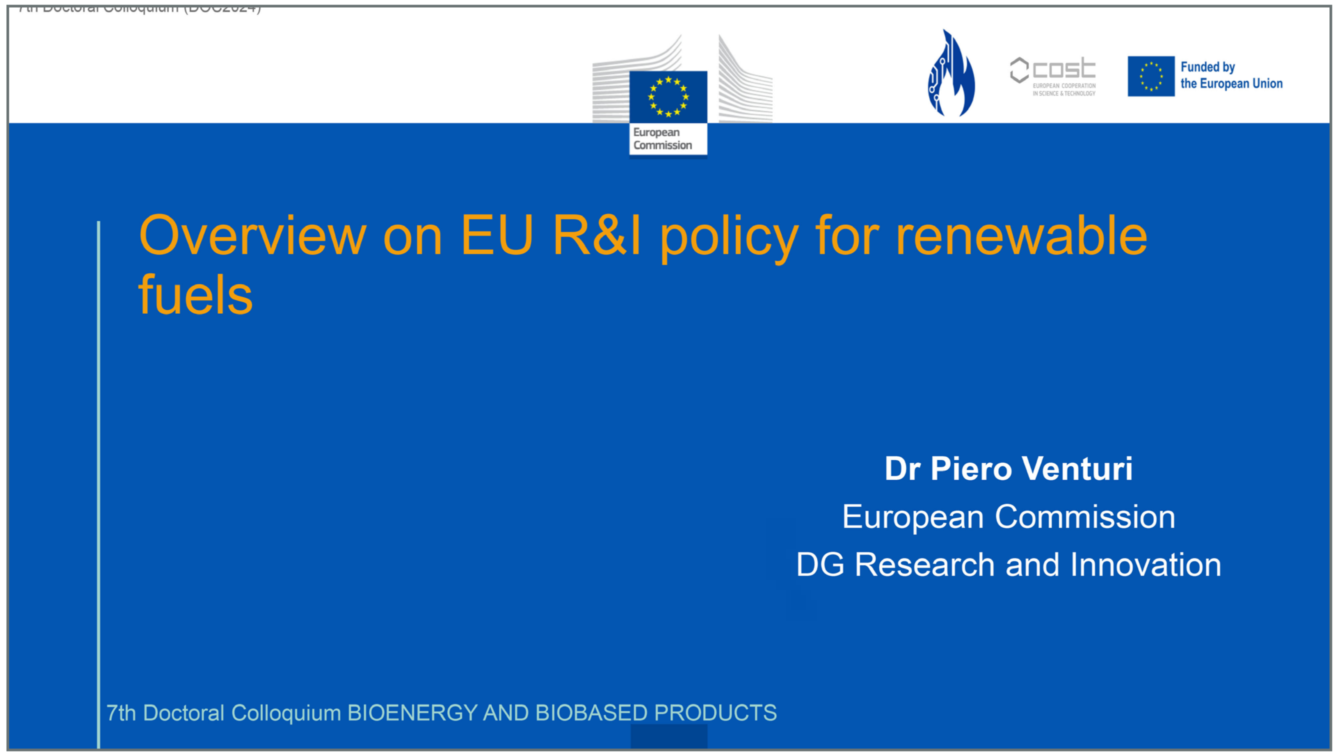
Keywords: EU, Green Deal, Horizon Europe, Clean Energy Transition Partnership

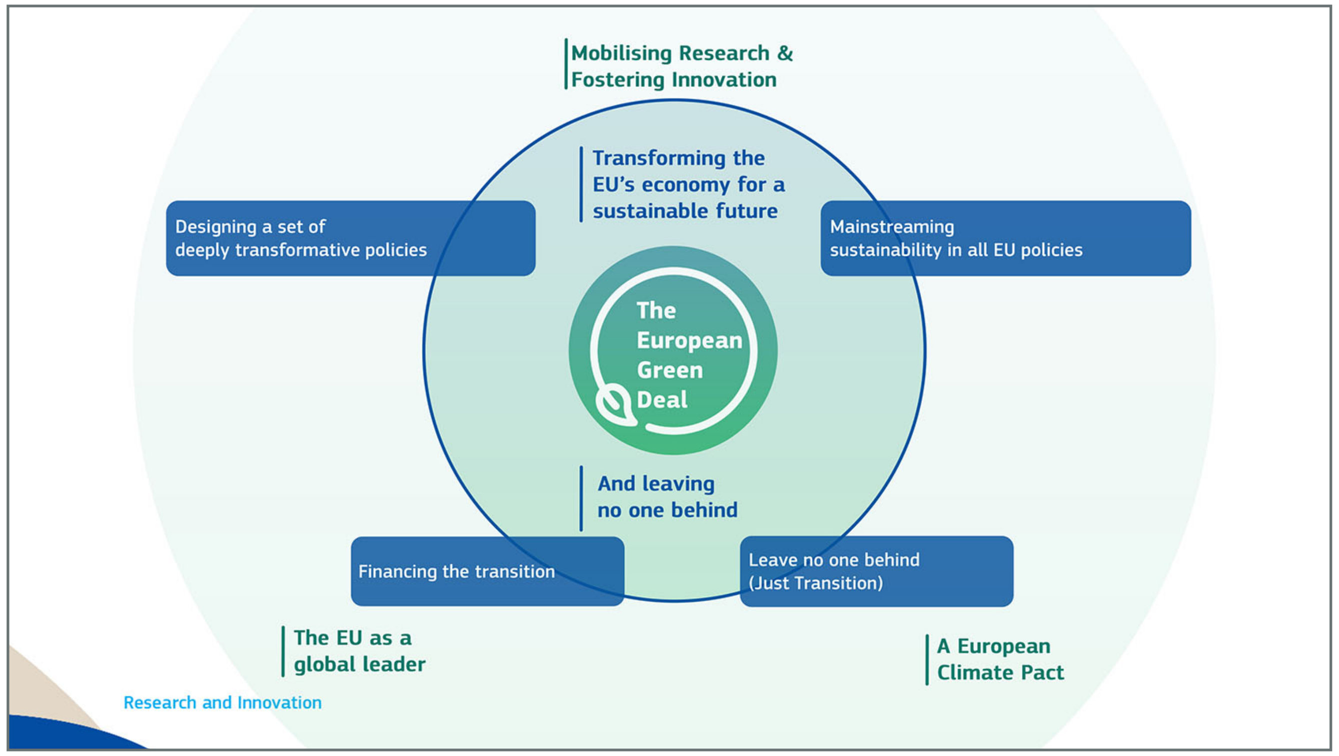
The presentation will analyse the political background behind European Commission's programme on R&I for biomass and renewables. The European Green Deal's concept paved the way to several actions. At present the 'second van der Leyen Commission' is considering a more industry oriented approach. Horizon Europe is the R&I framework programme of the EC and will last until 2027 with a total budget of 1000 billion Euros.

Other platforms could provide opportunities for participating to calls for projects on Renewables as the Clean Energy Transition Partnership (CETP) and the Integrated Biorefinery Mission of Mission Innovation. Finally, few thoughts about the interaction between Science and Policy will be given.

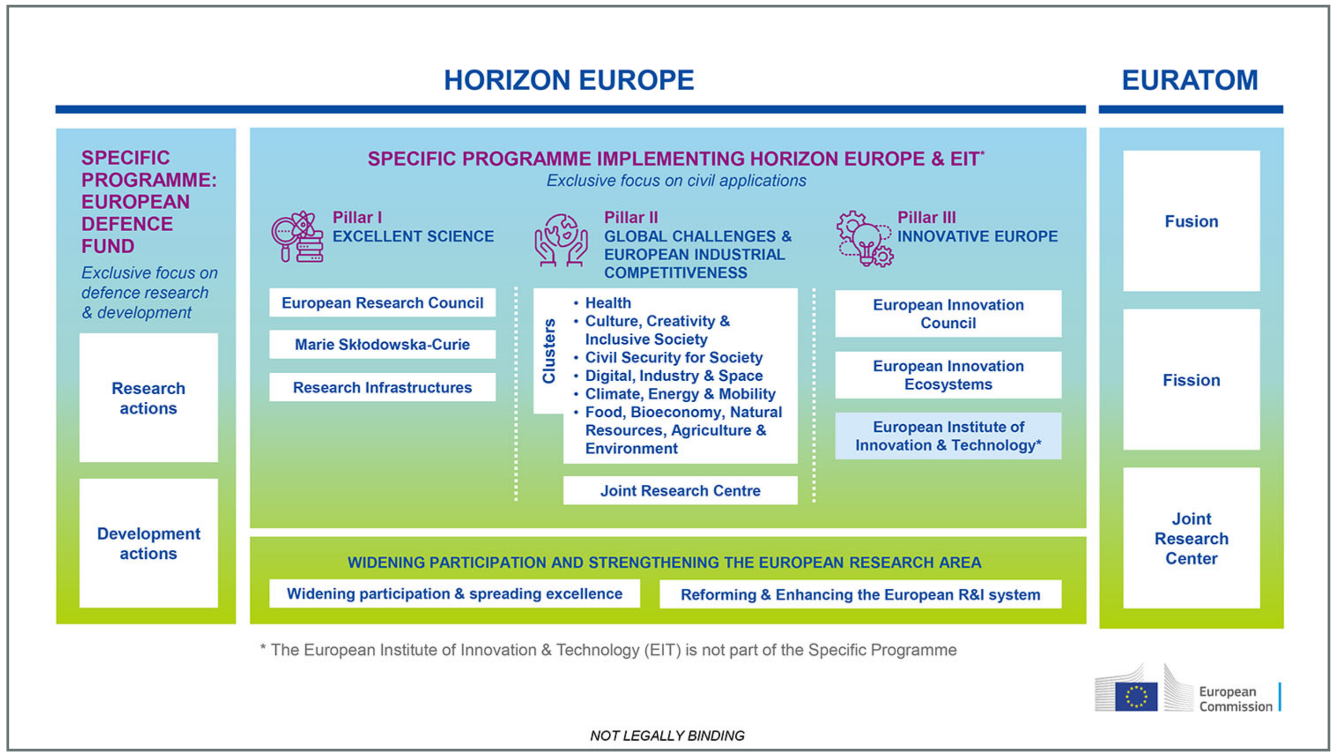



Cost of non-action on environment, health, economy
European Commission
What if we do not act?
The European Green Deal
"The cost of the transition will be big, but the cost of non-action will be much bigger."
Ursula von der Leyen, President of the European Commission
Without action on climate change, the EU will see, in the lifetime of our children:
Pollution
400,000
per year today due to air pollution. This figure is expected to soar
Heat and drought
90,000
660,000
16%
Water and flooding
40%
in southern regions of the European Union
Half a million
2.2 million
Economics
€190 billion
50 million
20%
€40 billion
The longer we wait, the harder it becomes to reach low temperature targets and the more expensive the necessary efforts will become.


Designing a set of deeply transformative policies
The European Green Deal
CLIMATE PACT AND CLIMATE LAW
INVESTING IN SMARTER, MORE SUSTAINABLE TRANSPORT
STRIVING FOR GREENER INDUSTRY
ELIMINATING POLLUTION
ENSURING A JUST TRANSITION FOR ALL
FINANCING GREEN PROJECTS
MAKING HOMES ENERGY EFFICIENT
LEADING THE GREEN CHANGE GLOBALLY
FROM FARM TO FORK
PROTECTING NATURE
PROMOTING CLEAN ENERGY
Research and Innovation


Mobilising Research & Fostering Innovation
Transforming the EU's economy for a sustainable future
Designing a set of deeply transformative policies
Mainstreaming sustainability in all EU policies
The European Green Deal
And leaving no one behind
Financing the transition
Leave no one behind (Just Transition)
The EU as a global leader
A European Climate Pact
Research and Innovation


European Commission
#HorizonEU
HORIZON EUROPE
THE EU RESEARCH & INNOVATION PROGRAMME 2021 – 27
#EUGreenDeal
Research and Innovation


HORIZON EUROPE
EURATOM
SPECIFIC PROGRAMME: EUROPEAN DEFENCE FUND
Exclusive focus on defence research & development
Research actions
Development actions
SPECIFIC PROGRAMME IMPLEMENTING HORIZON EUROPE & EIT*
Exclusive focus on civil applications
Pillar I
EXCELLENT SCIENCE
Pillar II
GLOBAL CHALLENGES & EUROPEAN INDUSTRIAL COMPETITIVENESS
Pillar III
INNOVATIVE EUROPE
European Research Council
Marie Skłodowska-Curie
Research Infrastructures
Clusters
• Health
• Culture, Creativity & Inclusive Society
• Civil Security for Society
• Digital, Industry & Space
• Climate, Energy & Mobility
• Food, Bioeconomy, Natural Resources, Agriculture & Environment
Joint Research Centre
European Innovation Council
European Innovation Ecosystems
European Institute of Innovation & Technology*
Fusion
Fission
Joint Research Center
WIDENING PARTICIPATION AND STRENGTHENING THE EUROPEAN RESEARCH AREA
Widening participation & spreading excellence
Reforming & Enhancing the European R&I system
* The European Institute of Innovation & Technology (EIT) is not part of the Specific Programme
European Commission
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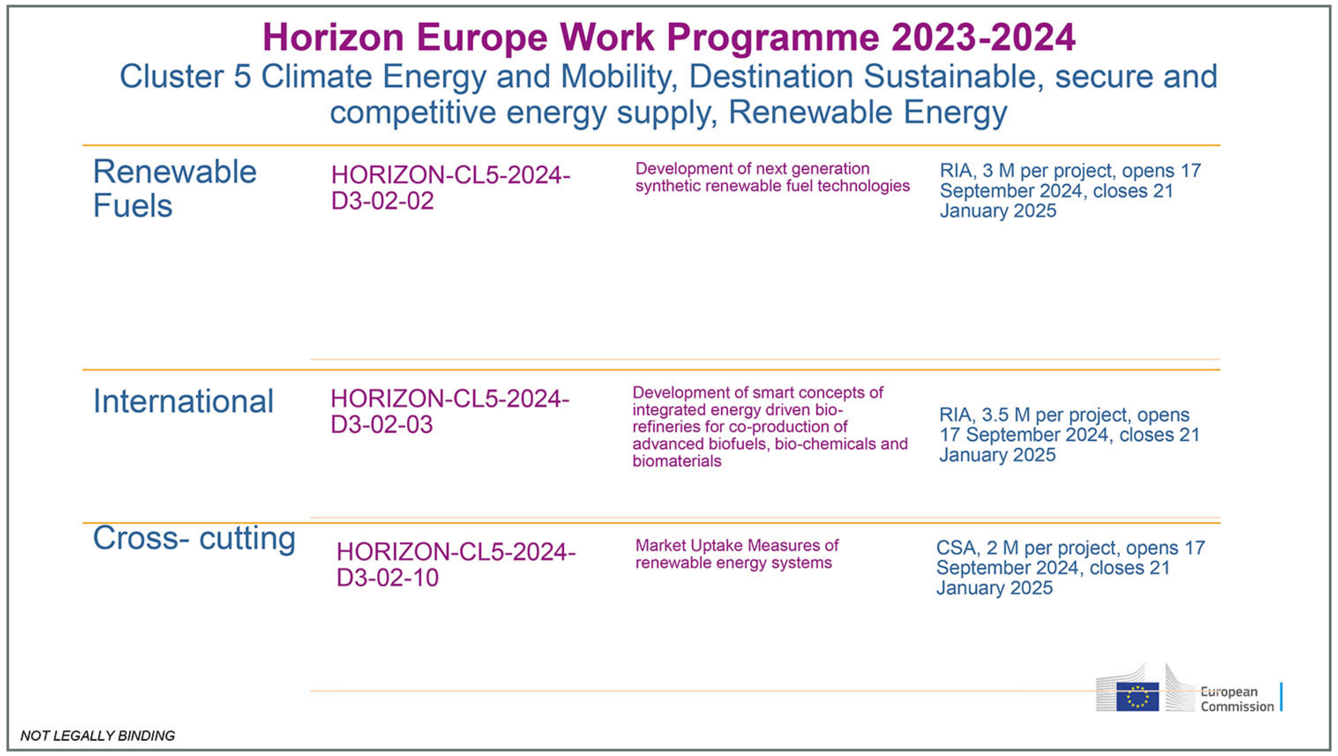
Horizon Europe Work Programme 2023-2024
Cluster 5 Climate Energy and Mobility, Destination Sustainable, secure and competitive energy supply, Renewable Energy
Renewable Fuels
HORIZON-CL5-2024-D3-02-02
Development of next generation synthetic renewable fuel technologies
RIA, 3 M per project, opens 17 September 2024, closes 21 January 2025
International
HORIZON-CL5-2024-D3-02-03
Development of smart concepts of integrated energy driven bio-refineries for co-production of advanced biofuels, bio-chemicals and biomaterials
RIA, 3.5 M per project, opens 17 September 2024, closes 21 January 2025
Cross- cutting
HORIZON-CL5-2024-D3-02-10
Market Uptake Measures of renewable energy systems
CSA, 2 M per project, opens 17 September 2024, closes 21 January 2025
European Commission
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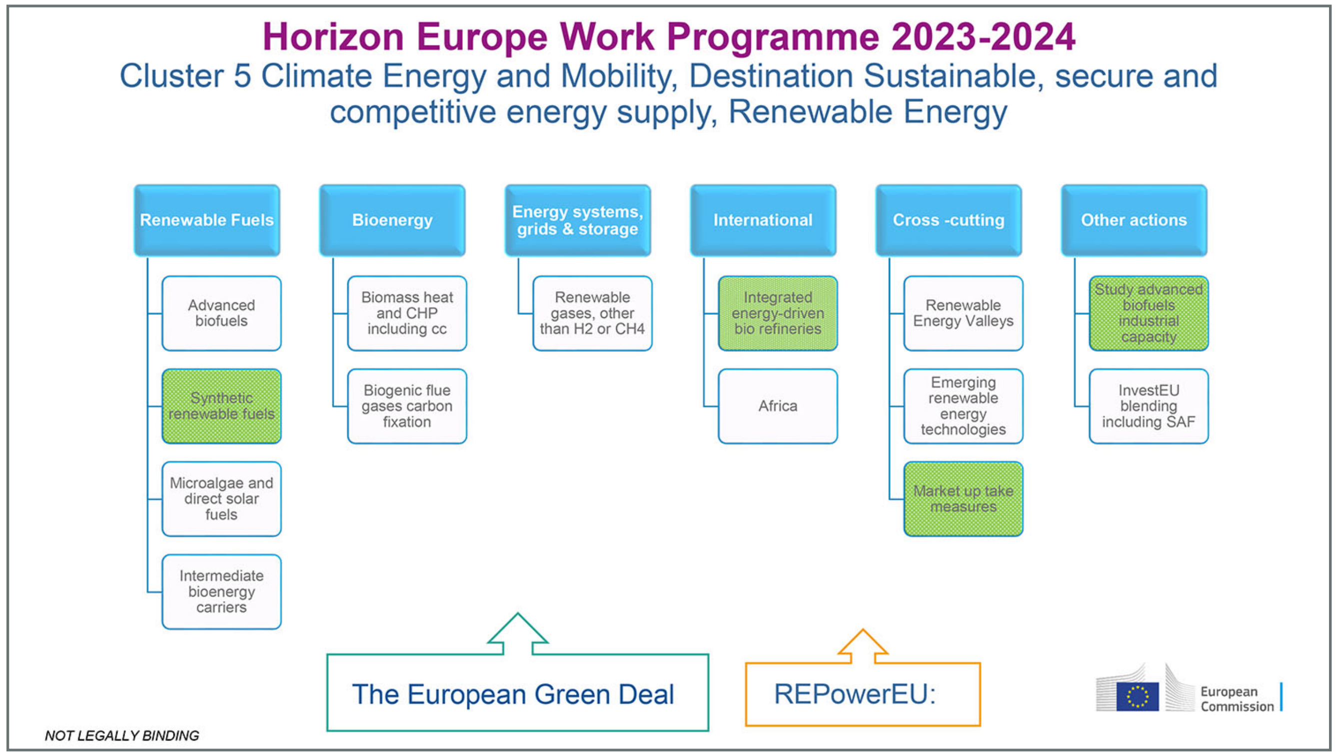
Horizon Europe Work Programme 2023-2024
Cluster 5 Climate Energy and Mobility, Destination Sustainable, secure and competitive energy supply, Renewable Energy
Renewable Fuels
Bioenergy
Energy systems, grids & storage
International
Cross -cutting
Other actions
Advanced biofuels
Synthetic renewable fuels
Microalgae and direct solar fuels
Intermediate bioenergy carriers
Biomass heat and CHP including cc
Biogenic flue gases carbon fixation
Renewable gases, other than H2 or CH4
Integrated energy-driven bio refineries
Africa
Renewable Energy Valleys
Emerging renewable energy technologies
Market up take measures
Study advanced biofuels industrial capacity
InvestEU blending including SAF
The European Green Deal
REPowerEU:
European Commission
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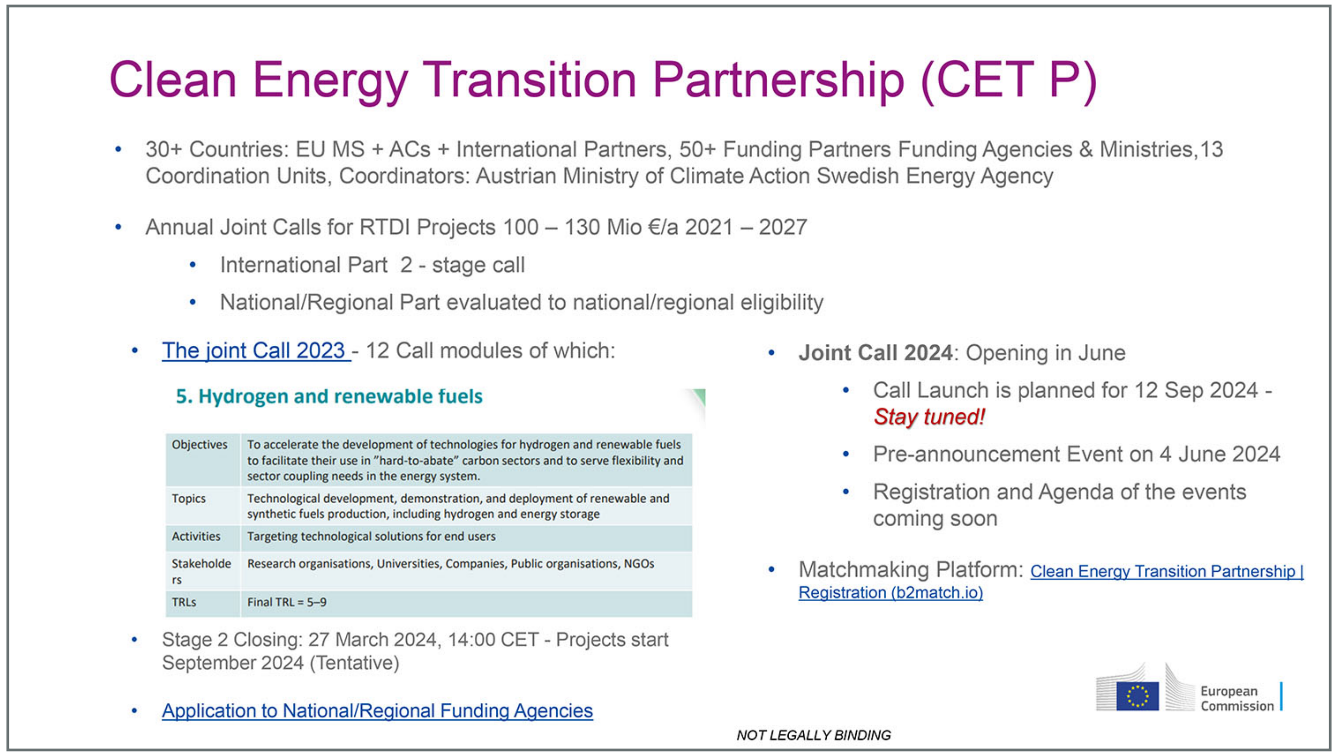
Clean Energy Transition Partnership (CET P)
• 30+ Countries: EU MS + ACs + International Partners, 50+ Funding Partners Funding Agencies & Ministries,13 Coordination Units, Coordinators: Austrian Ministry of Climate Action Swedish Energy Agency
• Annual Joint Calls for RTDI Projects 100 – 130 Mio €/a 2021 – 2027
• International Part 2 - stage call
• National/Regional Part evaluated to national/regional eligibility
• The joint Call 2023 - 12 Call modules of which:
5. Hydrogen and renewable fuels
Objectives | To accelerate the development of technologies for hydrogen and renewable fuels to facilitate their use in "hard-to-abate" carbon sectors and to serve flexibility and sector coupling needs in the energy system.
Topics | Technological development, demonstration, and deployment of renewable and synthetic fuels production, including hydrogen and energy storage
Activities | Targeting technological solutions for end users
Stakeholders | Research organisations, Universities, Companies, Public organisations, NGOs
TRLs | Final TRL = 5–9
• Stage 2 Closing: 27 March 2024, 14:00 CET - Projects start September 2024 (Tentative)
• Application to National/Regional Funding Agencies
• Joint Call 2024: Opening in June
• Call Launch is planned for 12 Sep 2024 - Stay tuned!
• Pre-announcement Event on 4 June 2024
• Registration and Agenda of the events coming soon
• Matchmaking Platform: Clean Energy Transition Partnership | Registration (b2match.io)
European Commission
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Mission Innovation 2.0 - Integrated Biorefineries Mission

Launched 4 April 2022

Develop and demonstrate innovative solutions to accelerate the commercialization of integrated biorefineries, with a target of replacing 10% of fossil-based fuels, chemicals and materials with bio-based alternatives by 2030

23 September 2022: Launch of the Integrated Biorefineries Mission Innovation Roadmap

Members will (a) promote research, development, and innovation across the biorefining supply and value chain, (b) advance pilot-scale demonstration projects for sustainable biorefining technologies, and (c) collaborate with industry and standards-setting organizations to support regulatory development for these new products

The Co -Leads	**India**: (Department of Biotechnology, Ministry of Science and Technology, Gov of India **Netherlands:** Ministry of Economic Affairs and Climate Policy
Members	Brazil, Canada, European Commission, United Kingdom
The Knowledge Partners	IEA, IEA Bioenergy (Task42), HLCAC, Nova Institute (Germany), CEM, Biofuture Initiative

European Commission

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Mission Integrated Biorefineries - Actions

3 Pillars	Research and Development	New products Improved efficiency	Workshops with Industry: Joint Research new products: Support efficiency improvement:: consortia for proposals to EU call
	Pilots and Demo	Showcase results Learn and Improve	Legislation and regulations: Integrated biorefinery business plan: Standards
	Market and Policies	Sustainability LCA and Carbon accounting	Collaboration with CEM Biofuture Campaign Collaboration with CEM Biofuture Campaign and UN LCA Initiative
Work Plan 2024	Increase deployment of innovative biorefineries for biofuels and chemicals	International collaboration with industries Matchmaking platform Financial instruments Possible joint calls	*Based on webinars and national consultations with industries, areas for collaboration will be identified and through the matchmaking tool and consultations with researchers and companies, collaboration will be initiated and executed, based on existing funding*
Bioresources in Missions and Initiatives	CEM Biofuture Initiative CEM Biofuture campaign with industry MI SAF Platform MI CDR/ BiCRS MI Zero Industries	Availability, Sustainability New Feedstocks Carbon Sequestration Fuels/ Chemicals SAF Carbon Storage Zero emission industries LCA	

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Renewable Fuels Horizon 2020 projects

From biomass residues and waste to drop-in aviation fuels

The transport sector guzzles liquid fuels. Hydrothermal liquefaction to produce feedstock-flexible advanced biofuels could slash global emissions.

HyFlexFuel - Hydrothermal liquefaction: Enhanced performance and feedstock flexibility for efficient biofuel production

COORDINATED BY Bauhaus Luftfahrt, Germany

H2020

Advanced process makes biodiesel greener, cheaper and competitive

Four newly developed technologies enhance the efficiency and effectiveness of biodiesel production from waste biomass through a biomethanol route.

CONVERGE - CarbON Valorisation in Energy-efficient Green fuels

COORDINATED BY The Polytechnic University of Milan, Italy

H2020

From domestic sewage waste to your gas tank: advanced biofuels from sewage

Naturally renewable, carbon-rich biogenic waste is turned into drop-in fuels for transport in the first industrial-scale demonstration of the process and product.

TO-SYN-FUEL - The Demonstration of Waste Biomass to Synthetic Fuels and Green Hydrogen

COORDINATED BY Fraunhofer Society for the Advancement of Applied Research, Germany

H2020

Exploiting available land to promote sustainable bioenergy in Europe

Freely accessible digital tool assesses the environmental, social and economic sustainability of producing biomass on marginal, underutilised and contaminated European lands, and finds great potential.

BIOPLAT-EU - Promoting sustainable use of underutilized lands for bioenergy production through a web-based Platform for Europe

COORDINATED BY WIP Renewable Energies, Germany

H2020

CORDIS results pack on renewable fuels - Publications Office of the EU (europa.eu)

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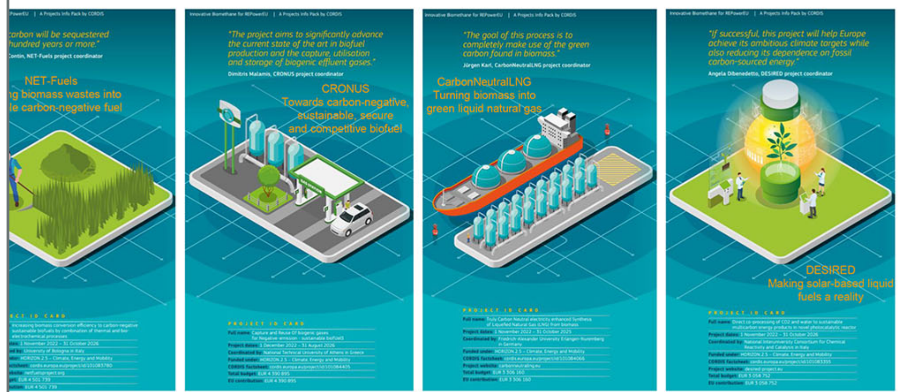
Carbon-negative Fuels Horizon Europe projects



- https://op.europa.eu/en/publication-detail/-/publication/c4651f9b-eaf2-11ed-a05c-01aa75ed71a1/language-en
  - video Innovative Biomethane for REPowerEU – A Cordis info Pack - YouTube

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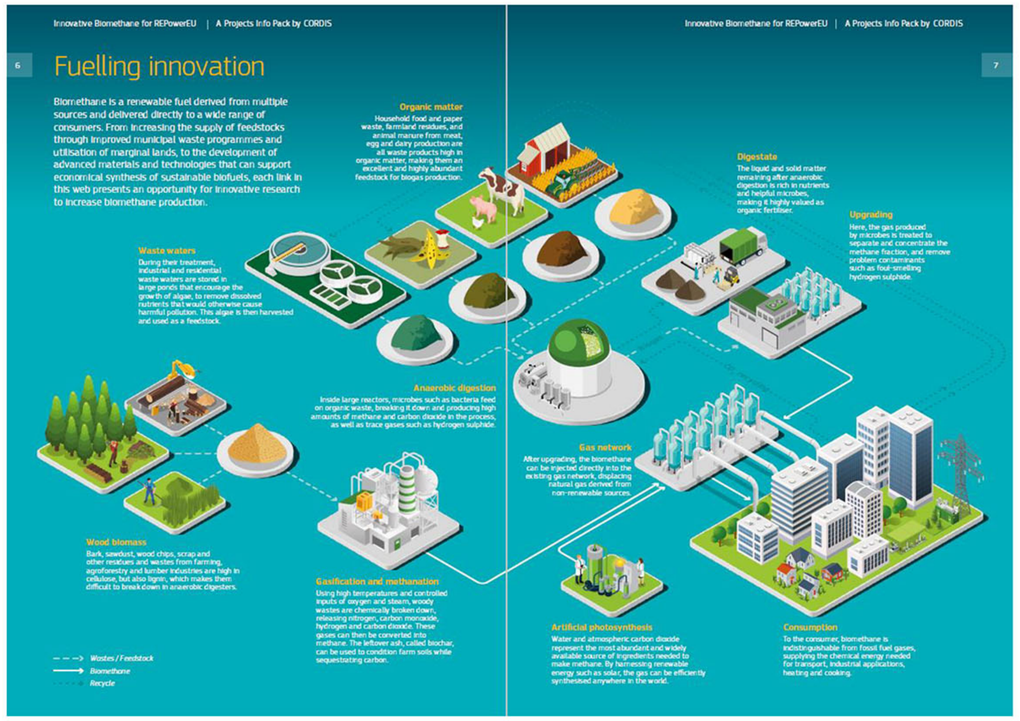

Innovative bio-methane production in the EU

European Commission

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Useful links

- **Horizon Europe Info Days – Cluster 5**

  Destination 3: Renewable solutions, Ocean energy, Carbon Capture and Utilisation (CCU)

  https://research-innovation-community.ec.europa.eu/events/4MjD45QEP6eLsP9j3MCEOc/programme

- **Horizon Europe Work Programme 2023-2024**

  8. Climate, Energy and Mobility

  https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2023-2024/wp-8-climate-energy-and-mobility_horizon-2023-2024_en.pdf

European Commission

The ~~three~~ four strands of science diplomacy

- **Diplomacy for Science**
  (= The use of diplomacy to foster international scientific cooperation)
- **Science for Diplomacy**
  (= The use of science to foster cooperation and good-will between nations)
- **Science in Diplomacy**
  (= The use of science to inform and advise foreign affairs policies)
- **Diplomacy in Science**
  (= The use of diplomatic instruments by science, such as restrictive measures)

The Royal Society / AAAS: New frontiers in science diplomacy – Navigating the changing balance of power, January 2010

European Commission

Thank you!

#HorizonEU

http://ec.europa.eu/horizon-europe

DG Research and Innovation: @EUScienceInnov @EU_H2020

https://www.facebook.com/EUScienceInnov/

The support of the COST Action CYPHER CA22151 and of the European Cooperation in Science and Technology (COST) association is acknowledged

Funded by the European Union

SESSION

BIOCHEMICAL CONVERSION

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

7TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Naga Sai Tejaswi Uppuluri, University of Hohenheim

Towards a Phos-for-us Sustainable future: Enhancing the recovery of Phosphorus from Biogas Digestates

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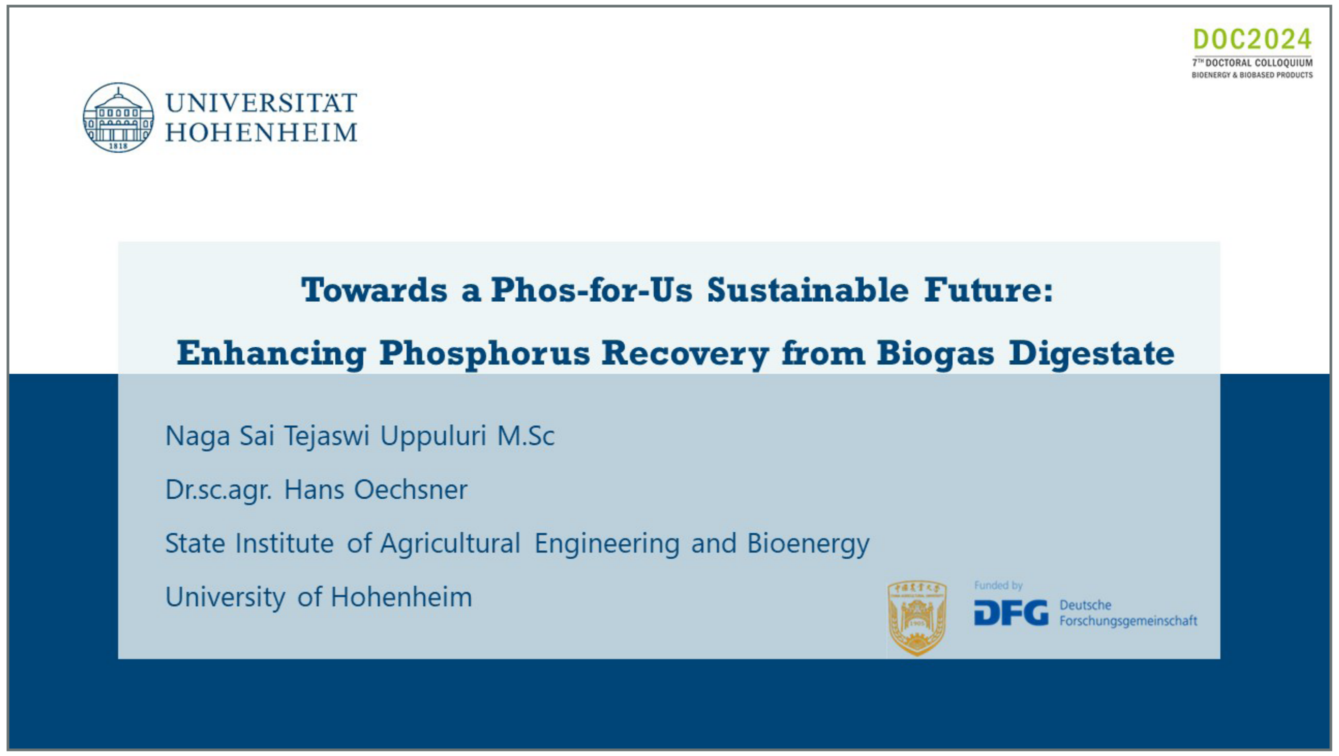
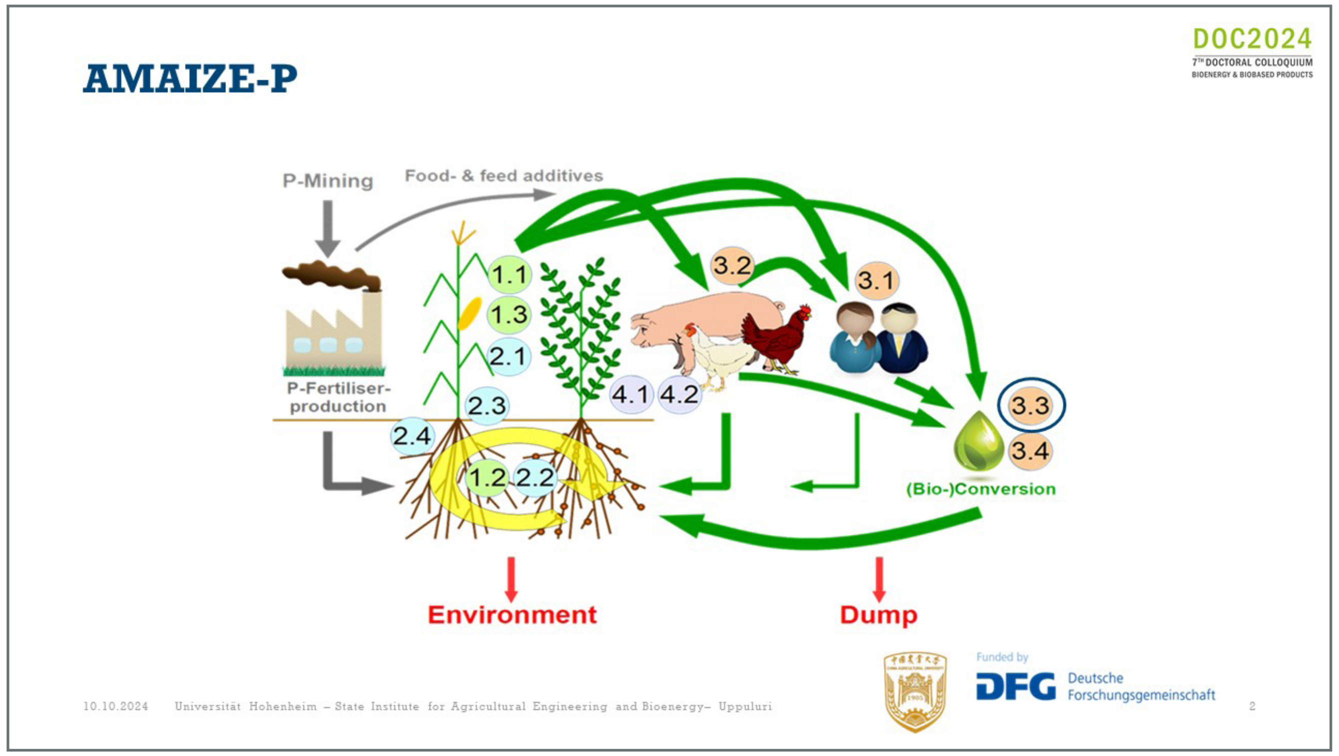
Keywords: Digestate, Solid-Liquid separation, Additive treatment, Phosphorus

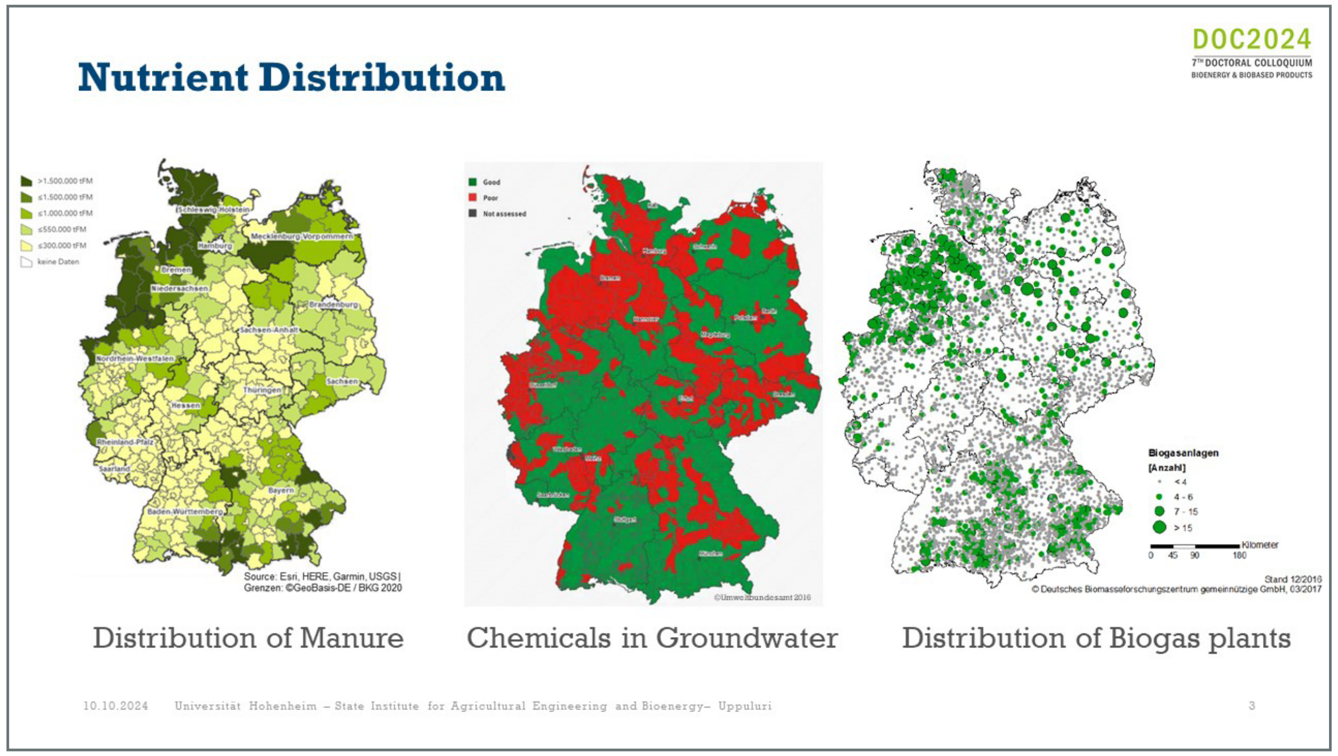
Recent geological surveys have reported on the necessity for investigation of methods to recover phosphorus (P) from waste resources to meet the needs of growing P fertilizer market. The digestate produced after the anaerobic digestion is nutrient-rich with elements like nitrogen (N), phosphorus (P) and potassium (K). The presence of these elements makes digestate a valuable resource for nutrient recovery. In the current study, we have focused on recovery of P from the biogas digestates. The high-water content (approx. 80 – 90 %) of digestate makes it difficult and expensive to transport it to far away fields, leading to nutrient accumulation. To tackle the problem of nutrient build-up, technologies such as chemical precipitation, ammonia stripping, among others, are employed to recover nutrients from digestate. Solid-liquid separation, often done with a screw press, produces a solid phase with a total P content ranging from 35-45 %. The objective of the experiments was to enhance P shift into the solid phase by using existing separation technologies and additives.

To improve P separation efficiency, an approach involving a combination of solid-liquid separation with additive treatment was implemented. The initial solid-liquid separations were conducted in a laboratory scale, where the digestate was treated with additives like kieserite ($MgSO_4 \cdot H_2O$), straw-flour, and biochar later followed by solid-liquid separation using a hydraulic tincture press. Based on the initial results, large-scale separation trials have been performed at the research biogas plant Unterer Lindenhof of the University of Hohenheim. Each separation trial involved treating nearly 10 m³ of digestate with additives and separating with a using screw press. Both in laboratory setting and in pilot trials, the influence of treatment time on shifting P into solid phase was also investigated. To gain further information on the effects of additives on P recovery, different soluble P fractions in the separated digestate were analysed using Hedley fractionation.

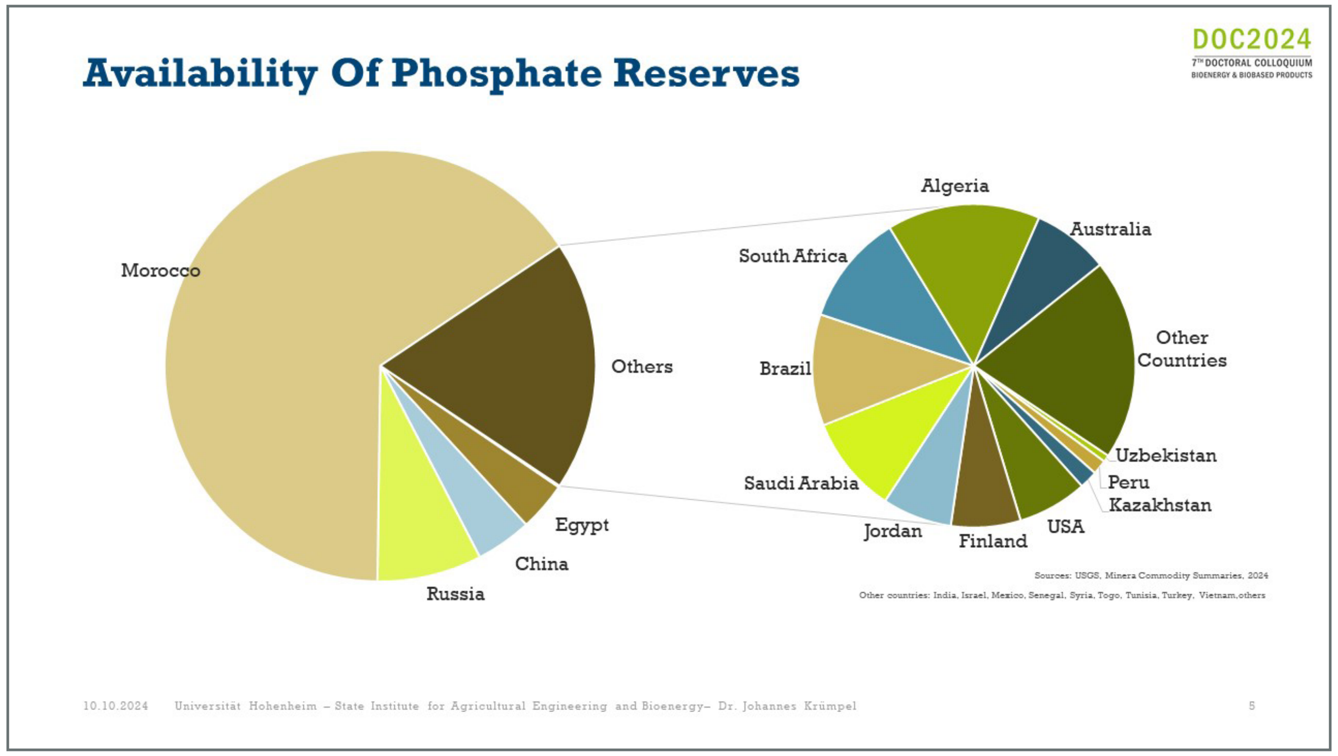
Initial results from the laboratory have shown that solid-liquid separation without additive treatment, nearly 40 % of the total P was bound to the solid phase. However, when treated with kieserite, the total P bound to the solid phase increased to almost 61 %. The results from pilot scale trials have also shown an increase in total P shifted to the solid phase with additive treatment. Kieserite treatment has shown a 33.5 % increase in the shift of P to solid phase compared to control. Overall, additive treatment of digestate can potentially be an economical method to shift more P in to solid phase.



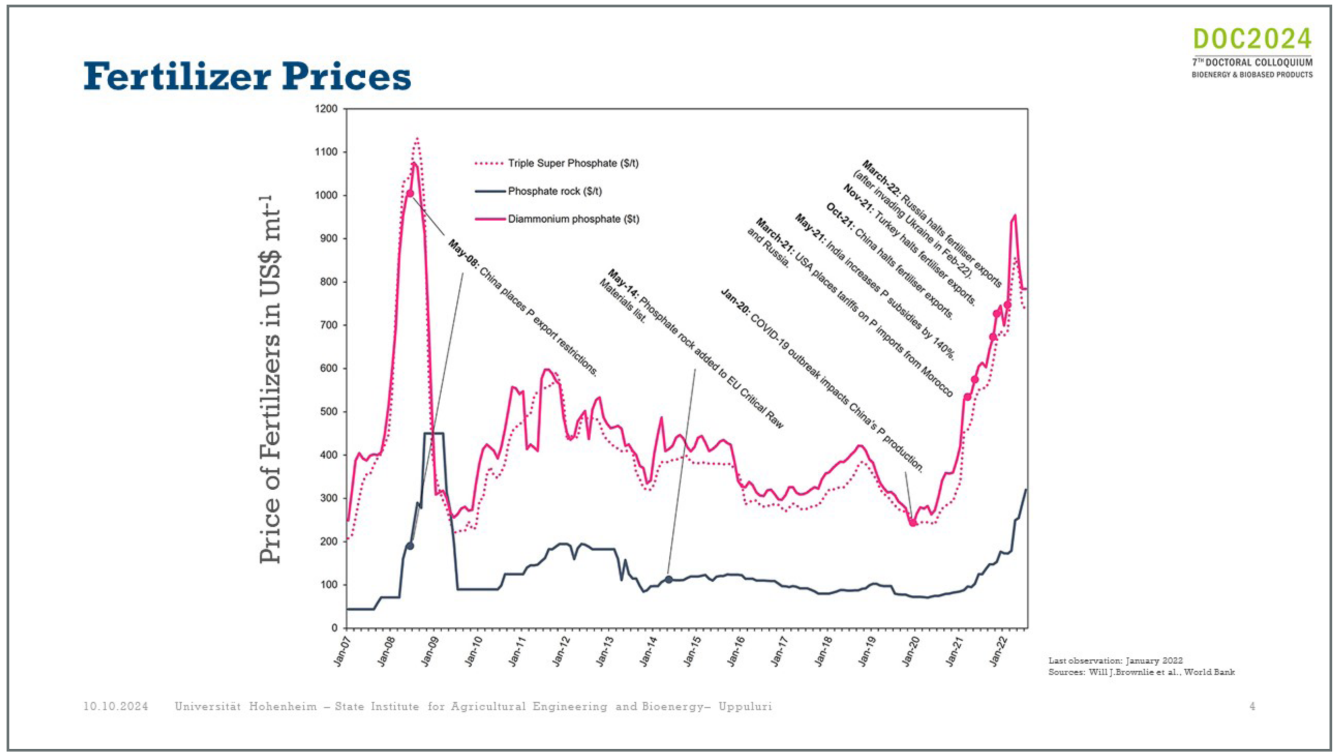




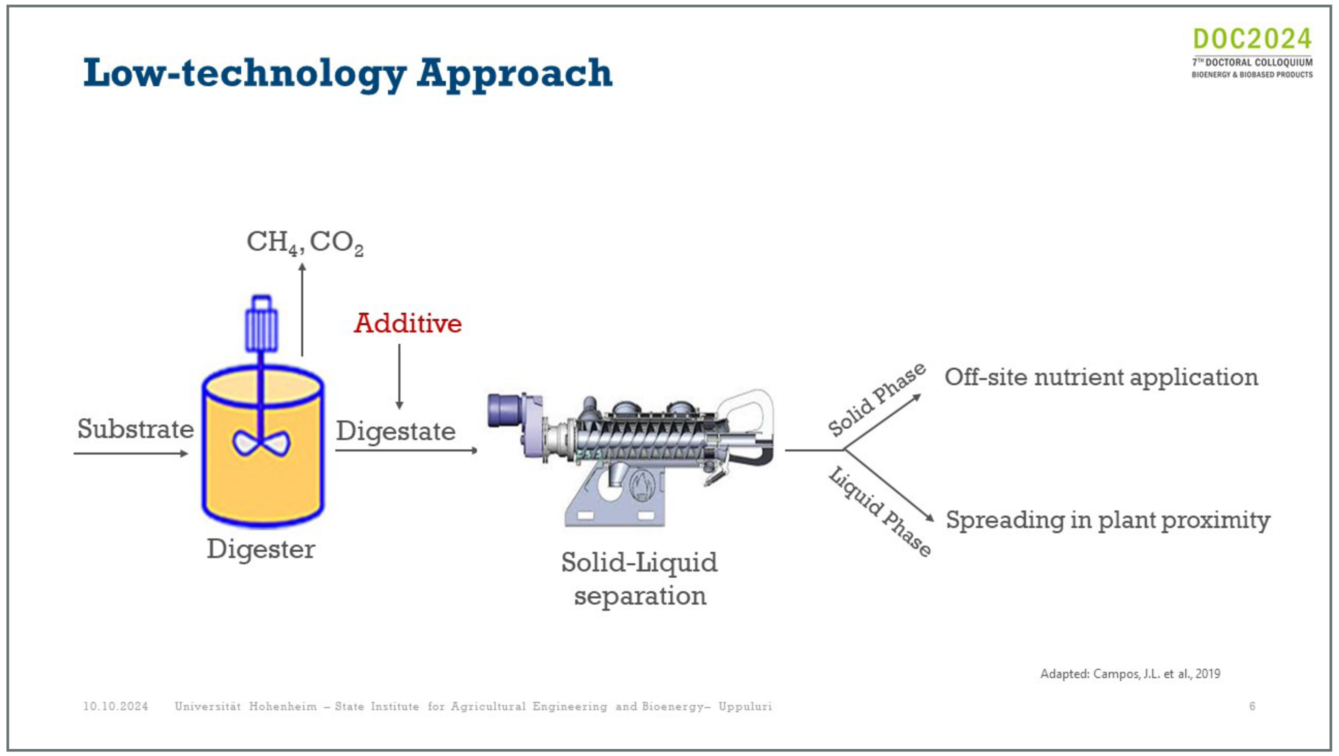
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Nutrient Distribution
Source: Esri, HERE, Garmin, USGS | Grenzen: ©GeoBasis-DE / BKG 2020
Good
Poor
Not assessed
Biogasanlagen [Anzahl]
< 4
4 - 6
7 - 15
> 15
Kilometer
Stand 12/2016
© Deutsches Biomasseforschungszentrum gemeinnützige GmbH, 03/2017
Distribution of Manure
Chemicals in Groundwater
Distribution of Biogas plants
10.10.2024 Universität Hohenheim – State Institute for Agricultural Engineering and Bioenergy– Uppuluri 3



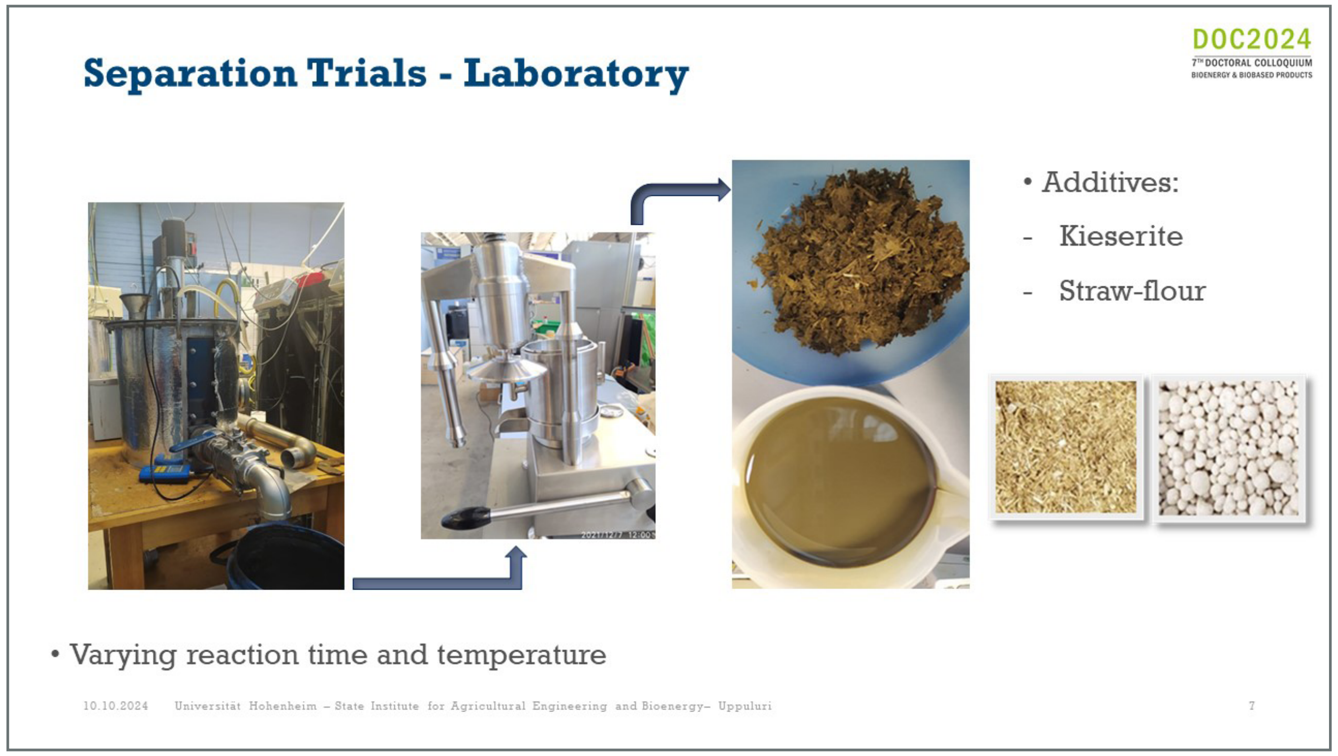
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Availability Of Phosphate Reserves
Morocco
Others
Egypt
China
Russia
Algeria
Australia
South Africa
Other Countries
Brazil
Saudi Arabia
Uzbekistan
Peru
Kazakhstan
Jordan
Finland
USA
Sources: USGS, Minera Commodity Summaries, 2024
Other countries: India, Israel, Mexico, Senegal, Syria, Togo, Tunisia, Turkey, Vietnam, others
10.10.2024 Universität Hohenheim – State Institute for Agricultural Engineering and Bioenergy– Dr. Johannes Krümpel 5

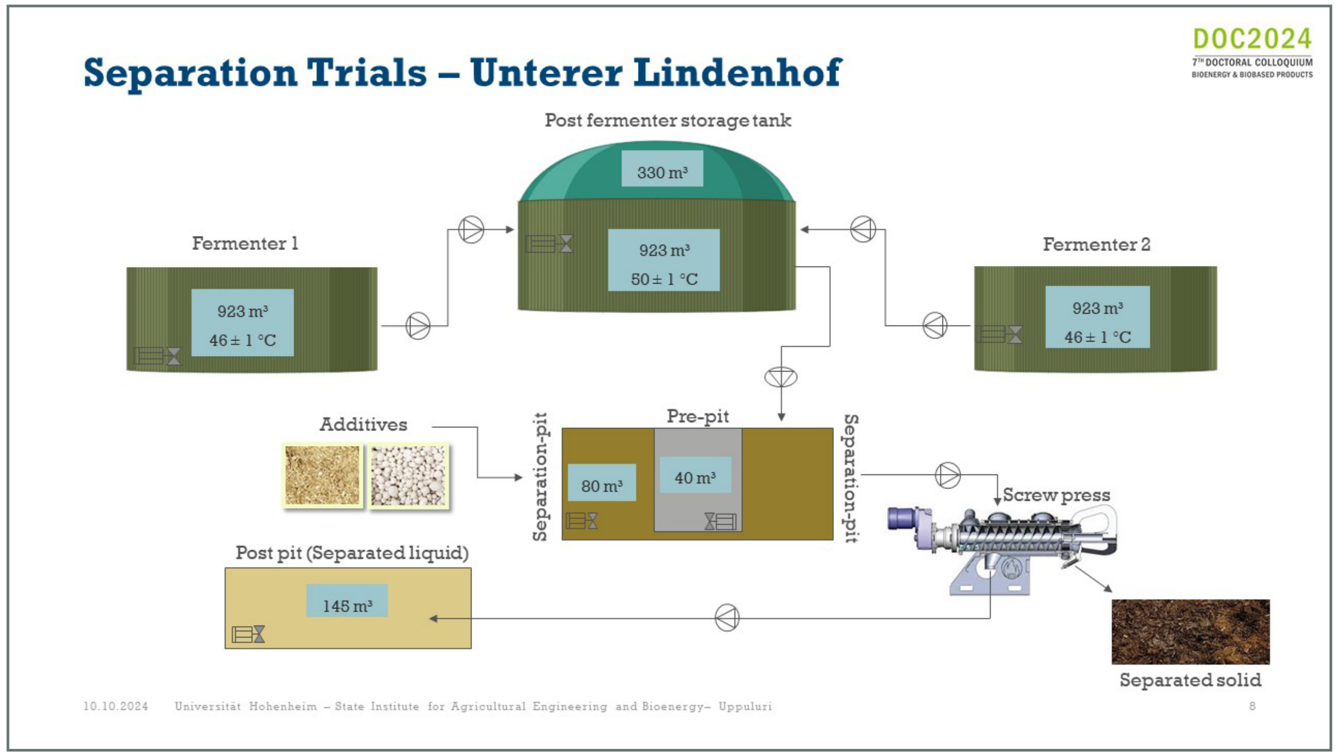


DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Fertilizer Prices
Price of Fertilizers in US$ mt-1
Triple Super Phosphate ($/t)
Phosphate rock ($/t)
Diammonium phosphate ($t)
May-08: China places P export restrictions.
May-14: Phosphate rock added to EU Critical Raw Materials list.
Jan-20: COVID-19 outbreak impacts China's P production.
March-21: USA places tariffs on P imports from Morocco and Russia.
May-21: India increases P subsidies by 140%.
Oct-21: China halts fertiliser exports.
Nov-21: Turkey halts fertiliser exports.
March-22: Russia halts fertiliser exports (after invading Ukraine in Feb-22).
Last observation: January 2022
Sources: Will J.Brownlie et al., World Bank
10.10.2024 Universität Hohenheim – State Institute for Agricultural Engineering and Bioenergy– Uppuluri 4



DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Low-technology Approach
CH4, CO2
Additive
Substrate
Digestate
Digester
Solid-Liquid separation
Solid Phase
Liquid Phase
Off-site nutrient application
Spreading in plant proximity
Adapted: Campos, J.L. et al, 2019
10.10.2024 Universität Hohenheim – State Institute for Agricultural Engineering and Bioenergy– Uppuluri 6


Separation Trials - Laboratory
DOC2024
7th DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
• Additives:
- Kieserite
- Straw-flour
• Varying reaction time and temperature
10.10.2024 Universität Hohenheim – State Institute for Agricultural Engineering and Bioenergy– Uppuluri
7


Separation Trials – Unterer Lindenhof
DOC2024
7th DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Post fermenter storage tank
330 m³
923 m³
50 ± 1 °C
Fermenter 1
923 m³
46 ± 1 °C
Fermenter 2
923 m³
46 ± 1 °C
Additives
Separation-pit
Pre-pit
80 m³
40 m³
Separation-pit
Screw press
Post pit (Separated liquid)
145 m³
Separated solid
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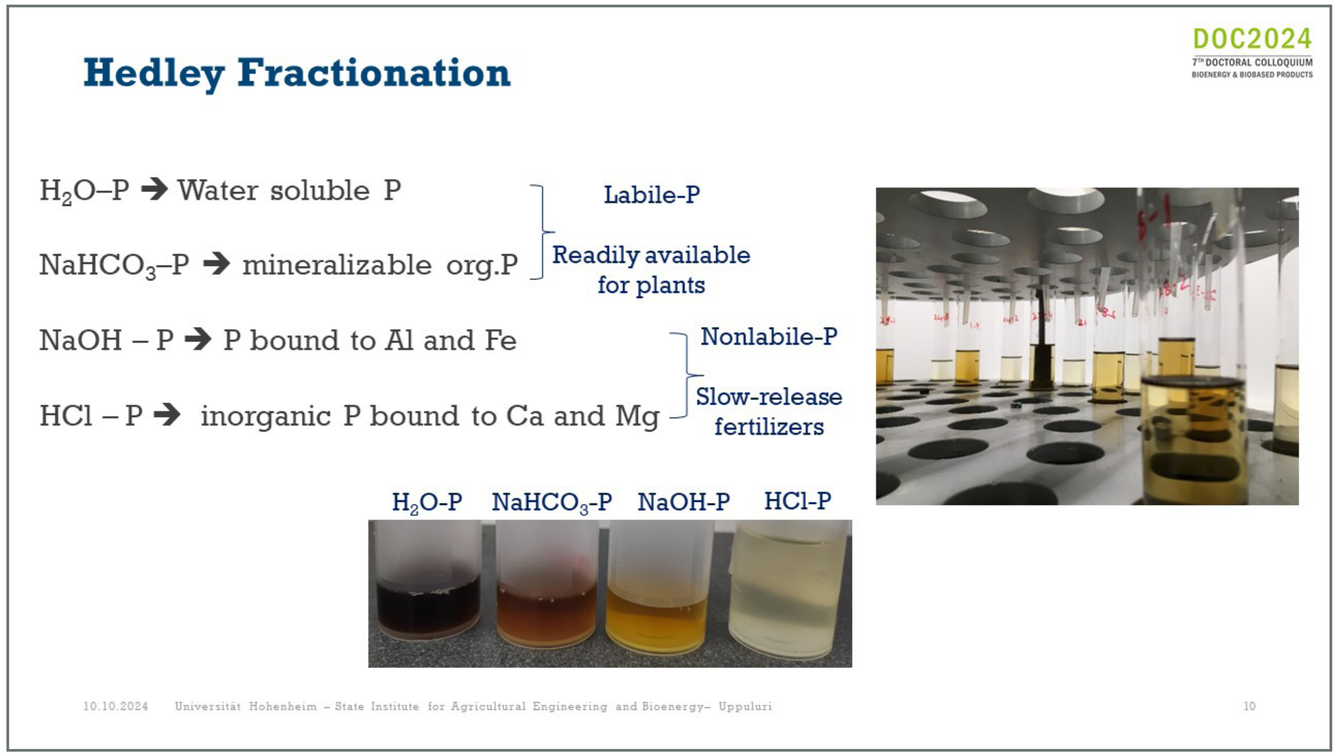
8


Separation Trials – Unterer Lindenhof
DOC2024
7th DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
• Additives:
- Kieserite
- Straw-flour
10.10.2024 Universität Hohenheim – State Institute for Agricultural Engineering and Bioenergy– Uppuluri


Hedley Fractionation
DOC2024
7th DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
H₂O–P ➔ Water soluble P
NaHCO₃–P ➔ mineralizable org.P
Labile-P
Readily available for plants
NaOH – P ➔ P bound to Al and Fe
HCl – P ➔ inorganic P bound to Ca and Mg
Nonlabile-P
Slow-release fertilizers
H₂O-P
NaHCO₃-P
NaOH-P
HCl-P
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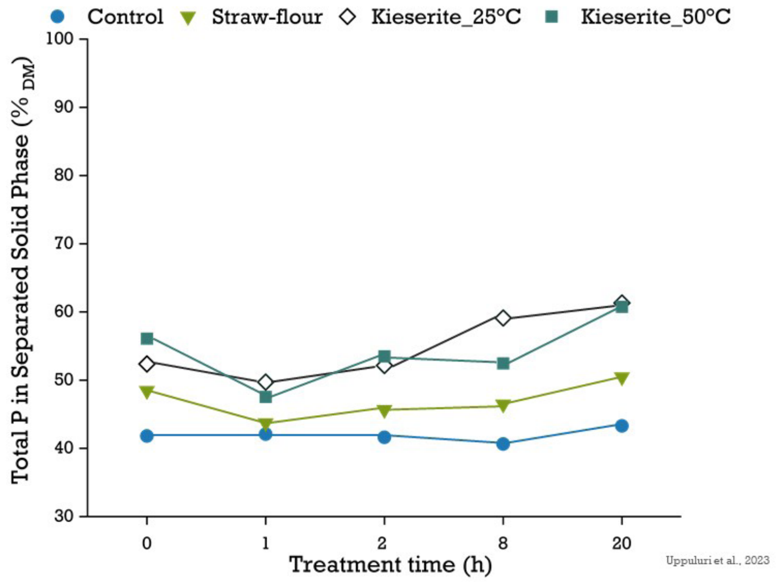
10

DOC2024

Total Phosphorus – Laboratory Trials



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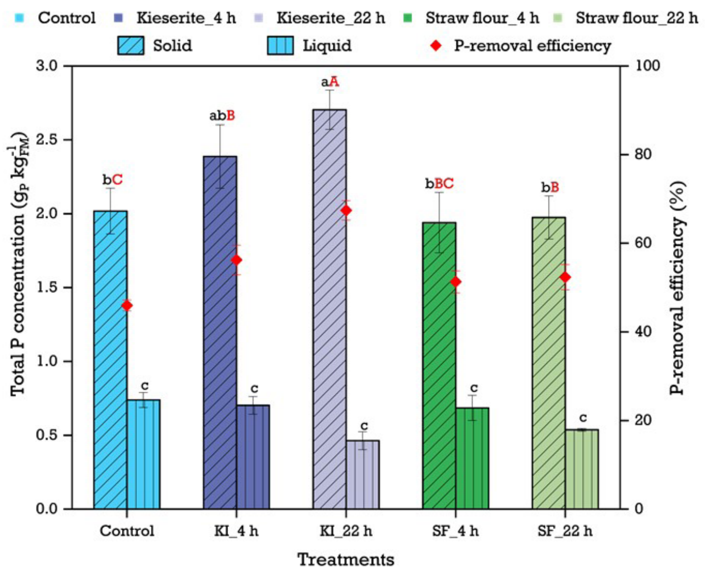
DOC2024

Total Phosphorus – Unterer Lindenhof



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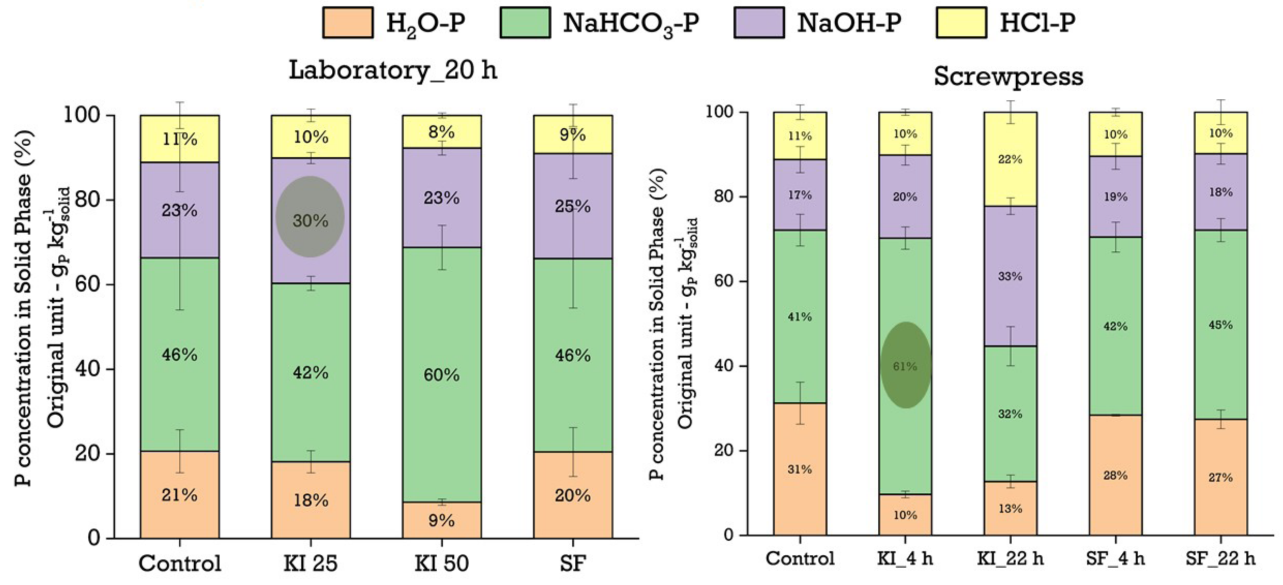
DOC2024

Hedley Fractionation



10.10.2024 Universität Hohenheim – State Institute for Agricultural Engineering and Bioenergy– Dr. Johannes Krümpel 13

DOC2024

Summary

- Increase in P-bound to solid phase with kieserite treatment.
- Straw flour treatments increased P-recovery. However, it was lower compared to kieserite.
- Kieserite treatment had an increased NaOH-P and HCl-P fractions.
- These two fractions are non-labile and act as slow-release fertilizers, thereby making kieserite treatment an effective method to treat digestate.

Digestate treatment with additives has a positive effect on shifting P to solid phase

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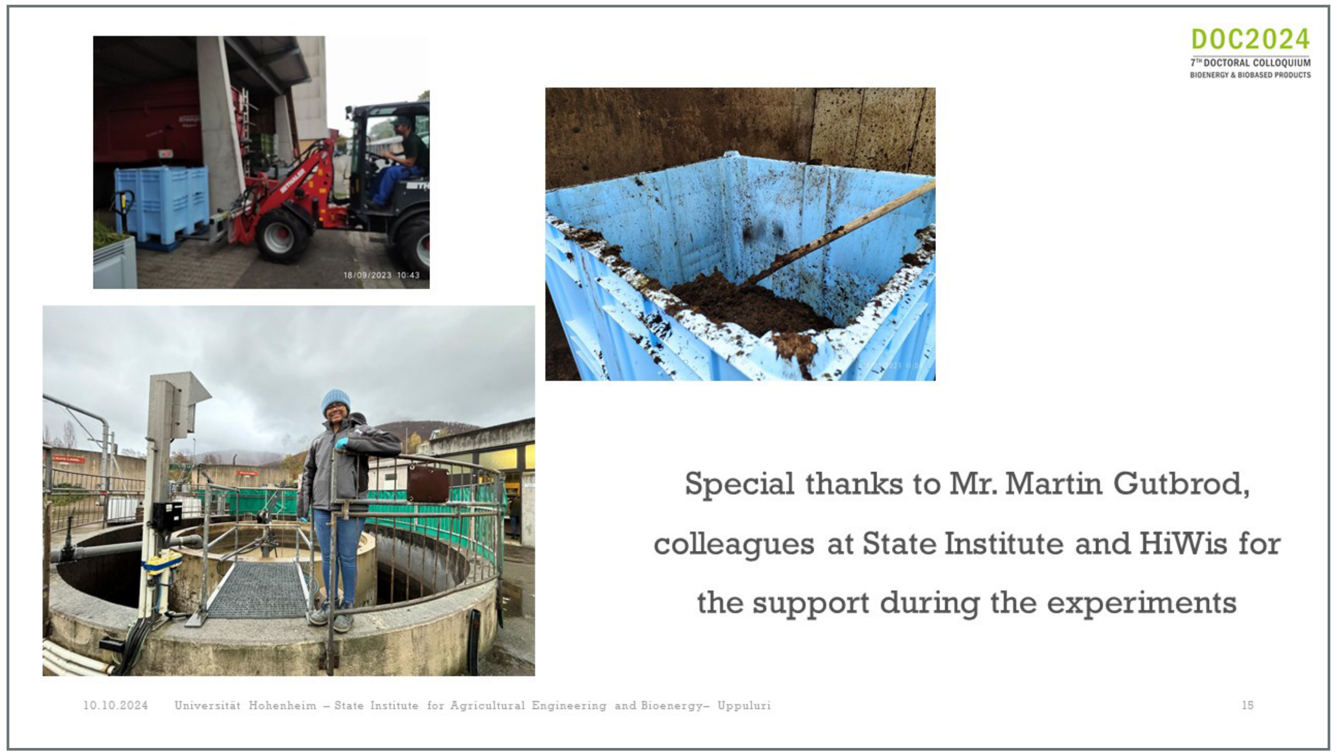

DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Special thanks to Mr. Martin Gutbrod, colleagues at State Institute and HiWis for the support during the experiments
10.10.2024 Universität Hohenheim – State Institute for Agricultural Engineering and Bioenergy– Uppuluri
15


DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
UNIVERSITÄT HOHENHEIM
THANK YOU FOR YOUR ATTENTION ☺
Naga Sai Tejaswi Uppuluri M.Sc.; Dr.sc.agr. Hans Oechsner
University of Hohenheim –State Institute of Agricultural Engineering and Bioenergy
Garbenstr. 9 | 70599 Stuttgart
E-Mail: naga.uppuluri@uni-hohenheim.de
Funded by
DFG Deutsche Forschungsgemeinschaft

Alberto Meola, Deutsches Biomasseforschungszentrum

Reinforcement learning for control of biogas plants with stability constraints

Alberto Meola, Oliver Kiefner, Félix Delory, Prof. Dr. Sören Weinrich
DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH
Torgauer Str. 116
04347 Leipzig
Phone: +49 (0)341 2434-374
E-Mail: alberto.meola@dbfz.de

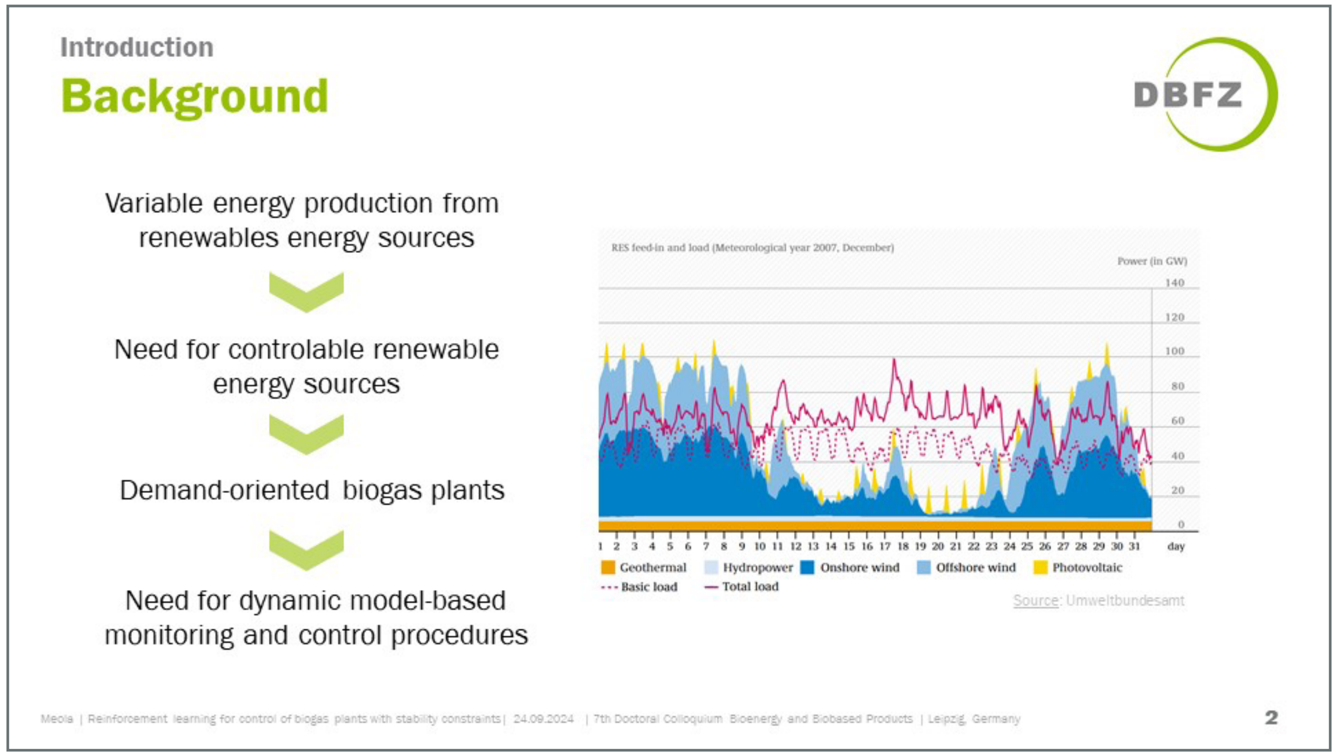
Keywords: Machine learning, anaerobic digestion, deep learning, energy markets, constrained optimization

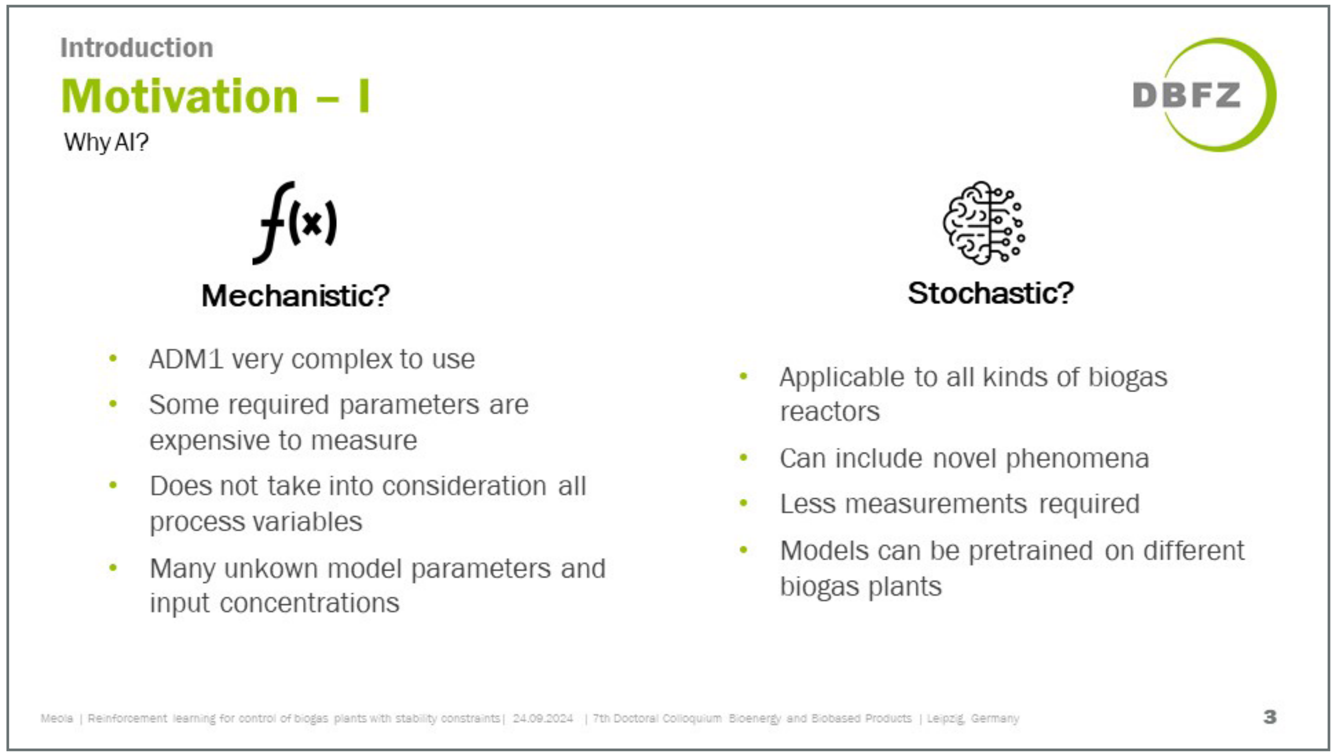
Biogas plants are generaly used for base load power supply in Germany, but their profitability without state subsidies is uncertain. The conversion of demand-oriented electricity for profitability increase requires advanced control techniques for the Anaerobic Digestion (AD) process. While Machine Learning (ML) techniques have been applied for process simulations, Reinforcement Learning (RL) algorithms applied to AD process control have been often neglected. This study demonstrates the application of the Proximal Policy Optimisation (PPO) algorithm – a RL algorithm – to a biogas plant for increased profitability, with knowledge based constraints to ensure process stability.

Approach and methods Biogas production data is generated from a simplified version of the ADM1 model, the ADM1-R3 [1], in response to the PPO agent actions at each iteration, and then fed back to the agent. The agent controls the substrate feed amount and timing, and the selling time of the electricity produced from the biogas. Agent's actions are constrained within process stability limits. In a first phase, the agent is rewarded only based on the total weekly biogas production, while in a second phase it is rewarded for both biogas production and for the selling time of the produced electricity. After each simulated week, the agent is rewarded and provided with the current state, and it subsequently generates a new configuration based on the current state and the gained reward.

The RL agent outperforms a naive scenario with constant feeding amount, time and electricity selling time in over 80% of the simulations, leading to an 8.5% increase in profitability compared to conventional approaches. In general, as the number of simulations increase, the agent is able to increase its cumulative reward, and to decrease the deviation from the optimal selling point. Agent performances and revenue might be further increased with the additional refining of the environment and the implementation of further previous knowledge during model training. To assess the efficacy of such methods in industrial applications, further research should consider multiple feeding and electricity provision times, as well as limited gas storage capacity.

References:
[1] Weinrich, S. Nelles, M. Systematic simplification of the Anaerobic Digestion Model No. 1 (ADM1) - Model development and stoichiometric analysis, Bioresource Technology, Volume 333, 2021, 125124. 2021.




Introduction
Motivation – I
Why AI?
DBFZ
f(x)
Mechanistic?
ADM1 very complex to use
Some required parameters are expensive to measure
Does not take into consideration all process variables
Many unkown model parameters and input concentrations
Stochastic?
Applicable to all kinds of biogas reactors
Can include novel phenomena
Less measurements required
Models can be pretrained on different biogas plants
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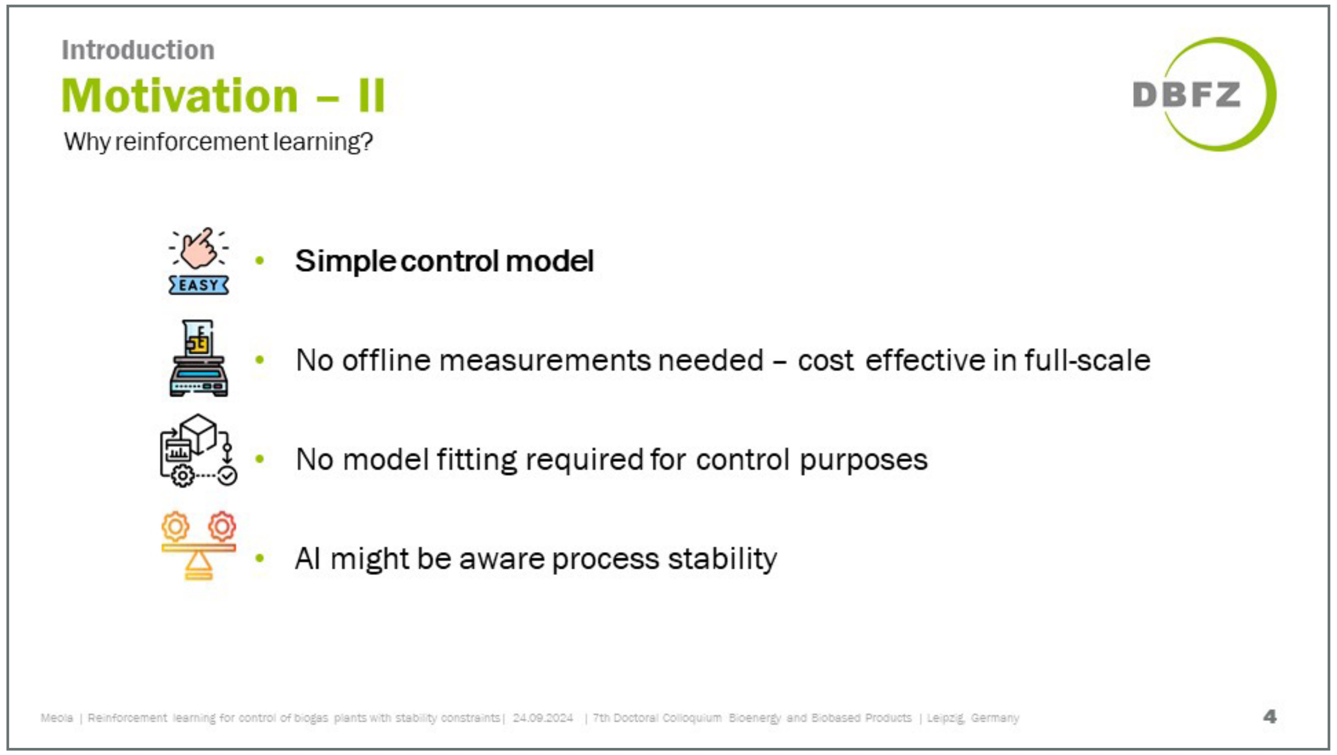
Introduction
Motivation – II
Why reinforcement learning?
DBFZ
EASY
Simple control model
No offline measurements needed – cost effective in full-scale
No model fitting required for control purposes
AI might be aware process stability
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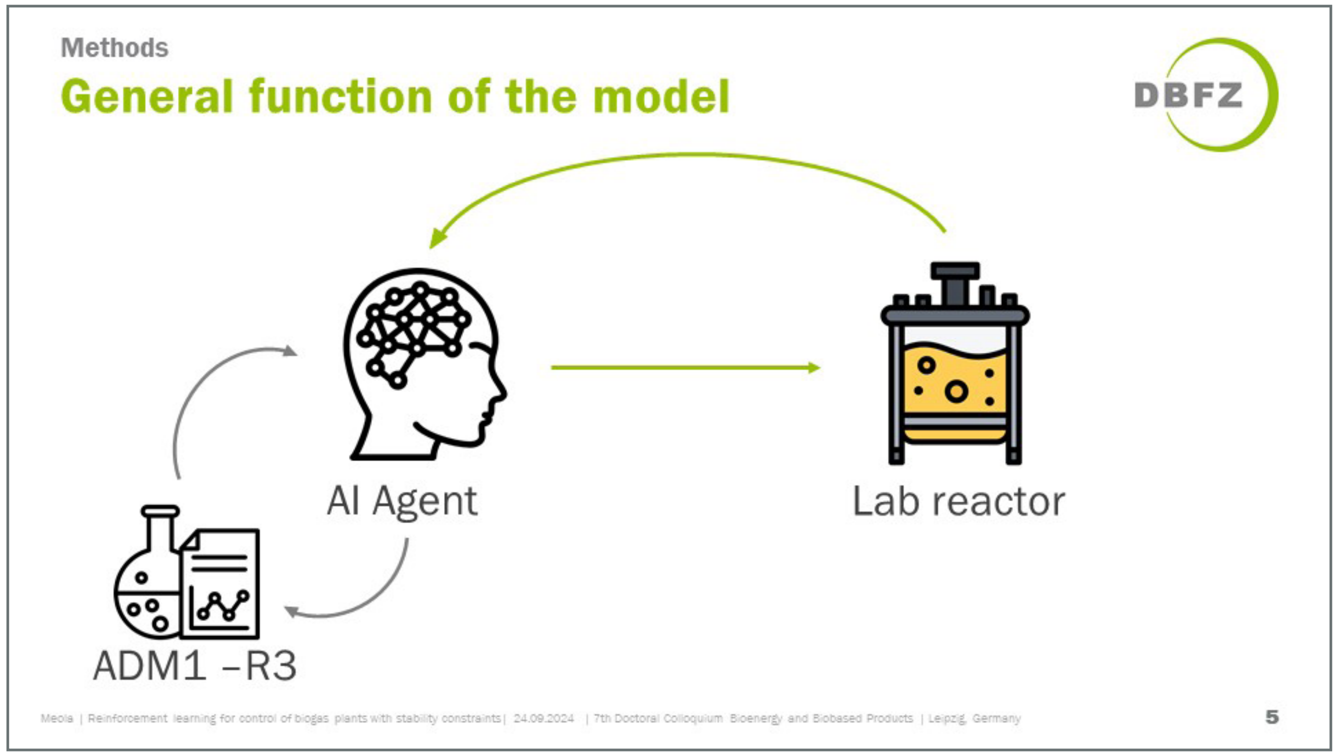
Methods
General function of the model
DBFZ
AI Agent
Lab reactor
ADM1 –R3
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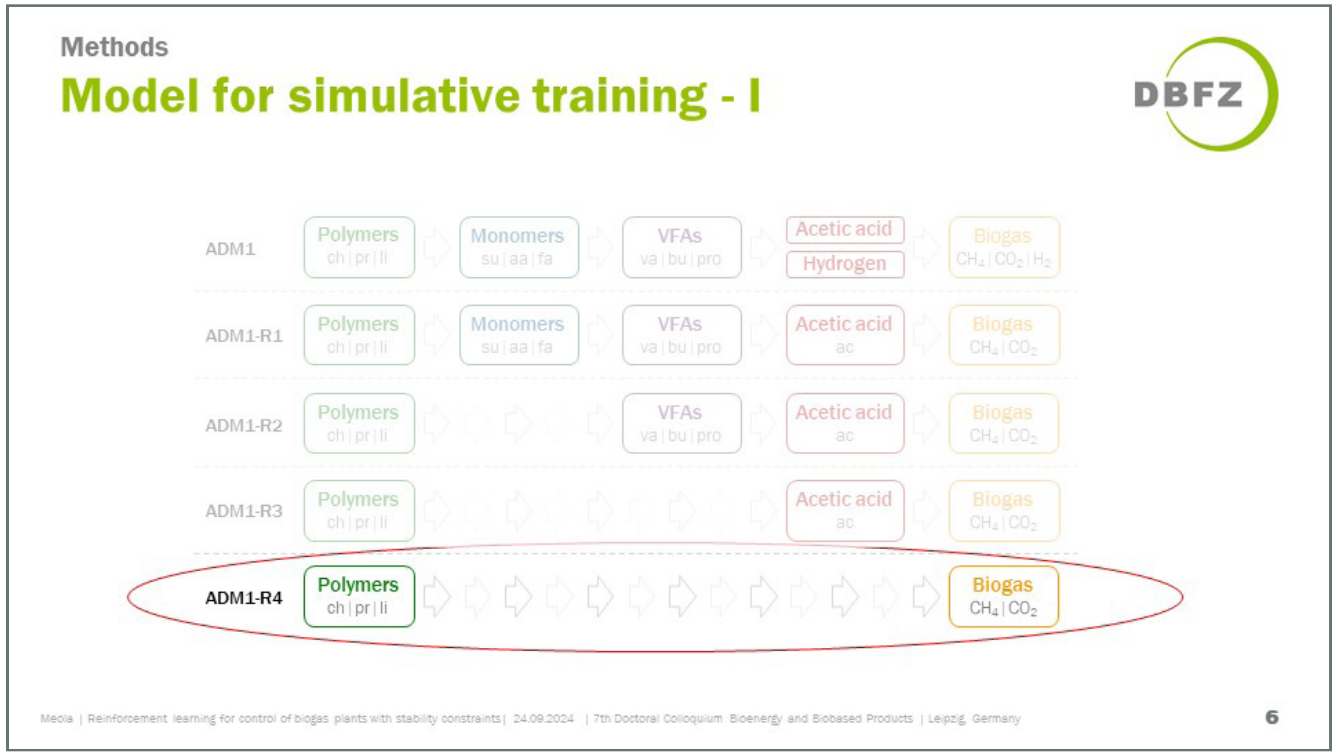
Methods
Model for simulative training - I
DBFZ
ADM1
ADM1-R1
ADM1-R2
ADM1-R3
ADM1-R4
Polymers
ch | pr | li
Monomers
su | aa | fa
VFAs
va | bu | pro
Acetic acid
Hydrogen
ac
Biogas
CH4 | CO2 | H2
CH4 | CO2
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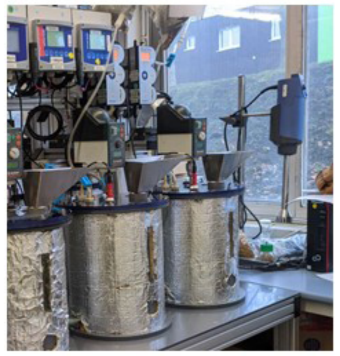
Methods

Model for simulative training - II

Fitted on...



- **12l reactor**
- 1:1 mixture of **corn silage and cow manure**
- Average of **287 g** of fresh mass fed per day

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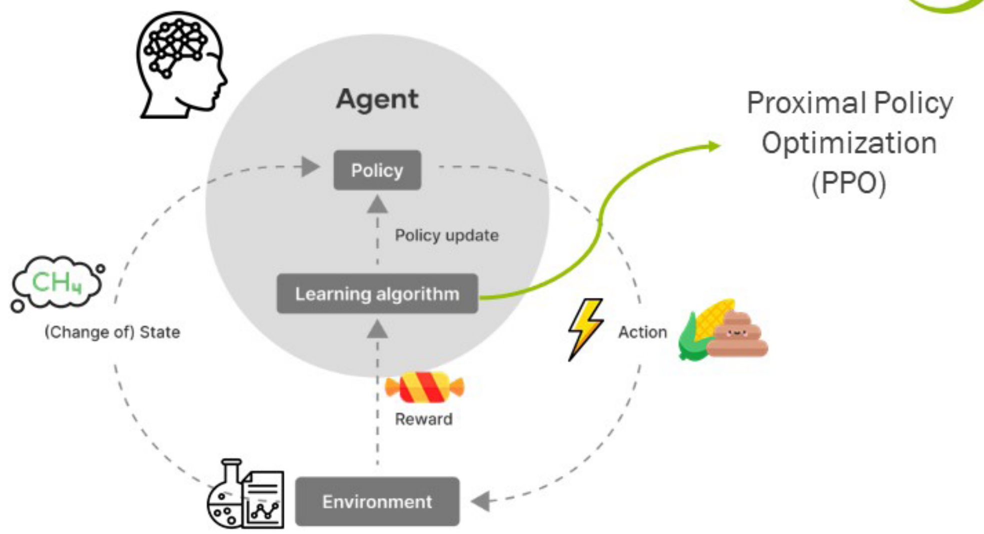
Methods

Reinforcement learning model



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Methods

Environment Constraints

Constraint type	Constraint value
Control horizon	7 days
Maximum weekly average VS feed	4.5 kg m^{-3} day^{-1}
Maximum VS per feed	7 kg m^{-3} day^{-1}
Maximum consecutive days with no feed	3 days
Feed time	Mo-Fri 07:00-15:00 Sa-So 10:00-12:00

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Methods

The comparison: Naïve Agent

Feed amount	→	4.5 kg VS m^3 day^{-1}
Feed time	→	Everyday 8 AM
Electricity selling time	→	Constant

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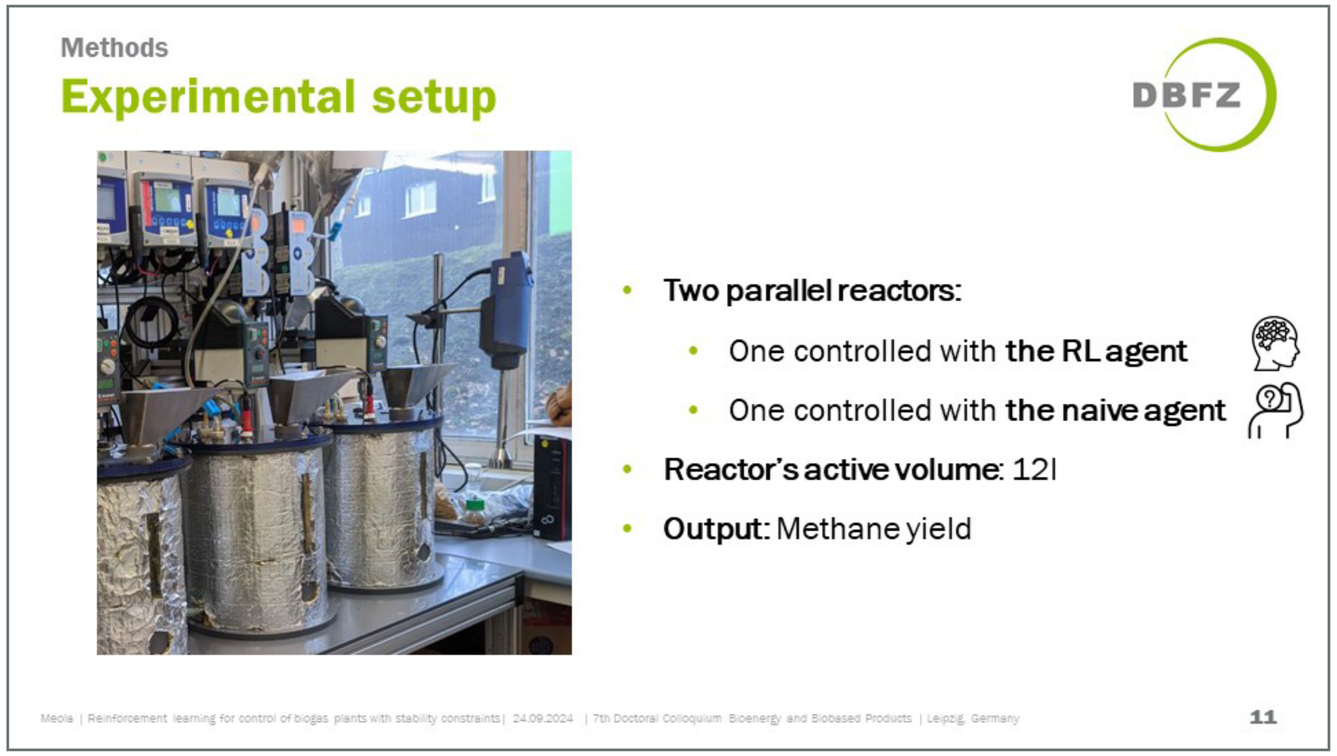
Methods
Experimental setup
DBFZ
Two parallel reactors:
One controlled with the RL agent
One controlled with the naive agent
Reactor's active volume: 12l
Output: Methane yield
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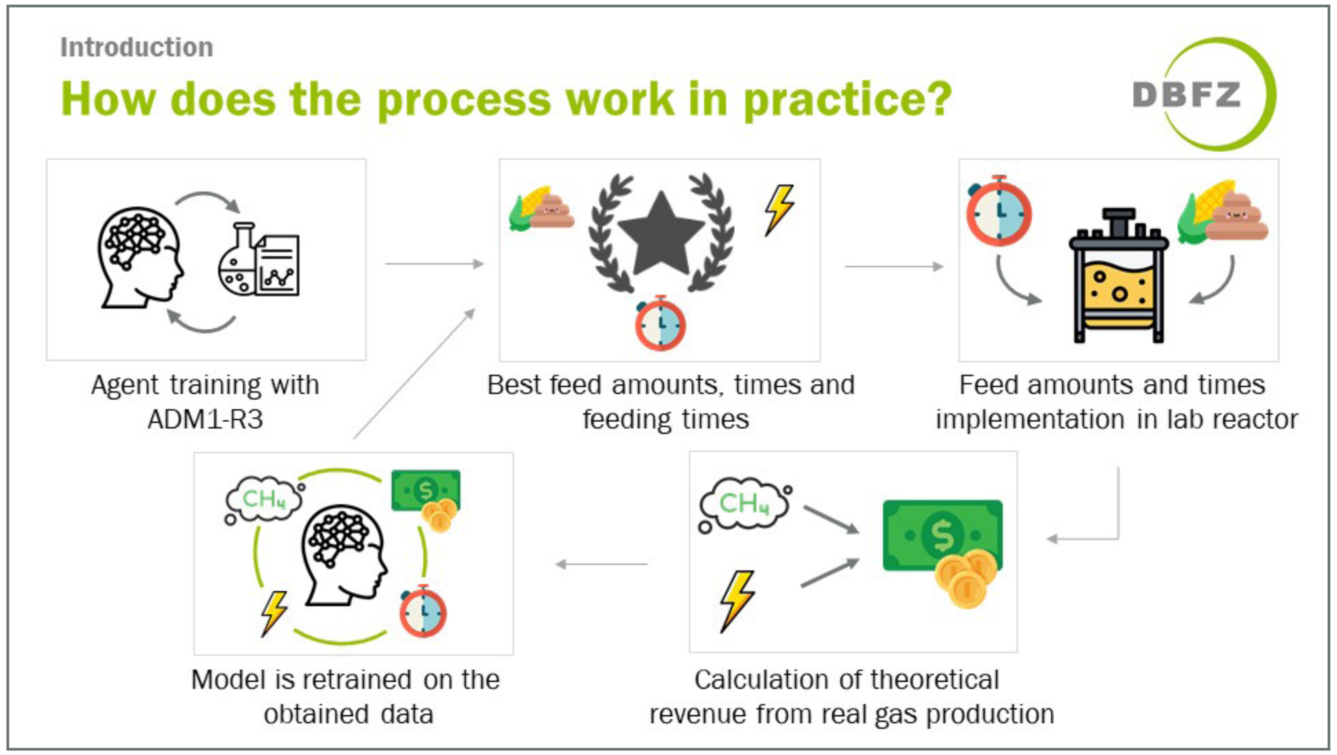
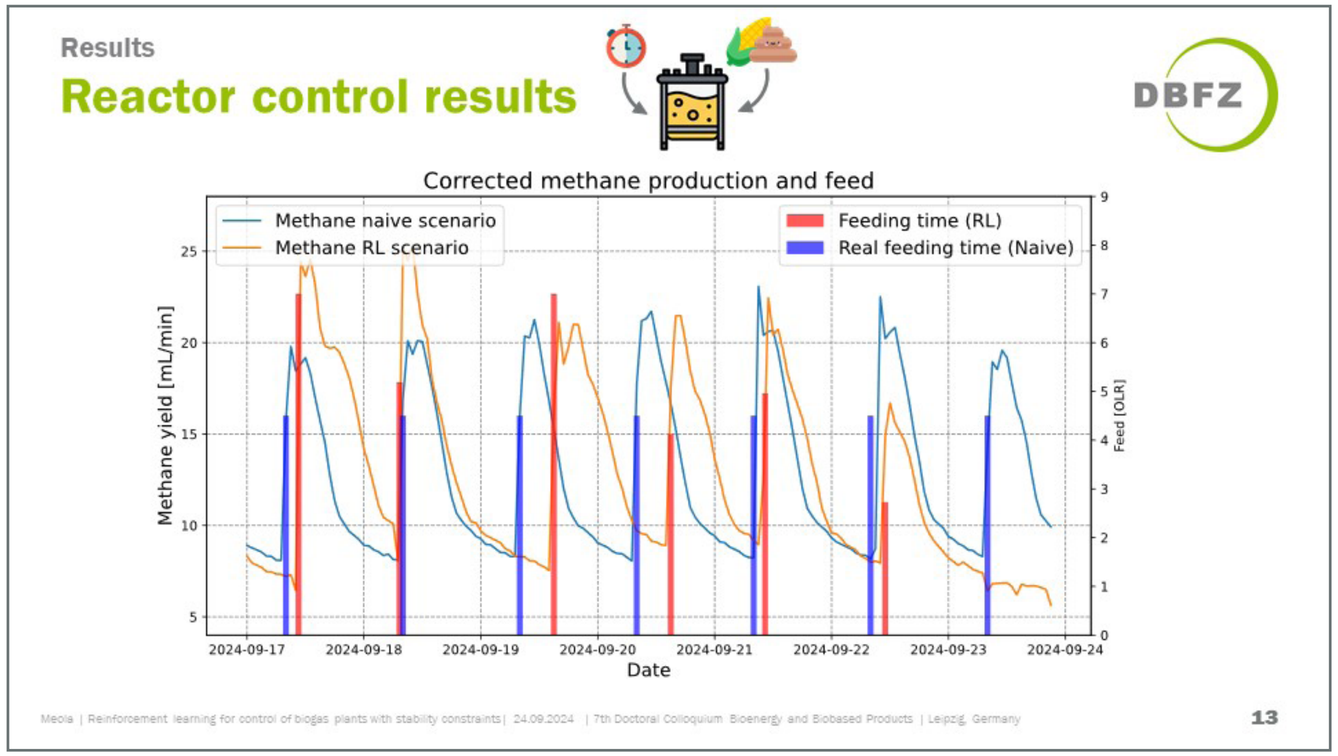

Introduction
How does the process work in practice?
DBFZ
Agent training with ADM1-R3
Best feed amounts, times and feeding times
Feed amounts and times implementation in lab reactor
Model is retrained on the obtained data
Calculation of theoretical revenue from real gas production
CH4
CH4


Results
Reactor control results
DBFZ
Corrected methane production and feed
Methane naive scenario
Methane RL scenario
Feeding time (RL)
Real feeding time (Naive)
Methane yield [mL/min]
Feed [OLR]
Date
2024-09-17
2024-09-18
2024-09-19
2024-09-20
2024-09-21
2024-09-22
2024-09-23
2024-09-24
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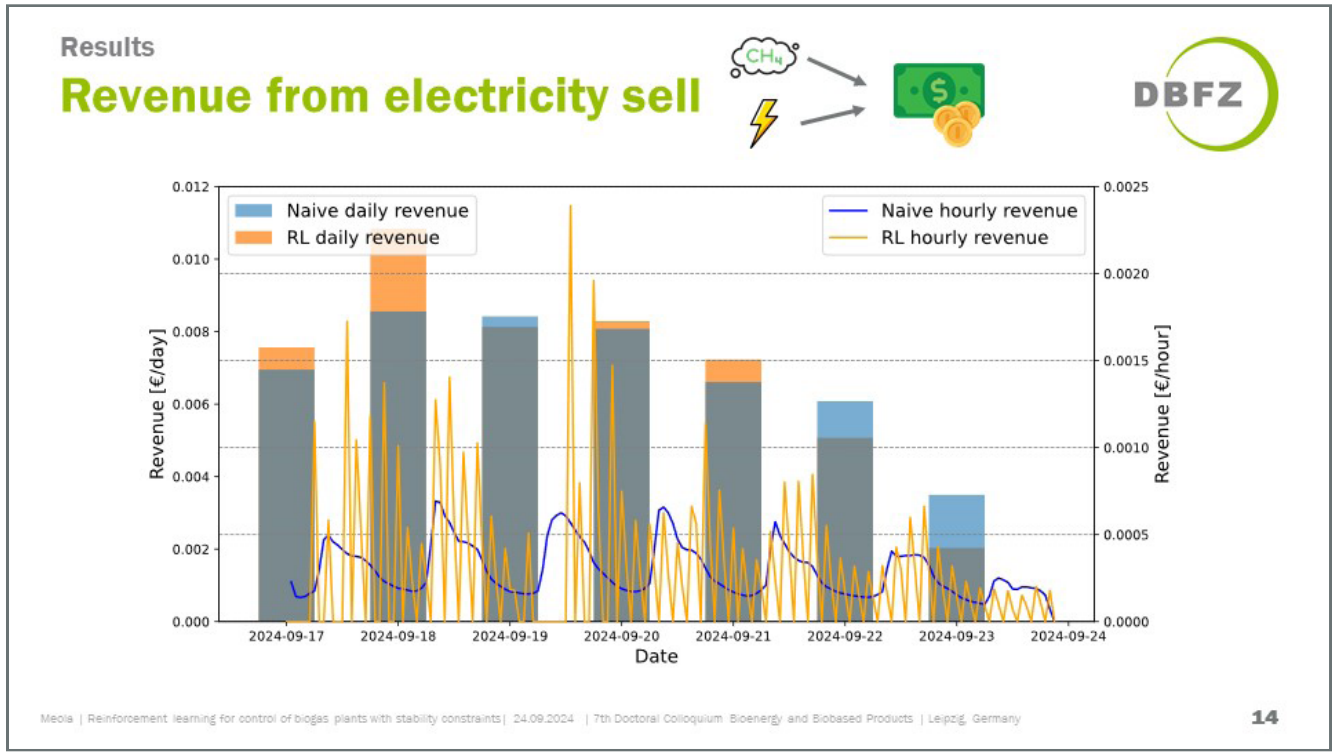
Results
Revenue from electricity sell
DBFZ
CH4
Naive daily revenue
RL daily revenue
Naive hourly revenue
RL hourly revenue
Revenue [€/day]
Revenue [€/hour]
Date
2024-09-17
2024-09-18
2024-09-19
2024-09-20
2024-09-21
2024-09-22
2024-09-23
2024-09-24
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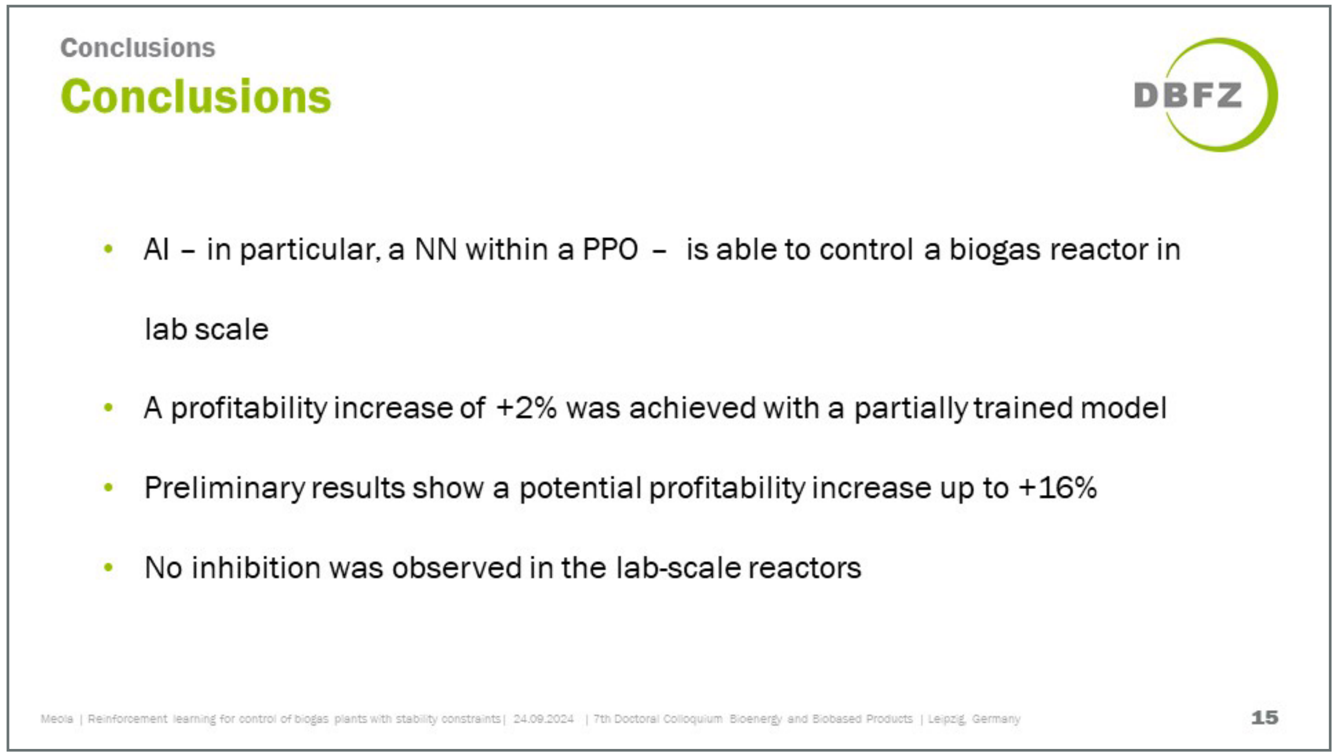
Conclusions
Conclusions
DBFZ
AI – in particular, a NN within a PPO – is able to control a biogas reactor in lab scale
A profitability increase of +2% was achieved with a partially trained model
Preliminary results show a potential profitability increase up to +16%
No inhibition was observed in the lab-scale reactors
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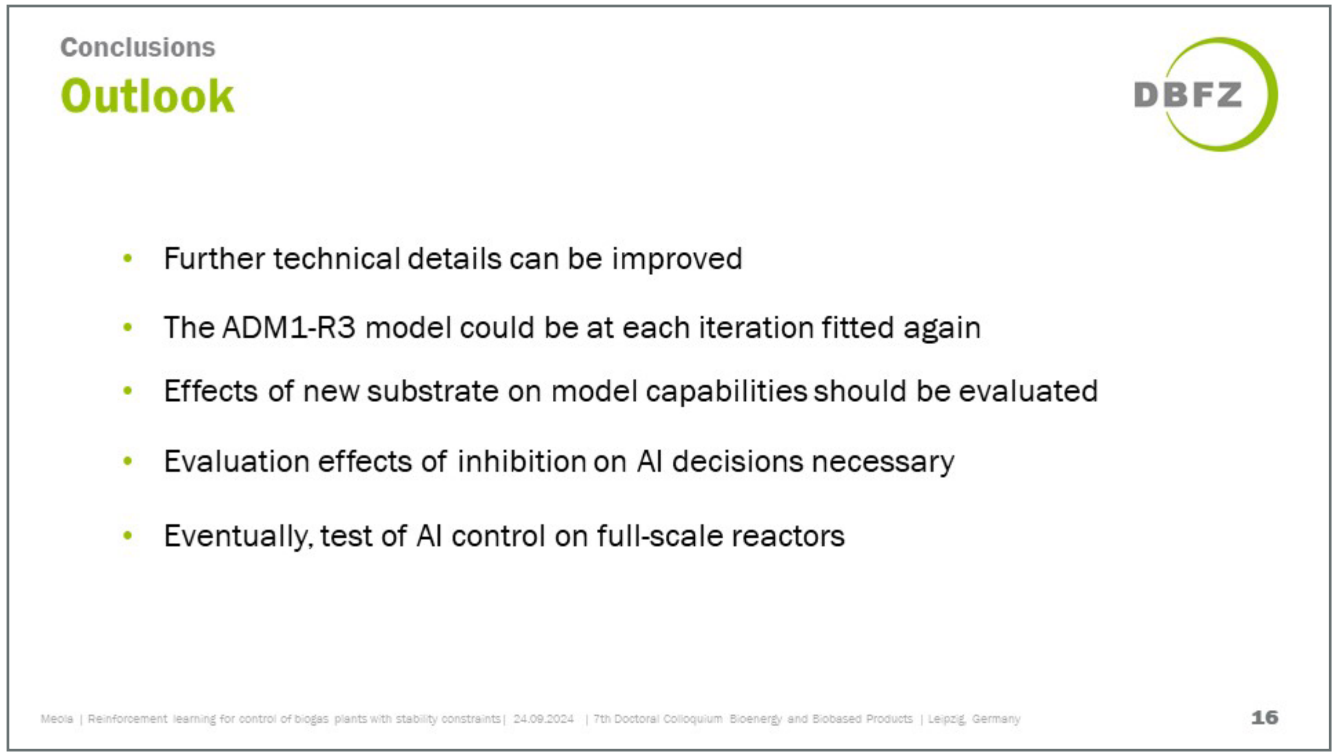
Conclusions
Outlook
DBFZ
Further technical details can be improved
The ADM1-R3 model could be at each iteration fitted again
Effects of new substrate on model capabilities should be evaluated
Evaluation effects of inhibition on AI decisions necessary
Eventually, test of AI control on full-scale reactors
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AD process modelling with transformer-based neural networks

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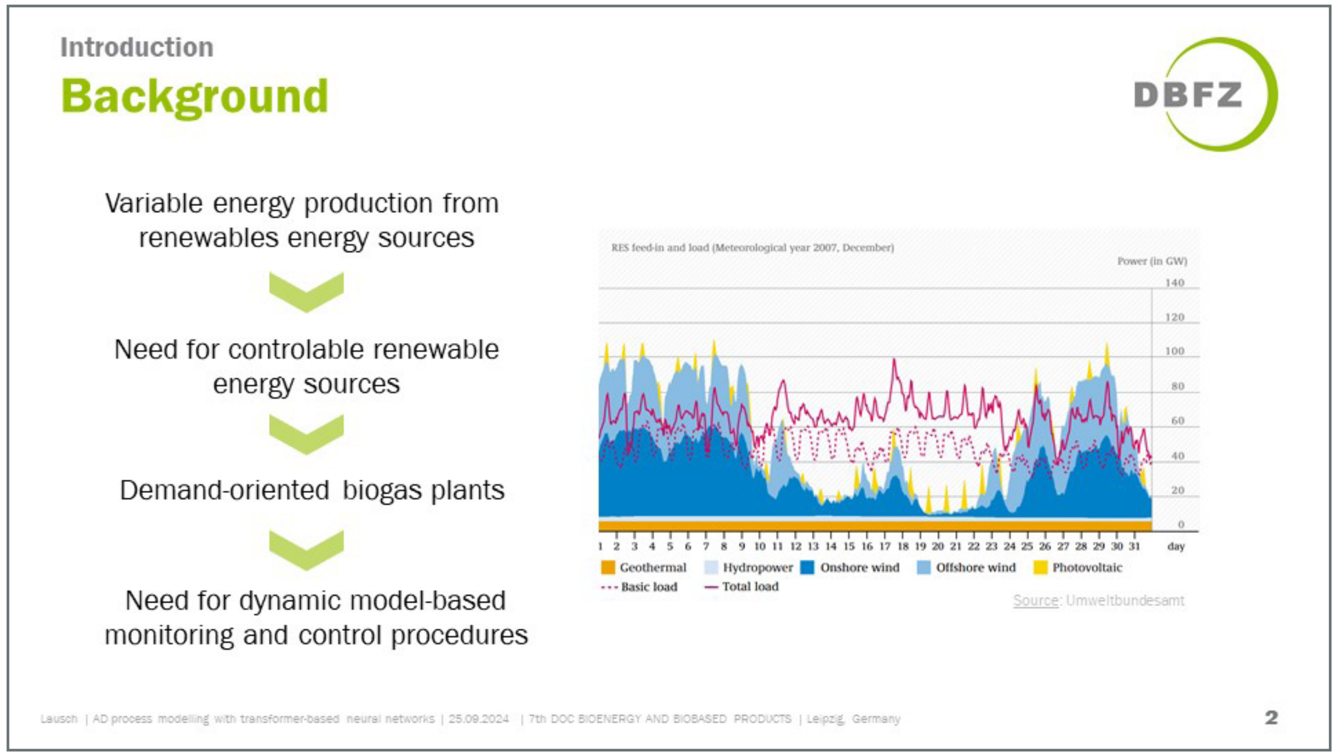
Keywords: biogas technology, artificial intelligence, deep learning, industrial applications, process prediction

The Anaerobic Digestion (AD) process can be used to provide demand-oriented power, mitigating the variability of renewable energy conversion. Thus, robust modelling techniques are needed for effective prediction and control of the process. Normally, the AD process is modelled with the Anaerobic Digestion Model No. 1 (ADM1), but the need for frequent and precise measurements make it hard to implement during regular industrial operations. While stochastic modelling techniques such as Machine Learning (ML) and Neural Networks (NN) are currently being tested on the AD process, many algorithms might be susceptible to measurement errors and might not be able to accurately depict long-term dependencies.

Transformer based models – such as ChatGPT – gained popularity in the past few years due to their robustness to inconsistencies in the input data and their capacity of correctly modelling long-term dependencies. Among the transformer-based models showing promising results with time series data, informer shows optimal performances and natively supports time-series data.

An informer was applied to predict the methane produced in a 12L lab-scale digester (Dataset A) and a 188 m³ industrial-scale digester (Dataset B). In Dataset A, cow manure, grass silage, straw pellets and grist were alternatively digested under variable OLR between 0 and 8 kg VS m-3 d-1 over a period of 287 days, with variable HRT. In Database B, corn silage and cattle manure were digested under variable OLR between 2 and 16 kg VS m-3 d-1, for 165 days, with variable HRT. While Dataset B was simulated one point per time 24h in advance, Dataset A was simulated one point per time 24h in advance in Scenario 1 and for 72h in a row in Scenario 2.

The informer was able to predict the biomethane yield in Dataset A with a 78.5 % RMSSE, improving the performance of an LSTM NN tested in previous studies of 95.2 %. While modelling the methane yield in Dataset B and Scenario 1, the informer was able to improve the performances of the LSTM NN – 125 % – to 93 %. In Scenario 2, the informer provided an RMSE of 0.145. This study demonstrates the successful application of a transformer-based model – the informer – to the prediction of methane yield from lab-scale and full-scale AD dynamic process. Such models can be applied to industrial-scale biogas plants and be combined with prior knowledge models to stochastically control biogas plants.



Introduction

Motivation

Why Transformer based models?

- **Problems with RNNs and classical machine learning models:**
  - They forget
- **Solution: Transformer**
  - Build for language processing e.g. translation tasks
  - Using complex matrix operations to achieve this
- Time series could be seen the same a text
  - Translation of input to output data

Das ist ein Satz

↓

This is a sentence

=

0.24 0.89 0.87 0.38 0.74

↓

0.50 0.30 0.10 0.20 0.40

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Methods

Experimental setup

- **Reactor's active volume**: 188 m^3
- Online sensors (biogas, temperature, etc..)

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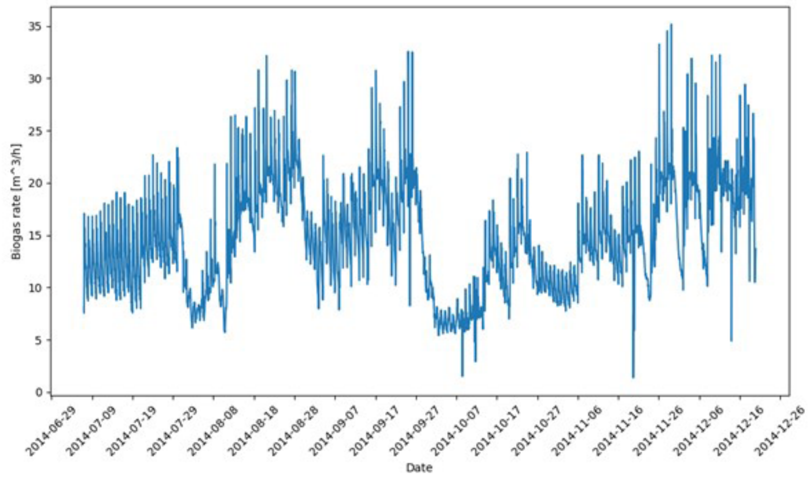
Methods

Data availability

- **Resolution**: 1h
- **OLR**: 2-16 $\frac{kg_{vs}}{m^3 \cdot day}$
- **HRT**: variable
- **Substrate**:
  - Corn silage
  - Cattle manure
- **Duration**: 165 days
- **Train**: 70% / 115 days
- **Val**: 20% / 33 days
- **Test**: 10% / 17 days



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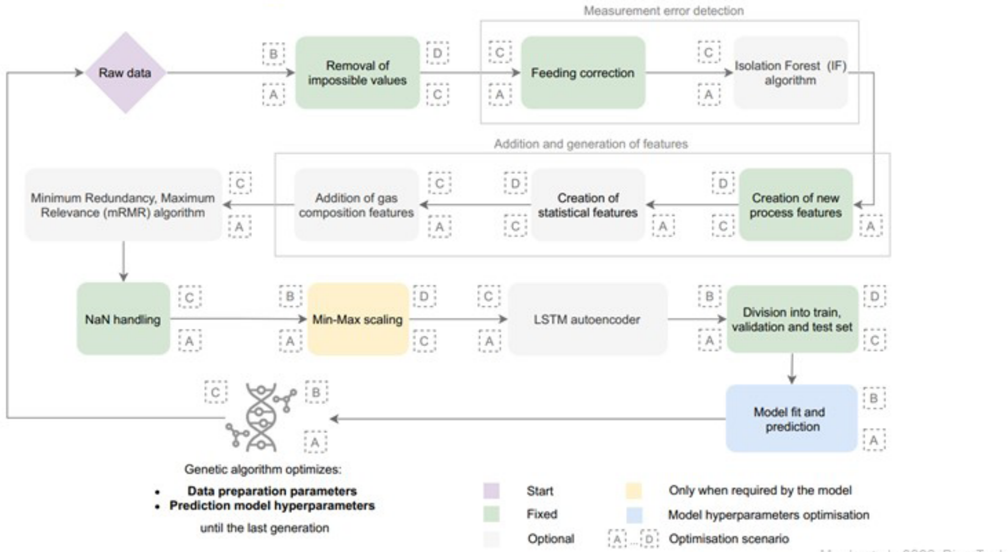
Methods

Optimisation Pipeline



Meola et al., 2023, Bior. Tech.

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Methods

Simulations scenarios

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Time Scenarios

- **Single step**
  - 24 hour forecast
- **Multistep**
  - 1 Week forecast

Model Scenarios

- **Vanilla Informer**
- **Hybrid Model**

  Using the DVS Model:
  1. Output as additional feature
  2. Output Difference

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Methods

Informer Model

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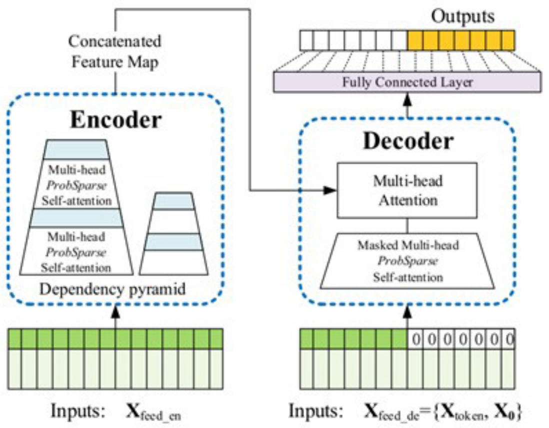
- **Transformer based model**
- Takes all features and past (known) outputs as input to predict future outputs
- **Allows for prediction of multistep series**



Source: Zhou et al. 2021 AAAI

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Methods

DVS Model

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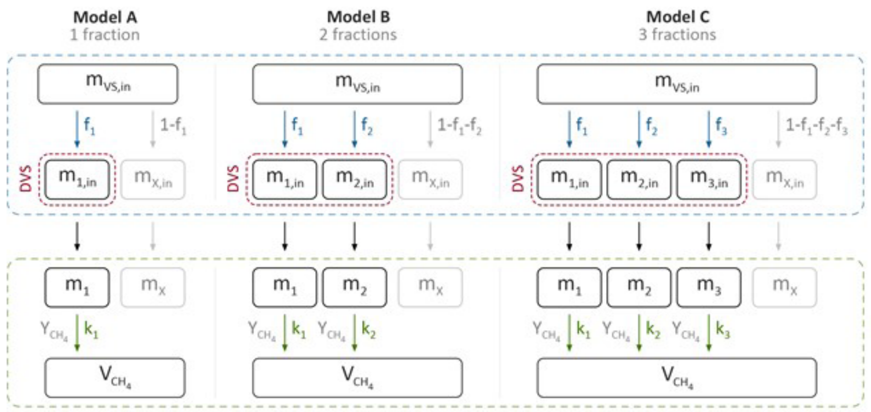

Source: Weinrich et al., 2022, 17th World Conference on Anaerobic Digestion

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Methods

DVS Model - Results

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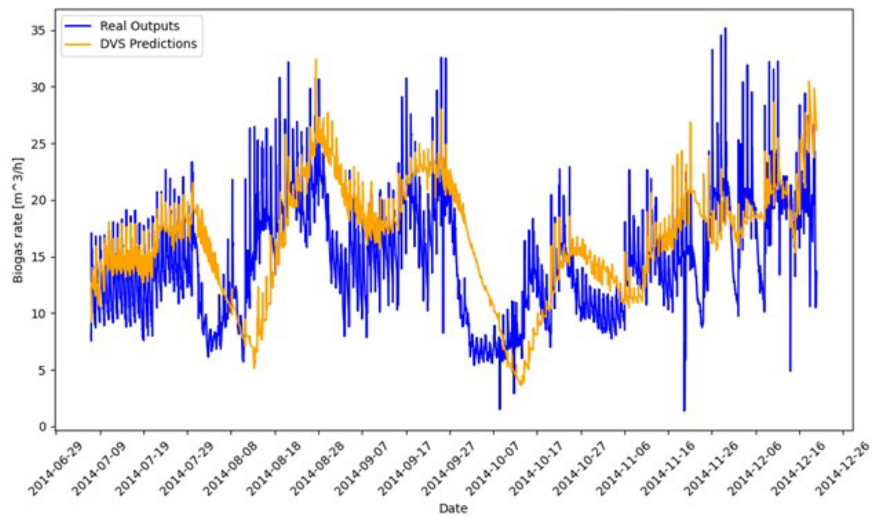

- Trained using a sliding window
- **Window sizes**:
  - Initial values: 1 week
  - Training window: 2 Weeks

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Methods

Hybrid model Type 1 – Use as additional input

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- Use the DVS outputs as an additional input
- Informer then learns how useful this input is

Time	Feature 1	Feature 2
00:00	1	10
01:00	0.5	12
02:00	0.4	28
03:00	0.6	14
04:00	0.8	3

➡

Time	Feature 1	Feature 2	DVS-Outputs
00:00	1	10	20
01:00	0.5	12	18
02:00	0.4	28	16
03:00	0.6	14	22
04:00	0.8	3	24

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Methods

Hybrid model Type 2 – Output Difference

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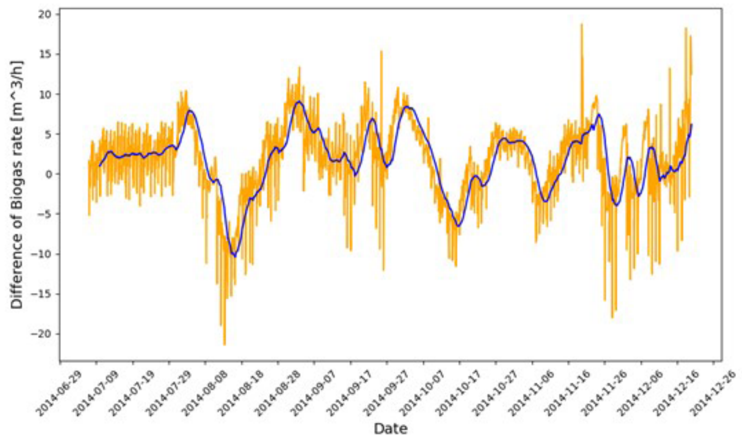
- Predict the **difference** between the DVS results and the real value
- **Idea:**
  - DVS can predict an acceptable baseline
  - Informer compensates for the weaknesses of DVS



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Results

Results – Single step prediction

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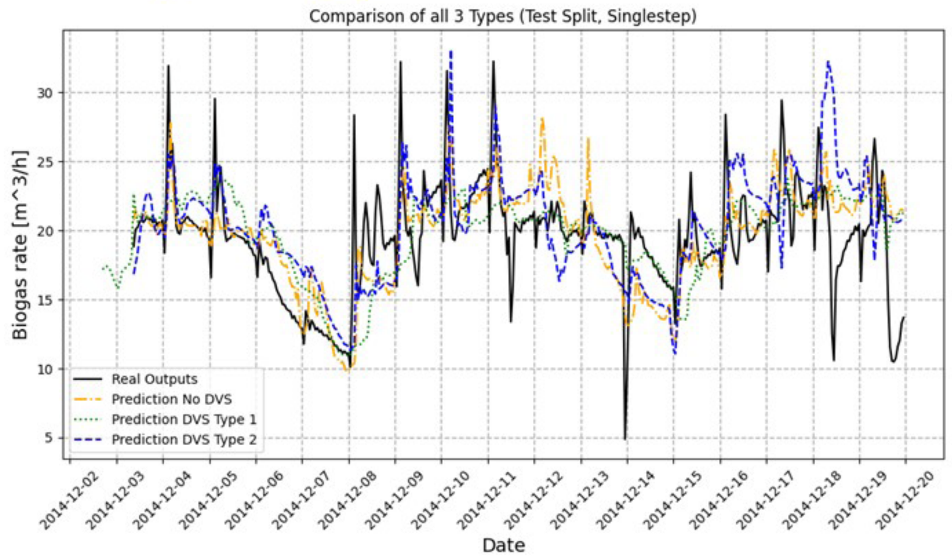

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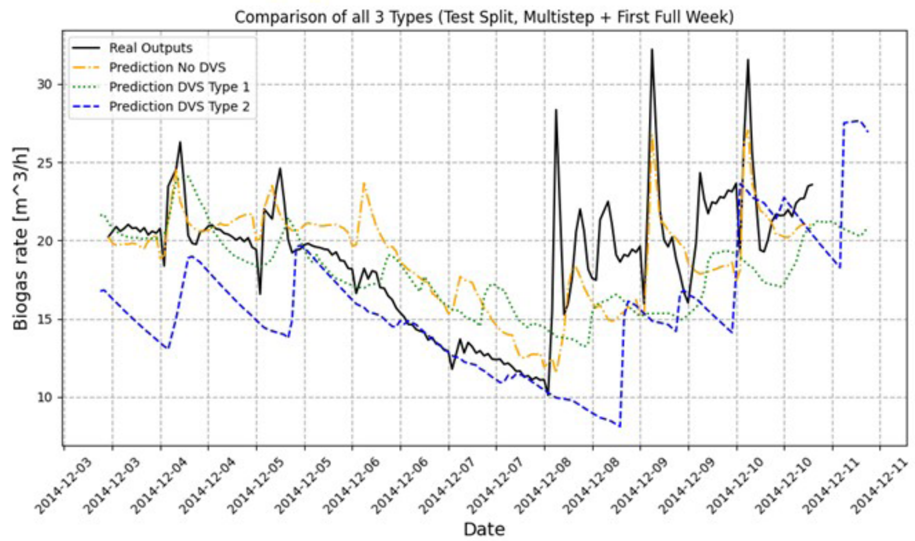
Results

Results – Multistep prediction

DBFZ



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Results

Comparison of simulation scenarios

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Single Step 24 Hours	RMSSE Val %	RMSSE Test %
No DVS	**64.42**	71.80
DVS as Feature	69.02	**69.52**
DVS Output Difference	70.70	83.76

Multistep 1 Week	RMSSE Val %	RMSSE Test %
No DVS	**57.47**	**51.73**
DVS as Feature	61.72	61.72
DVS Output Difference	89.66	77.55

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Conclusions

Conclusions

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- Transformer-based models can succesfully be used to predict output on full scale data
- Combination with DVS slightly improves the results in Single Step
- No improvements with DVS in Multistep
- Multistep forecast works well but the prediction accuracy is decreasing in the more future timesteps

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Conclusions

Outlook

DBFZ

- Different transformer-based models can be tested
- Different ways to implement the hybrid part could be explored
  - e.g.: Usage of another neural network to connect the outputs of both models
- Testing of different resolutions and prediction lengths

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DBFZ

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Pictures: DBFZ, Jan Gutzeit, DREWAG/Peter Schubert (Startpage, right)

SESSION

CARBON MATERIALS AND SEQUESTRATION

Dr. Kathrin Weber
Prof. Dr. Nicolaus Dahmen

7TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Fatou Balleh Jobe, University of Rostock

Exploring Bioenergy with Carbon Capture and Storage (BECCS) Technologies - Current Applications and Gaps: A review

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Keywords: Net-zero emissions, BECCS, Technological readiness

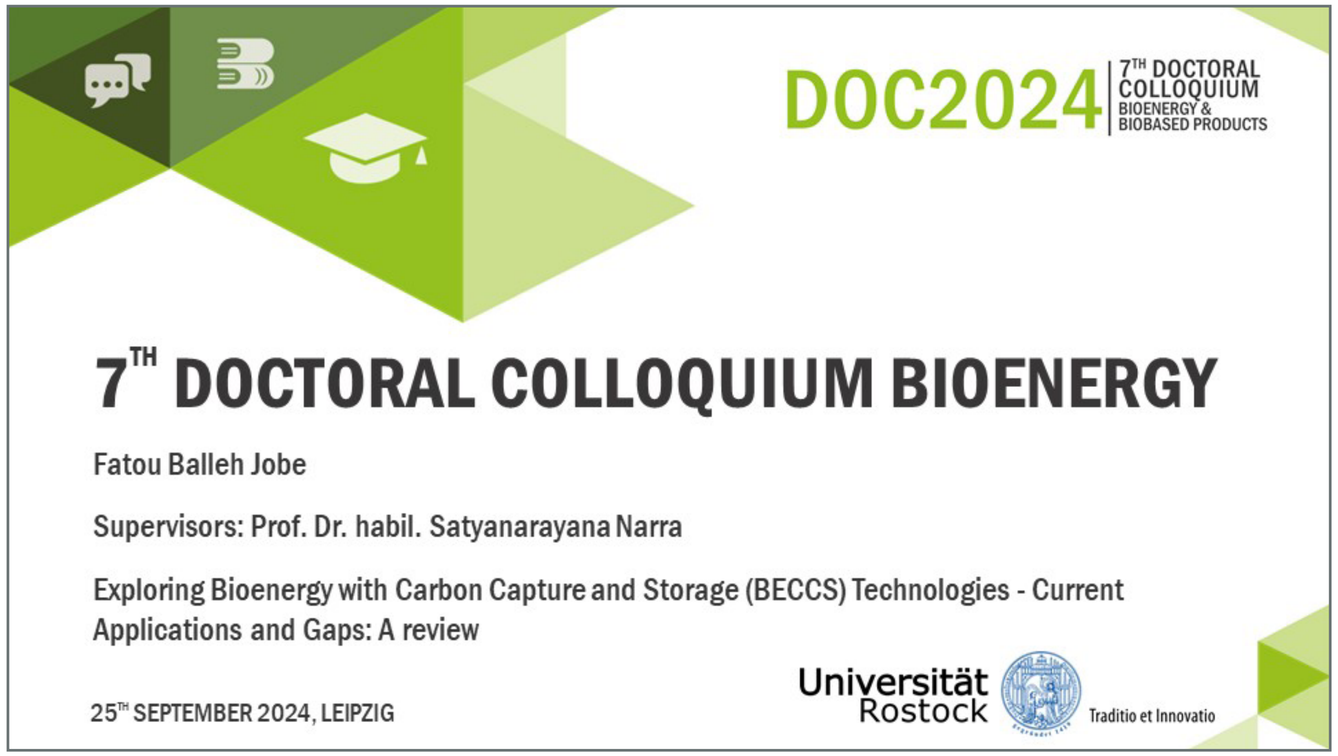
Bioenergy generation is a widely adopted approach that is considered to be carbon-neutral. Even though it is neutral, the CO_2 released from biomass-generated energy contributes to the same atmospheric effects as CO_2 obtained from fossil fuels. Bioenergy with Carbon Capture and Storage (BECCS) is a decarbonization tool for mitigating climate change. This advanced technology involves capturing, transporting, and storing the resulting CO_2 produced from any energy pathway derived from a biogenic source such as biofuels, electricity, heat, or hydrogen.

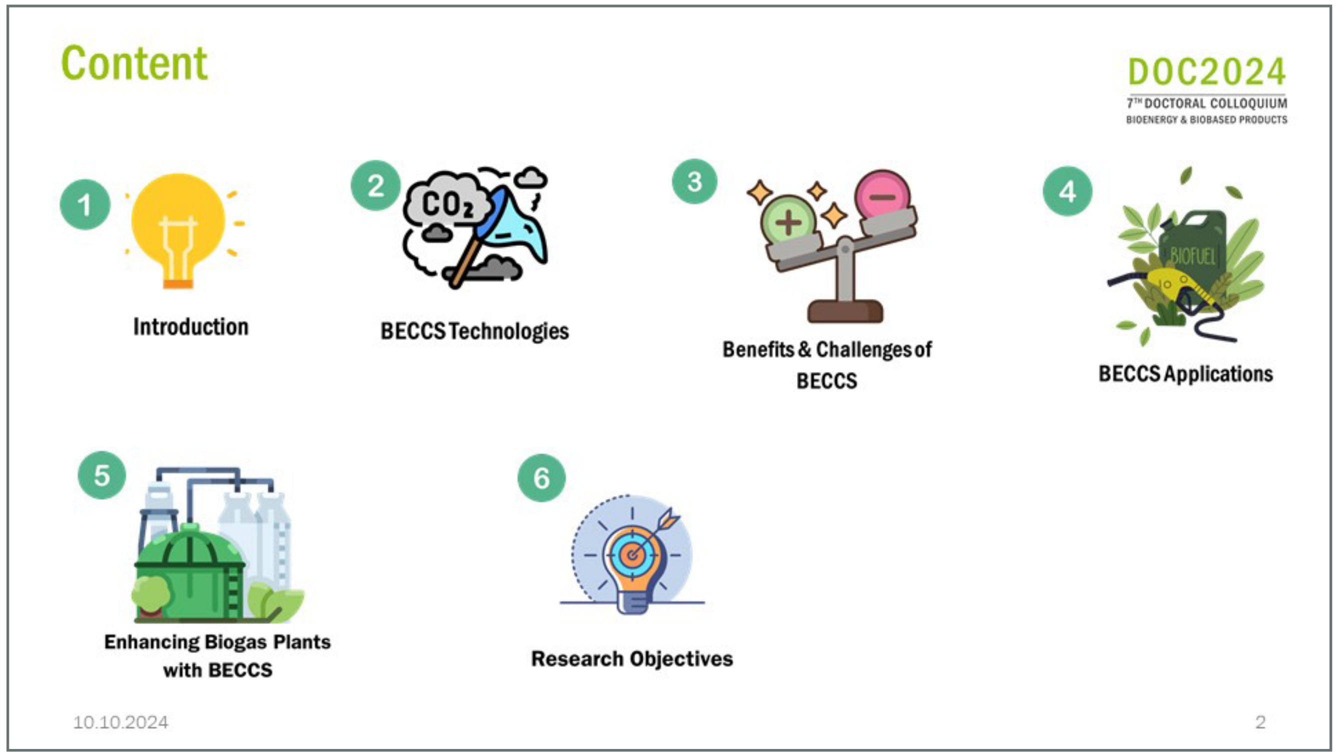
Carbon capture technologies used in bioenergy include absorption, adsorption, membrane separation, chemical looping, cryogenic distillation, and hydrate-based separation. These carbon capture and storage (CCS) technologies are being modified to fit into bioenergy technologies making up BECCS technologies. Based on the literature BECCS technologies being investigated comprise woody biomass combustion, fermentation, gasification, biogas upgrading, municipal solid waste combustion or landfill gas combustion with CCS, and algae-based BECCS through thermochemical processes.

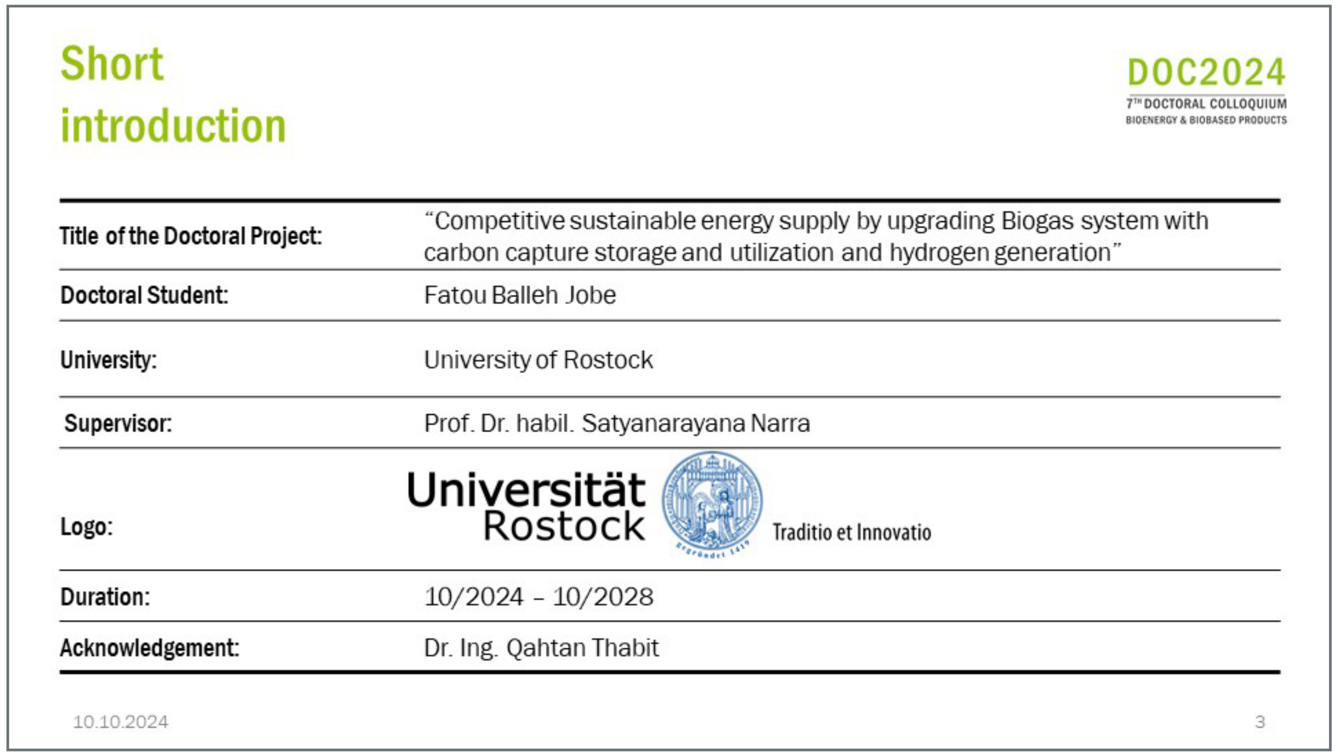
Although BECCS is currently more prevalent in bio-ethanol/methanol production its usage in other forms of biofuels and electricity generation is gradually increasing. The potential to capture and sequester carbon from bioenergy generated from the organic fraction of municipal solid waste and agricultural residue is lower than the amount required to achieve the net-zero scenario. Meeting this target puts pressure on the utilization of first, second, and third-generation biomass leading to environmental sustainability and economic concerns. These challenges include sustainable biomass, land use change, soil erosion, biodiversity loss, and water use.

Some literatures highlight economic challenges such as price increases on agricultural commodities through competition for land. From a technological perspective, low energy efficiency due to the high energy consumption of BECCS technologies is also a major challenge.

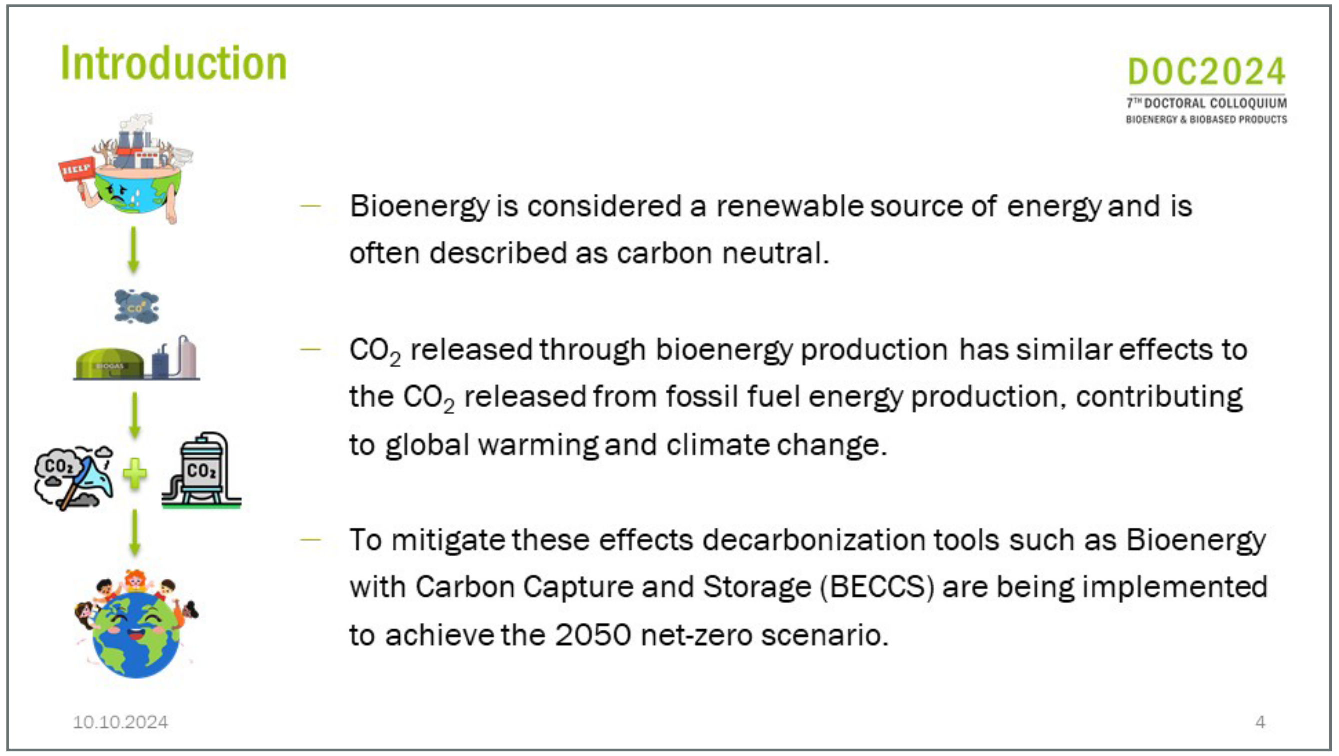
This study aims to investigate the latest developments in BECCS, evaluating its advantages and obstacles while also identifying areas that require further attention. The research will also explore potential strategies for integrating carbon capture, storage, and utilization into biogas generation facilities, with the goal of decarbonizing the process, expanding the range of outputs, and improving the economic viability of such facilities.

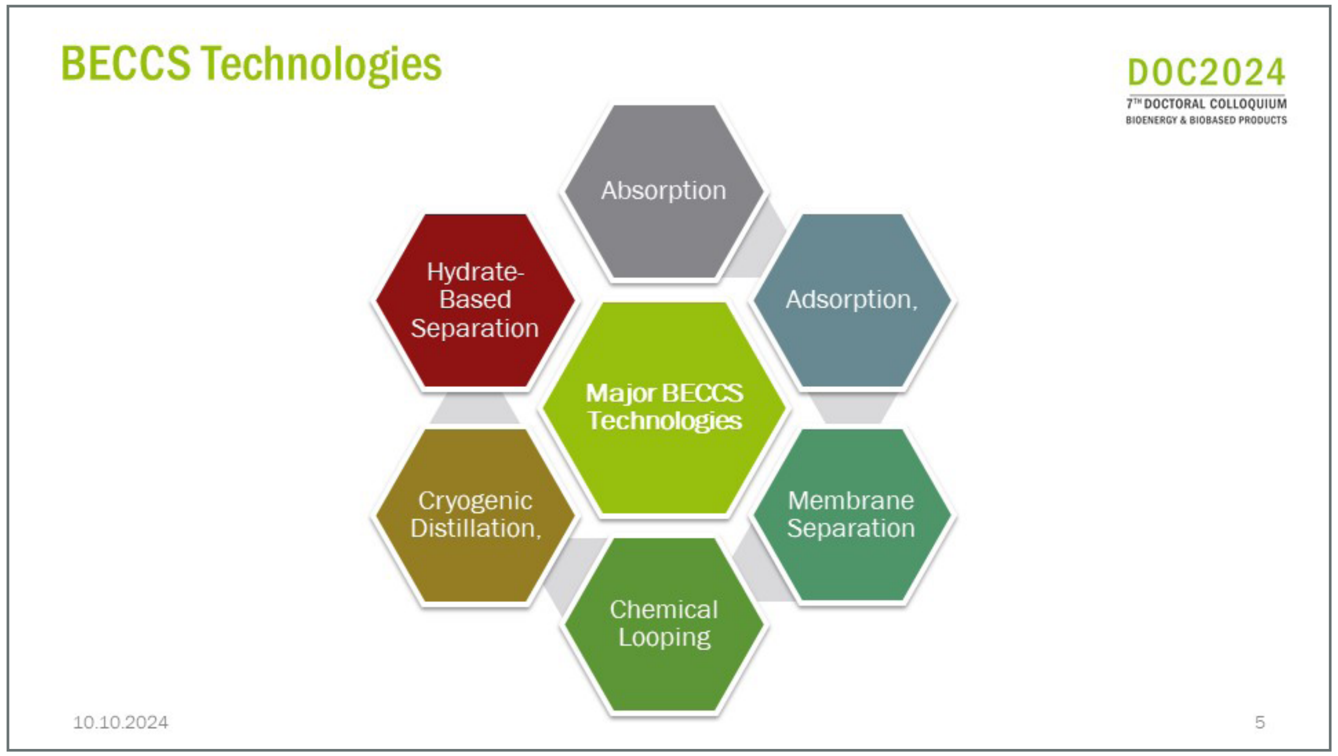


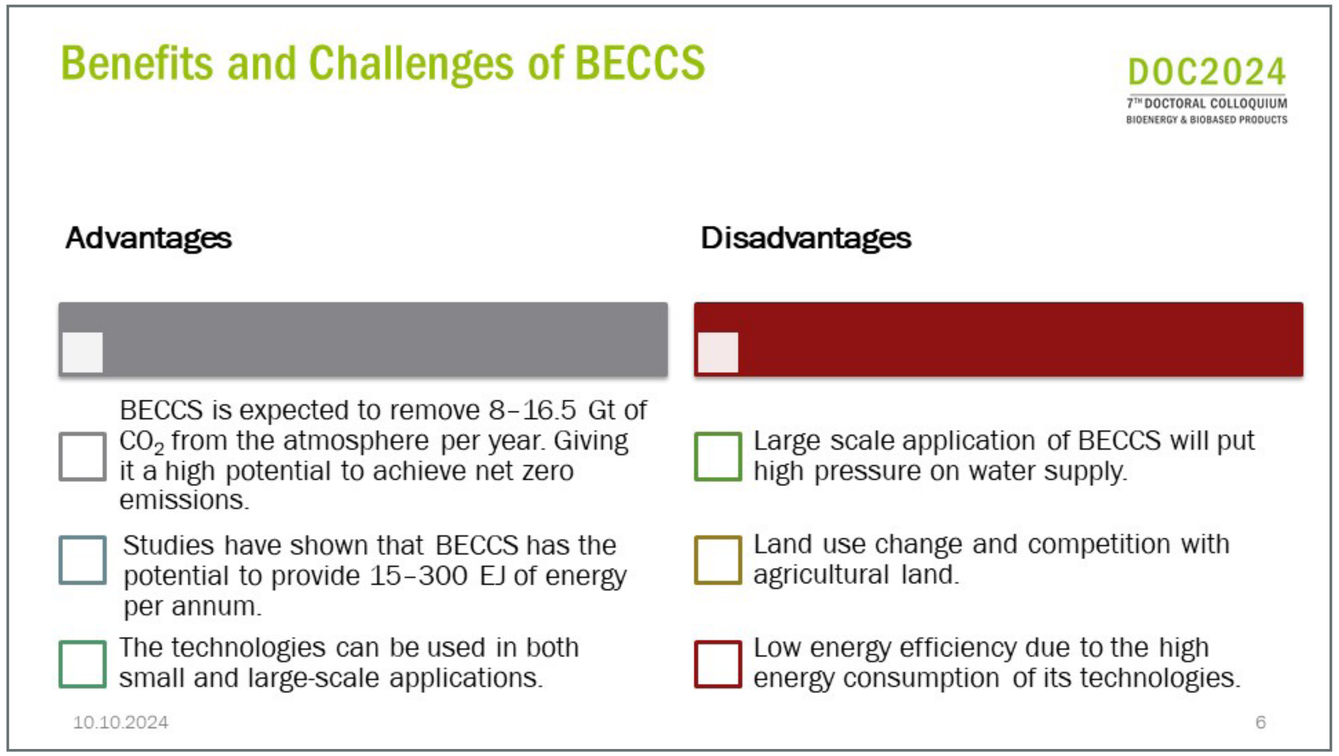




Title of the Doctoral Project:	"Competitive sustainable energy supply by upgrading Biogas system with carbon capture storage and utilization and hydrogen generation"
Doctoral Student:	Fatou Balleh Jobe
University:	University of Rostock
Supervisor:	Prof. Dr. habil. Satyanarayana Narra
Logo:	Universität Rostock Traditio et Innovatio
Duration:	10/2024 – 10/2028
Acknowledgement:	Dr. Ing. Qahtan Thabit







BECCS Applications

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BECCS technologies are primarily implemented in the context of bioenergy generation, with a focus on the following applications at different scales:

- Woody Biomass Combustion
- Fermentation
- Gasification
- Biogas Upgrading
- Municipal Solid Waste Based BECCS
- Algae-Based BECCS

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Biogas Plants Without BECCS

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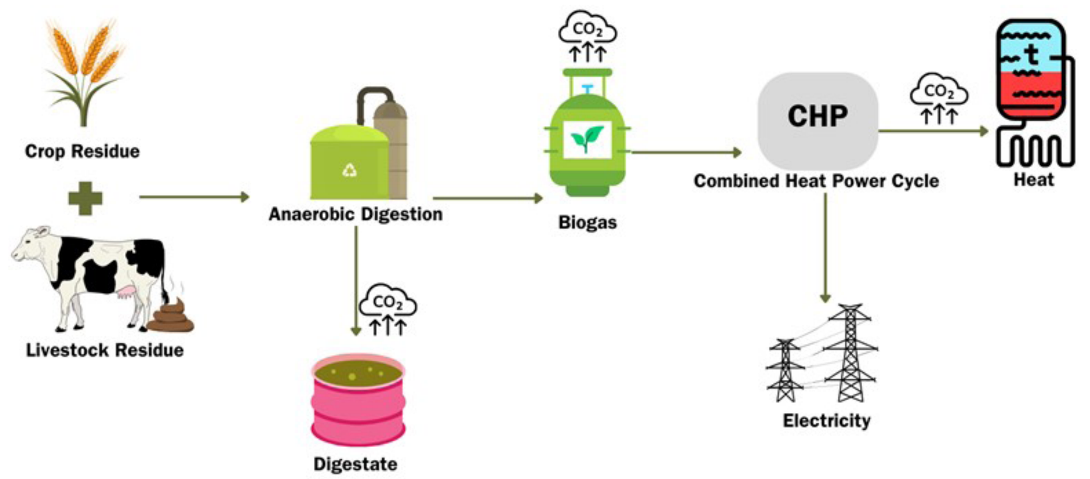

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Enhancing Biogas Plants With BECCS {1/2}

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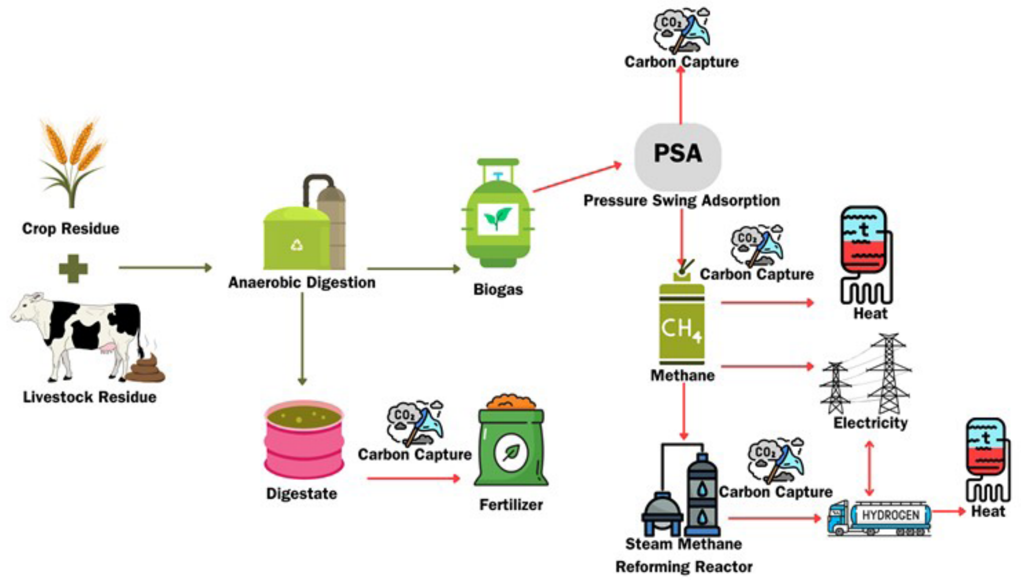

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Enhancing Biogas Plants With BECCS {2/2}

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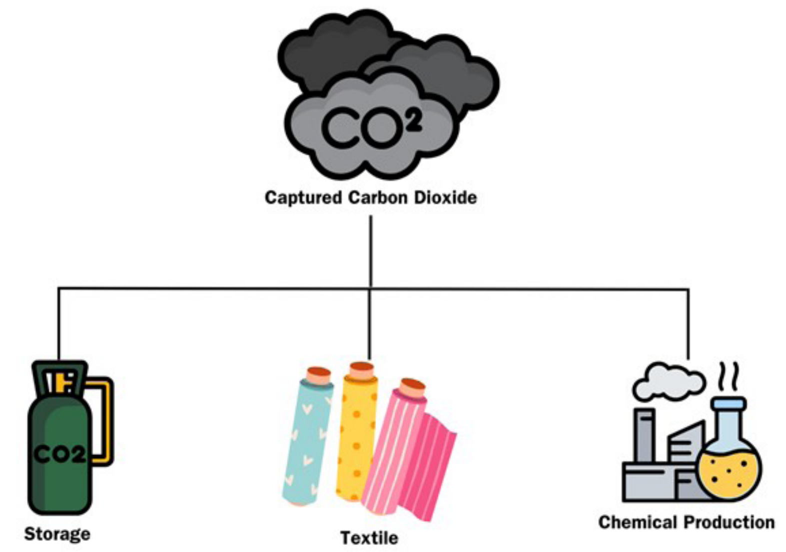

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Research Objectives

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Main objective: To advance biogas plants by integrating bioenergy with carbon capture, storage, and utilization (CCSU), as well as diversifying outputs to promote sustainability.

1. Quantify CO_2 emissions from existing biogas generation facilities.
2. To model and analyze varied scenarios of the incorporation of CCSU and output diversification of biogas plants.
3. Carry out a life cycle analysis for an enhanced biogas plant with CCSU.
4. Conduct a techno-economic analysis to evaluate the feasibility and economic potential of enhancing and diversifying biogas plants with carbon capture, storage, and utilization.

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References

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Wenxuan Li, Karlsruhe Institute of Technology

Preparation of high-performance support Nb2O5-active carbon for hydrodeoxygenation

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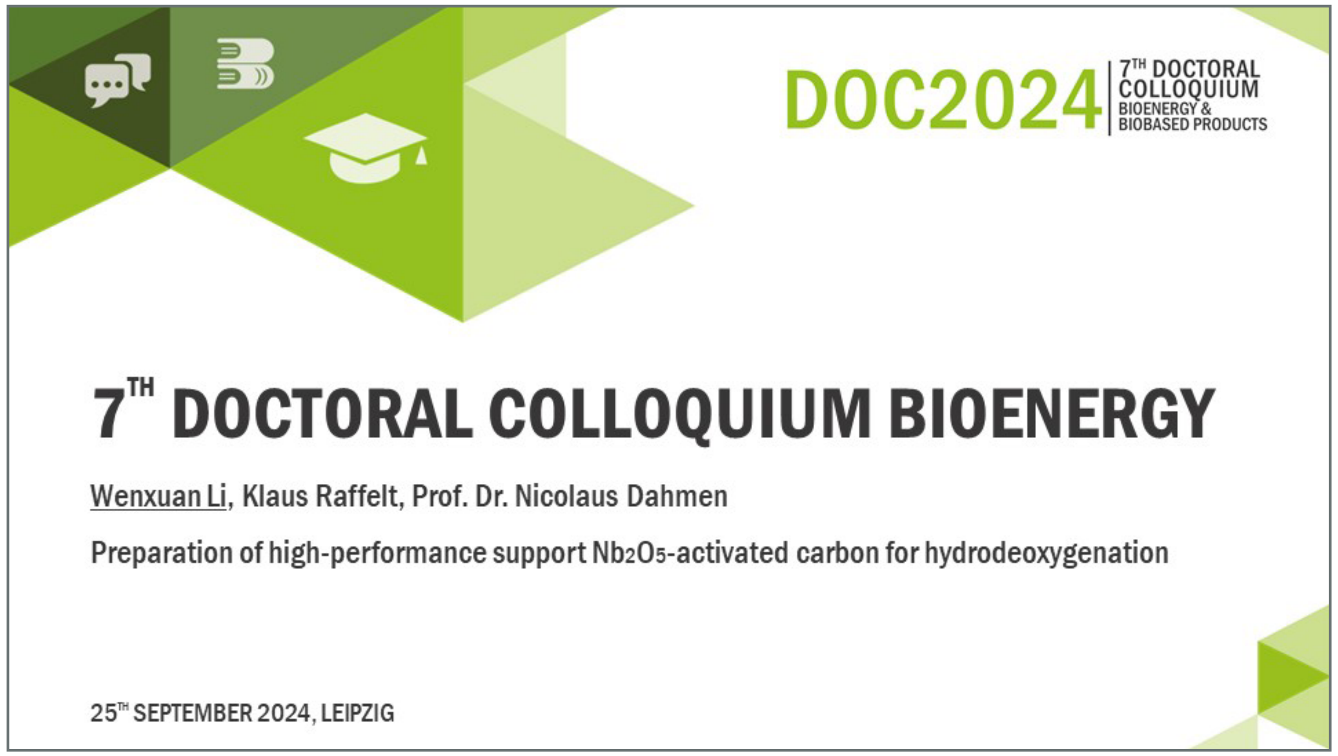
Keywords: Hydrodeoxygenation, catalyst support, guaiacol, Nb2O5-AC

Niobium pentoxide as a support shows good deoxidation performance in hydrodeoxygenation (HDO), but lower specific surface area has some limitations on catalytic effect. To address this problem, we studied a new type of support that combines niobium pentoxide and activated carbon, the support is prepared by utilizing the rich specific surface area of activated carbon while retaining the hydrodeoxygenation performance of niobium pentoxide.

Uniform mixing of niobium and carbon by sol-gel method, then carbonize and activate the product get the niobium pentoxide-Active Carbon(Nb2O5-AC). The support is loaded with transition metals such as nickel, iron and cobalt to form Ni/Nb2O5-AC, Fe/Nb2O5-AC, Co/Nb2O5-AC, which are used to treat guaiacol to test the HDO catalytic, the reaction products was tested by GCMS and compared with the effect of the noble metal catalyst.

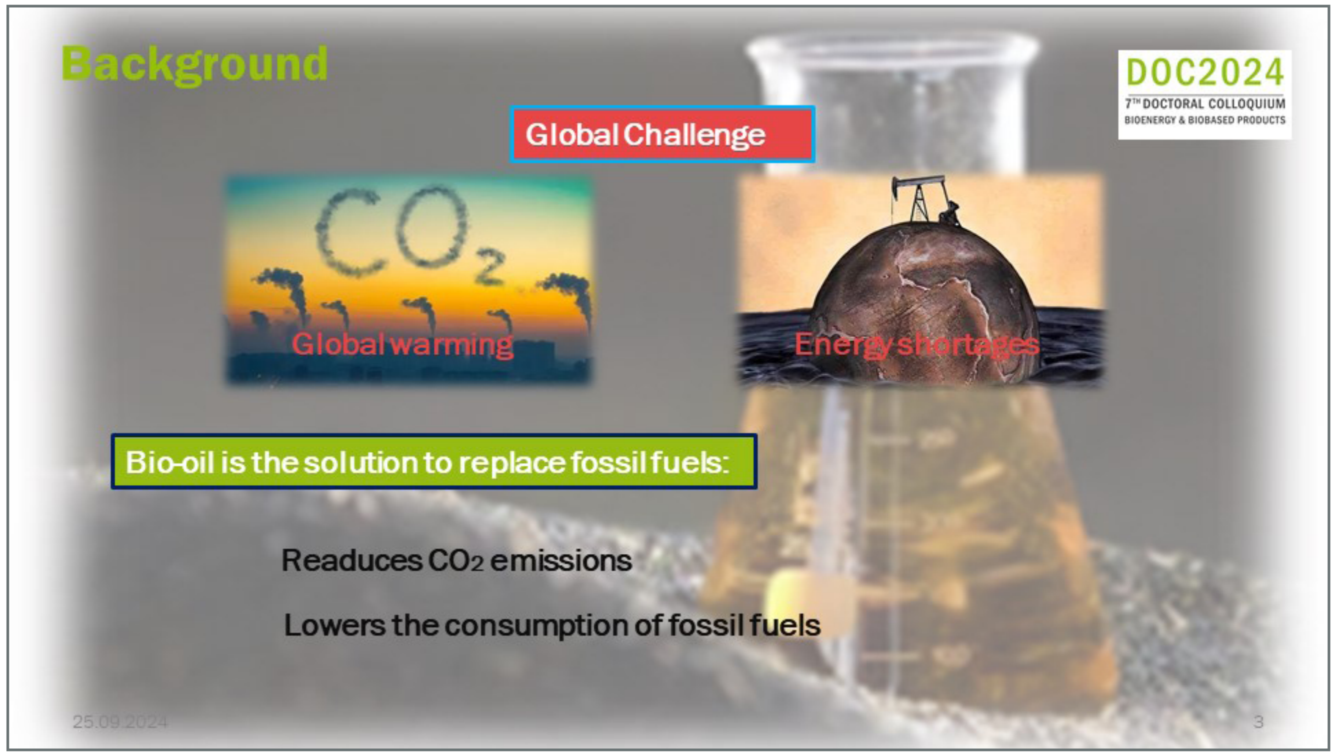
The preparation of Nb2O5-Active carbon by sol-gel method and the process can be briefly stated as follows: 3.2 g Niobium ammonium oxalate dissolved in the 10 ml distilled water at 50°C, add 6.2 g citric acid, and react for 30 min. Next raise the temperature up to 90°C and react for 30 min, then adding the 1.86 g ethylene glycol and react for 60 min, cool to room temperature and dry at 95° C for 24 h, after grinding the obtained dry product and adding zinc chloride, the product was calcined at 300° C for 6 h under a nitrogen atmosphere, then washed repeatedly with 2 mol/L HCl and distilled water until the pH of the filtrate is 6~7, and the Nb2O5-AC was obtained after drying.

New support compared to Nb2O5, the conversion of guaiacol and cyclohexanol selectivity are significantly improved. The HDO of guaiacol tends to be hydroisomerized first and then deoxygenated when using Ni/Nb2O5-AC, It needs to be further verified by examining the changes in product composition at different reaction times to explain the reaction mechanism.



Short introduction

Doctoral Student:	Wenxuan Li
University Supervisor:	Prof. Dr. Nicolaus Dahmen
Funding / Scholarship provider: Logo:	China Scholarship Council
Duration:	02/2023 – 01/2027


Background
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Global Challenge
CO2
Global warming
Energy shortages
Bio-oil is the solution to replace fossil fuels:
Readuces CO2 emissions
Lowers the consumption of fossil fuels
25.09.2024
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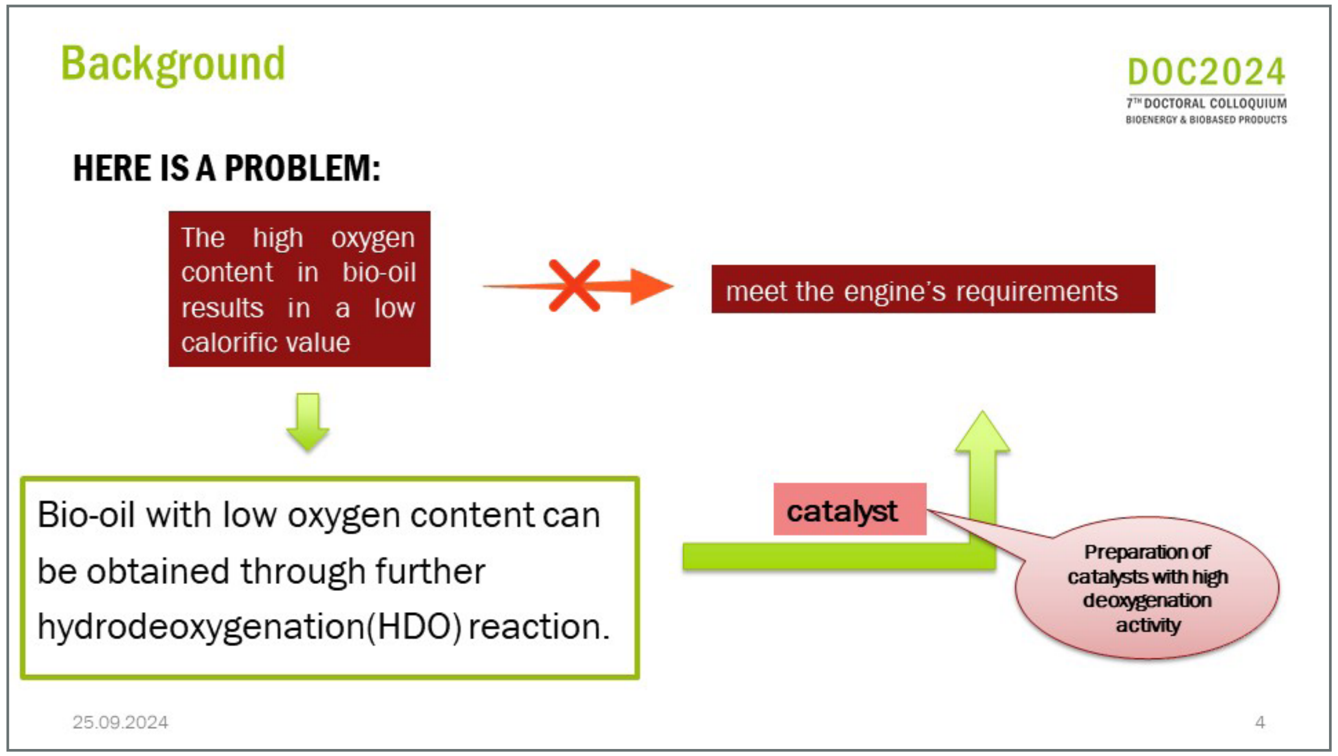
Background
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HERE IS A PROBLEM:
The high oxygen content in bio-oil results in a low calorific value
meet the engine's requirements
Bio-oil with low oxygen content can be obtained through further hydrodeoxygenation(HDO) reaction.
catalyst
Preparation of catalysts with high deoxygenation activity
25.09.2024
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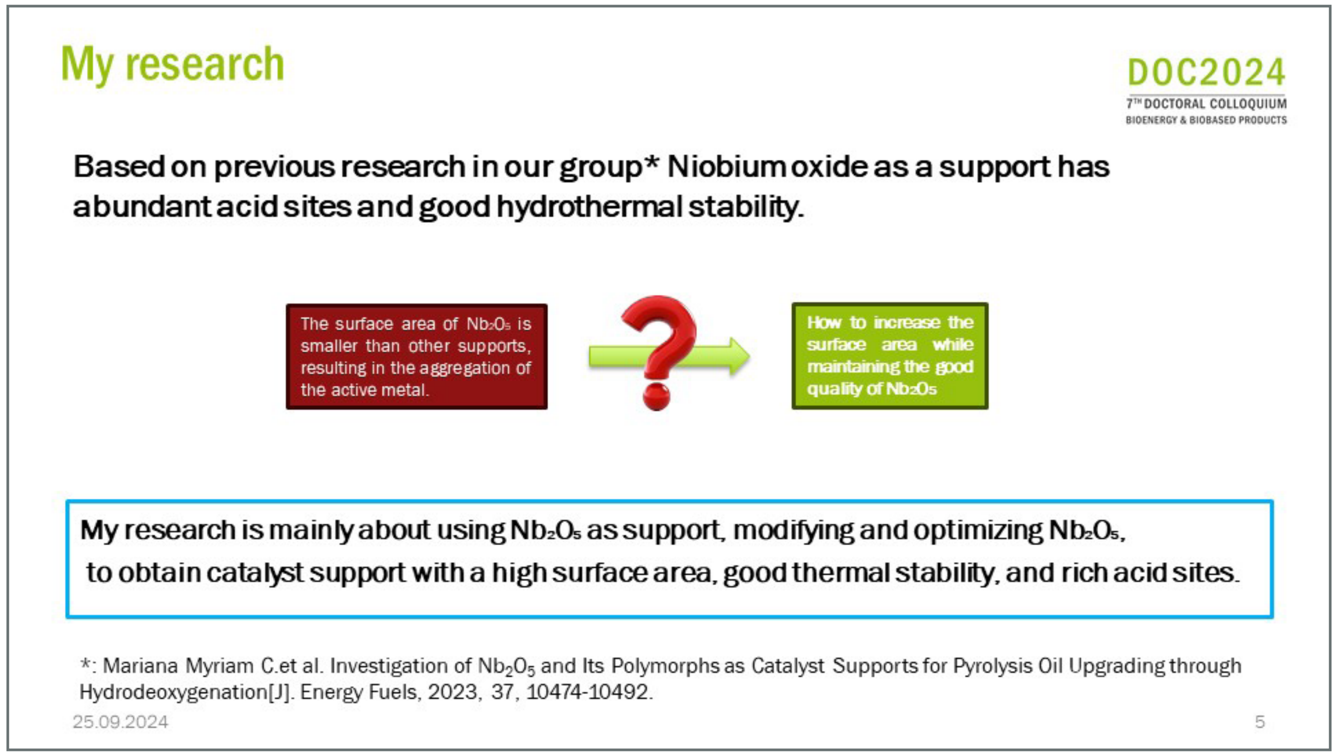
My research
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Based on previous research in our group* Niobium oxide as a support has abundant acid sites and good hydrothermal stability.
The surface area of Nb2O5 is smaller than other supports, resulting in the aggregation of the active metal.
How to increase the surface area while maintaining the good quality of Nb2O5
My research is mainly about using Nb2O5 as support, modifying and optimizing Nb2O5,
to obtain catalyst support with a high surface area, good thermal stability, and rich acid sites.
*: Mariana Myriam C.et al. Investigation of Nb2O5 and Its Polymorphs as Catalyst Supports for Pyrolysis Oil Upgrading through Hydrodeoxygenation[J]. Energy Fuels, 2023, 37, 10474-10492.
25.09.2024
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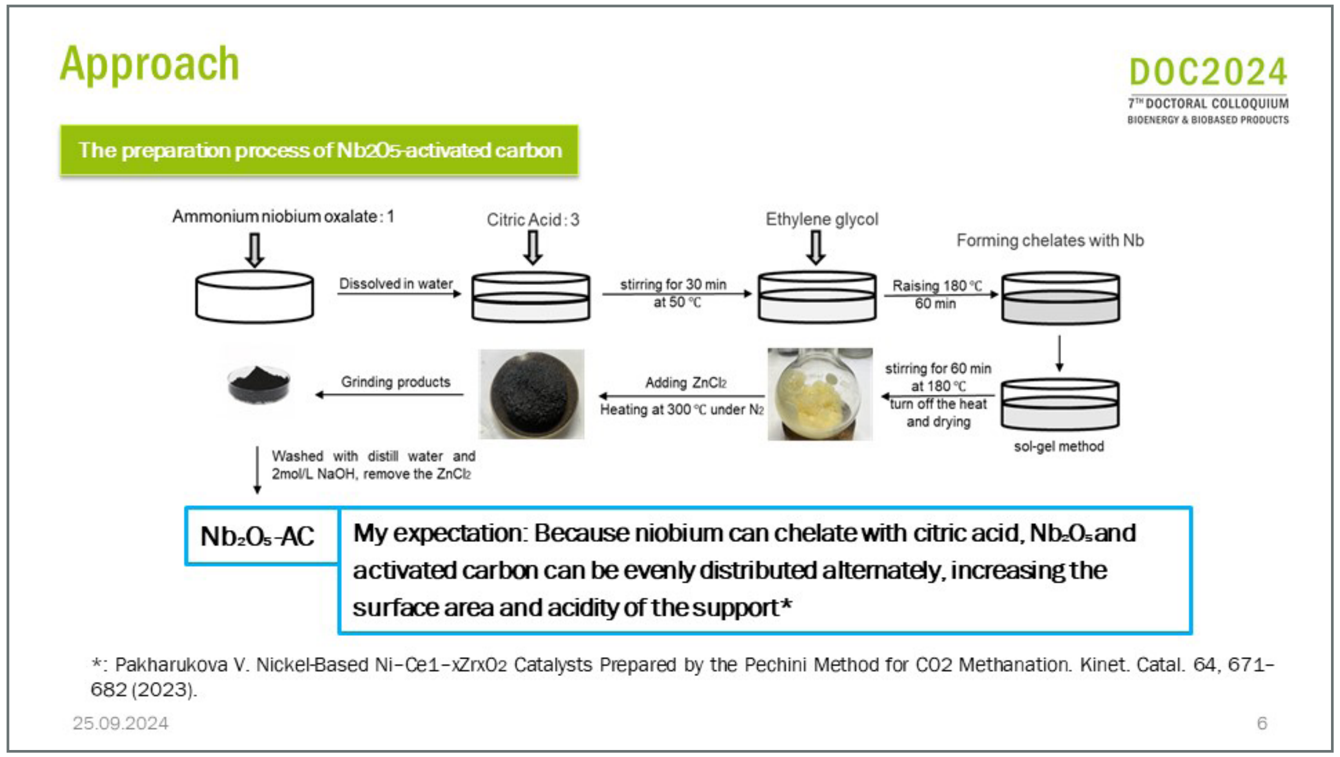
Approach
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The preparation process of Nb2O5-activated carbon
Ammonium niobium oxalate : 1
Citric Acid : 3
Ethylene glycol
Forming chelates with Nb
Dissolved in water
stirring for 30 min at 50 ℃
Raising 180 ℃ 60 min
stirring for 60 min at 180 ℃ turn off the heat and drying
sol-gel method
Adding ZnCl2
Heating at 300 ℃ under N2
Grinding products
Washed with distill water and 2mol/L NaOH, remove the ZnCl2
Nb2O5-AC
My expectation: Because niobium can chelate with citric acid, Nb2O5 and activated carbon can be evenly distributed alternately, increasing the surface area and acidity of the support*
*: Pakharukova V. Nickel-Based Ni−Ce1−xZrxO2 Catalysts Prepared by the Pechini Method for CO2 Methanation. Kinet. Catal. 64, 671–682 (2023).
25.09.2024
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XRD Characterization

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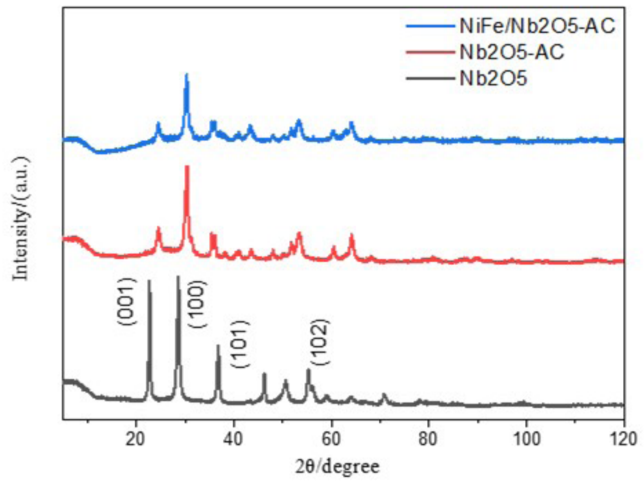

XRD results of Nb_2O_5, Nb_2O_5-AC, NiFe/ Nb_2O_5-AC

The position of the characteristic peak of Nb_2O_5-AC prepared by our designed method has shifted and is significantly different from the peak of Nb_2O_5. **This shows that Nb_2O_5-AC has formed.**

Due to the low content of iron and nickel, the characteristic peaks of nickel and iron cannot be measured.

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Results

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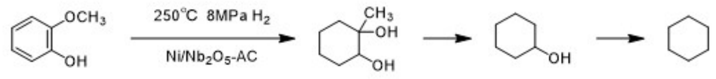
The new reaction pathway of guaiacol observed during HDO testing using the NiFe/Nb_2O_5-AC catalyst. As shown in the figure below



When using the NiFe/Nb_2O_5-AC, guaiacol is more likely to Hydroisomerization first then removing the hydroxyl.

With new support compared to Nb_2O_5-T, Activated carbon, and TiO_2 the conversion of guaiacol and cyclohexanol selectivity is significantly improved.

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HDO Testing

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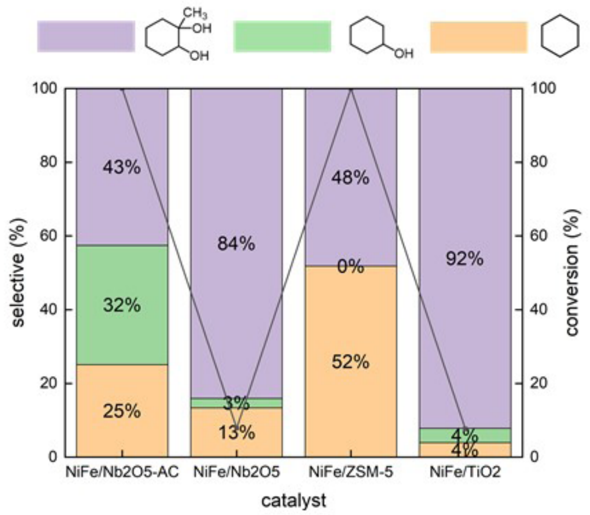

GC-MS&FID HDO reaction results of guaiacol with various catalysts, reaction condition: 1g guaiacol, 19g decalin, 0.5g catalyst, 80bar H_2, 250°C, 2h, 400rpm.

1. The Nb_2O_5 -AC compared with Nb_2O_5 and AC, the conversion is increased from 7.87 to 100%

2. The Nb_2O_5-AC achieves a 100% conversion compared to commercial zeolite ZSM-5, but its selectivity remains significantly lower, indicating that further improvements to the support are necessary.

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SESSION

SUSTAINABLE RESOURCE BASE

PD Dr. Kurt Möller
Dr. Omar Hijazi
Prof. Walter Zegada Lizarazu

7TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Maria Giovanna Sessa, Università di Bologna

Evaluation of carinata-based SAF in the Mediterranean

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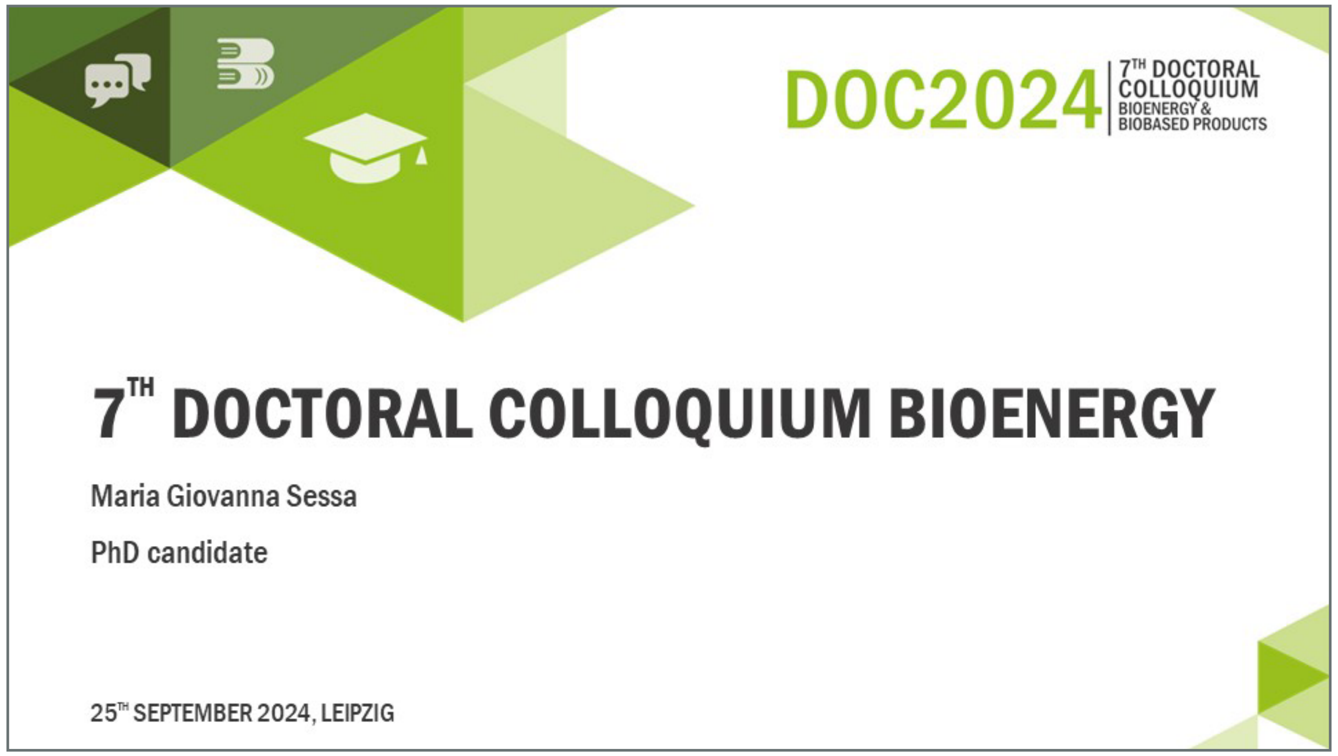
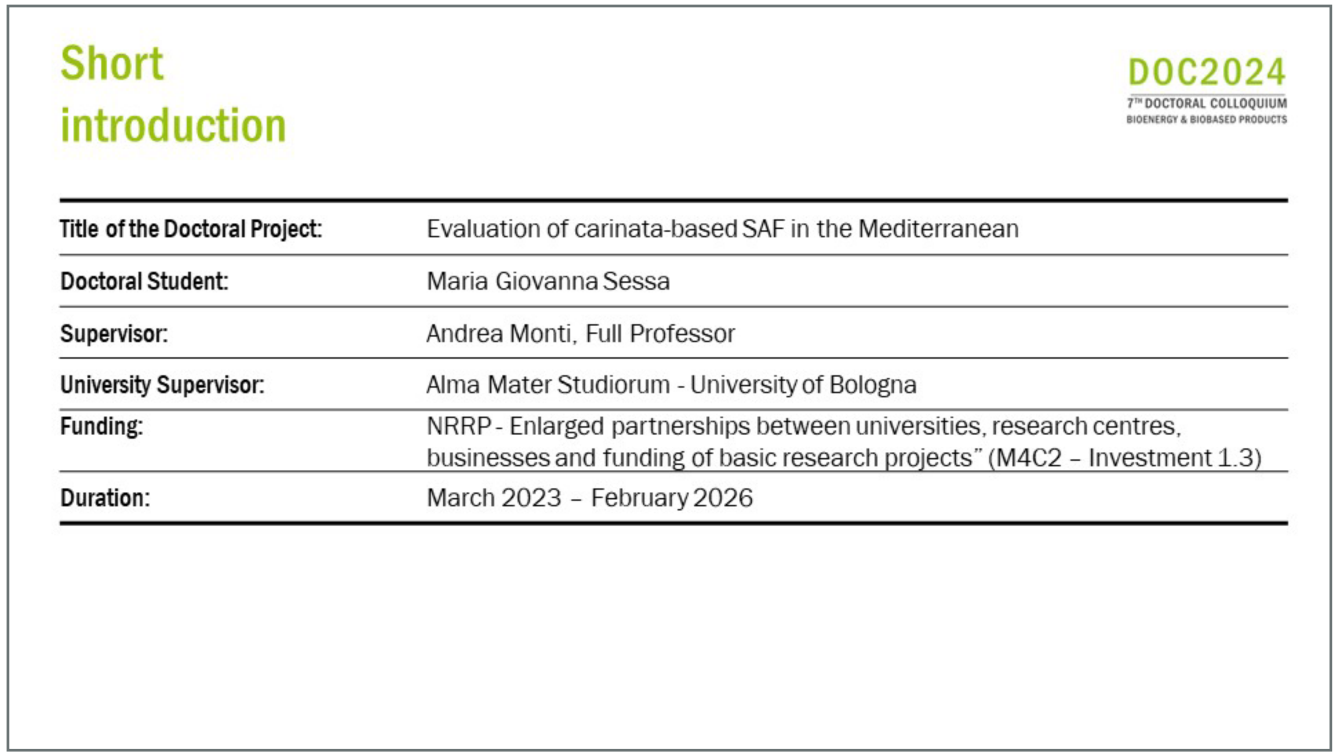
Keywords: ReFuelEU, SAF. Aviation, Carinata, Agriculture

Sustainable aviation fuels (SAF) are considered one of the most valuable options to mitigate climate change (Qasem, 2024). On 18 October 2023, the European Parliament and Council adopted a final act (ReFuelEU 2023/2405) that sets minimum obligations for all fuel suppliers to gradually increase the share of SAF (including synthetic aviation fuels also known as e-fuels) at EU airports. According to the ReFuelEU, in 2030 the minimum share of SAF should be 5 % increasing to 63 % in 2050. SAF obtained from biomass feedstocks, particularly from non-edible vegetable oils, can efficiently contribute to decreasing the greenhouse effect by buffering the CO_2 (Seber, 2022). Among others, in recent years, there has been growing interest in an easy-to-grow oilseed crop: carinata (Brassica carinata). The present study aims to: i) evaluate the agronomic performance of carinata within different cropping systems (i.e., main crop, intercropping, relay-cropping); ii) assess the environmental benefits of carinata-based SAF.

Carinata has been included in three field experiments testing different cropping systems at the UNIBO experimental farm (Bologna, Italy). In the first experiment, four different carinata varieties (supplied by Nuseed and AAFC, Agriculture Agri-Food Canada) were tested in two different sowing dates (spring and autumn) to evaluate the adaptability of the crop to the pedo-climatic conditions of the Mediterranean region as main crop. Additionally, to avoid the competition for the land use and natural resources between industrial crops and food crops, an intercropping field trial, including carinata (Nujet 350) and chickpea, has been established in November 2023 and compared with the respective sole-crops. Finally, in the third experiment, a relay-cropping system with carinata relay-sown in spring on a barley stand (planted in the preceding autumn) has been arrange in large strips (>5000 m²). After the harvest, representative seed samples from all experiments will be collected and characterized (oil content and fatty acid profile). The SimaPro 9.4.0.3 will be used to evaluate the life cycle assessment of carinata-based SAF.

So far, results only on the spring sowing of carinata screening trial are available. The crop showed massive injury caused by the attack of flea beetles. Carinata seeds yield of the variety trials was on average 0.7 Mg ha-1 and the mean of the oil content was 25 %. For all the other experiments, only preliminary data are available since they are all currently ongoing in the field. So additional results will be obtained after the harvest of the crops expected in summer. Nevertheless, carinata sown in autumn in the screening trial shows a much growth compared to the spring sown trial. The results of the ongoing study will be used to set the environmental impacts of the carinata-based SAF value chain.





Title of the Doctoral Project:	Evaluation of carinata-based SAF in the Mediterranean
Doctoral Student:	Maria Giovanna Sessa
Supervisor:	Andrea Monti, Full Professor
University Supervisor:	Alma Mater Studiorum - University of Bologna
Funding:	NRRP - Enlarged partnerships between universities, research centres, businesses and funding of basic research projects" (M4C2 – Investment 1.3)
Duration:	March 2023 – February 2026

Scientific Background

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- RED III (Directive (EU) 2023/2413): at least **42.5%** energy from renewable sources in the EU Member States by 2030.
- Green Deal (Regulation (EU) 2021/1119): reduce GHG emissions by at least **55%** by 2030 and carbon neutrality by 2050.
- Agriculture sources **11%** of all GHG emitted in the EU. (Source: European Environment Agency).
- Agricultural production in Europe: cereals (wheat **46%**, corn **25%**, barley **20%**); oilseeds (rapeseed **60%**, sunflower **30%**) (Source: FAO, EUROSTAT).
- Unused and abandoned land in Europe: **14,8%** (Source: Bioenergy Europe).

3

BRASSICA CARINATA (A. Braun)

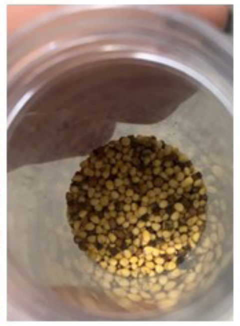
Annual oilseed crop: *Brassicaceae*

Seed production: 1.4-2.4 Mg DM ha^{-1}

Oil content: 35-45%

Protein content: 19-28%

Multi-purpose uses: bio-based applications



Sustainable Aviation Fuel (SAF)

- Currently, SAF supply remains <0.05% of total EU aviation fuel used.
- The ReFuelEU proposal aims at reaching the share of 63% SAF by the 2050.

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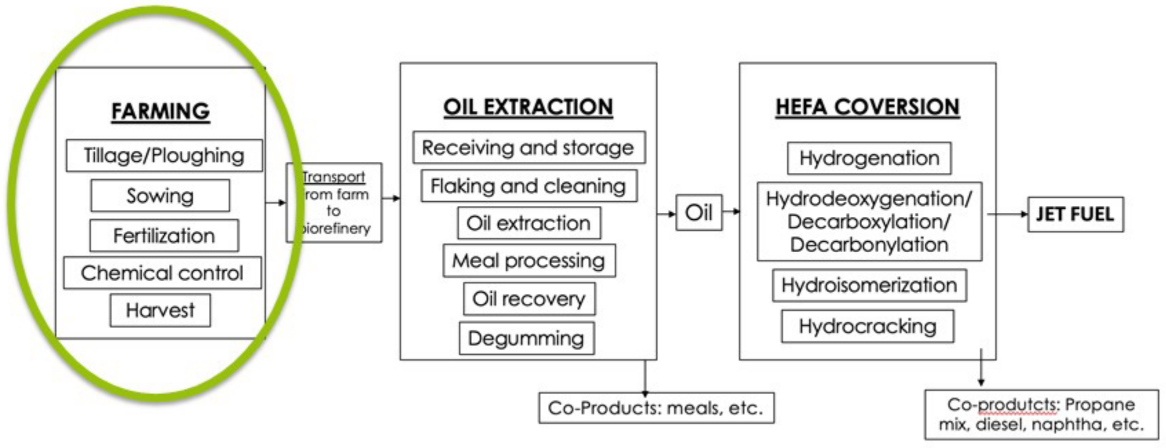
Schematic flowchart for the HEFA-jet fuel pathway from oilseed crops



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Aim of the project

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EVALUATE THE AGRONOMIC PERFORMANCE AND OIL QUALITY OF *BRASSICA CARINATA* IN A FOOD/NON-FOOD CROPPING SYSTEM IN THE MEDITERRANEAN REGION, AIMING TO CREATE A SUSTAINABLE VALUE CHAIN FOR SAF

Four research questions:

1. Which is the most suitable carinata variety for the Mediterranean region? (2023-2024)
2. Is carinata more suitable for cultivation as a summer or a winter cover crop? (2023- in progress)
3. Which is the optimal agronomic management for carinata integrated into inter-, relay-cropping systems with food crops? (2023- in progress)
4. Is the production chain of carinata, from cultivation to SAF production, environmentally sustainable? (2024-in progress)

6

Materials & Methods

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7TH DOCTORAL COLLOQUIUM BIOENERGY & BIOBASED PRODUCTS

Cadriano, Bologna (Italy)
44° 33′N, 11° 23′E

3 different field trials

		Sowing date	Growing season
1) VARIETY/CASH COVER CROP	Carinata	Spring/autumn	2023-2024
2) INTERCROPPING SYSTEM	Carinata Chickpea	Spring/autumn	2023-2024
3) RELAY-CROPPING SYSTEM	Carinata Barley	Spring/autumn	2023-2024

7

Materials & Methods

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What is the most suitable carinata variety for the Mediterranean region?

VARIETY TRIAL

Genotypes	6310 6325 C31-526 E18-0030 E18-0082 HYB087
Sowing date	Aprile 2023
Harvest Date	July 2024
Fertilization	50 kg N/ha as urea
Pest	Flea beetle
Pest control	Dimethoate (1.3%) Deltamethrin (3%) Acetamiprid (5%)
Irrigation	Rainfed

Results

VARIETY TRIAL

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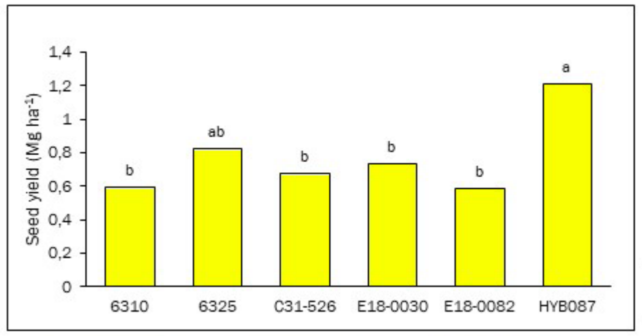
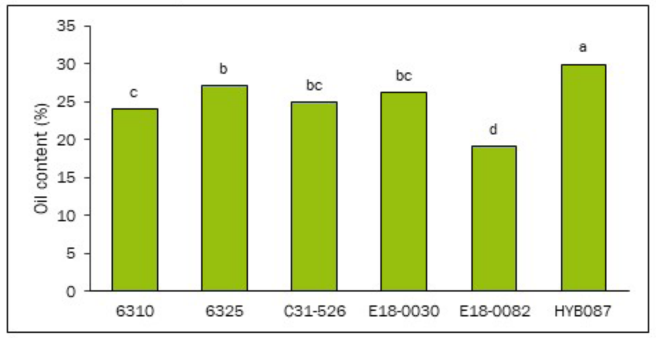


Flea beetle attack
(May 2023)



Material & Methods

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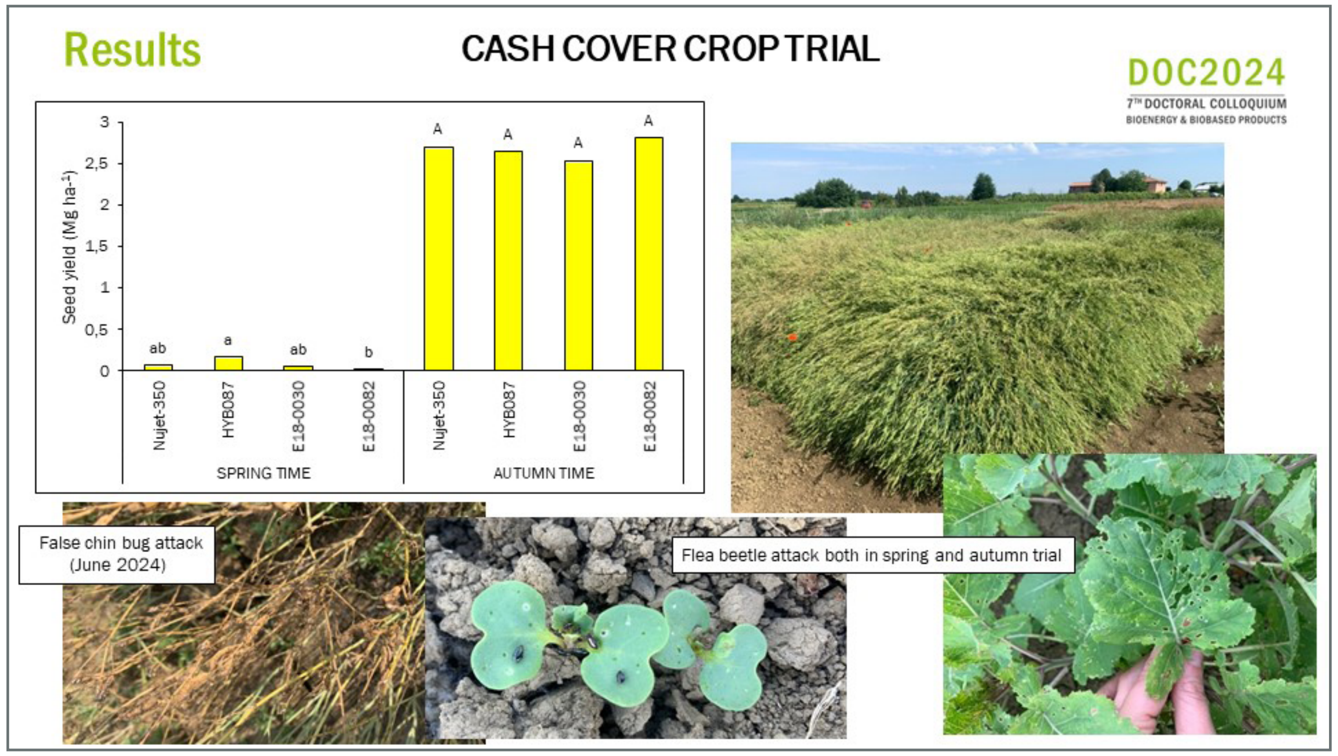
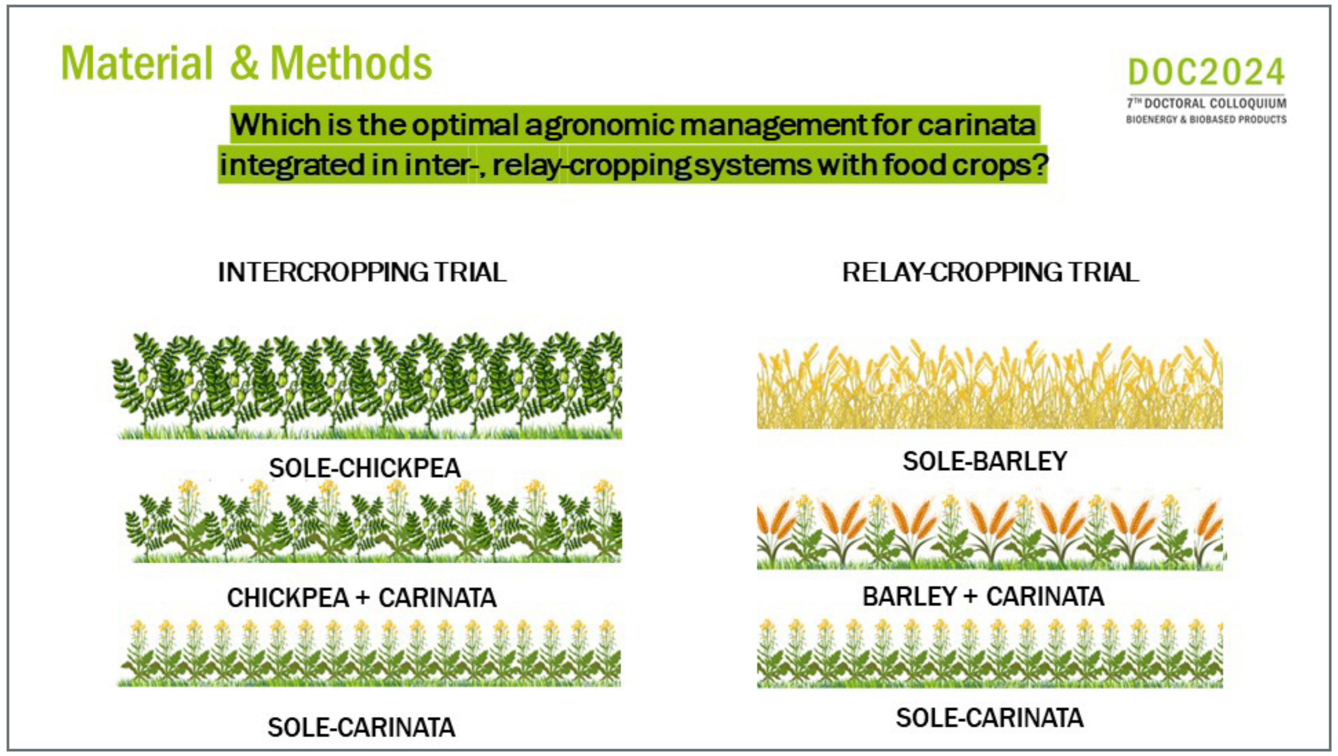
Is carinata more suitable as a summer cover crop or winter cover crop?

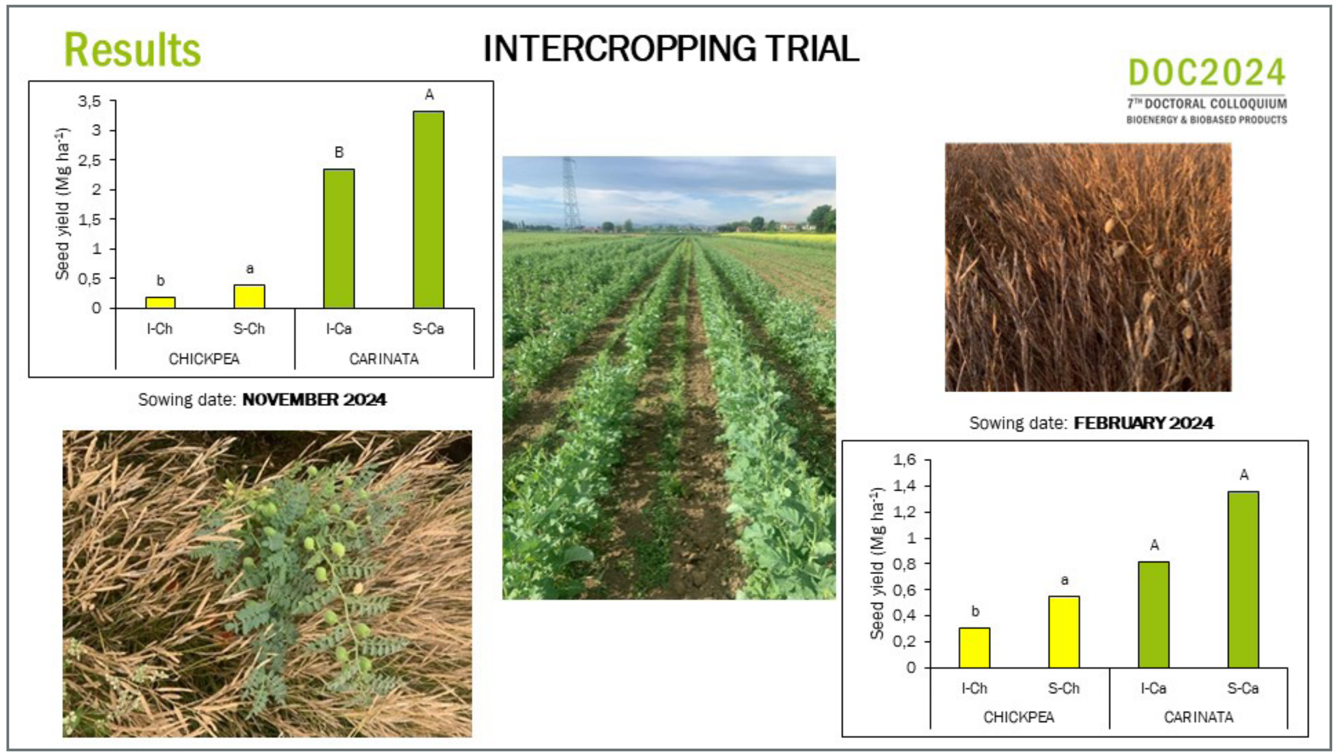
CASH COVER CROP TRIAL

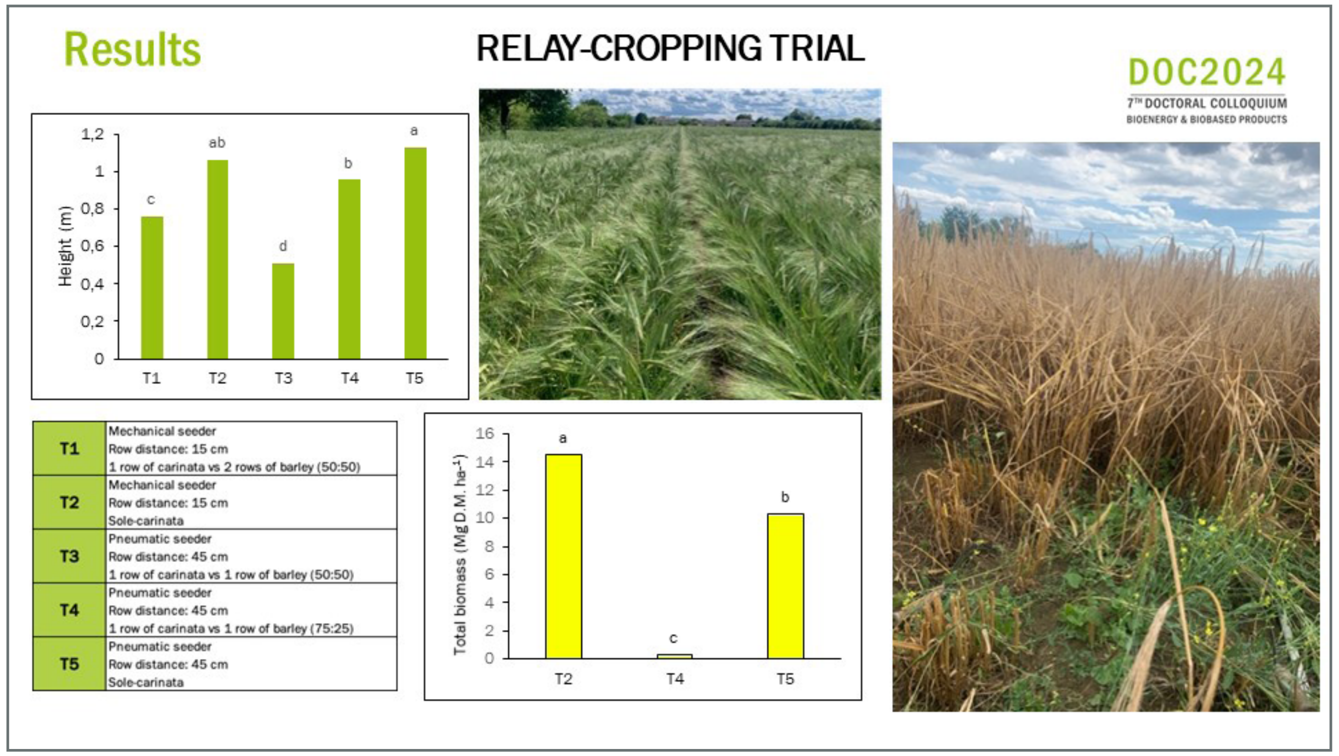
AUTUMN SOWING DATE	
Genotypes	Nujet-350 HYB087 E18-0030 E18-0082
Sowing date	November 2023
Harvest date	June 2024
Fertilization	50 kg N/ha as urea
Pest	Flea beetle Pollen beetle Cabbage weevil
Pest control	Lambda- cyhalothrin
Irrigation	Rainfed

SPRING SOWING DATE	
Genotypes	Nujet-350 HYB087 E18-0030 E18-0082
Sowing date	April 2024
Harvest date	July 2024
Fertilization	50 kg N/ha as urea
Pest	Flea beetle False chin bug
Pest control	Lambda- cyhalothrin
Irrigation	Rainfed


Results
CASH COVER CROP TRIAL
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Seed yield (Mg ha-1)
Nujet-350
HYB087
E18-0030
E18-0082
SPRING TIME
AUTUMN TIME
False chin bug attack
(June 2024)
Flea beetle attack both in spring and autumn trial


Material & Methods
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Which is the optimal agronomic management for carinata
integrated in inter-, relay-cropping systems with food crops?
INTERCROPPING TRIAL
RELAY-CROPPING TRIAL
SOLE-CHICKPEA
SOLE-BARLEY
CHICKPEA + CARINATA
BARLEY + CARINATA
SOLE-CARINATA
SOLE-CARINATA


Results
INTERCROPPING TRIAL
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Seed yield (Mg ha-1)
I-Ch
S-Ch
I-Ca
S-Ca
CHICKPEA
CARINATA
Sowing date: NOVEMBER 2024
Sowing date: FEBRUARY 2024


Results
RELAY-CROPPING TRIAL
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Height (m)
T1
Mechanical seeder
Row distance: 15 cm
1 row of carinata vs 2 rows of barley (50:50)
T2
Mechanical seeder
Row distance: 15 cm
Sole-carinata
T3
Pneumatic seeder
Row distance: 45 cm
1 row of carinata vs 1 row of barley (50:50)
T4
Pneumatic seeder
Row distance: 45 cm
1 row of carinata vs 1 row of barley (75:25)
T5
Pneumatic seeder
Row distance: 45 cm
Sole-carinata
Total biomass (Mg D.M. ha-1)

CONCLUSIONS…. for now

DOC2024
7TH DOCTORAL COLLOQUIUM BIOENERGY & BIOBASED PRODUCTS

VARIETY/CASH COVER CROP TRIAL

Carinata confirms its resiliency and seems to be more suitable for autumn sowing in the Mediterranean region.

INTER-/REALY-CROPPING SYSTEM TRIAL

It is necessary to identify the correct neighbouring model for the inter-/relay-cropping systems.

What's next? In progress…

- To test new cropping systems including carinata and typical food crops.
- To analyze the oil content of carinata.
- To evaluate the life cycle assessment of carinata-based SAF.

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Olivier Hirschler, Thünen Institute

Availability and challenges of using biomass as peat substitutes for horticultural growing media

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Keywords: Peat, Peat substitutes, Growing media, Availability, Material use

Peat is the most used constituent in horticultural growing media for the hobby and the professional market in Germany. Due to the climate impacts of peat, the German government has implemented a voluntary Peat Use Reduction Strategy since 2019 and has set targets for the end of peat use. Bio-based products – consisting nowadays mostly of green waste compost, coniferous wood fibres, composted bark, and imported coir products – can be used as peat substitutes. Although the use of these alternatives has increased in the past years, current trends indicate that, under the current conditions, the official goals for peat use reduction are likely not to be fulfilled. According to professionals, peat replacement has two main challenges: (1) the fulfilment of quality requirements for growing media and (2) the availability of biomass for the industry.

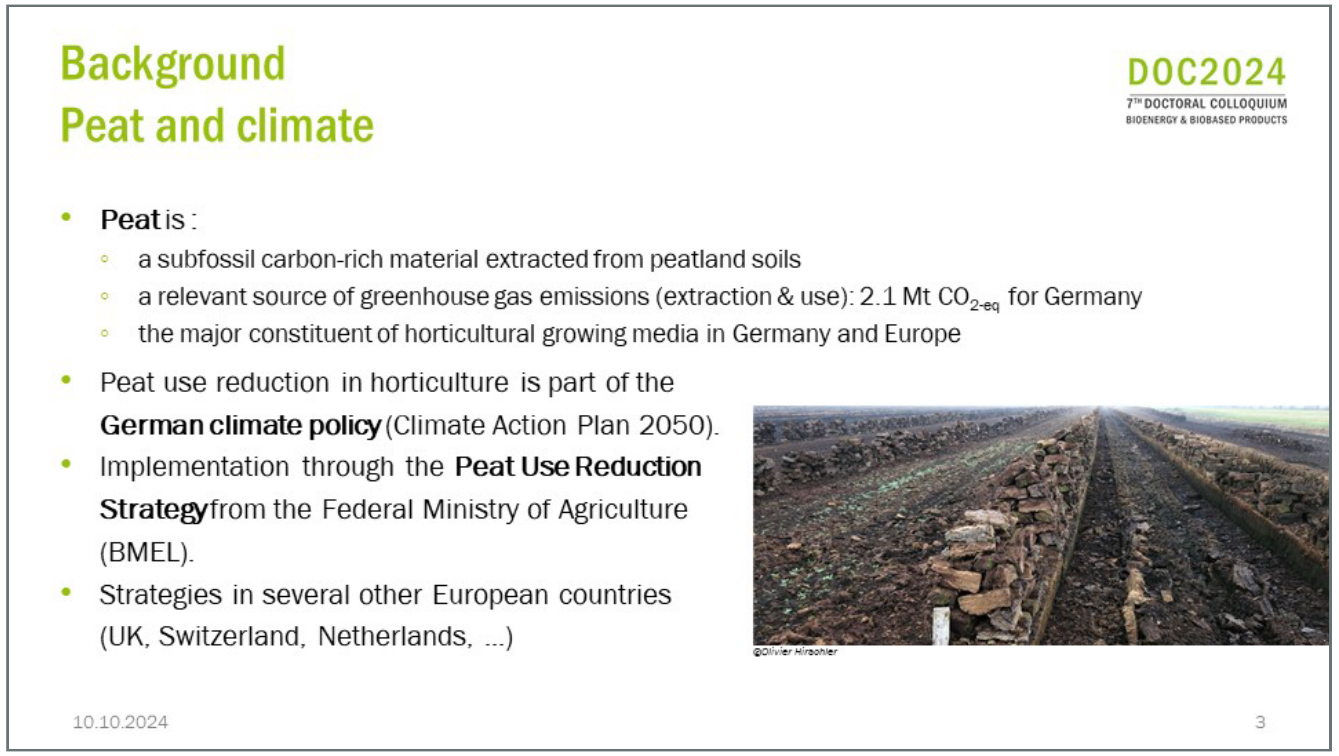
In this project, we aim to define more precisely the second challenge associated with the "availability" of peat alternatives and evaluate ways to overcome it. First, a potential analysis evaluated the physical amounts of biomass theoretically available for the growing media industry. Then, a qualitative analysis of deep-dive interviews identified the driving and limiting factors of the use of constituents for the industry. In a next step, market prices of constituents and potting soils for hobby gardeners were collected and analysed to calculate the price differences of peat and peat-containing products compared to alternatives.

The results show that physical amounts of biomass are more than sufficient to replace peat for growing media. However, the use of peat substitutes is limited by the existing supply chain and the competition with other sectors, both affecting transportation costs, quality of material, security of the supply and prices. The analysis of prices shows that the price advantage of peat, if it exists, is small compared to alternatives. This implies that the economic advantage of peat can not be reduced to its market price. Results also show that the price of peat-free products is higher than those of peat-containing products, which can be assumed to limit the shift of the demand towards peat alternatives. Based on these results, we explored, quantified and discussed market-based measures to make peat substitutes and peat-free potting soils more competitive.

Short introduction

DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

Title of the Doctoral Project:	Conditions and options for a transformation of the horticultural growing media industry toward the reduction of peat use in Germany
Doctoral Student:	M.Sc. Olivier Hirschler
Cooperating University:	Universität Leipzig
University Supervisor:	Prof. Dr.-Ing. Daniela Thrän
Employment and supervisor:	Johann Heinrich von Thünen Institute Dipl.-Ing. agr. Bernhard Osterburg THÜNEN
Duration:	01/2019 – today


Background
Peat and climate
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Peat is :
a subfossil carbon-rich material extracted from peatland soils
a relevant source of greenhouse gas emissions (extraction & use): 2.1 Mt CO2-eq for Germany
the major constituent of horticultural growing media in Germany and Europe
Peat use reduction in horticulture is part of the German climate policy (Climate Action Plan 2050).
Implementation through the Peat Use Reduction Strategy from the Federal Ministry of Agriculture (BMEL).
Strategies in several other European countries (UK, Switzerland, Netherlands, …)
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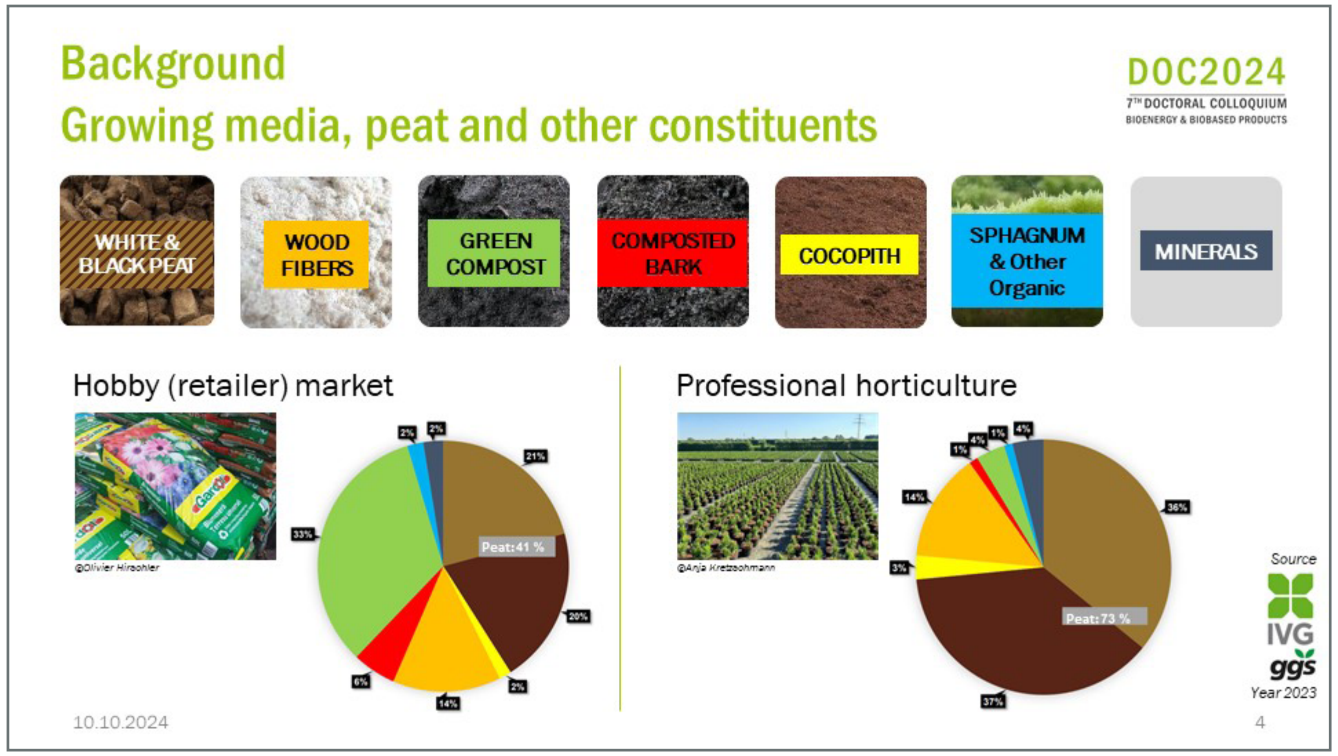
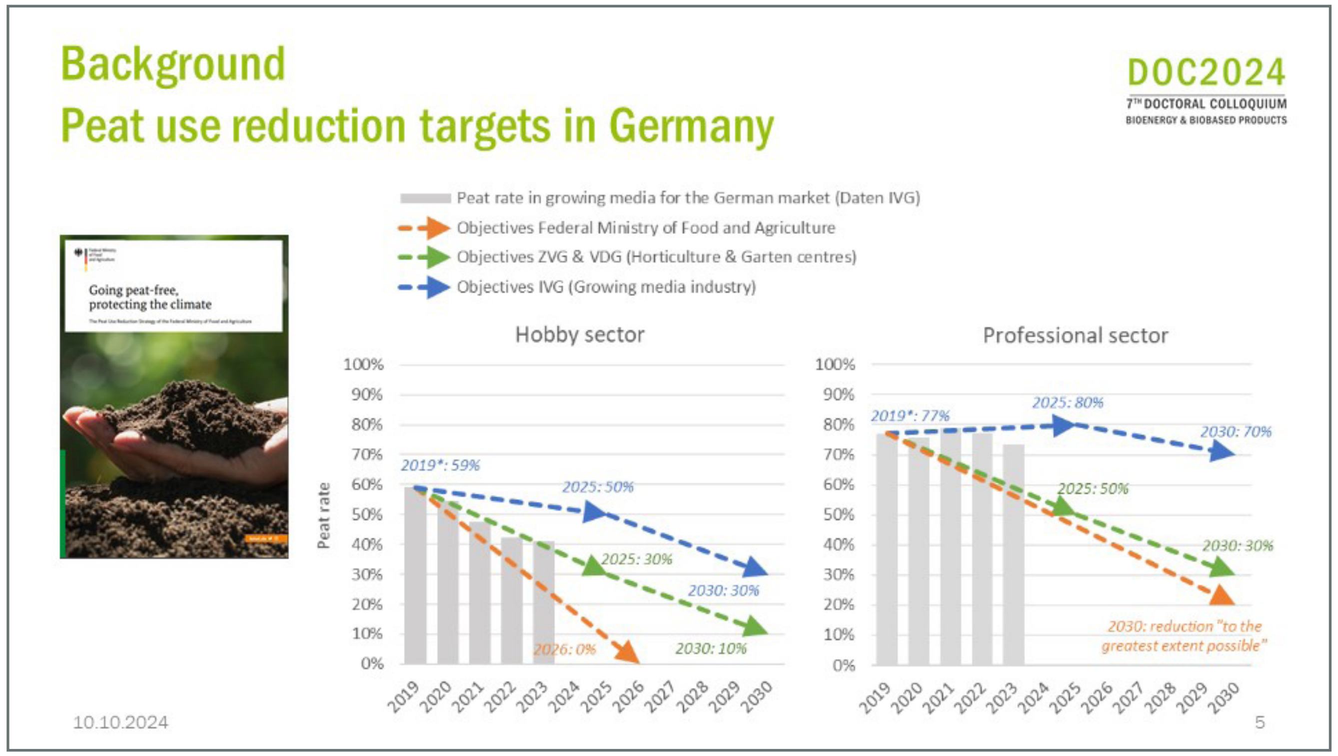

Background
Growing media, peat and other constituents
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
WHITE & BLACK PEAT
WOOD FIBERS
GREEN COMPOST
COMPOSTED BARK
COCOPITH
SPHAGNUM & Other Organic
MINERALS
Hobby (retailer) market
©Olivier Hirschler
Peat: 41 %
21%
20%
2%
14%
6%
33%
2%
2%
Professional horticulture
©Anja Kretzschmann
Peat: 73 %
36%
37%
3%
14%
1%
4%
1%
4%
Source
IVG
ggs
Year 2023
10.10.2024
4


Background
Peat use reduction targets in Germany
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Going peat-free, protecting the climate
Peat rate in growing media for the German market (Daten IVG)
Objectives Federal Ministry of Food and Agriculture
Objectives ZVG & VDG (Horticulture & Garten centres)
Objectives IVG (Growing media industry)
Hobby sector
Professional sector
Peat rate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2019*: 59%
2025: 50%
2025: 30%
2030: 30%
2026: 0%
2030: 10%
2019*: 77%
2025: 80%
2030: 70%
2025: 50%
2030: 30%
2030: reduction "to the greatest extent possible"
2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030
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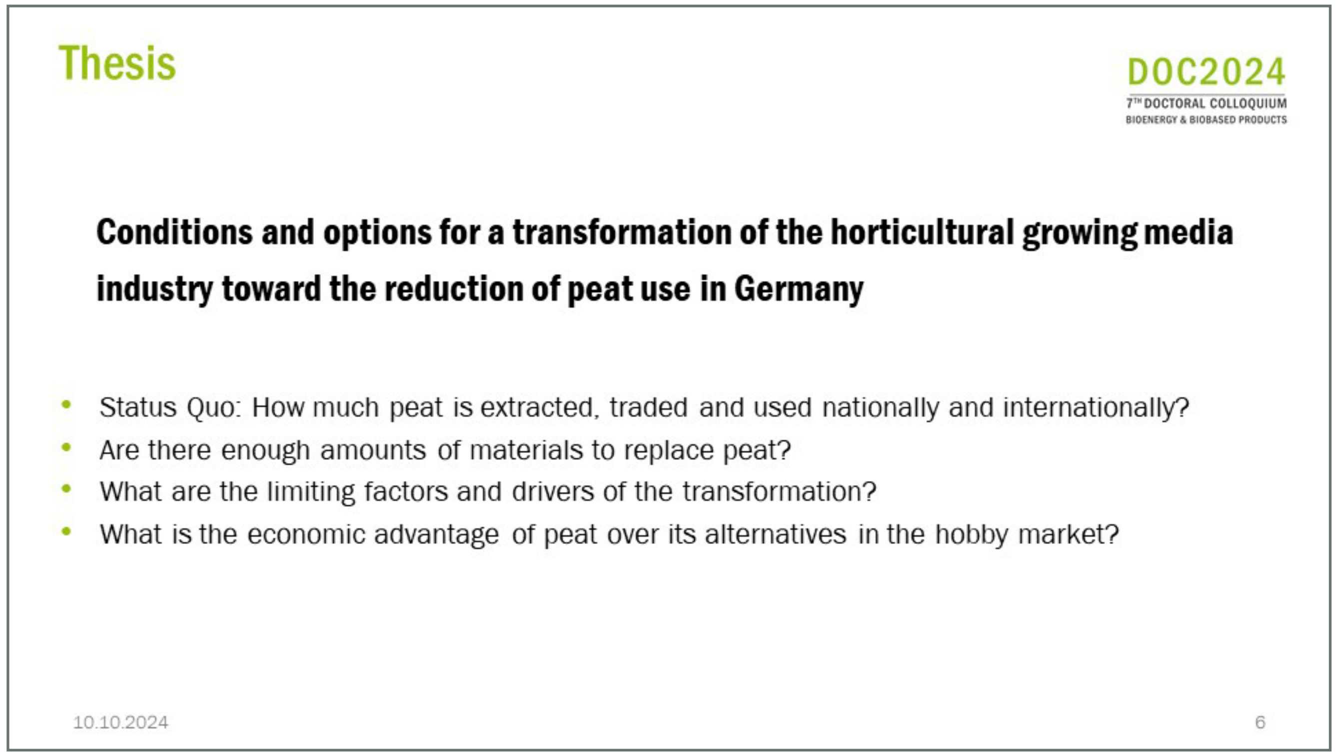
Thesis
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Conditions and options for a transformation of the horticultural growing media industry toward the reduction of peat use in Germany
Status Quo: How much peat is extracted, traded and used nationally and internationally?
Are there enough amounts of materials to replace peat?
What are the limiting factors and drivers of the transformation?
What is the economic advantage of peat over its alternatives in the hobby market?
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Status Quo: How much peat is extracted, traded and used nationally and internationally?

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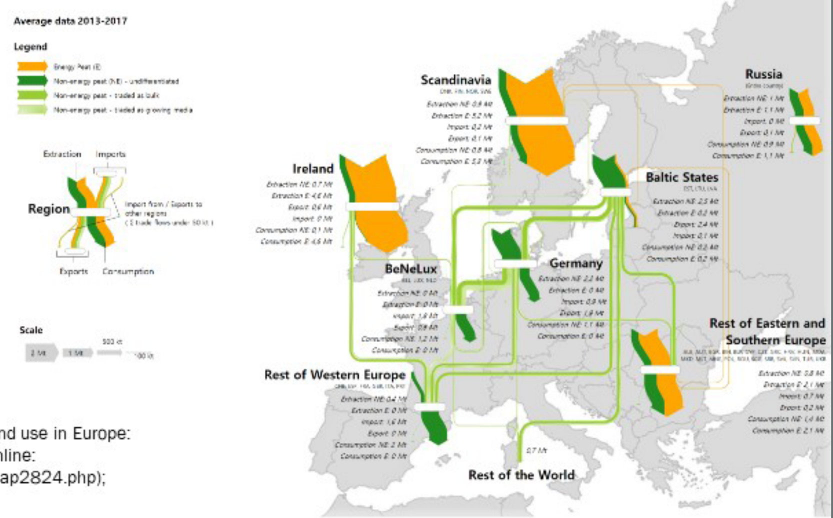
- Method: **Material flow analysis**
- Data: national, industry, international sources on extraction and trade
- Results:
  - Data discrepancies
  - Importance of Germany
  - Importance of intra-European trade



Hirschler, O., Osterburg, B. (2022) Peat extraction, trade and use in Europe: a material flow analysis. *Mires and Peat*, 28, 24, 27pp. (Online: http://www.mires-and-peat.net/pages/volumes/map28/map2824.php); doi: 10.19189/MaP.2021.SNPG.StA.2315

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Are there enough amounts of materials to replace peat? (I)

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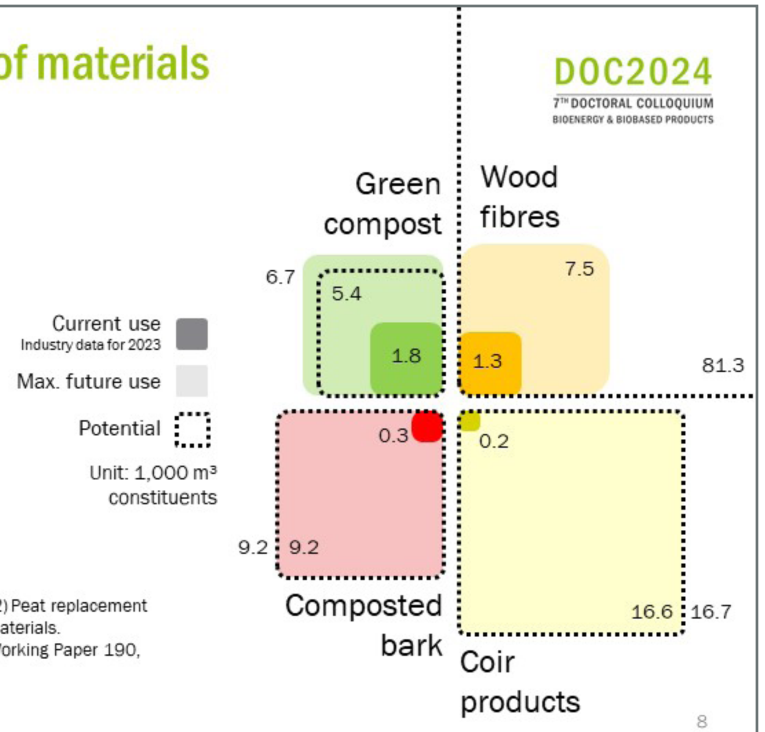
BIOENERGY & BIOBASED PRODUCTS

- **Insufficient availability** of alternatives one of the main challenges of peat reduction for the industry
- Method:
  - Current use and complete peat replacement scenario (for each constituent: highest technically achievable share)
  - **Potentials** based on raw materials on the market



Hirschler O, Osterburg B, Weimar H, Glasenapp S, Ohmes M-F (2022) Peat replacement in horticultural growing media: Availability of bio-based alternative materials. Braunschweig: Johann Heinrich von Thünen-Institut, 64 p, Thünen Working Paper 190, DOI:10.3220/WP1648727744000

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Are there enough amounts of materials to replace peat? (II)

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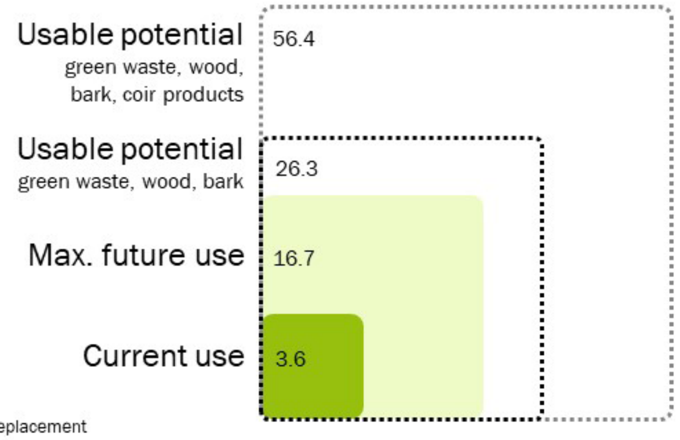
BIOENERGY & BIOBASED PRODUCTS

- **Quantities** of raw materials for the production of peat substitutes present on the market **do not limit their use** neither today nor in the future
- The limited „availability" for constituents is due to **other factors / constraints**



Hirschler O, Osterburg B, Weimar H, Glasenapp S, Ohmes M-F (2022) Peat replacement in horticultural growing media: Availability of bio-based alternative materials. Braunschweig: Johann Heinrich von Thünen-Institut, 64 p, Thünen Working Paper 190, DOI:10.3220/WP1648727744000

10.10.2024 9

What are the limiting factors and drivers of the transformation?

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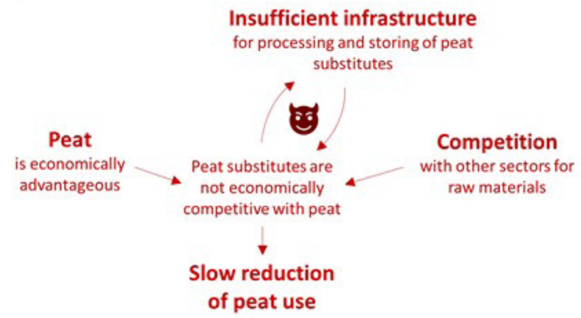
BIOENERGY & BIOBASED PRODUCTS

- Method: **Deep-dive interviews** and qualitative analysis
- „Availability problem" for peat substitutes:
  - **Lack of infrastructure**
  - **Competition with other sectors**
  - Consequence: long transportation distances, low market availability, low quality, high price
- Peat is economically more advantageous
- Drivers of peat use reduction:
  - Increasing demand for peat-free products
  - Threat of further political measures
  - End of peat extraction in Germany



Hirschler, O.; Thrän, D. (2023) Peat Substitution in Horticulture: Interviews with German Growing Media Producers on the Transformation of the Resource Base. *Horticulturae*, 9, 919. https://doi.org/10.3390/horticulturae9080919

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What is the economic advantage of peat over its alternatives in the hobby market?

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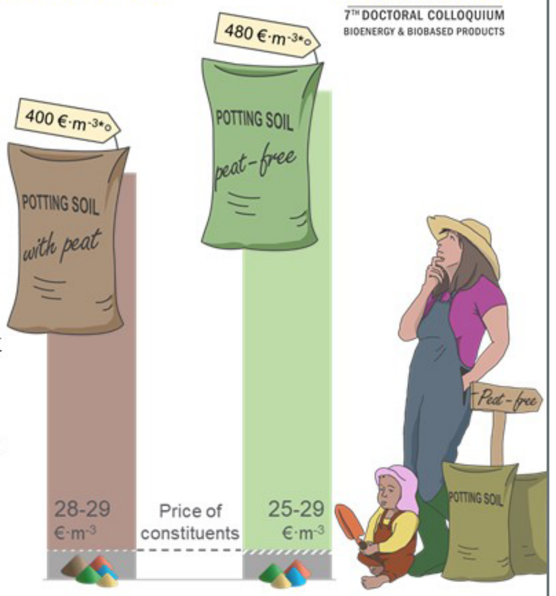
BIOENERGY & BIOBASED PRODUCTS

- Context:
  - **Hobby market = lowest-hanging fruit**
  - Expansion of the peat-free segment
- Method: Price data collection from industry partners, standardization and comparison
- Results:
  - Peat-free is on average **20% more expensive** than with peat
  - Although constituents do not cost more
  - Policy options:
    - Peat tax, subsidy for peat substitutes or carbon pricing would be to complicated to implement
    - **Peat ban**: Efficient, implementable



Hirschler, O.; Osterburg, B. (in review) Achieving peat-free hobby gardening for climate mitigation in Germany: Insights into prices of growing media constituents, potting soils and policy measures. *Resources Conservation and Recycling*

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DOC2024 7TH DOCTORAL COLLOQUIUM BIOENERGY & BIOBASED PRODUCTS

Questions?
Comments?

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Christoph Siol, Deutsches Biomasseforschungszentrum

Developing an assessment framework for sustainable extraction and utilization of agricultural residues with spatially resolved LCIA results

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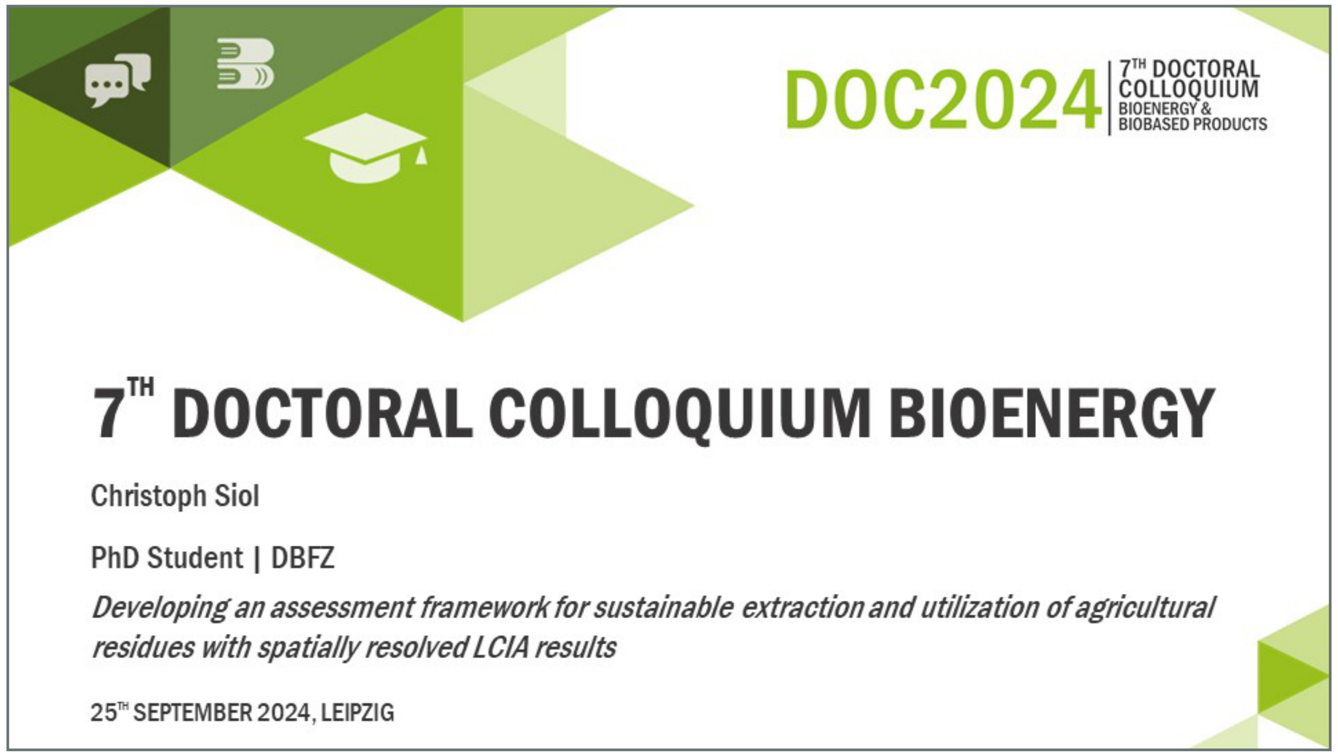
Keywords: Agricultural residues; Life-Cycle Sustainability Assessment; Soil organic carbon (SOC); Circular bioeconomy; Regionalized LCSA; Sustainable Soil Management

Increasing exploitation of residual biomasses to produce bio-based energy and materials raises the question of limits and trade-offs regarding sustainability. There is a controversial debate on this topic, not least because of vague requirements for farmers and operators to monitor the complex effects on soil health and fertility resulting from an extraction of residual biomasses from agriculture. A previous investigation [1] has shown that there is a need for an advanced and comprehensive assessment framework which is capable of addressing complex interactions from a life-cycle sustainability perspective, focussing on assets and drawbacks of different management practices and utilization strategies depending on site-specific conditions. Extraction and utilization of residual biomasses could either be a promising way of decoupling economic activity from resource use and environmental impacts or a lost opportunity to preserve planetary boundaries.

Against this background, the objective of this research is to provide a framework for life-cycle sustainability assessment, based on a set of appropriate indicators and methods, which allows scientists to face the various uncertainties and shortcomings of conventional life-cycle assessments and contributes to the ongoing debate about benefits and trade-offs of sustainable utilization of residual biomasses from agriculture. Therefore, spatially resolved information about soil and weather conditions as well as management practices are combined with soil and agroecosystem models to predict actual and site-specific impacts and benefits of residual biomass extraction from a strong sustainability perspective with regionalized LCIA results.

References:

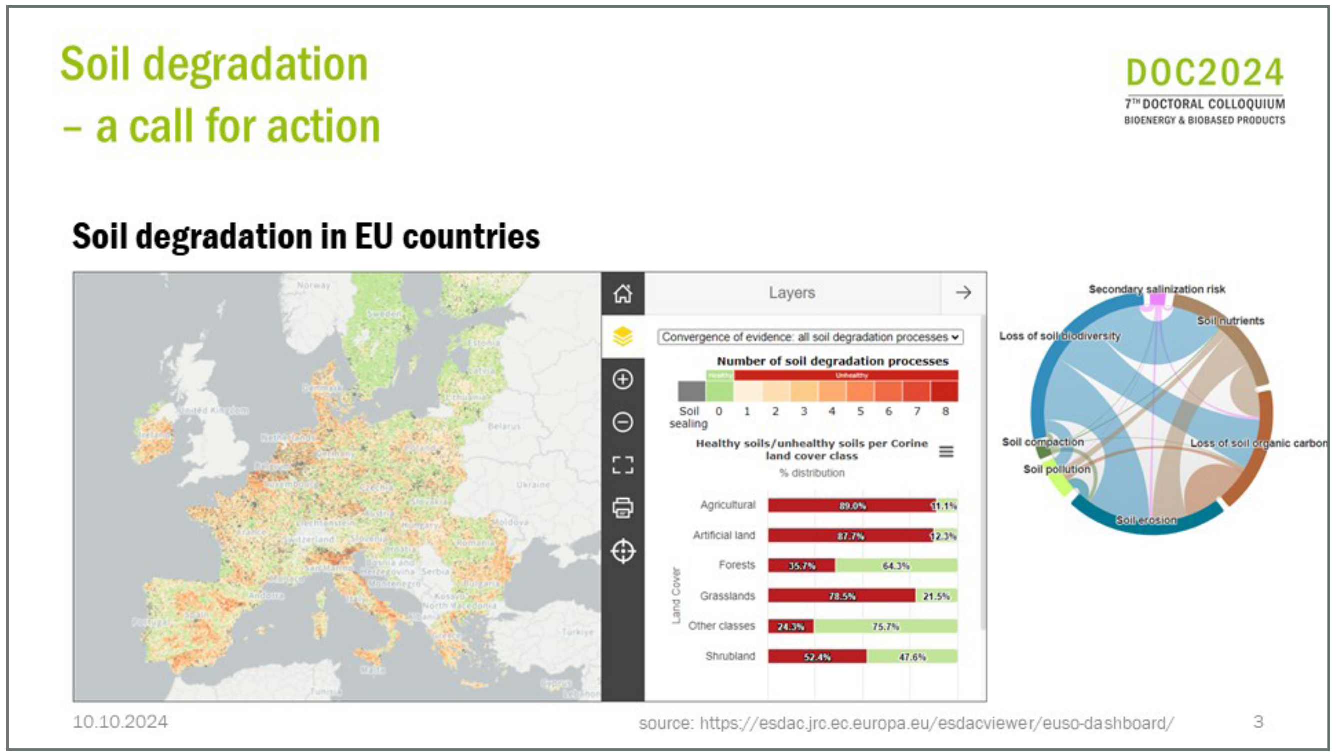
[1] Siol, Christoph; Thrän, Daniela; Majer, Stefan (2023): Utilizing residual biomasses from agriculture and forestry: Different approaches to set system boundaries in environmental and economic life-cycle assessments. In: Biomass and Bioenergy 174, S. 106839



Short introduction

DOC2024 7TH DOCTORAL COLLOQUIUM BIOENERGY & BIOBASED PRODUCTS

Title of the Doctoral Project:	Assessing the technological utilization of biogenic residues with Life-Cycle Sustainability Assessment
Doctoral Student:	Christoph Siol
DBFZ Supervisor:	Stefan Majer
Cooperating University:	Leipzig University
University Supervisor:	Prof. Dr. Daniela Thrän
Funding / Scholarship provider:	German Biomass Research Centre (DBFZ) gGmbH
Duration:	04.2020 – 03/2025


Soil degradation
– a call for action
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Soil degradation in EU countries
Layers
Number of soil degradation processes
Healthy soils/unhealthy soils per Corine land cover class
Agricultural
Artificial land
Forests
Grasslands
Other classes
Shrubland
Secondary salinization risk
Soil nutrients
Loss of soil biodiversity
Soil compaction
Soil pollution
Loss of soil organic carbon
Soil erosion
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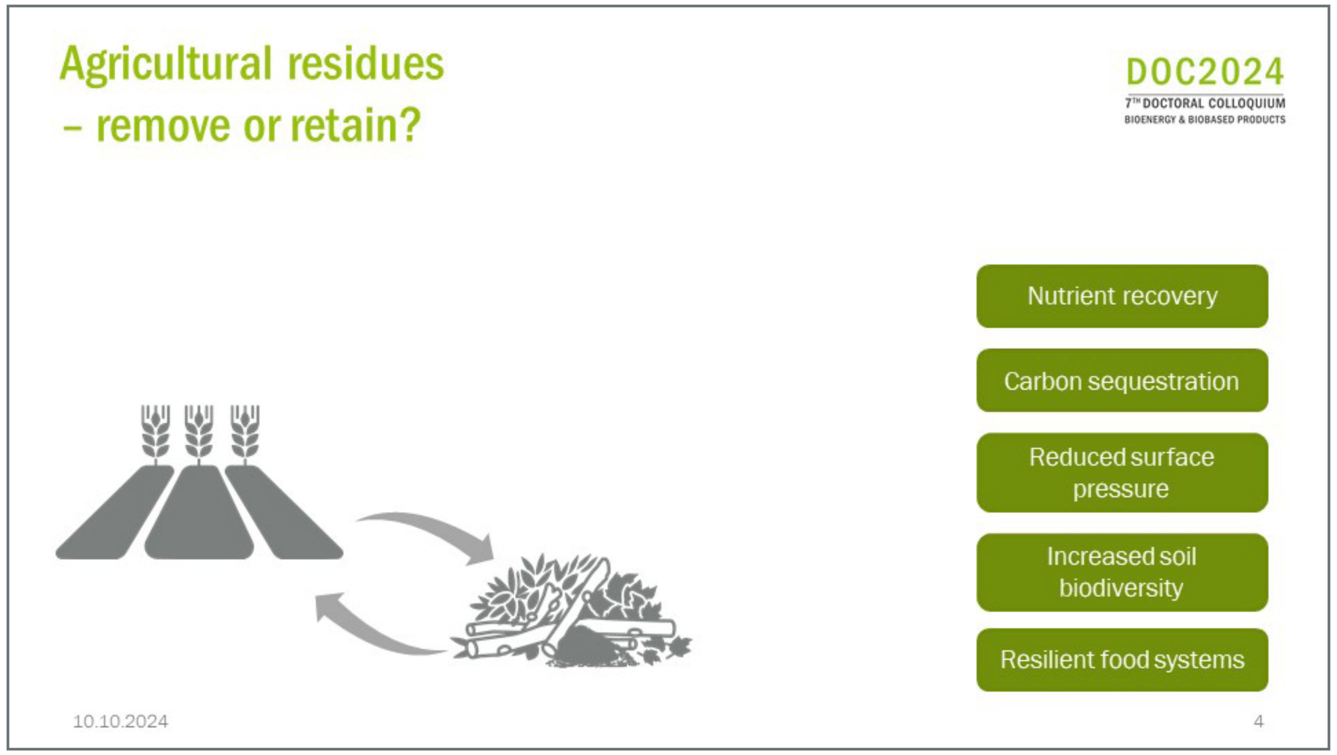
source: https://esdac.jrc.ec.europa.eu/esdacviewer/euso-dashboard/
3


Agricultural residues
– remove or retain?
DOC2024
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BIOENERGY & BIOBASED PRODUCTS
Nutrient recovery
Carbon sequestration
Reduced surface pressure
Increased soil biodiversity
Resilient food systems
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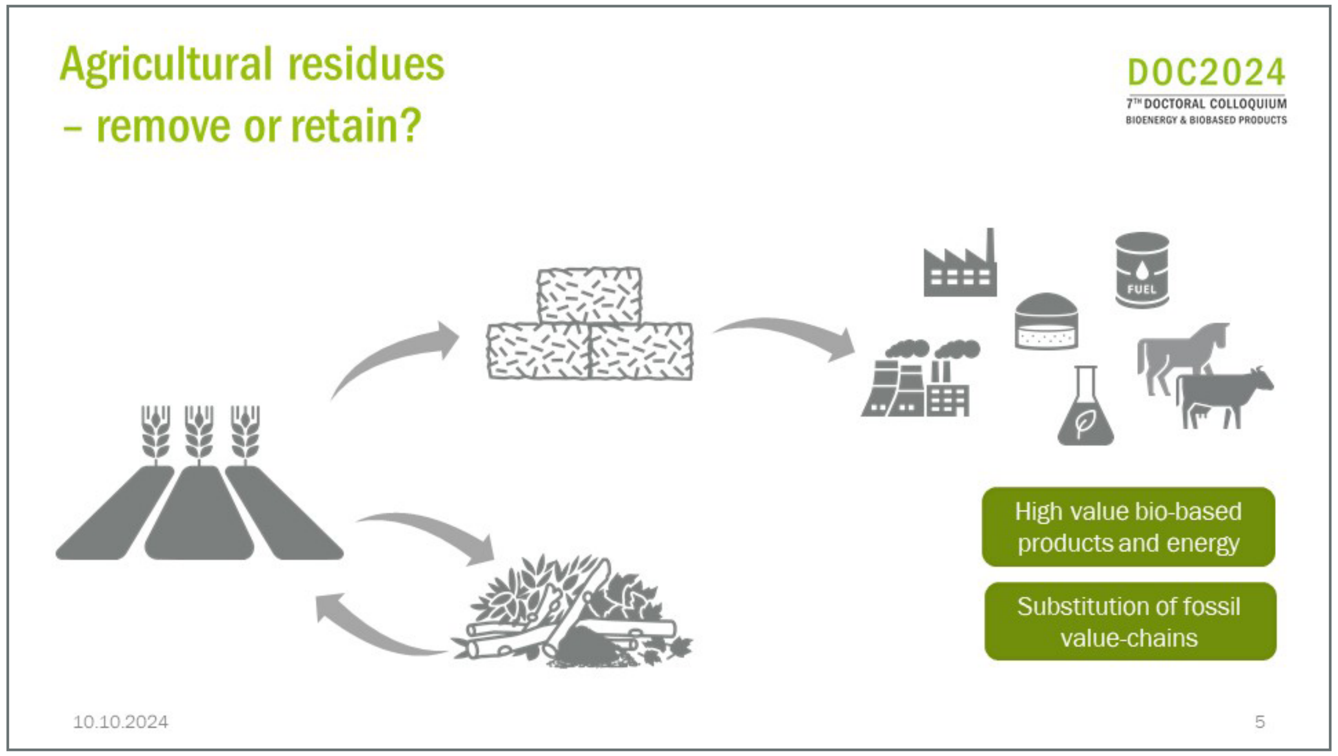
4


Agricultural residues
– remove or retain?
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
FUEL
High value bio-based products and energy
Substitution of fossil value-chains
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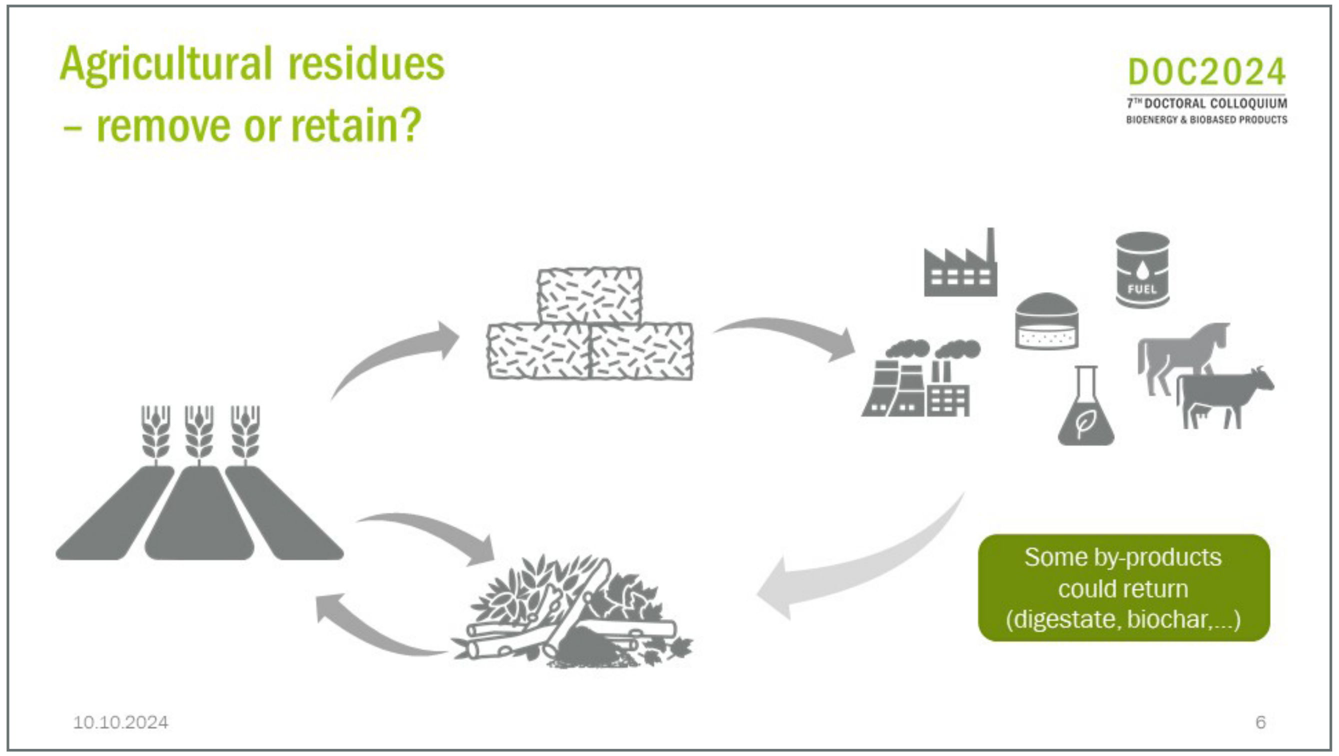
Agricultural residues
– remove or retain?
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
FUEL
Some by-products could return (digestate, biochar,...)
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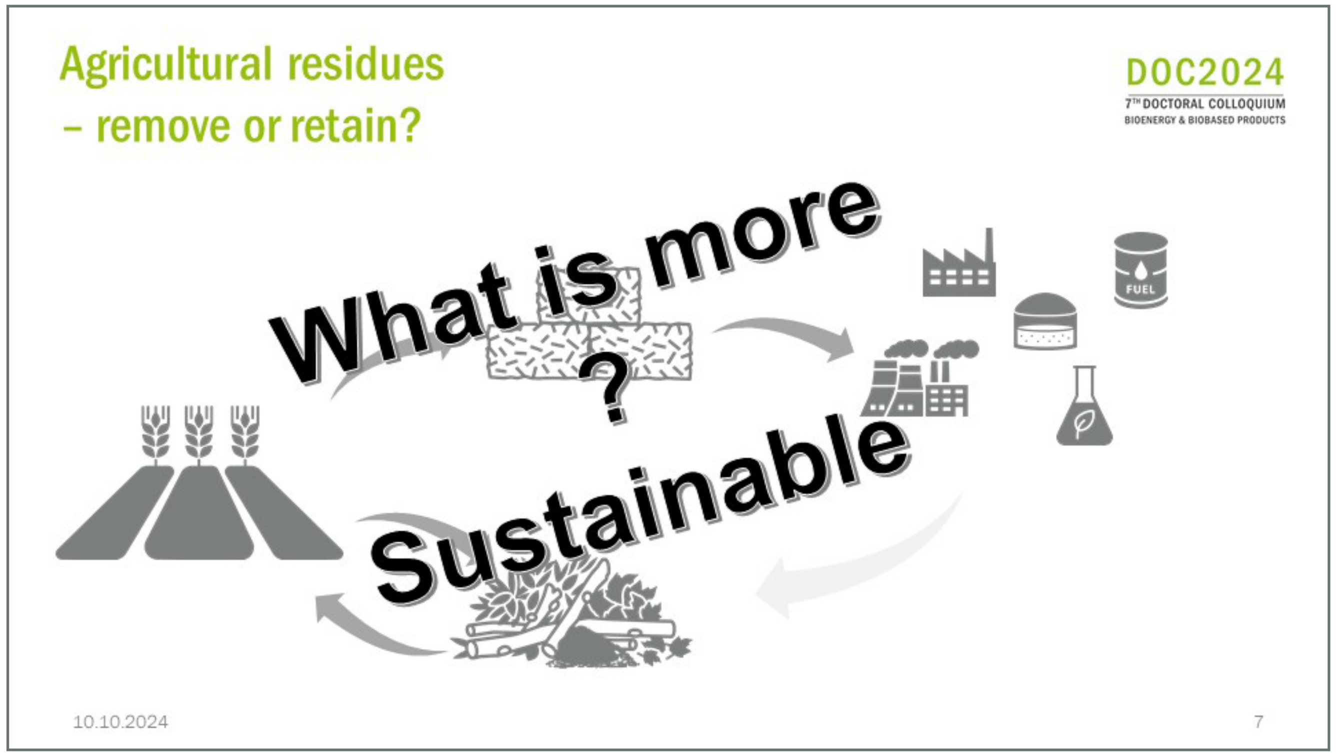
Agricultural residues
– remove or retain?
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
What is more
?
Sustainable
FUEL
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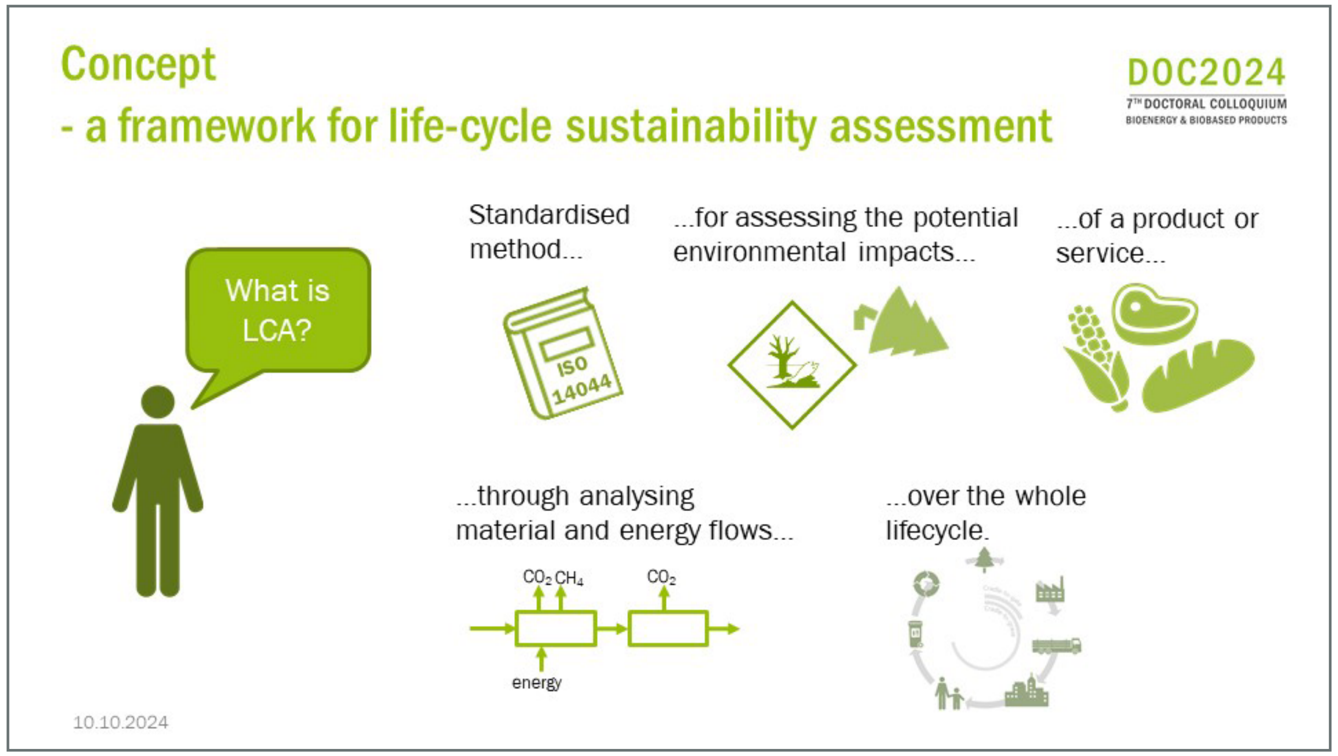
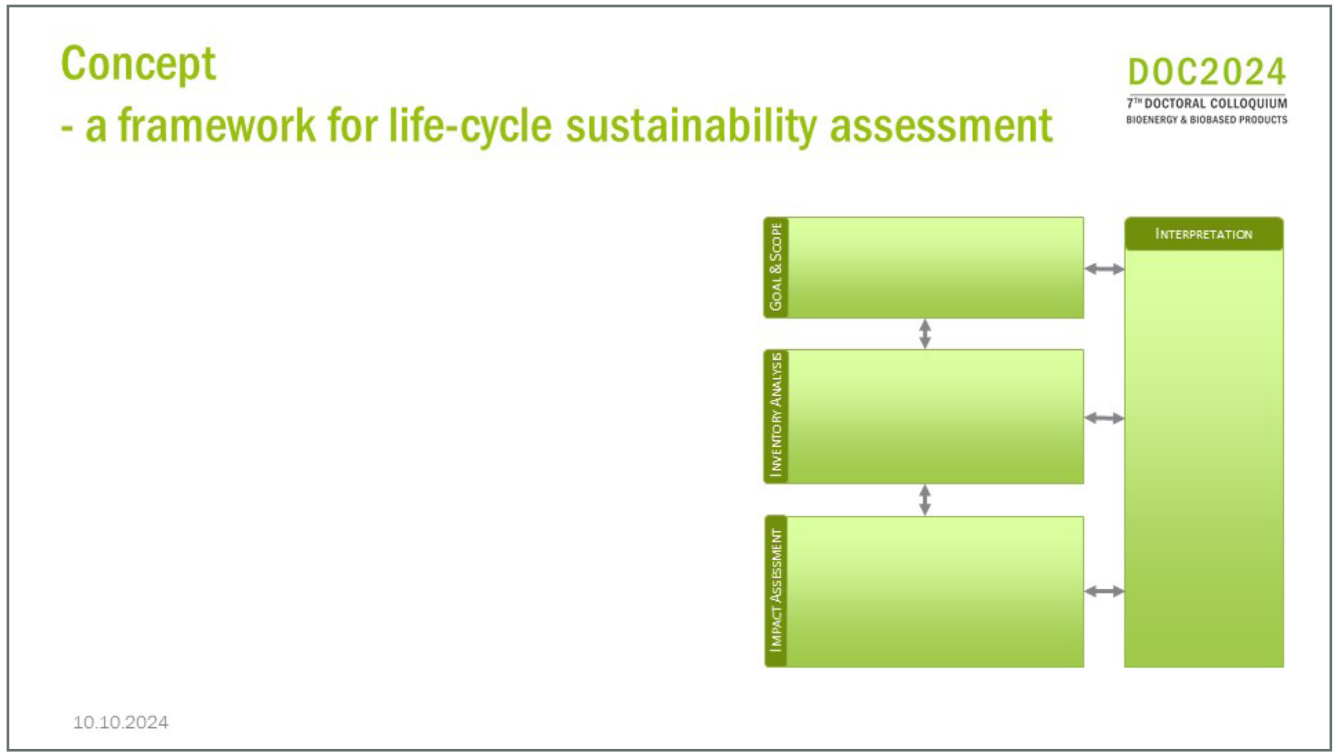
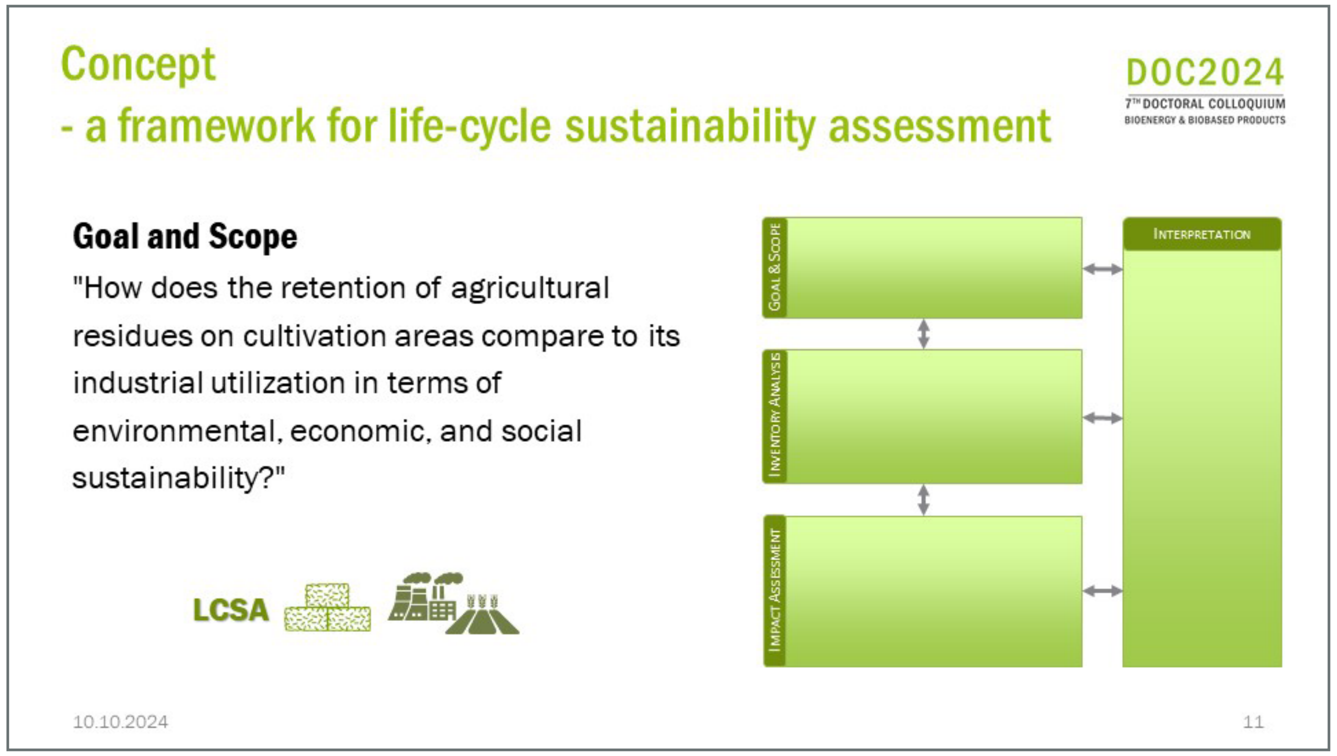
7


Agricultural residues
– remove or retain?
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
How can we assess…
What is more
?
Sustainable
FUEL
10.10.2024
8


Concept
- a framework for life-cycle sustainability assessment
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
What is LCA?
Standardised method...
...for assessing the potential environmental impacts...
...of a product or service...
ISO 14044
...through analysing material and energy flows...
...over the whole lifecycle.
CO2 CH4
CO2
energy
10.10.2024


Concept
- a framework for life-cycle sustainability assessment
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Goal & Scope
Inventory Analysis
Impact Assessment
Interpretation
10.10.2024


Concept
- a framework for life-cycle sustainability assessment
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Goal and Scope
"How does the retention of agricultural residues on cultivation areas compare to its industrial utilization in terms of environmental, economic, and social sustainability?"
LCSA
Goal & Scope
Inventory Analysis
Impact Assessment
Interpretation
10.10.2024
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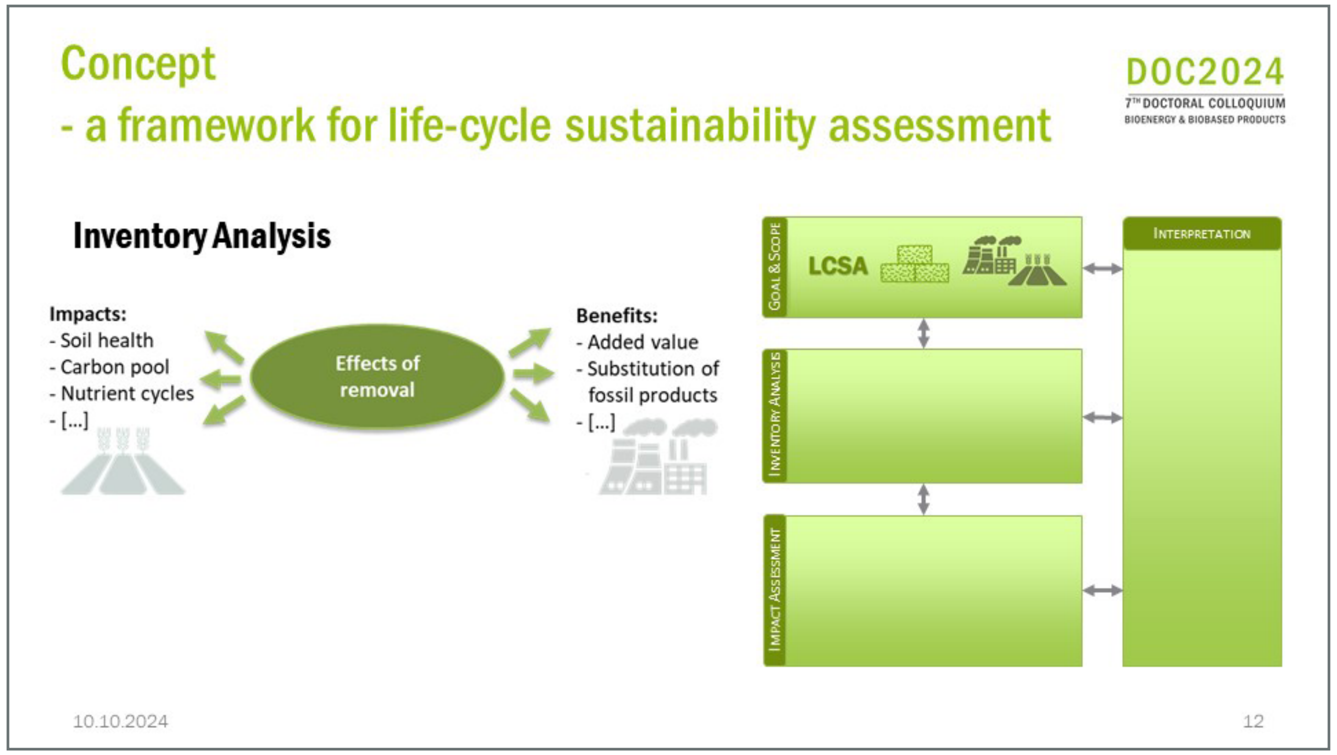
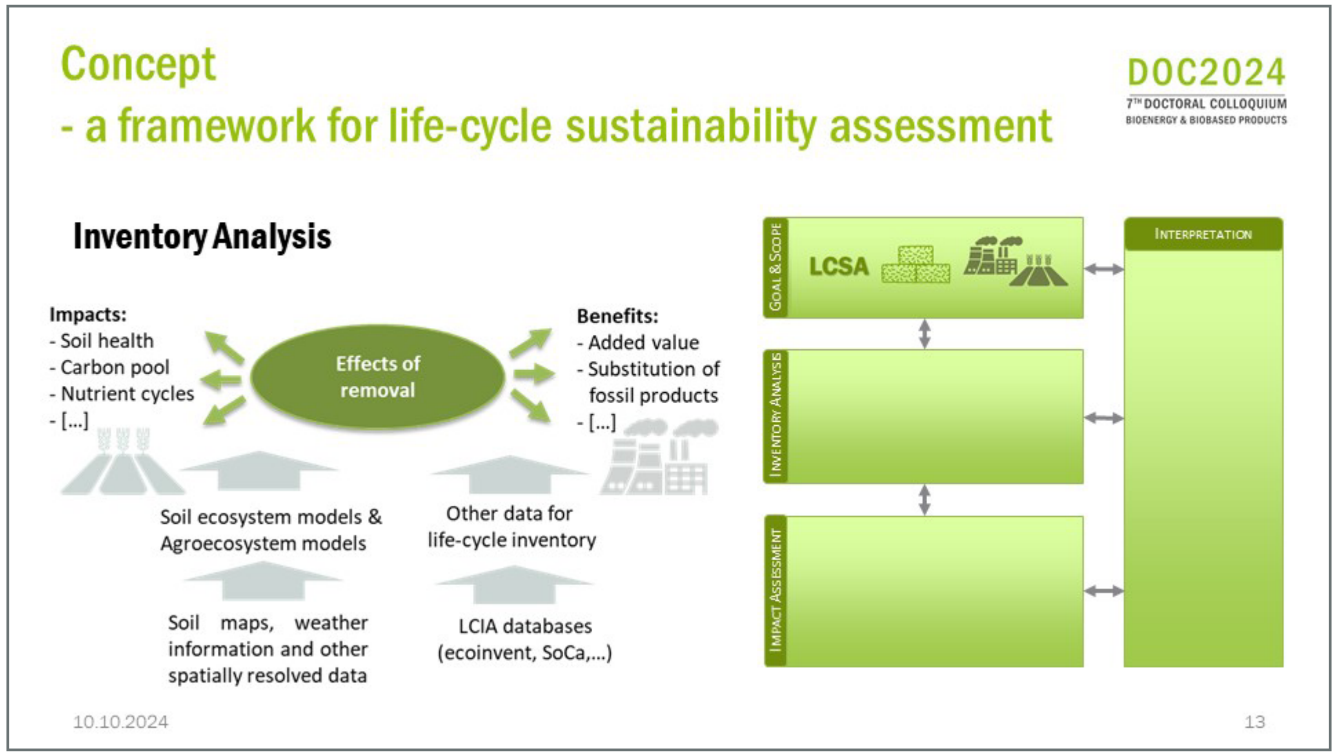
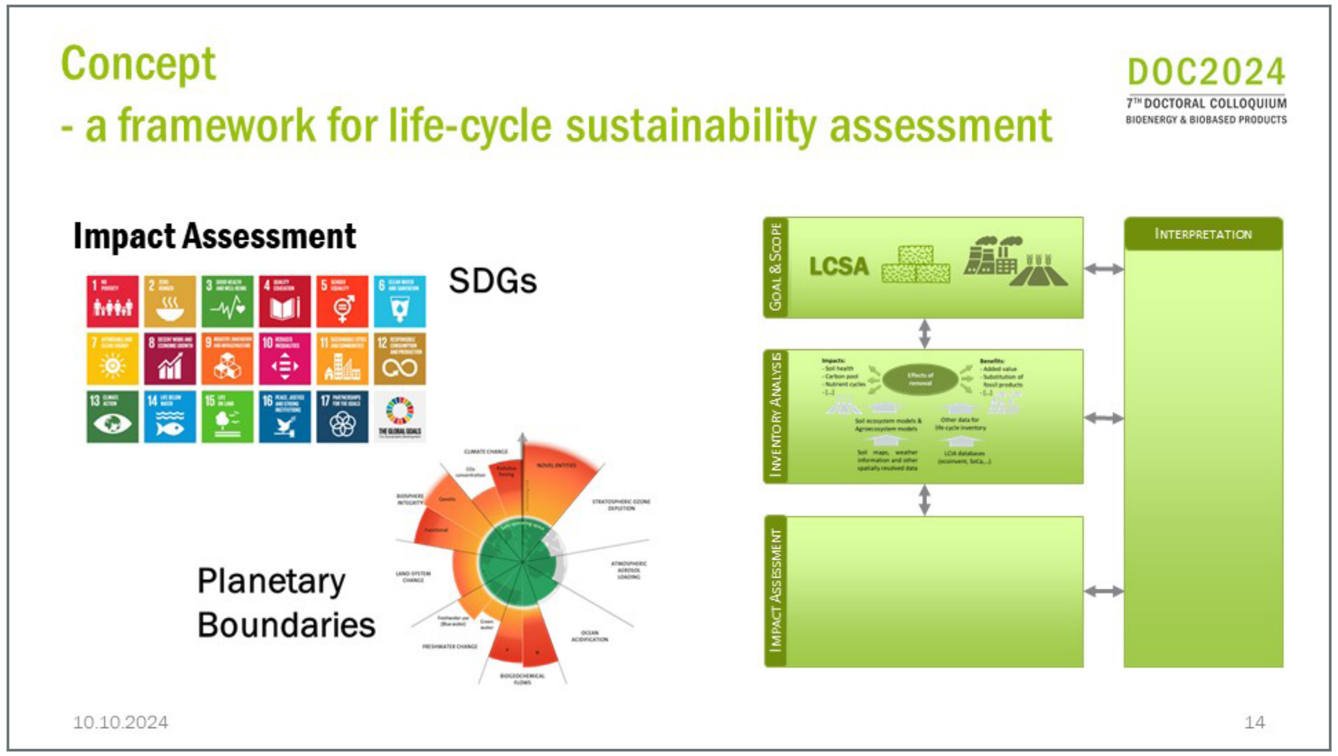
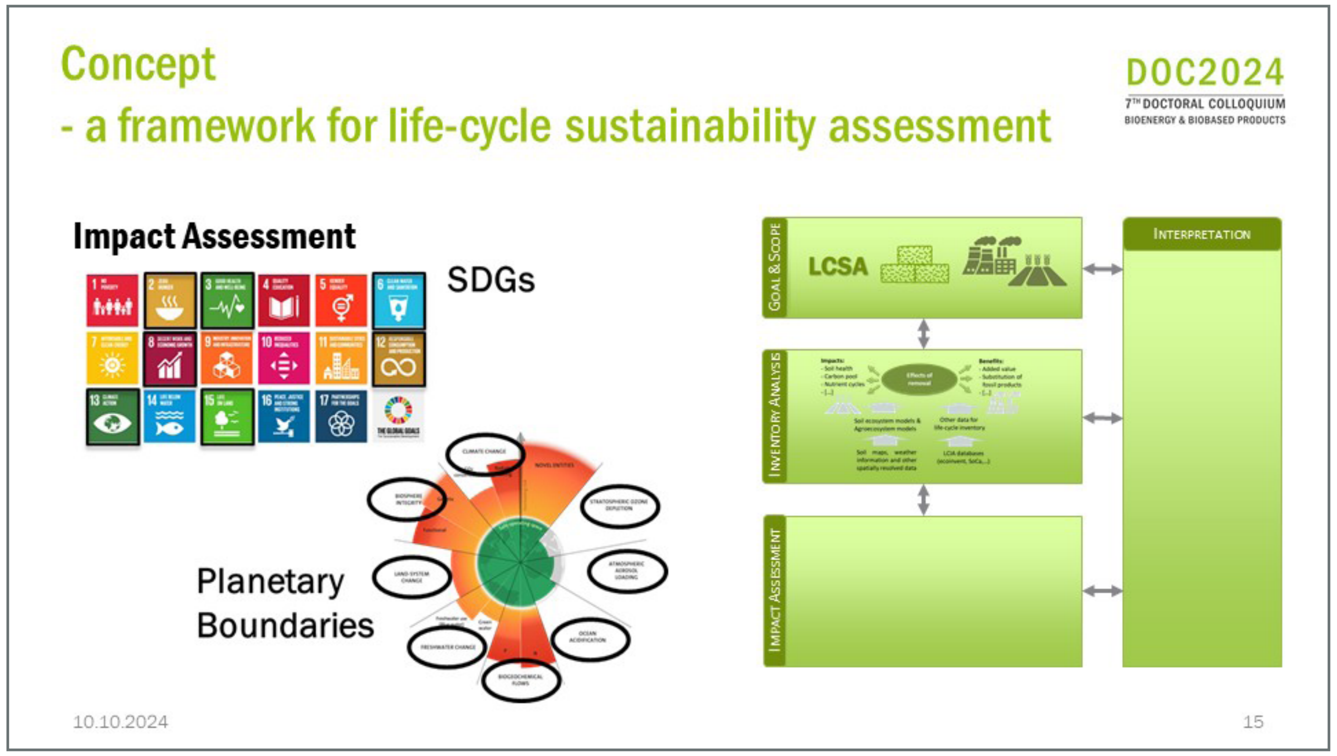
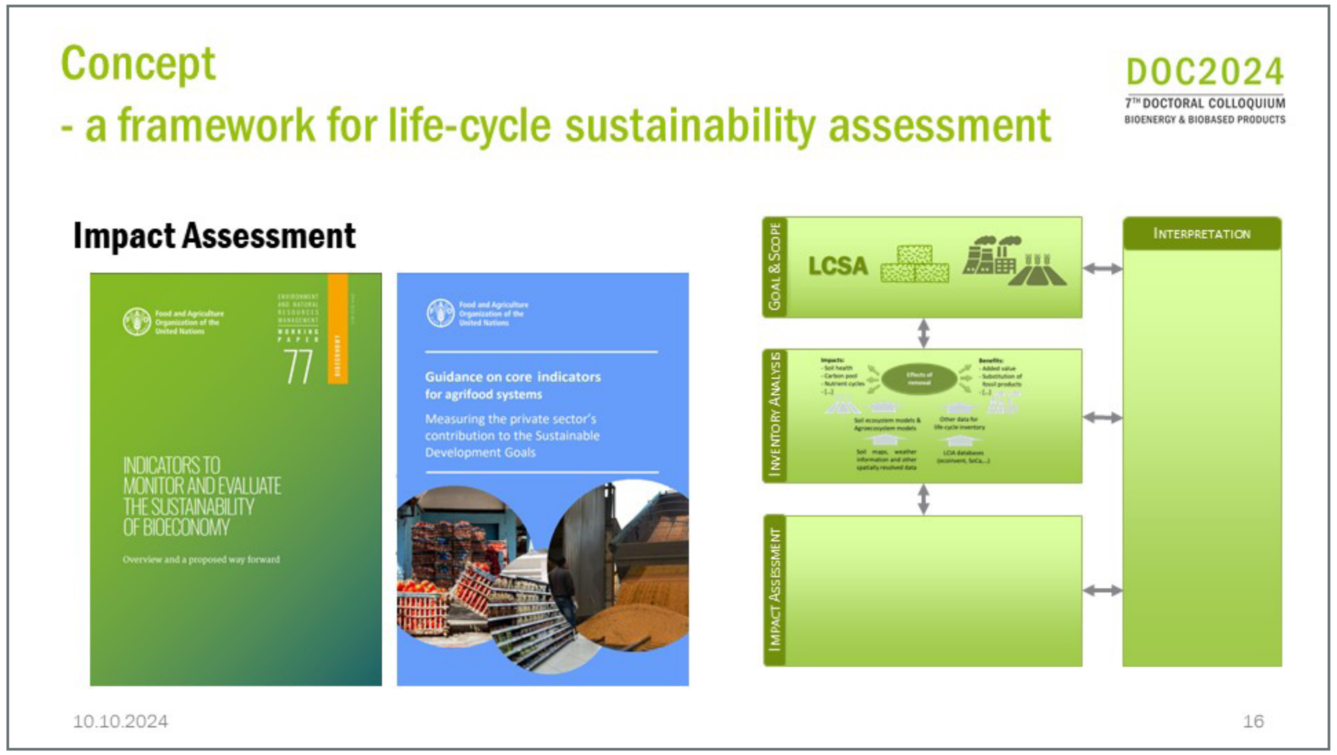
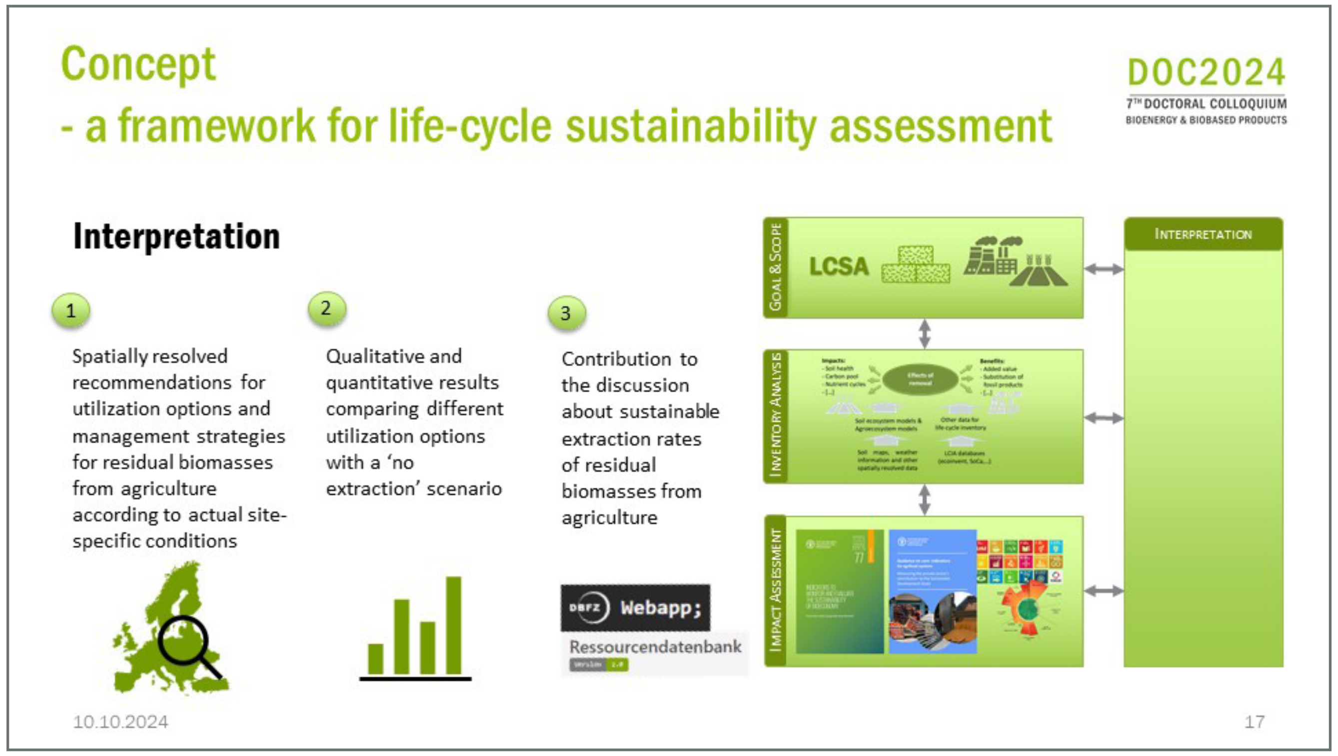

Concept
- a framework for life-cycle sustainability assessment
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Inventory Analysis
Impacts:
- Soil health
- Carbon pool
- Nutrient cycles
- [...]
Effects of removal
Benefits:
- Added value
- Substitution of fossil products
- [...]
LCSA
Goal & Scope
Inventory Analysis
Impact Assessment
Interpretation
10.10.2024
12

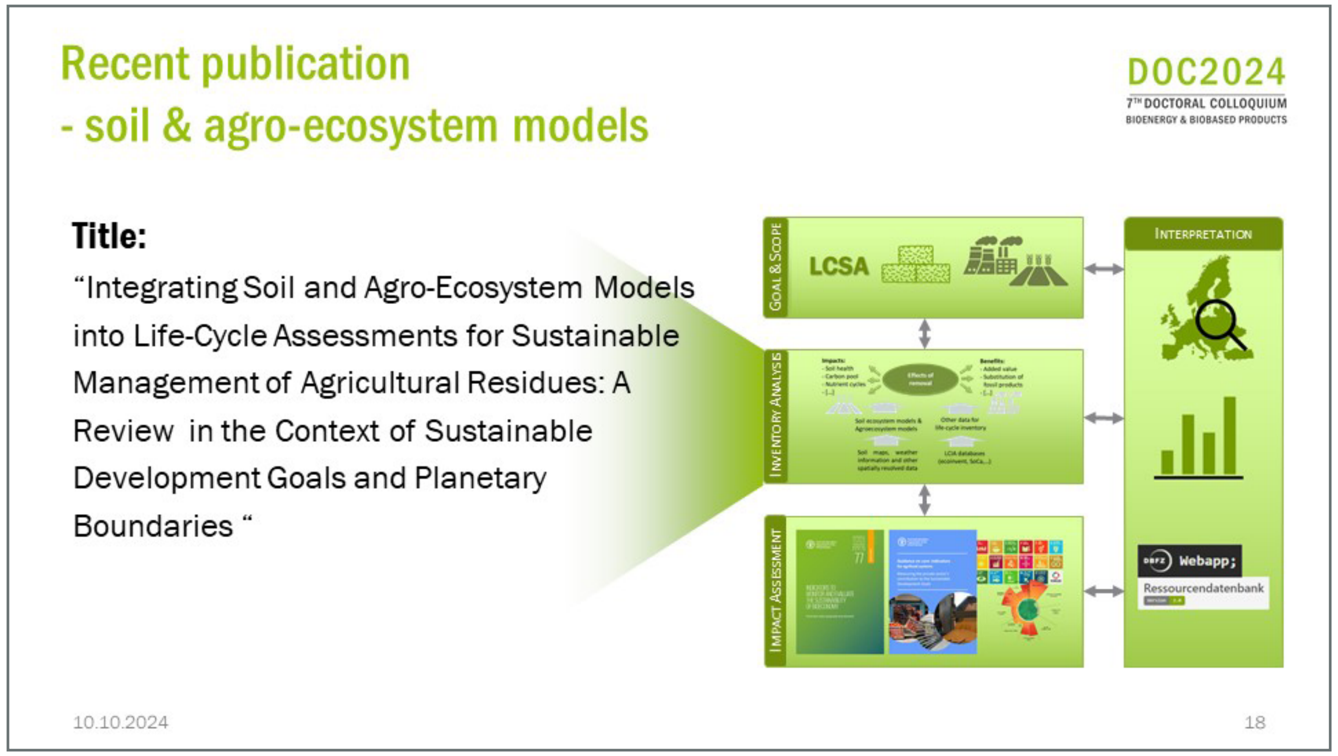

Concept
- a framework for life-cycle sustainability assessment
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Inventory Analysis
Impacts:
- Soil health
- Carbon pool
- Nutrient cycles
- [...]
Effects of removal
Benefits:
- Added value
- Substitution of fossil products
- [...]
Soil ecosystem models & Agroecosystem models
Other data for life-cycle inventory
Soil maps, weather information and other spatially resolved data
LCIA databases (ecoinvent, SoCa,...)
LCSA
Goal & Scope
Inventory Analysis
Impact Assessment
Interpretation
10.10.2024
13


Concept
- a framework for life-cycle sustainability assessment
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Impact Assessment
SDGs
Planetary Boundaries
LCSA
Goal & Scope
Inventory Analysis
Impact Assessment
Interpretation
10.10.2024
14









7TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Recent publication
- soil & agro-ecosystem models

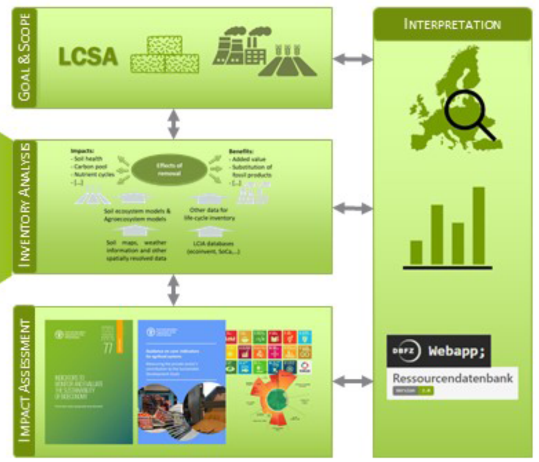
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

Title:

"Integrating Soil and Agro-Ecosystem Models into Life-Cycle Assessments for Sustainable Management of Agricultural Residues: A Review in the Context of Sustainable Development Goals and Planetary Boundaries"

> 100 analysed LCA studies

> 40 soil & agro-ecosystem models included in search string



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Recent publication
- soil & agro-ecosystem models

DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

Main results and findings:

- Suitability matrix linking different soil and agro-ecosystem models with specific indicators they have been used to simulate

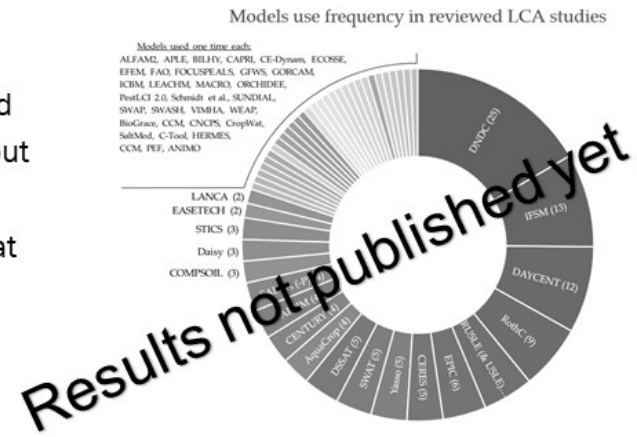
10.10.2024 20

Recent publication
- soil & agro-ecosystem models

DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

Main results and findings:

- Use frequency of different models
- Soil maps, land-use information and weather data that were used as input data
- SDGs and Planetary Boundaries that were referred to



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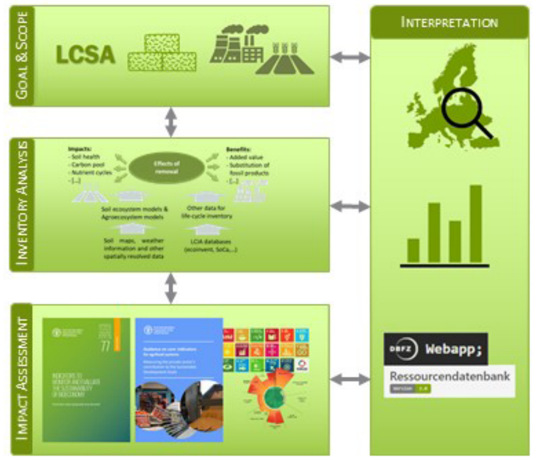
Outlook
- future publications

DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

Framework publication:

- Selecting appropriate indicators from FAO indicator sets
- Linking each indicator to corresponding soil and agro-ecosystem models or LCIA databases
- Selecting appropriate data sources for modeling (soil maps, weather information, land-use databases)
- Description and publication of the framework with its capabilities and limitations



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Outlook
- future publications

DOC2024
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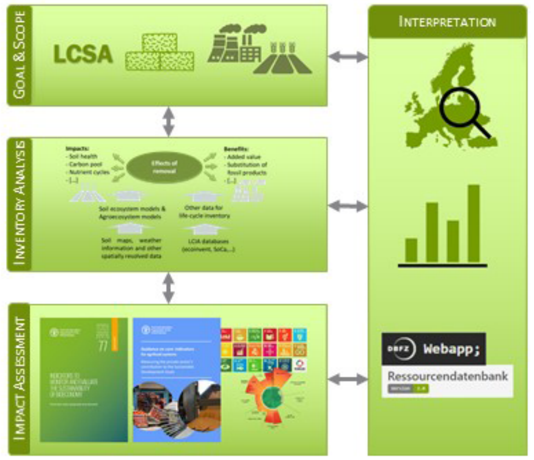
Framework application:

- Automate assessment process
- Develop LCIA result maps for different utilization options according to site-specific conditions
- Refine the debate about sustainable resource potentials



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DOC2024 7TH DOCTORAL COLLOQUIUM BIOENERGY & BIOBASED PRODUCTS

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SESSION

BIOREFINERIES (INCL. BIOFUELS)

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

7TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Guido Ceragioli, Politecnico di Torino

Development of an integrated Hydrothermal Liquefaction Wet Oxidation process

Guido Ceragioli, Carolin Eva Schuck, Dr. Giuseppe Pipitone, Dr. Giulia Zoppi, Prof. Konstantinos Anastasakis, Prof. Samir Bensaid, Prof. Raffaele Pirone, Prof. Patrick Biller
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Keywords: Hydrothermal liquefaction, Wet oxidation, process integration, energy efficiency

Hydrothermal liquefaction (HTL) is a leading technology for converting wet biomass into biofuels, but the effective use of its aqueous phase (AP) by-product remains a challenge. Among the option, wet oxidation (WO) has gained interest as a method for treating the AP. It is a hydrothermal exothermic process where organic compounds degrade in water under an oxidative atmosphere.

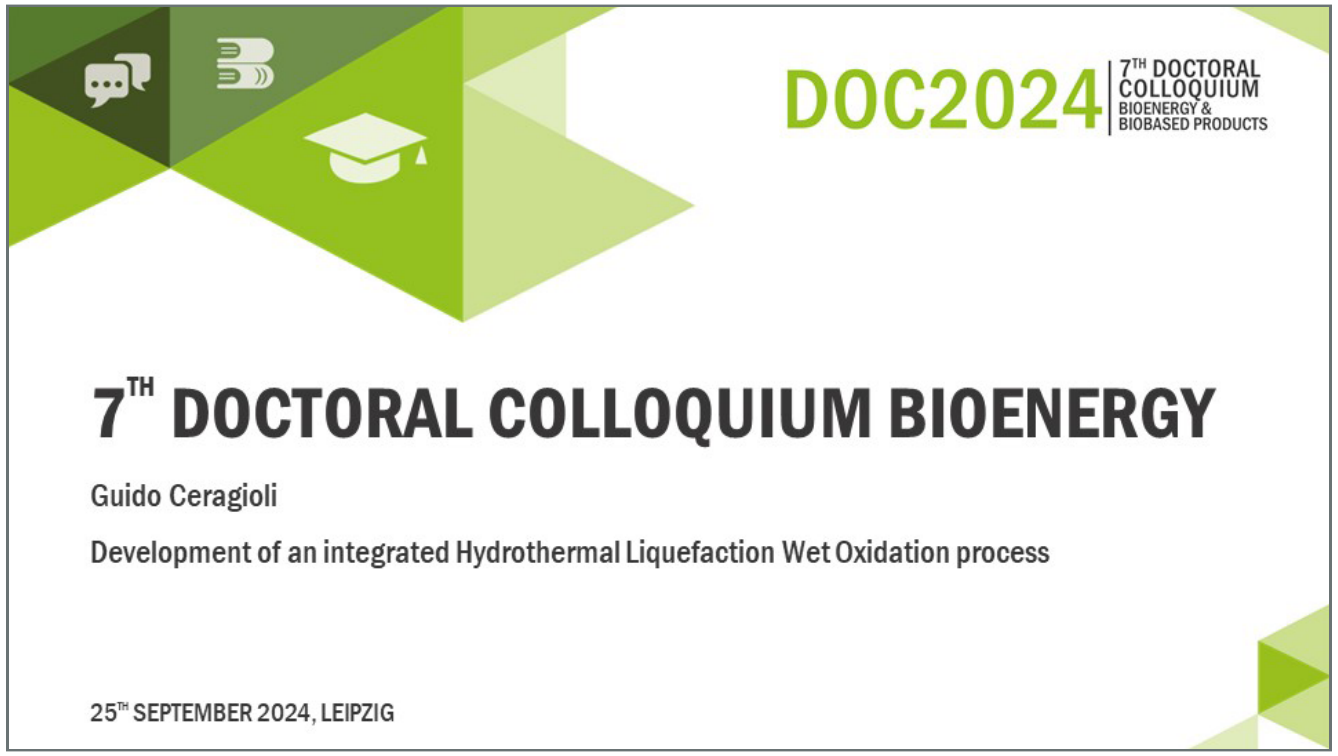
This study explores the integration of WO heat output with HTL energy needs. First a batch experimental campaign was conducted to test the HTL at different operative conditions using as feedstock a 50/50 % blend of wheat straw and cow manure at 15 % dry matter. The quality of the biocrude was established with its high heating value, while the AP was characterized according to its total chemical oxygen demand (COD). Next, Aspen Plus® software was utilized to simulate the WO process with its kinetic under different conditions [1], examining heat generation and output stream composition. Subsequently, a MATLAB script was developed to simulate both HTL stand-alone configuration and the HTL-WO process integration, evaluating for each one an optimal heat exchanger network.

Finally, the residual COD removed to reach the European limit for effluent discharge (0.125 g/L of COD) was assumed considering the energy expenditure of waste water treatment plant (WWT).

1 kg/s of slurry was set as basis for calculation. The indicator for the comparison was identified in the Net Energy Ratio (NER) defined as the process energy output over the input.

The energetic expenditures *Pox* and *Pcomp* are present for WO scenario and consider the oxygen production and compression. The integration of the two processes resulted in notable improvements, with the total energy expenditure reduced by over half. Consequently, these findings hold promise for the widespread adoption of advanced biofuels.

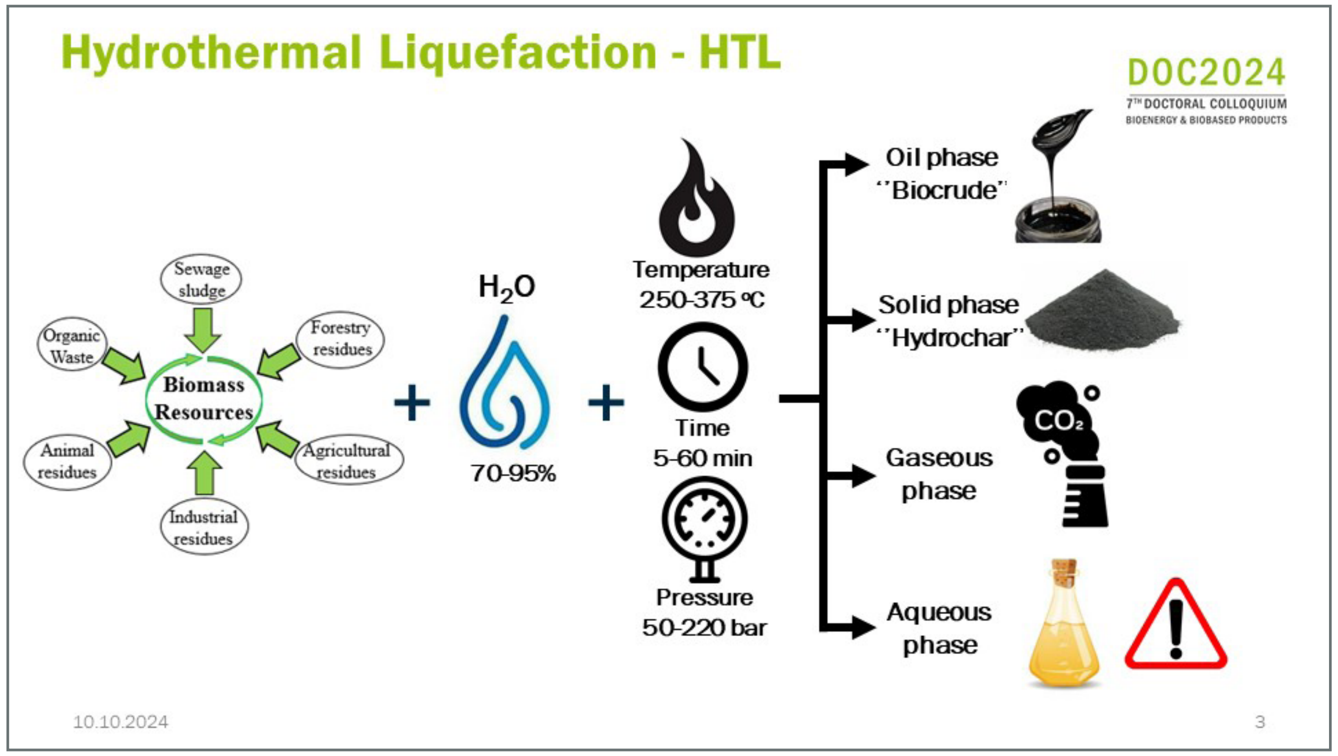
References:
[1] C. E. Schuck, T. Schäfer, and K. Anastasakis, "Predictive Modeling and scale-up of Wet Oxidation for Hydrothermal Liquefaction Process Water treatment," Computer Aided Chemical Engineering, vol. 52, pp. 2229–2234, Jan. 2023, doi: 10.1016/B978-0-443-15

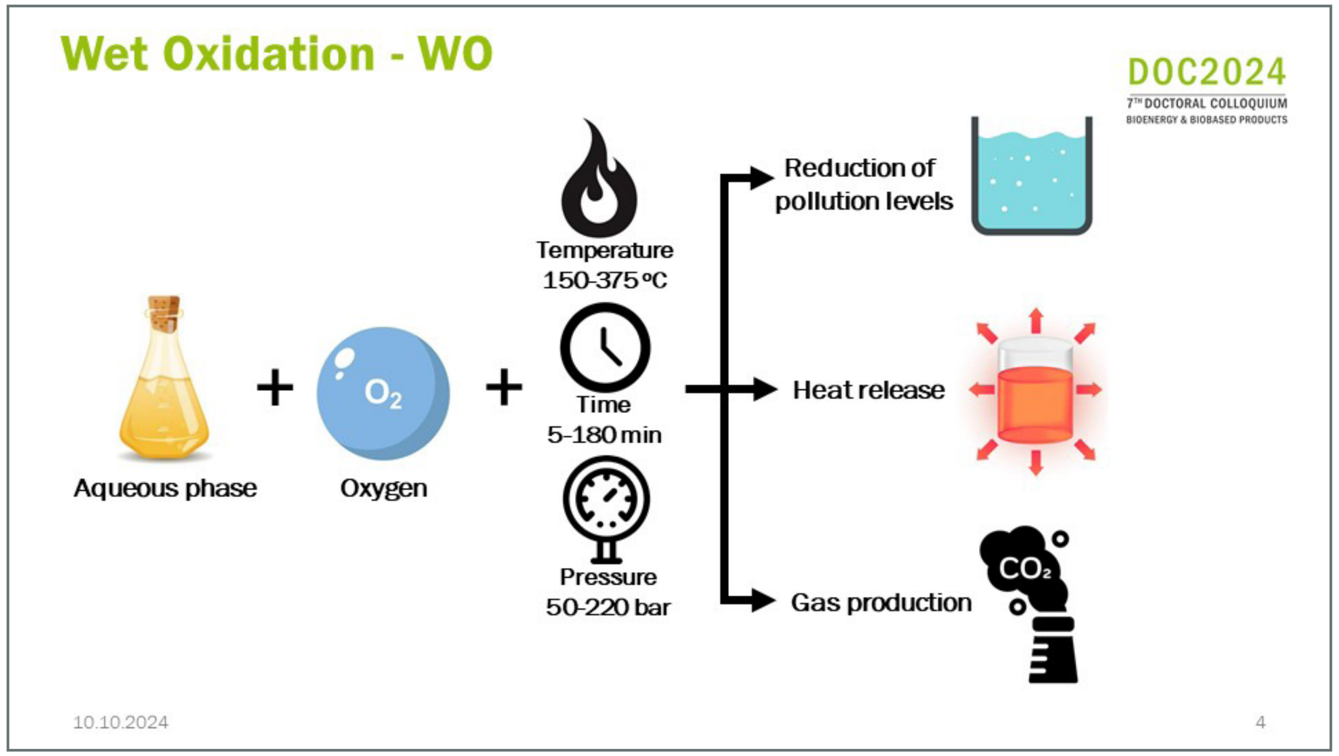


Short introduction

DOC2024
7TH DOCTORAL COLLOQUIUM BIOENERGY & BIOBASED PRODUCTS

Title of the Doctoral Project:	Waste valorization for the generation of energy carriers
Doctoral Student:	Guido Ceragioli
University:	Polythecnic of Turin, Department of chemical engineering
University Supervisor:	Prof. Raffaele Pirone (PoliTo) Prof. Samir Bensaid (PoliTo) Dr. Giuseppe Pipitone (PoliTo) Prof. Patrick Biller (AU) Prof. Konstantinos Anastasakis (AU) Dr. Giulia Zoppi (AU)
Logo	Politecnico di Torino; AARHUS UNIVERSITY





Objectives

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BIOENERGY & BIOBASED PRODUCTS

1. Investigation of HTL process through batch experiments
2. Characterization of the WO process through Aspen plus simulation
3. Design of a heat exchanger network to integrate the heat released by WO in HTL
4. Evaluation the processes' integration effectiveness compared to HTL standalone configuration

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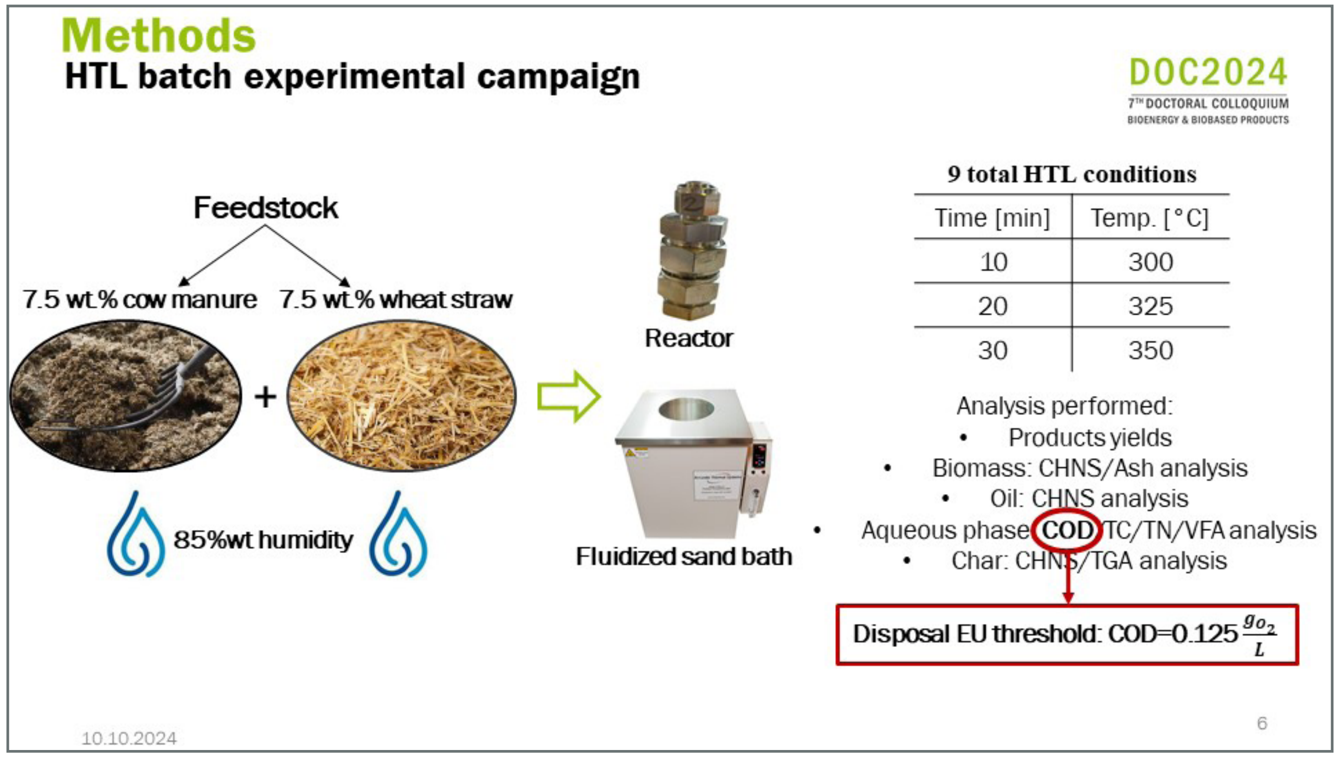

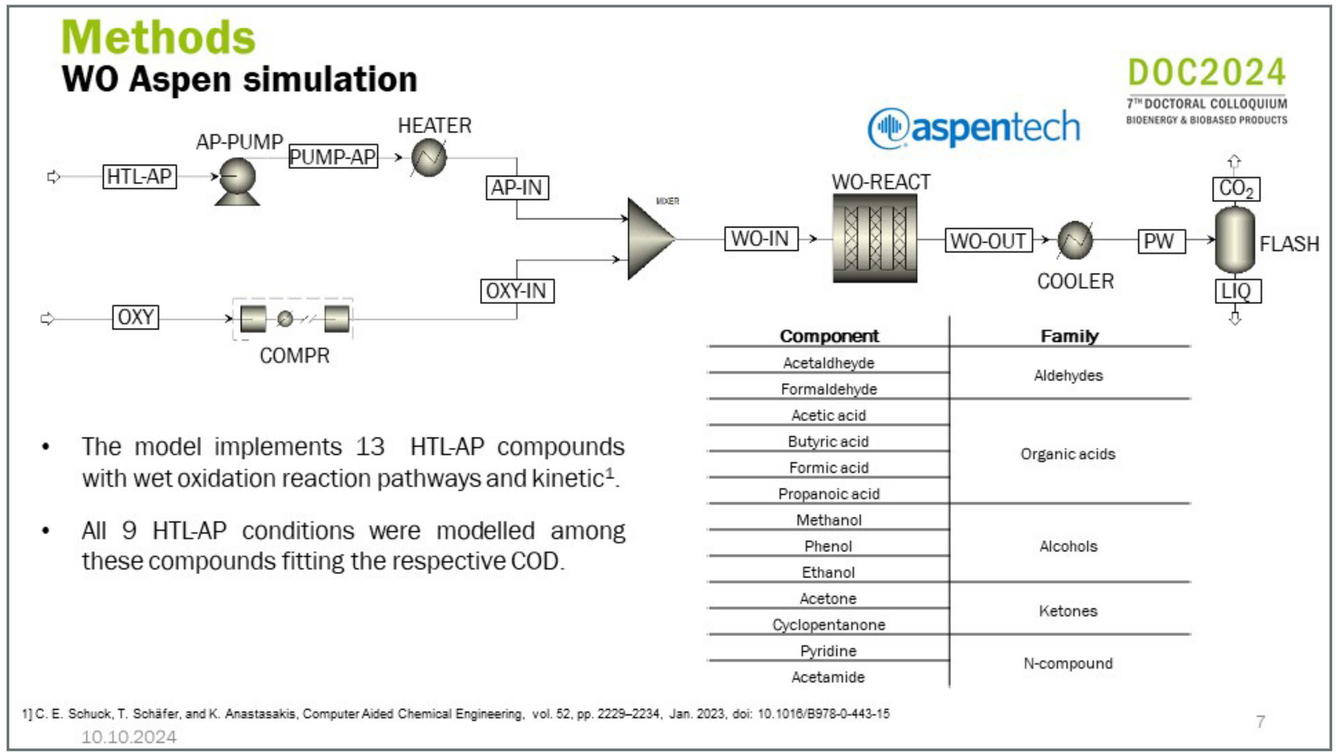
Methods
WO Aspen simulation
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
aspentech
HTL-AP
AP-PUMP
PUMP-AP
HEATER
AP-IN
MIXER
WO-IN
WO-REACT
WO-OUT
COOLER
PW
CO2
FLASH
LIQ
OXY-IN
OXY
COMPR
• The model implements 13 HTL-AP compounds with wet oxidation reaction pathways and kinetic1.
• All 9 HTL-AP conditions were modelled among these compounds fitting the respective COD.
Component | Family
Acetaldheyde, Formaldehyde | Aldehydes
Acetic acid, Butyric acid, Formic acid, Propanoic acid | Organic acids
Methanol, Phenol, Ethanol | Alcohols
Acetone, Cyclopentanone | Ketones
Pyridine, Acetamide | N-compound
1] C. E. Schuck, T. Schäfer, and K. Anastasakis, Computer Aided Chemical Engineering, vol. 52, pp. 2229–2234, Jan. 2023, doi: 10.1016/B978-0-443-15
10.10.2024
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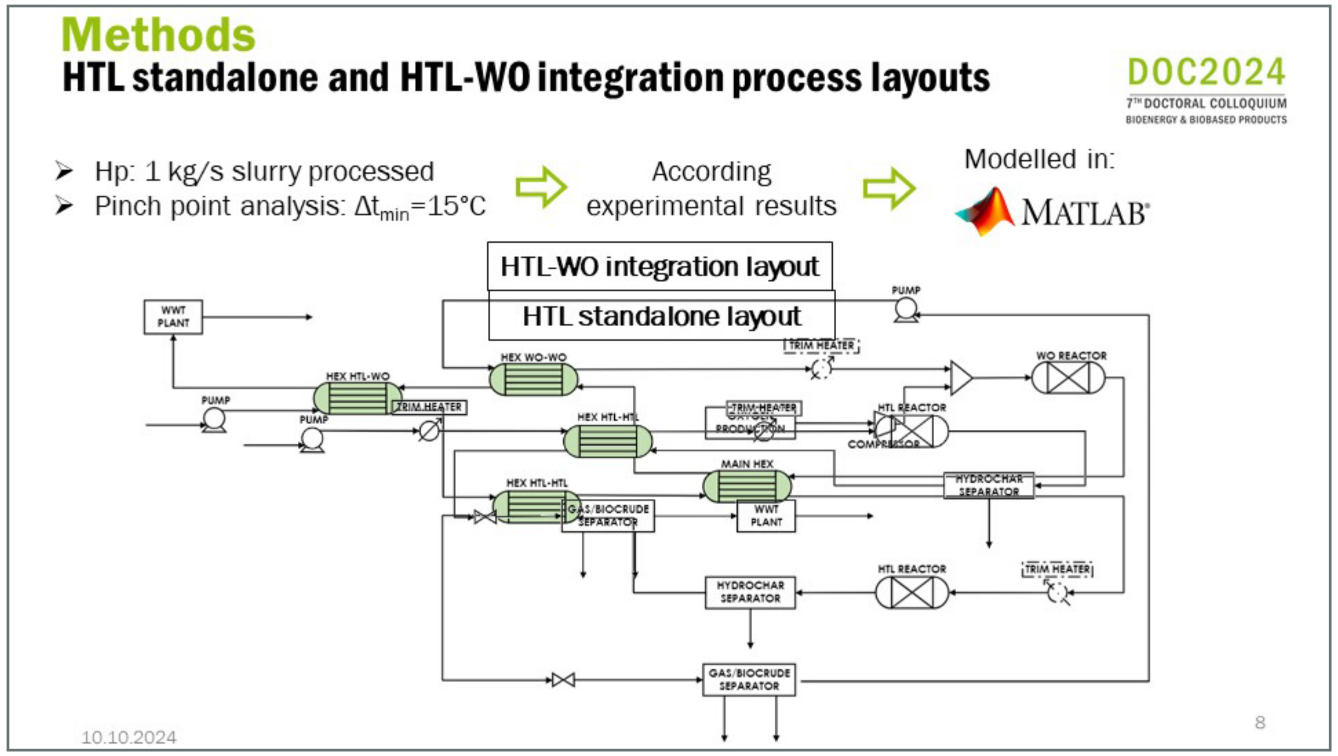
Methods
HTL standalone and HTL-WO integration process layouts
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
➢ Hp: 1 kg/s slurry processed
➢ Pinch point analysis: Δtmin=15°C
According experimental results
Modelled in:
MATLAB
HTL-WO integration layout
HTL standalone layout
WWT PLANT
PUMP
HEX HTL-WO
TRIM HEATER
HEX WO-WO
HEX HTL-HTL
OXYGEN PRODUCTION
COMPRESSOR
HTL REACTOR
WO REACTOR
MAIN HEX
HYDROCHAR SEPARATOR
GAS/BIOCRUDE SEPARATOR
10.10.2024
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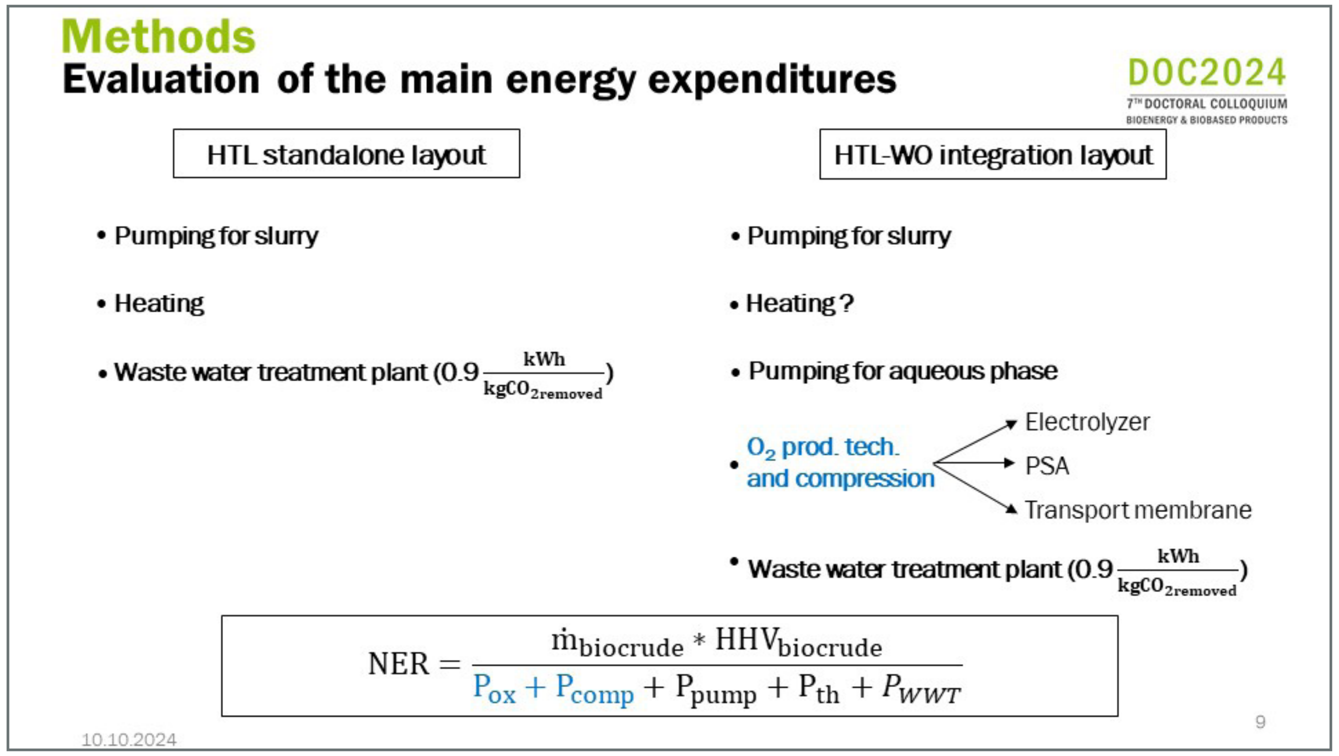
Methods
Evaluation of the main energy expenditures
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BIOENERGY & BIOBASED PRODUCTS
HTL standalone layout
• Pumping for slurry
• Heating
• Waste water treatment plant (0.9 kWh/kgCO2removed)
HTL-WO integration layout
• Pumping for slurry
• Heating?
• Pumping for aqueous phase
• O2 prod. tech. and compression
Electrolyzer
PSA
Transport membrane
• Waste water treatment plant (0.9 kWh/kgCO2removed)
NER = ṁbiocrude * HHVbiocrude / (Pox + Pcomp + Ppump + Pth + PWWT)
10.10.2024
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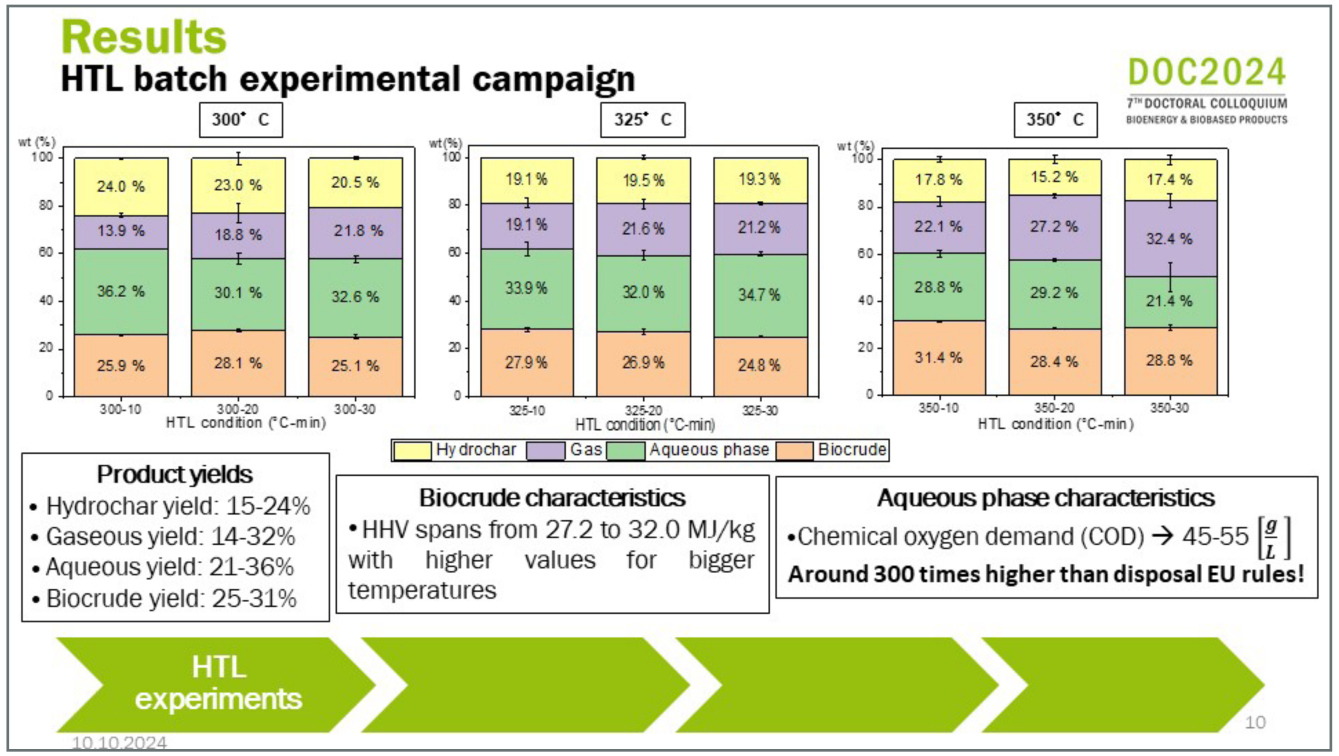
Results
HTL batch experimental campaign
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
300° C
325° C
350° C
wt (%)
HTL condition (°C-min)
Hydrochar
Gas
Aqueous phase
Biocrude
Product yields
• Hydrochar yield: 15-24%
• Gaseous yield: 14-32%
• Aqueous yield: 21-36%
• Biocrude yield: 25-31%
Biocrude characteristics
• HHV spans from 27.2 to 32.0 MJ/kg with higher values for bigger temperatures
Aqueous phase characteristics
• Chemical oxygen demand (COD) → 45-55 [g/L]
Around 300 times higher than disposal EU rules!
HTL experiments
10.10.2024
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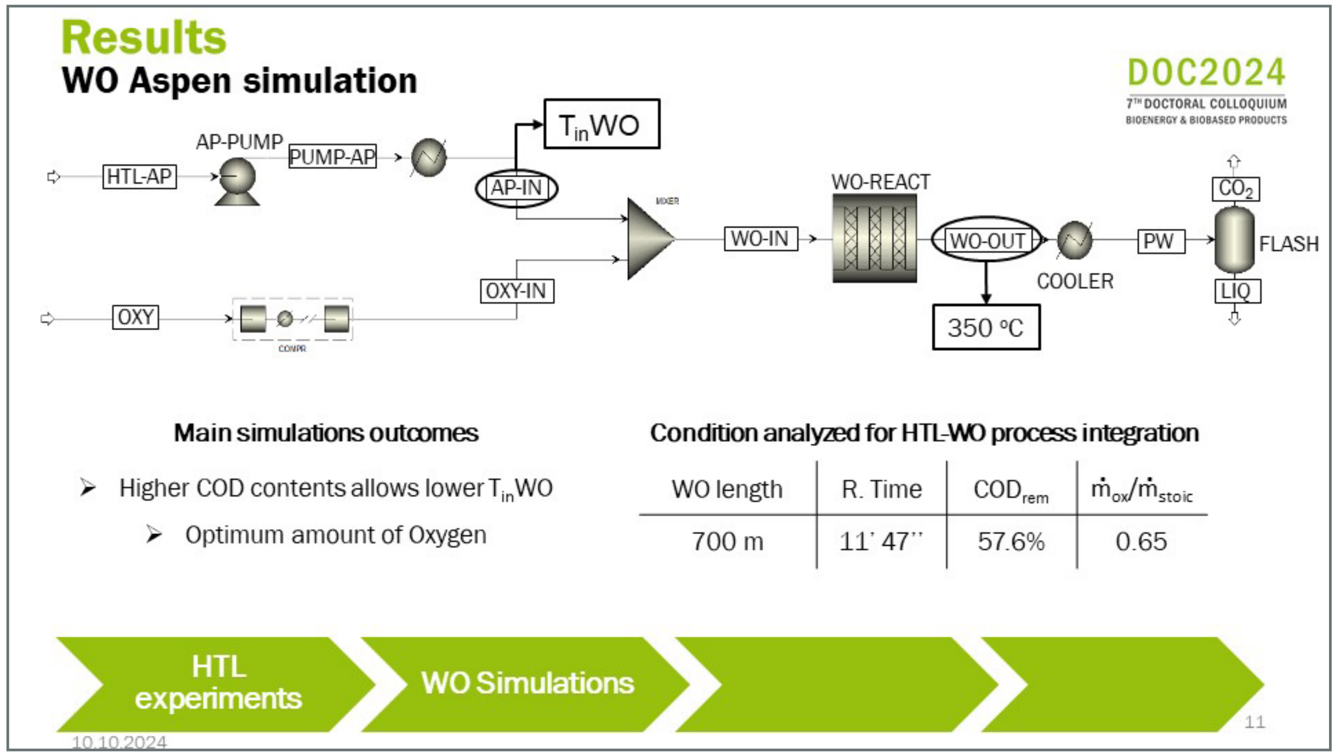
Results
WO Aspen simulation
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
TinWO
AP-PUMP
HTL-AP
PUMP-AP
AP-IN
WO-REACT
WO-IN
WO-OUT
COOLER
PW
CO2
FLASH
LIQ
OXY
OXY-IN
350 °C
Main simulations outcomes
Higher COD contents allows lower TinWO
Optimum amount of Oxygen
Condition analyzed for HTL-WO process integration
WO length | R. Time | CODrem | ṁox/ṁstoic
700 m | 11' 47'' | 57.6% | 0.65
HTL experiments
WO Simulations
10.10.2024
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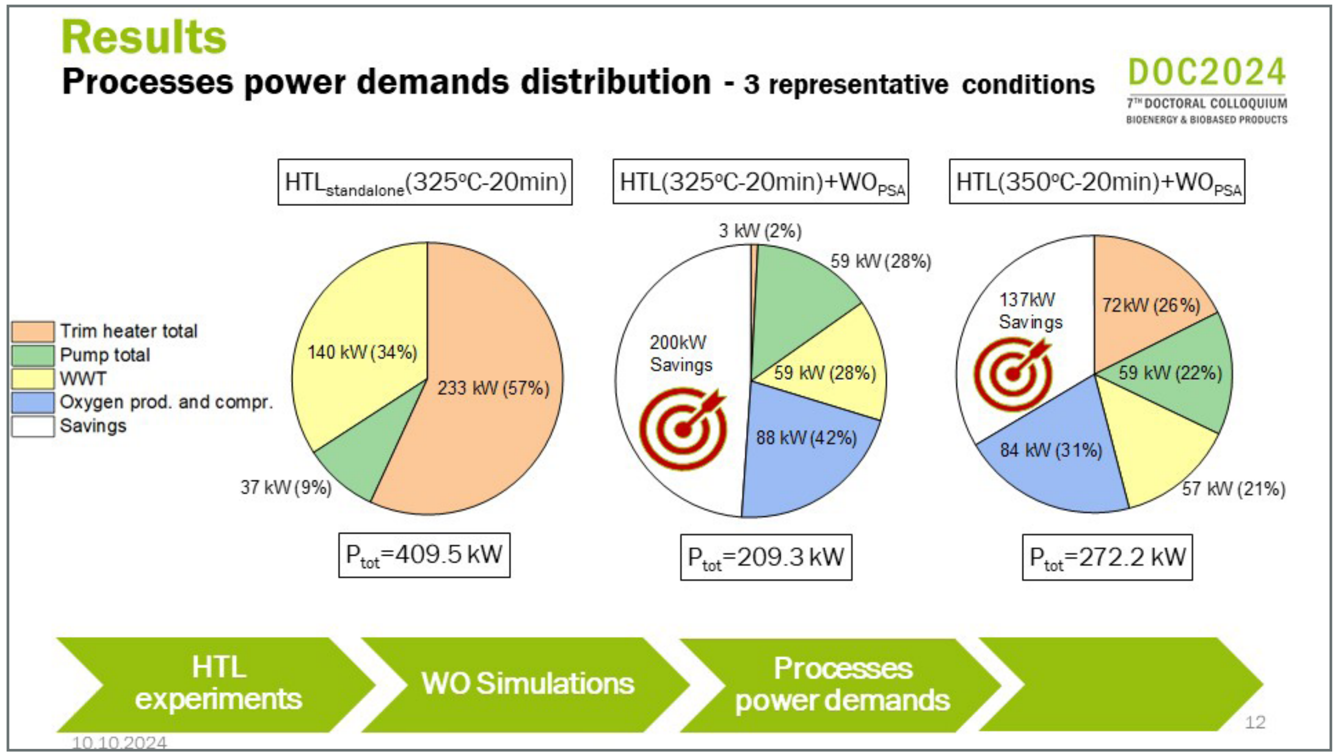
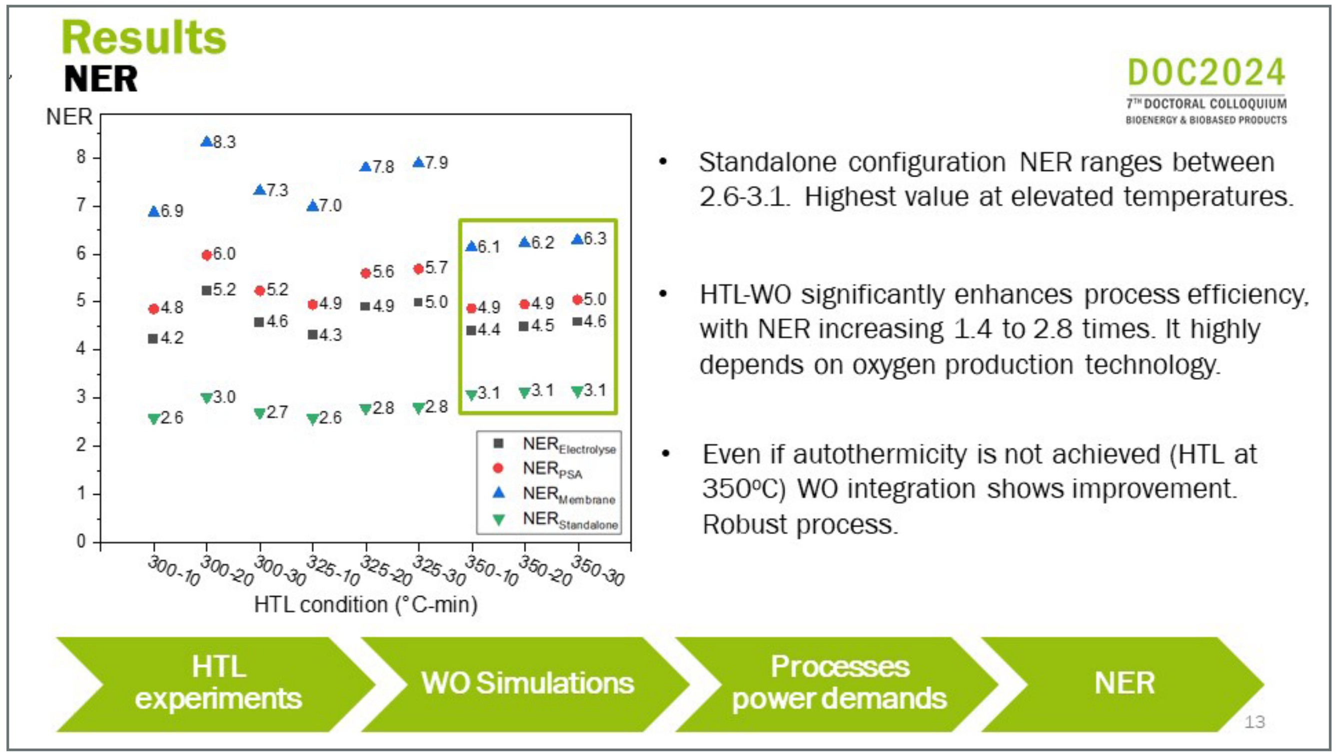
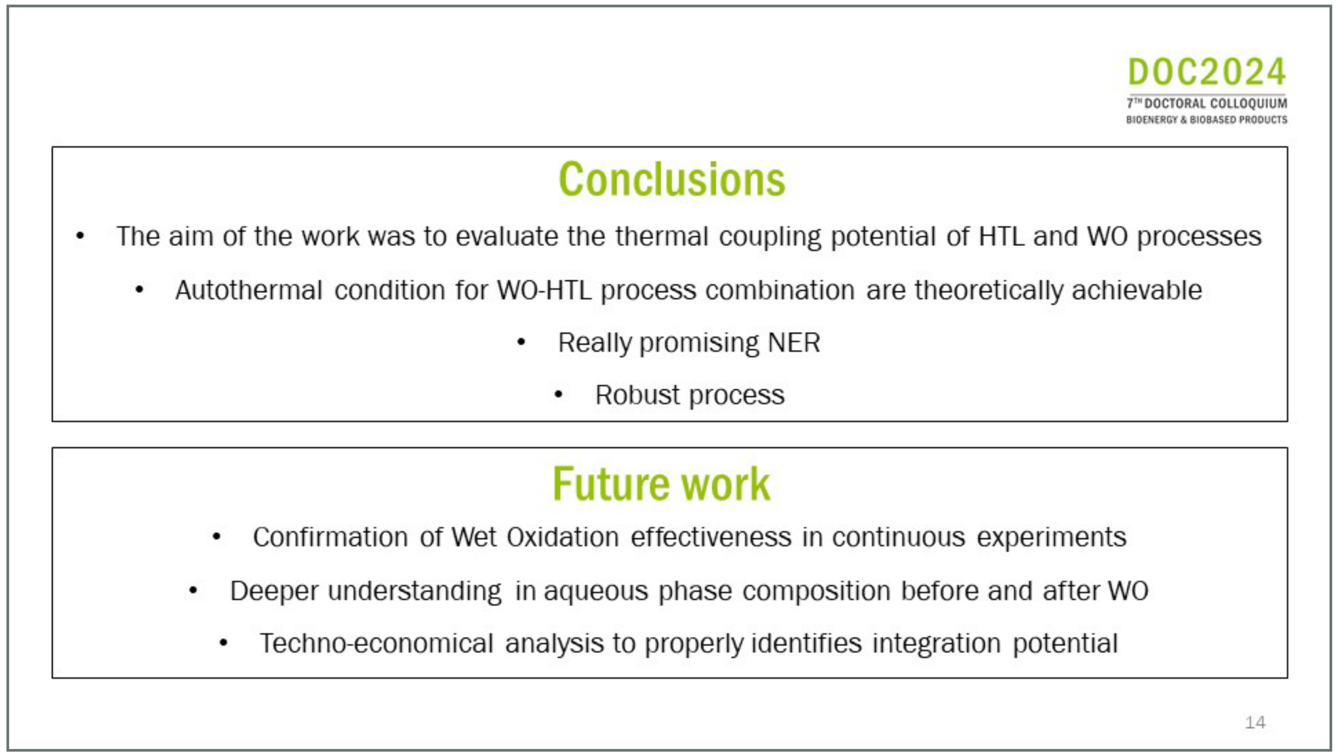

Results
Processes power demands distribution - 3 representative conditions
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
HTLstandalone(325°C-20min)
HTL(325°C-20min)+WOPSA
HTL(350°C-20min)+WOPSA
Trim heater total
Pump total
WWT
Oxygen prod. and compr.
Savings
140 kW (34%)
233 kW (57%)
37 kW (9%)
3 kW (2%)
59 kW (28%)
200kW Savings
59 kW (28%)
88 kW (42%)
137kW Savings
72 kW (26%)
59 kW (22%)
84 kW (31%)
57 kW (21%)
Ptot=409.5 kW
Ptot=209.3 kW
Ptot=272.2 kW
HTL experiments
WO Simulations
Processes power demands
10.10.2024
12


Results
NER
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
NER
HTL condition (°C-min)
300-10
300-20
300-30
325-10
325-20
325-30
350-10
350-20
350-30
NERElectrolyse
NERPSA
NERMembrane
NERStandalone
Standalone configuration NER ranges between 2.6-3.1. Highest value at elevated temperatures.
HTL-WO significantly enhances process efficiency, with NER increasing 1.4 to 2.8 times. It highly depends on oxygen production technology.
Even if autothermicity is not achieved (HTL at 350°C) WO integration shows improvement. Robust process.
HTL experiments
WO Simulations
Processes power demands
NER
13


DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Conclusions
The aim of the work was to evaluate the thermal coupling potential of HTL and WO processes
Autothermal condition for WO-HTL process combination are theoretically achievable
Really promising NER
Robust process
Future work
Confirmation of Wet Oxidation effectiveness in continuous experiments
Deeper understanding in aqueous phase composition before and after WO
Techno-economical analysis to properly identifies integration potential
14

Maximilian Wörner, Karlsruhe Institute of Technology

From Pulp to Aromatic Products – Description of a reaction mechanism for lignin depolymerization during hydrothermal liquefaction

Maximilian Wörner, Ursel Hornung, Prof. Dr. Nicolaus Dahmen
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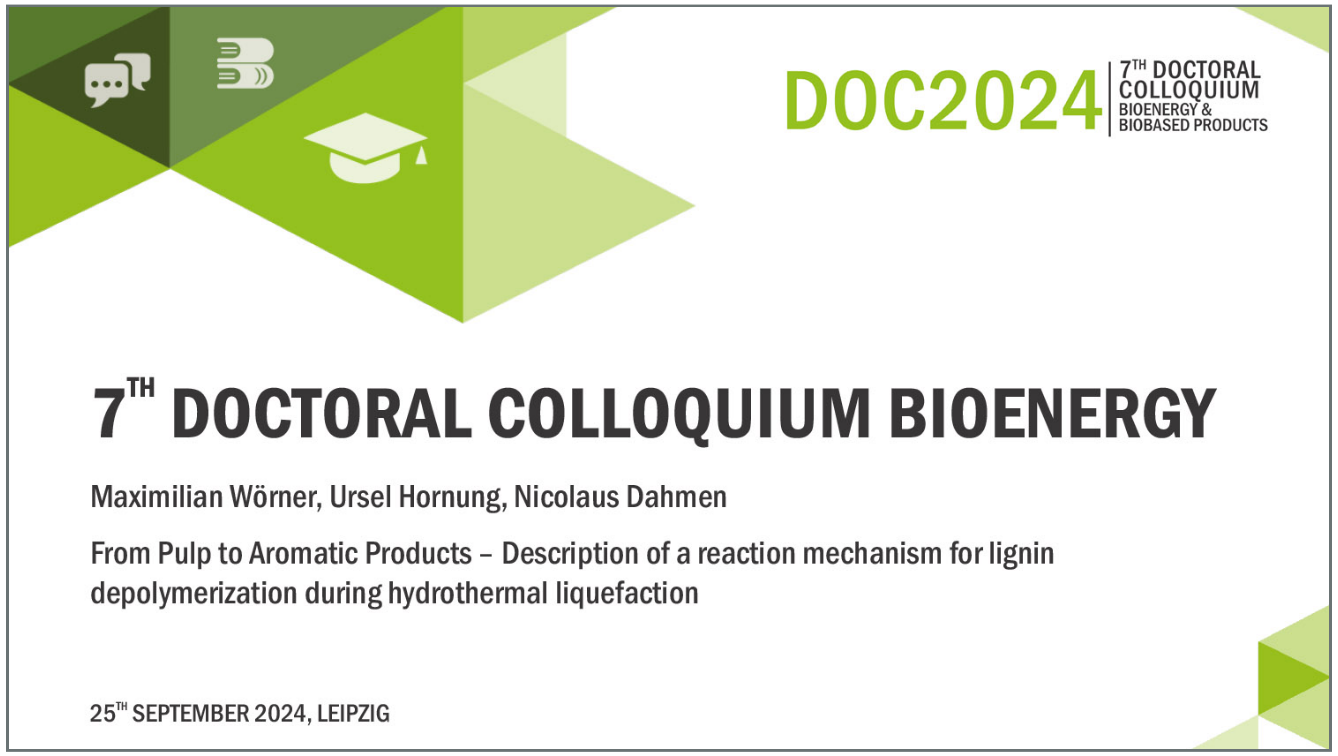
Keywords: Lignin depolymerization, hydrothermal liquefaction, biomass conversion, black liquor,

Lignin is a promising renewable raw material that can be used in the future as a basis for the production of important platform chemicals or energy carriers. The biopolymer has a large number of aromatic rings that are linked to each other via various chemical bonds. Depolymerization of the macromolecule can therefore be used to produce interesting aromatic compounds. The largest producer of lignin is the paper industry with around 50 million tons per year. These are currently burned almost exclusively to generate energy. A more sustainable use, which also has economic potential, is the material valorization of the lignin. Most of the lignin produced is dissolved in the form of black liquor.

A suitable process for directly processing the lignin contained in the black liquor is hydrothermal liquefaction, which is carried out at process conditions close to the critical point of the water (374 °C, 221 bar). It offers the elegant option of using the black liquor directly without having to separate and dry the lignin first, which is energy-intensive, as the HTL can also process wet biomass with a very high-water content and also needs water as a basic requirement. The depolymerization of lignin is a very complex reaction with many products, therefore, the formulation of a reaction mechanism is of advantage to design processes for recovery of aromatic products from lignin.

We carried out batch and continuous tests with black liquor, extracted lignin and model substances at temperatures between 250 and 400 °C and residence times of 0 to 30 minutes. With the help of various analytic tools like 31P NMR, GC-MS/FID, ICP, elemental analysis, mass balances of aromatic products describing monomers and oligomers as well as solids and gases are determined and chemical composition are described depending from temperature and residence time during HTL.

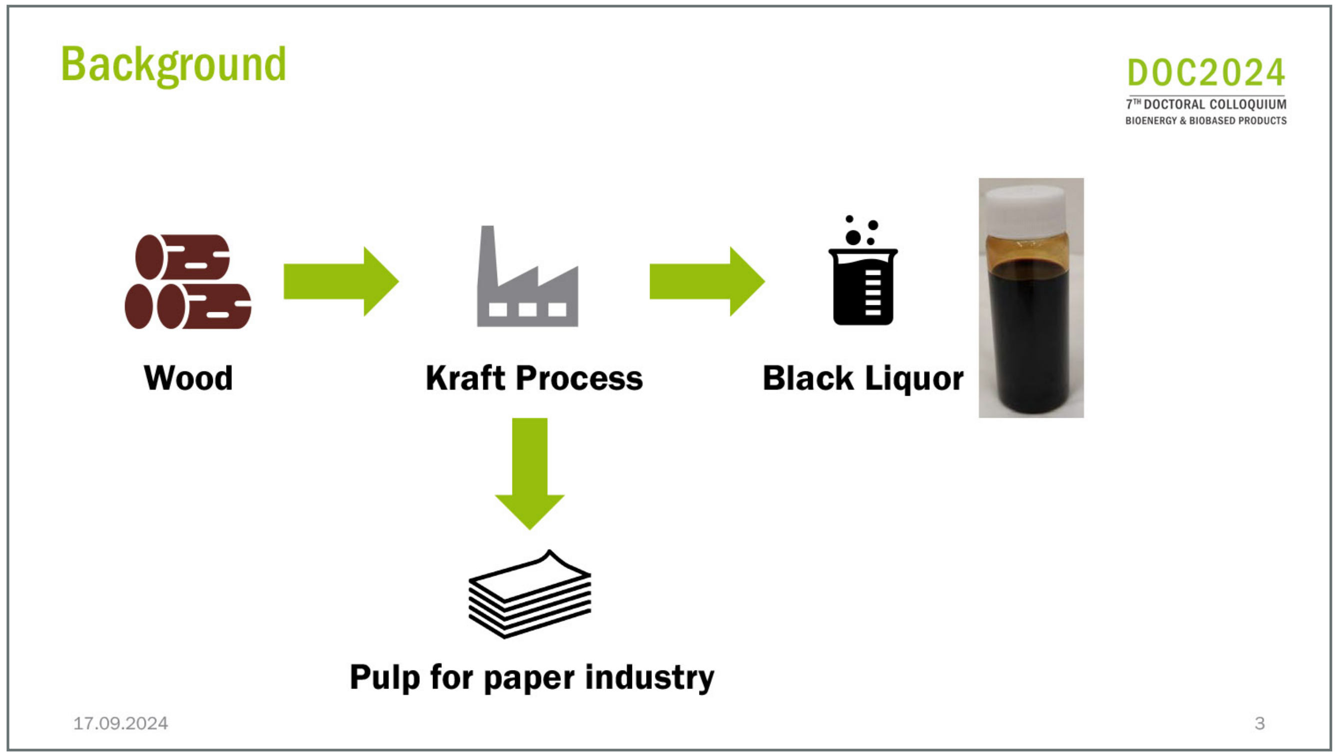
31P NMR and 13C solid state NMR elucidated the functionalities of the lignin degradation products and proved that demethylation, demethoxylation and radical methylation reactions of monomers and oligomers are comparable. Based on these results, a reaction network is created, which on the one hand represents specific reactions at the functional groups and on the other hand provides information about the degree of depolymerization by means of the molecular weight and the carbon mass balance. From this reaction network, a lumped reaction model is developed that can satisfactorily describe the depolymerization.

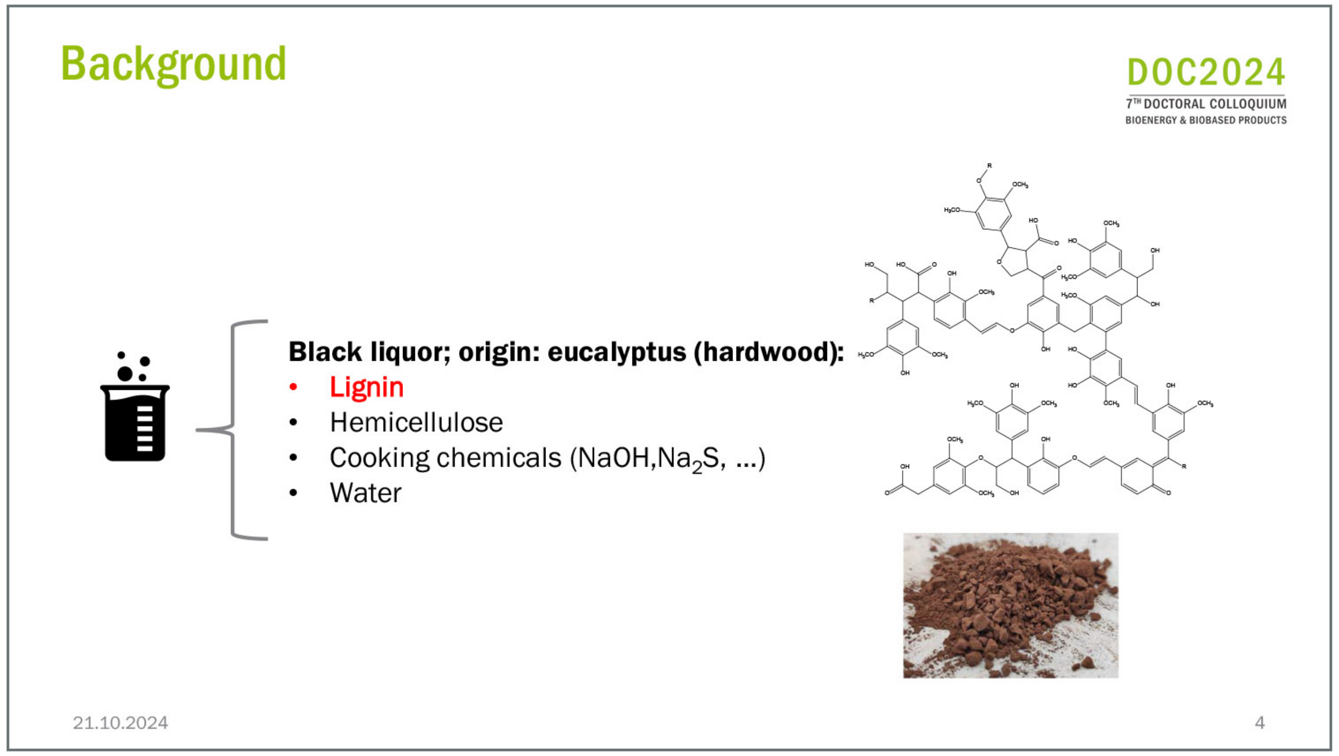


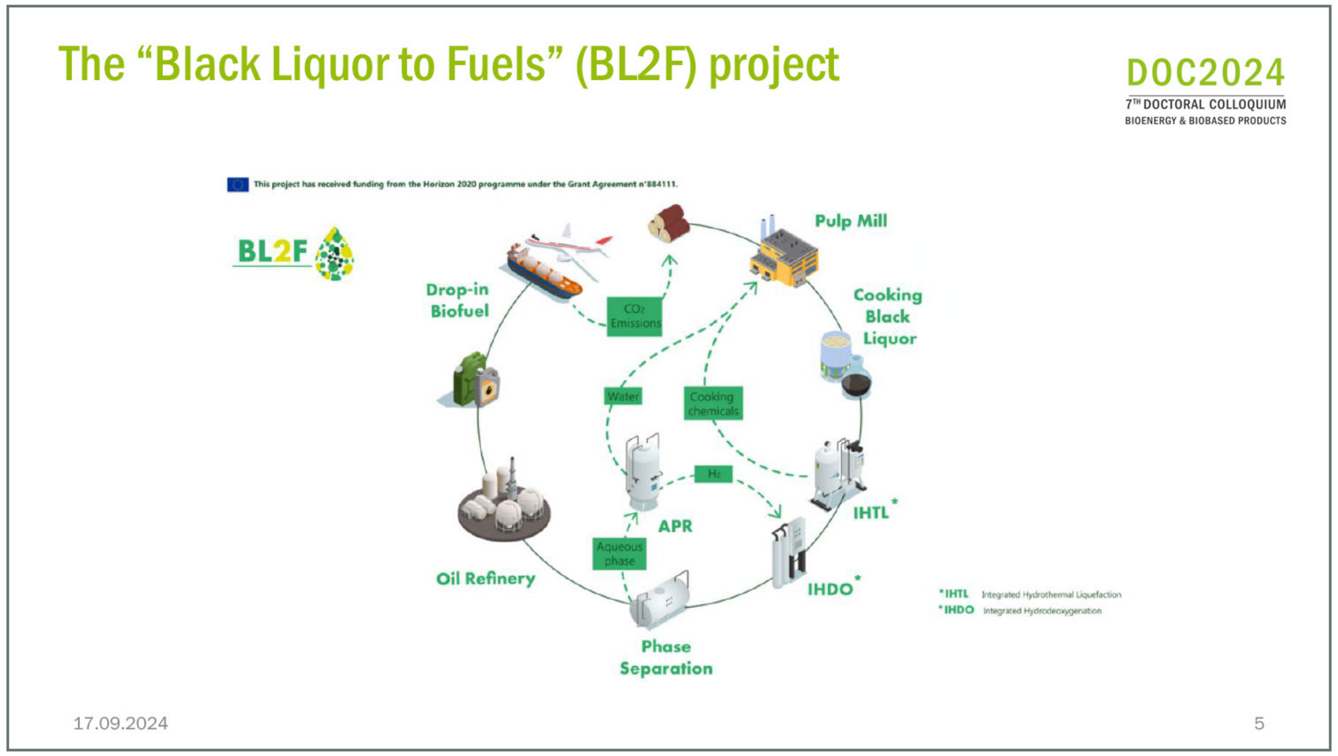
Short introduction

DOC2024 7TH DOCTORAL COLLOQUIUM BIOENERGY & BIOBASED PRODUCTS

Title of the Doctoral Project:	Hydrothermal liquefaction of black liquor – Depolymerization of lignin in water under near-critical conditions under the influence of salts
Doctoral Student:	Maximilian Wörner
DBFZ Supervisor:	-
University:	Karlsruhe Institute of Technology (KIT) Institute of Catalysis Research and Technology
University Supervisor:	Prof. Dr. Nicolaus Dahmen
Funding / Scholarship provider: **Logo:**	European Union Horizon 2020: Black Liquor to Fuels (BL2F) project Grant Agreement Number: 884111
Duration:	05/2020 – 10/2024


Background
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Wood
Kraft Process
Black Liquor
Pulp for paper industry
17.09.2024
3


Background
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Black liquor; origin: eucalyptus (hardwood):
Lignin
Hemicellulose
Cooking chemicals (NaOH,Na2S, ...)
Water
21.10.2024
4


The “Black Liquor to Fuels” (BL2F) project
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
BL2F
Pulp Mill
Cooking Black Liquor
IHTL*
IHDO*
Phase Separation
APR
Oil Refinery
Drop-in Biofuel
CO2 Emissions
Water
Cooking chemicals
H2
Aqueous phase
17.09.2024
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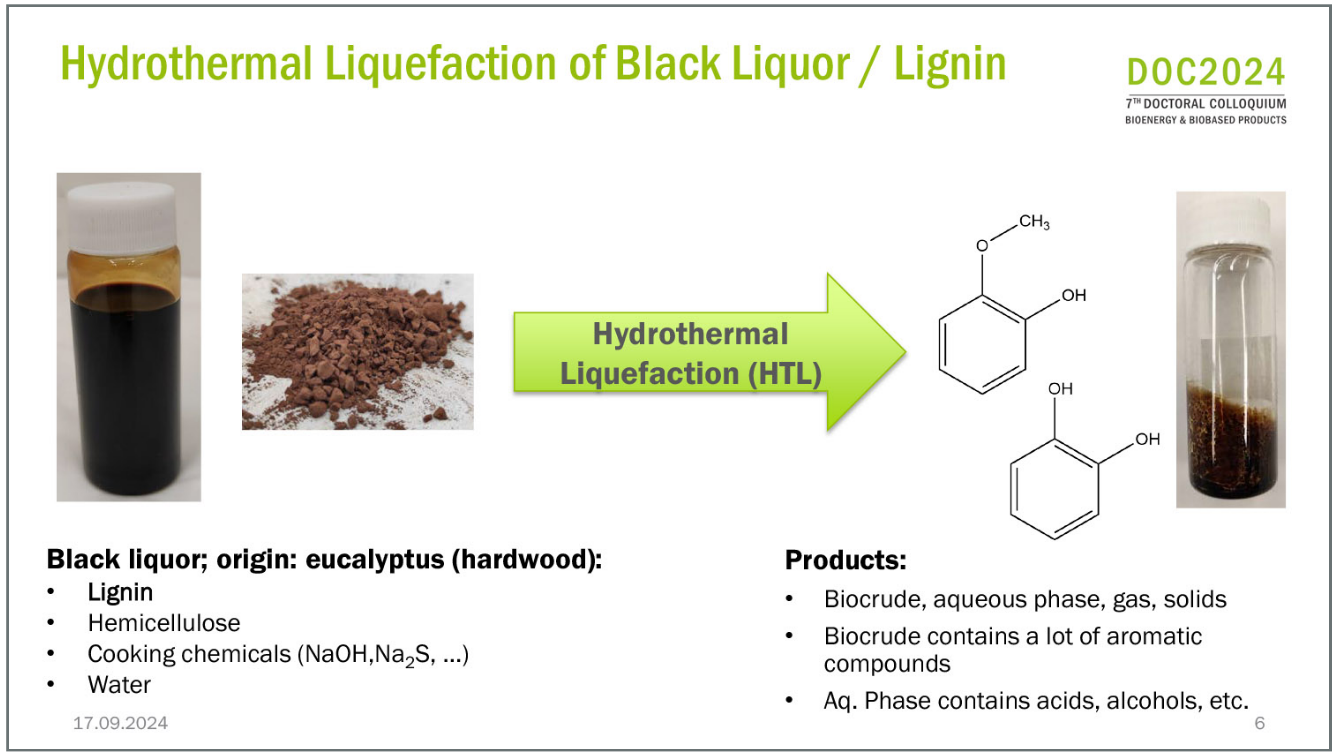
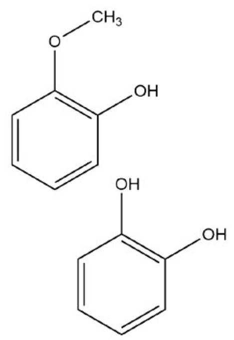

Hydrothermal Liquefaction of Black Liquor / Lignin
DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Hydrothermal Liquefaction (HTL)
CH3
O
OH
OH
OH
Black liquor; origin: eucalyptus (hardwood):
Lignin
Hemicellulose
Cooking chemicals (NaOH,Na2S, ...)
Water
Products:
Biocrude, aqueous phase, gas, solids
Biocrude contains a lot of aromatic compounds
Aq. Phase contains acids, alcohols, etc.
17.09.2024
6

Hydrothermal Liquefaction of Black Liquor / Lignin

DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS



Focus on aromatic monomer compounds

- What are the product yields after lignin depolymerization during direct HTL of BL?
- Which are the best parameters for the process?
- What are the reaction pathways for lignin depolymerization under these conditions?

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Experimental Setup (II)

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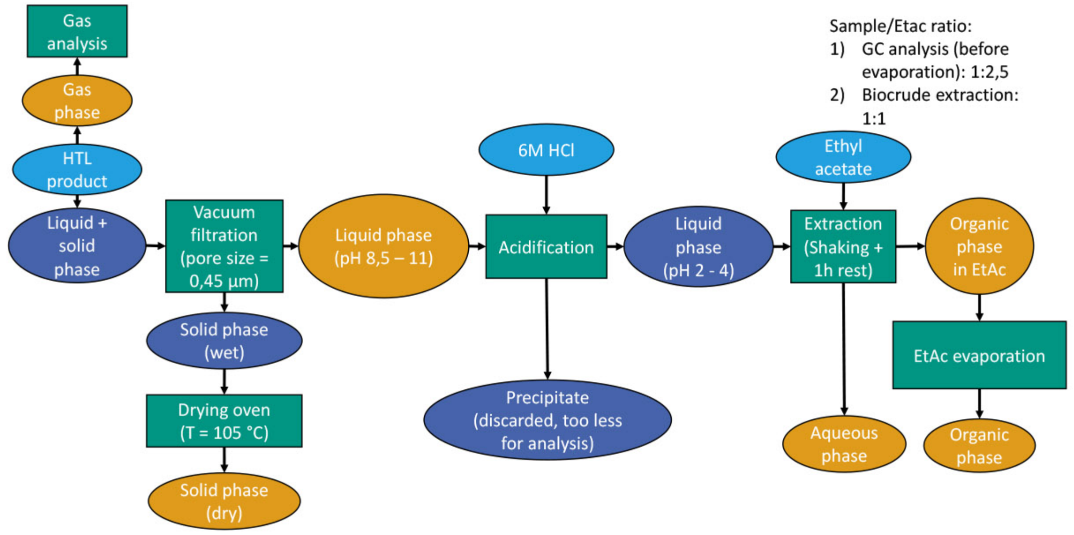
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

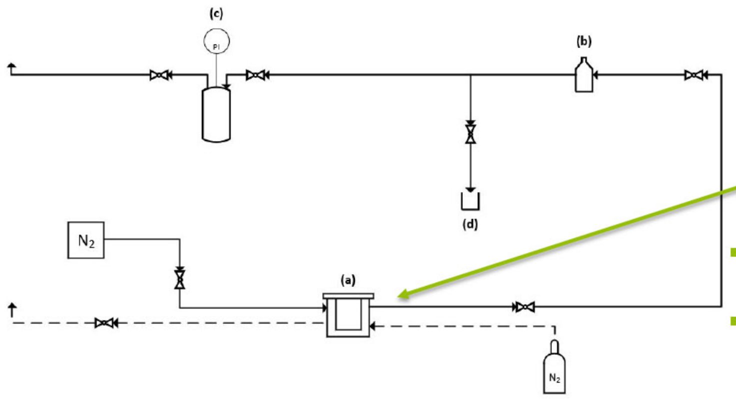


Sample/Etac ratio:
1) GC analysis (before evaporation): 1:2,5
2) Biocrude extraction: 1:1

20.09.2024 9

Experimental Setup (I)

DOC2024
7TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS



Micro autoclaves, V = 25 mL

- Heating process in sand bath
  - t_H = 10 min
- Investigated conditions:
  - T_R = 250 – 400 °C (t_R = 20 min)
  - t_R = 0 – 30 min (T_R = 300 °C, 325 °C, 375 °C)
  - Pressure: around 200 – 250 bar (via fill level)

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HTL of black liquor: monomer products (I)

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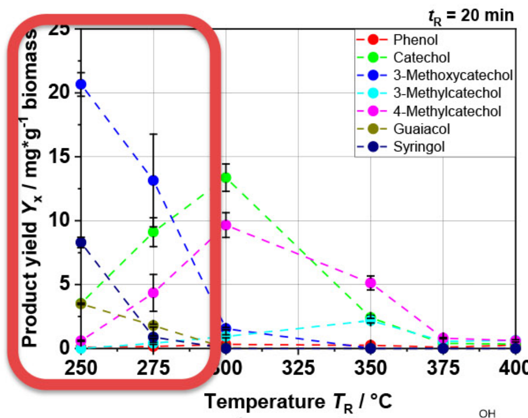
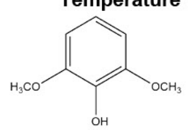
BIOENERGY & BIOBASED PRODUCTS

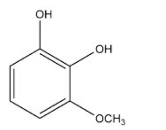


Catechols are the main aromatic monomer products

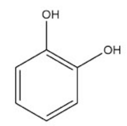
1) Decline of Methoxygroups
2) Increase of (methylated) catechols



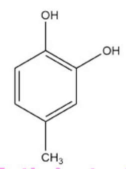
Syringol



3-Methoxycatechol



Catechol



4-Methylcatechol

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HTL of black liquor: monomer products (II)

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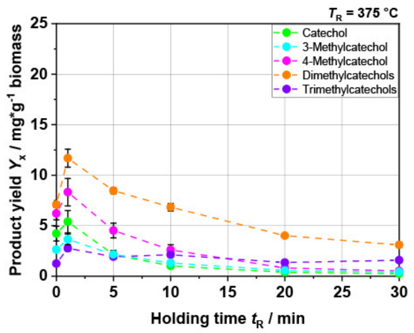
BIOENERGY & BIOBASED PRODUCTS

T_R = 375 °C



- T_R = 375 °C
  - Low overall yields and decrease to almost zero with increasing holding time t_R
  - high methylated/non-methylated catechols ratio

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HTL of black liquor: monomer products (II)

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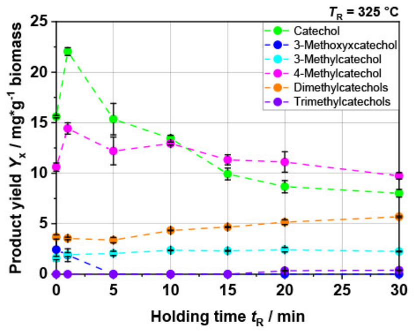
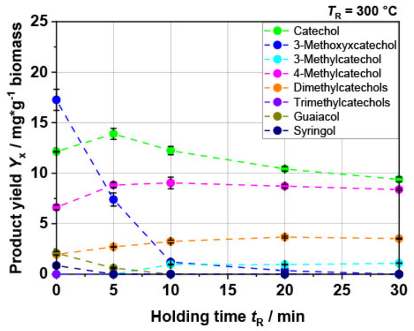
T_R = 325 °C T_R = 300 °C





- T_R = 325 °C, 300 °C
  - Highest overall yields at short holding times and T_R = 325 °C
  - Methylation ratio drops with lower temperature/ shorter holding time
  - Repolymerization reactions and/or decomposition of aromatics are enhanced at higher temperature

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HTL of model substances

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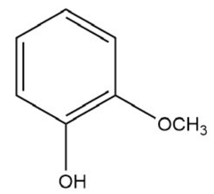
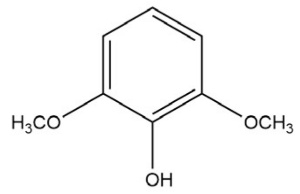
Additional experiments with model substances



Guaiacol



Syringol

Preparation of model liquor with **same salt concentration** as real BL, **same experimental setup**

Why these two compounds?
1) Typical monomer intermediates during lignin depolymerization
2) Reference to softwood and hardwood origin

Aim: more insight into **reaction pathways** under HTL conditions

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HTL of model substances

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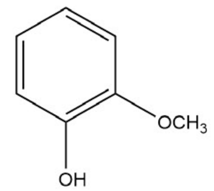
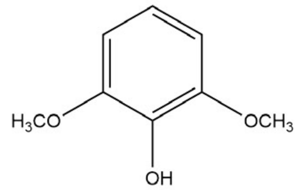
BIOENERGY & BIOBASED PRODUCTS

Additional experiments with model substances

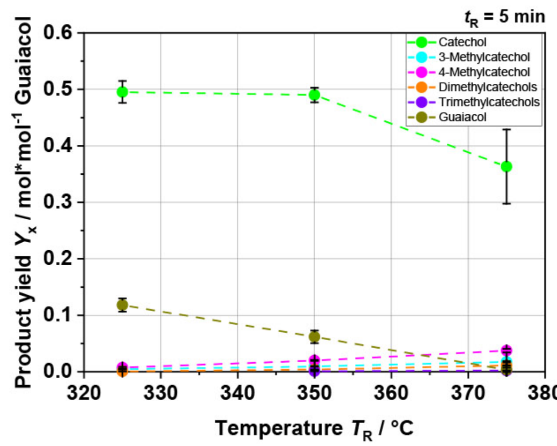


Guaiacol



Syringol

Guaiacol:
- Mainly produced Catechol
- Slight increase in methylated catechols



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HTL of model substances

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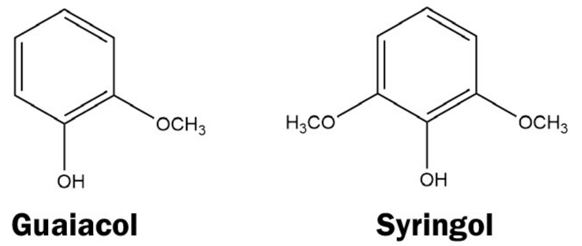
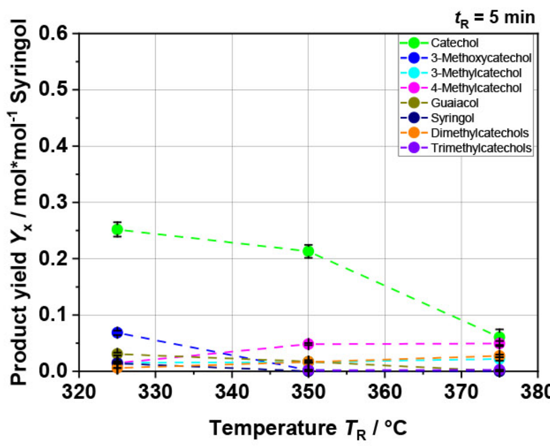
Additional experiments with model substances



Syringol:

- Catechol also main product but only half of the yield compared to Guaiacol
- Guaiacol and 3-Methoxycatechol as intermediates
- Slightly more methylated catechols



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HTL of black liquor: oligomer products

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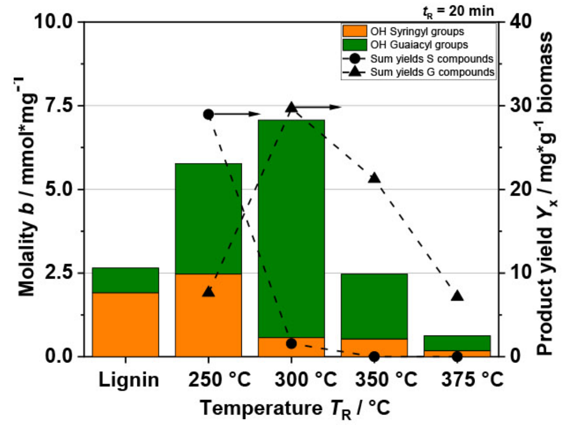
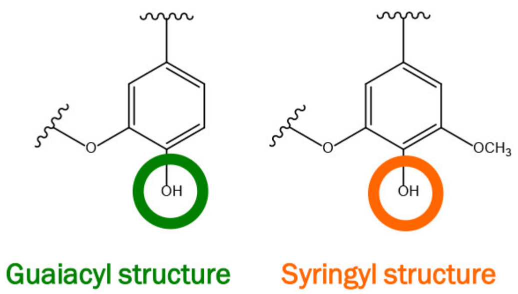
^{31}P NMR of extracted biocrude





- Quantification of phosphorylated –OH groups ↑
- G = Guaiacyl – OH (+ 3-methoxycatechol & catechol); S = Syringyl – OH
- Confirms the pathway observed with monomer analysis: S -> G

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HTL of black liquor: oligomer products

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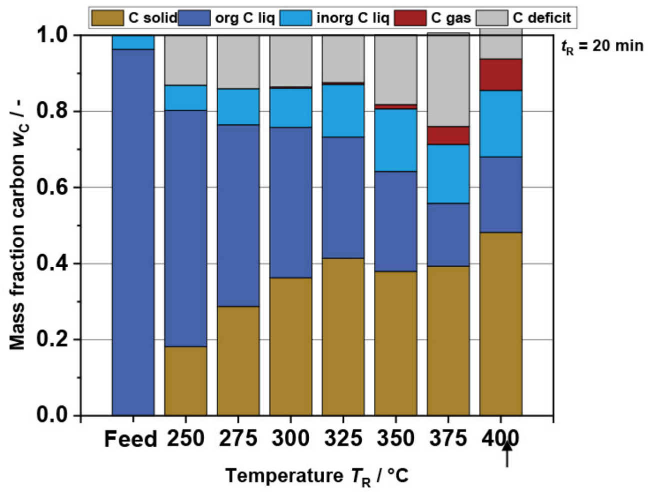
Large part of the reactions happens in oligomeric structures



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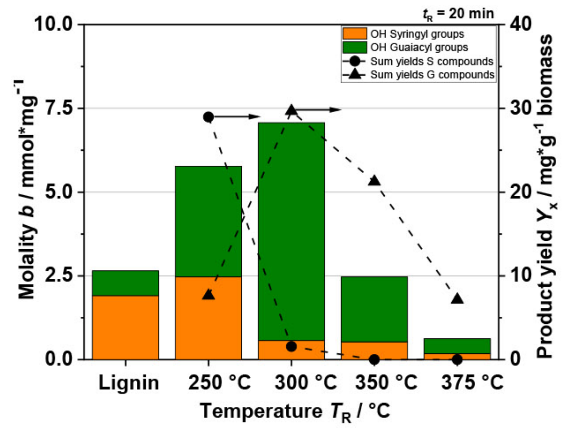
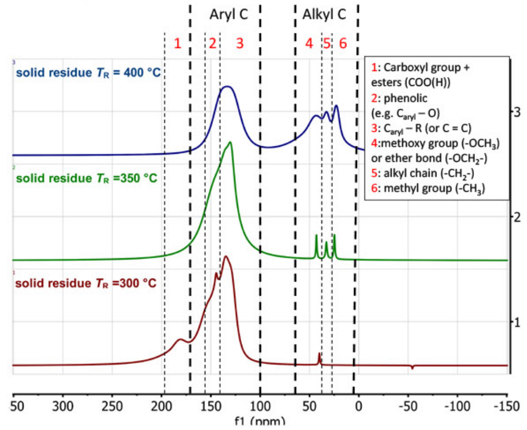
HTL of black liquor: oligomer products

DOC2024 7TH DOCTORAL COLLOQUIUM BIOENERGY & BIOBASED PRODUCTS

^{31}P NMR of extracted biocrude



^{13}C solid state NMR of produced char



- Aryl/alkyl C ratio in solid char equalizes with T_R↑
- Confirms increase in methylation
- Explains the lower yields at T_R↑-> repolymerization effects

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Summary of the results: Reaction model

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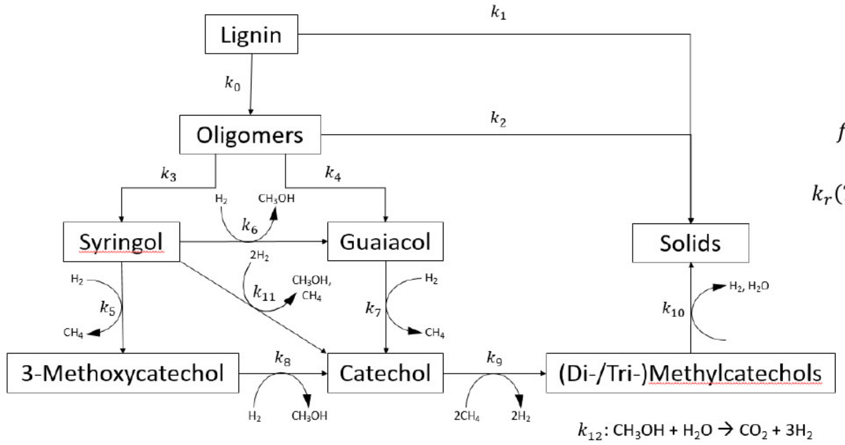
- Reaction model based on the experimental results
- Should be able to describe the lignin depolymerization under the influence of salts (BL) under HTL conditions



k_{12}: $CH_3OH + H_2O \rightarrow CO_2 + 3H_2$

$$f(\vec{k}) = \sum_{i=1}^{l} \sum_{n=1}^{\xi} (w_i^x [y_{i,n}^{meas} - y_i^{calc}(\vec{k})]^2)$$

$$k_r(T) = A_r * \exp\left(-\frac{E_{A,r}}{RT}\right), R = 8.314 \frac{J}{mol\,K}$$

ODE System (13 equations)

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Hardwood vs softwood

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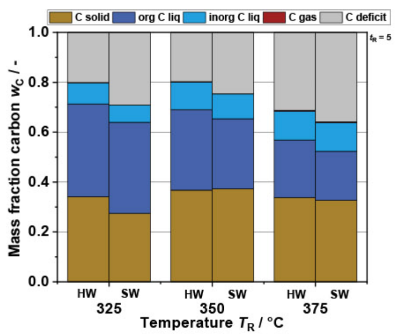
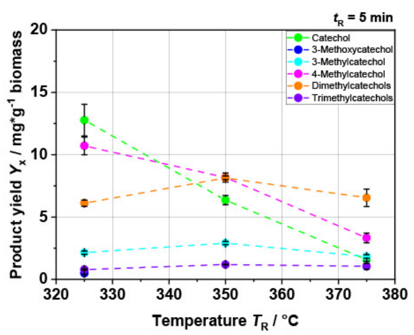
What can we expect from the model?

HW BL = hardwood based black liquor
SW BL = softwood based black liquor

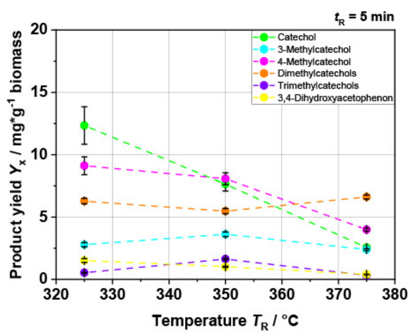
C balance HW & SW BL



Monomer products HW BL



Monomer products SW BL



- Model could be also useful for black liquors based on other wood types as long the salt composition stays similar

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Outlook

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- **Kinetic modelling is ongoing, expected to be finished soon**
  - **Modifications to the presented reaction network are possible during the process of modelling**
  - **Comparison with literature data**
  - **Comparison with continuous experiments**

Parts of the shown data and graphics can be found in:

M. Wörner, A. Barsuhn, T. Zevaco, U. Hornung, N. Dahmen – From Pulp to Aromatic Products – Reaction Pathways of Lignin Depolymerization, Energy Fuels 2024, 38, 7, 6020–6035; DOI: 10.1021/acs.energyfuels.3c04509

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Project funding

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This project has received funding from the European Union Grant Number 884111

Project partners

Tampere University, Brunel University London, KIT, The Navigator Company, SINTEF, Paul Scherrer Institut PSI, VTT, Ranido, Valmet, NESTE, LGi sustainable innovation

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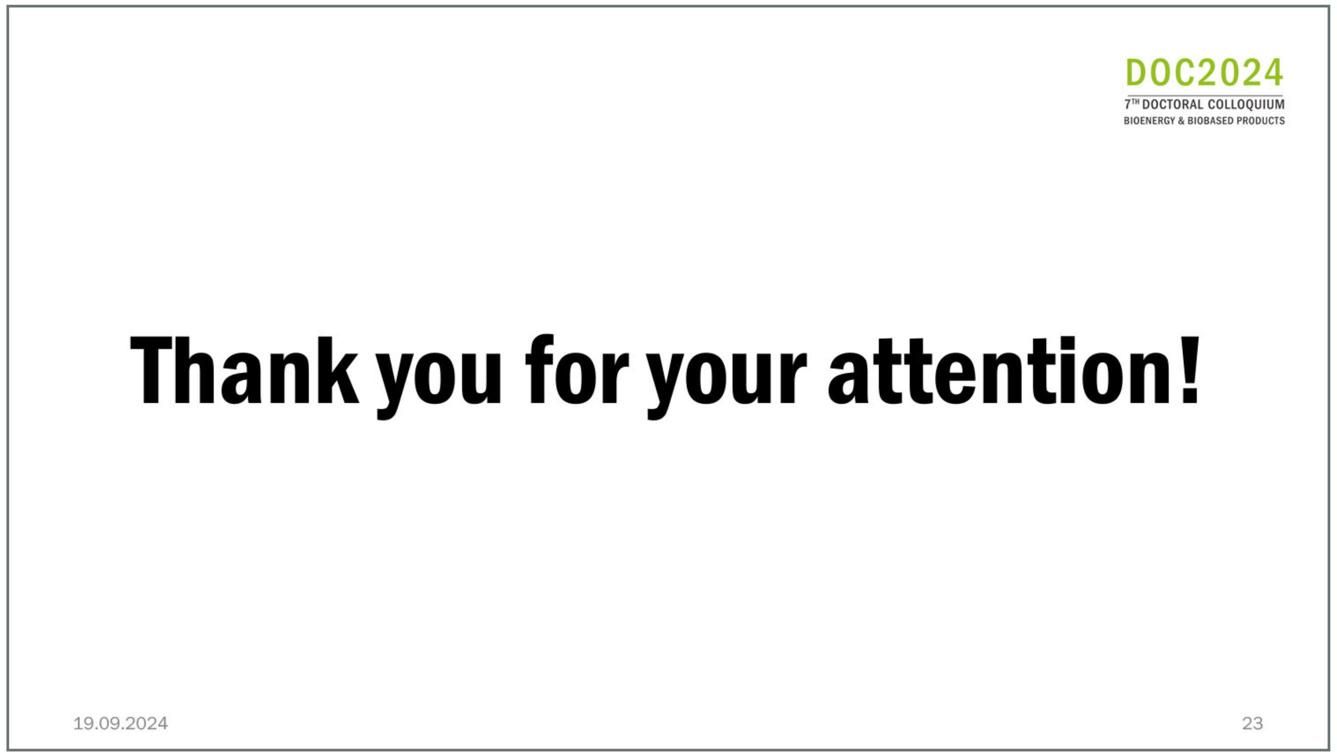
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Thank you for your attention!
19.09.2024
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Hydrothermal carbonization and pyrolysis in wetland engineering: Carbon sequestration, phosphorus recovery, and structural characterization of willow-based chars with X-ray based techniques

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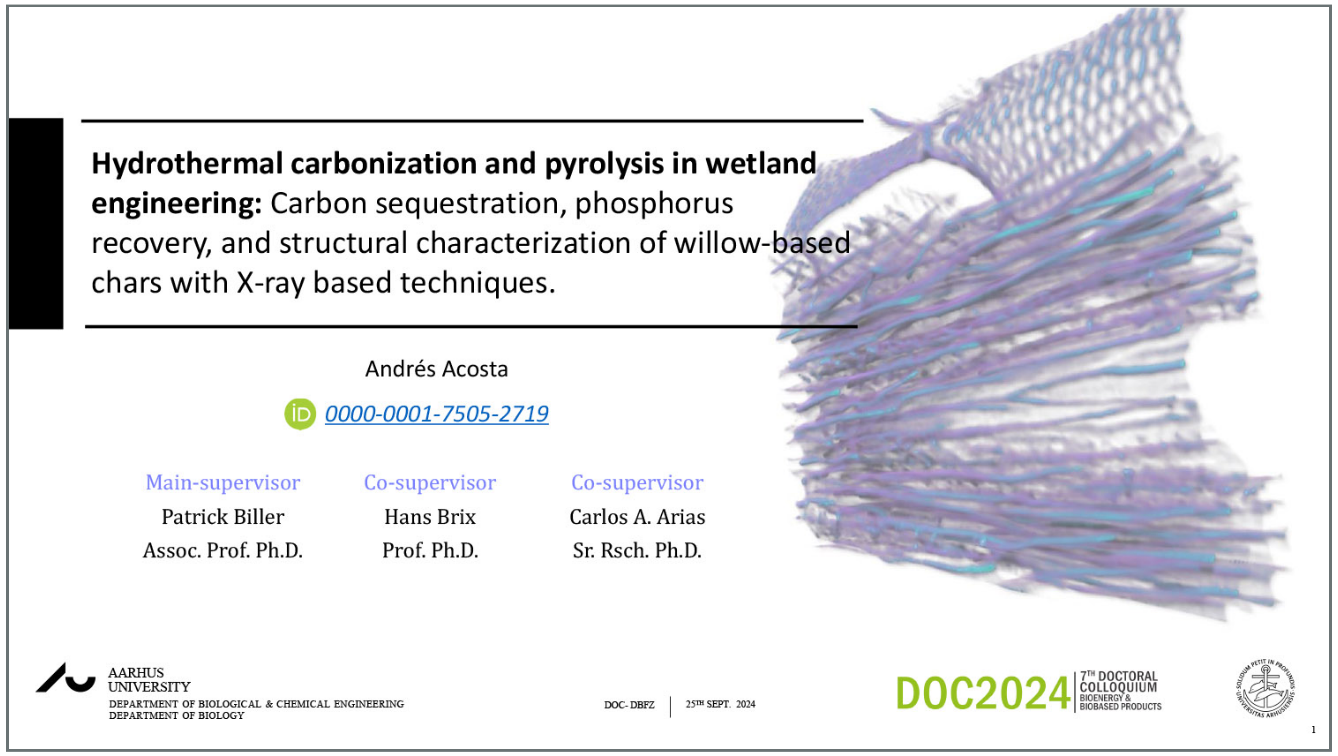
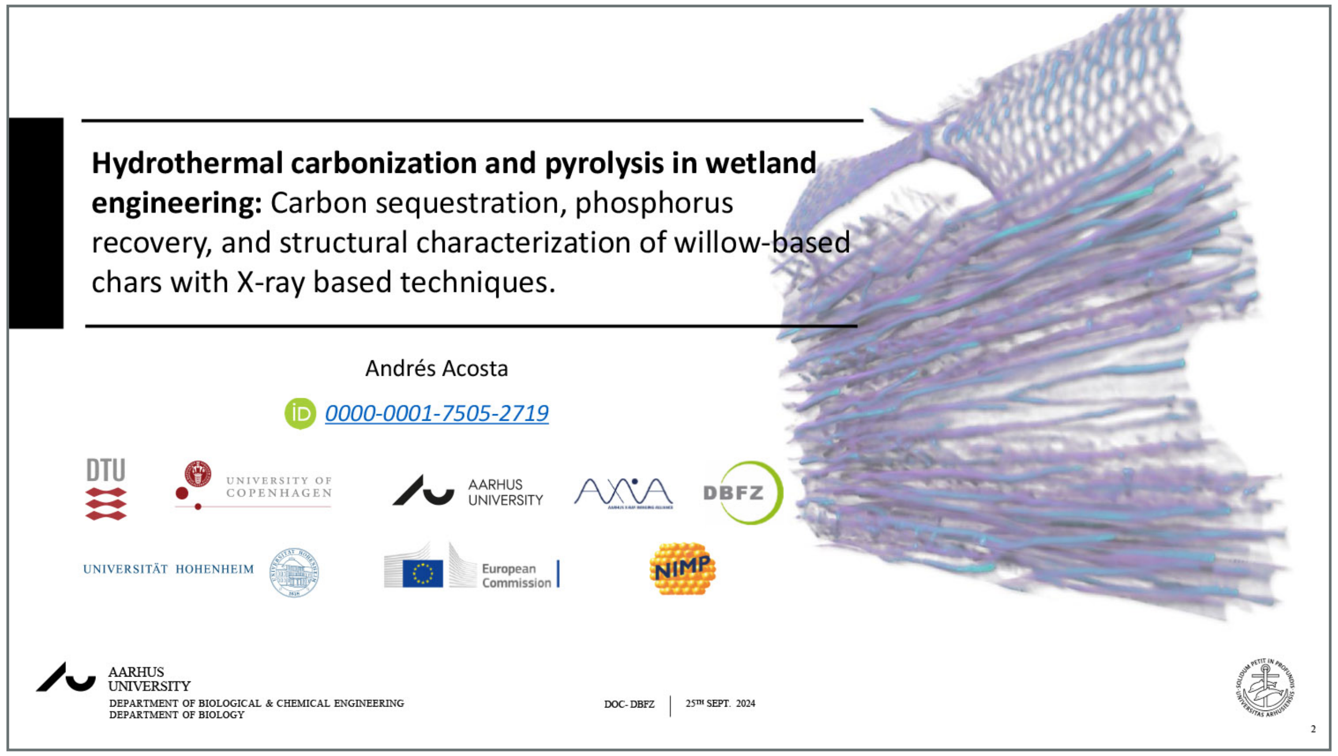
Keywords: Carbon sequestration; Engineered wetland systems; Hydrothermal carbonization; Phosphorus recovery; Pyrolysis

The immediate challenges we face in treating wastewater, recovering resources from waste streams, capturing CO_2 from the atmosphere, and transitioning from fossil-based chemicals to biomass-based refineries are topics of rising global interest. Engineered wetland systems (EWS), at the forefront of the expanding field of nature-based solutions (NBS), offer a sustainable approach to wastewater treatment and biomass production. Our study assesses their potential for nutrient recovery and carbon sequestration using slow pyrolysis (600 °C) and hydrothermal carbonization (250 °C). Here, we propose EWS-pyrochars as a ready-to-integrate opportunity for soil amendment, as they exhibit a predominant CO_2 release and the absence of harmful compounds in pyrolysis-chromatograms, indicating higher stability than hydrocars.

Using sequential Phosphorus-extractions—modified Hedley´s method, we observed a high P-bioavailability in the willow woodchips and a significant P-retention in EWS-chars - up to 92 % in pyrochars and near-complete retention in hydrochars, along with a higher labile-P fraction of 21 % in hydrochars than 5 % in pyrochars. Utilizing X-ray-based techniques, Raman spectroscopy, scanning electron microscopy, and gas physisorption, we characterized the EWS-chars‘ structures. We revealed innovative 3D-visualizations, which transcend previous literature by providing insights into the chars‘ internal porosity and quantifying, for the first time, their carbonaceous structural thickness via a meshing algorithm and the mean Feret diameter. EWS-pyrochars exhibit remarkable aromaticity with a higher concentration of overall sp2 C-atoms at 63 % vs. 43 % in hydrocars. Moreover, unlike hydrochars, which depicts occluded porosity, EWS-pyrochars exhibited 92 % water storage-like pores. Although hydrochars indicated lower carbonization and thermal stability than pyrochars, their higher carbon retention (54 % vs. 41 % in pyrochars) suggests superior annual benefits - on a 10 ha EWS scale - of 80 tons of carbon sequestration and 334 kg of phosphorus recovery versus 60 tons of carbon and 298 kg of phosphorus for pyrochars.

Our findings suggest innovative materials for resource recovery, moving advancing the field of engineered wetland systems, shifting their traditional use, and opening the opportunity for future integration into biorefineries.





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Title of the Project:	**Hydrothermal and Thermochemical Processing for Resource Recovery in Wetland Engineering:** *Synthesis and Characterization of Willow-Based Chars, Activated Carbons, and Platform Chemicals*
Doctoral Student:	Andrés Acosta
Cooperating University:	Aarhus University - Denmark
Supervisors:	Prof. Patrick Biller; Prof. Hans Brix; Dr. Carlos Arias
Funding / Scholarship provider: Logo:	DTU; University of Copenhagen; Aarhus University; DBFZ; Universität Hohenheim; European Commission; NIMP
Duration:	04/2020 – 05/2024

Agenda

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- **Part I: Introduction**
  - Challenges – Motivation
  - Concepts – Research questions
- **Part II: Material and Methods**
  - Engineered Wetland System (EWS)
  - Hydrothermal Carbonization (HTC) /Slow Pyrolysis
  - Chemical composition (ICP-OES, Hedley´s Phosphorus extraction, CHNS-O)
  - Bulk and surface chemistry (XRD, HR-XPS, XRF)
  - Morphology and Porosity (X-Ray µ-CT, SEM, HR-TEM, Gas Physisorption N_2 and CO_2)
  - Pyrolytic response (Raman Spectroscopy, TGA-DTG, PY-GC-MS)
- **Part II: Results and discussion**
- **Conclusion, perspectives and acknowledgements**

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Modern agriculture relies on phosphorus, with no substitutes available.

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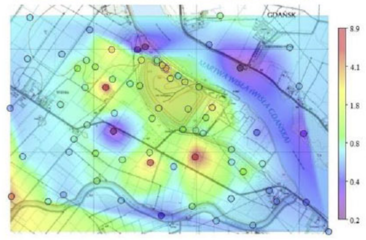
Phosphate rock by James St. John (CC BY 2.0)

The per capita demand for P worldwide is expected to rise from 1.32 in 2007 to 1.72 kg P per person in 2050 (Jama-Rodzenska et al. 2021).

Phosphorus (P) is an essential nutrient required for plant growth.

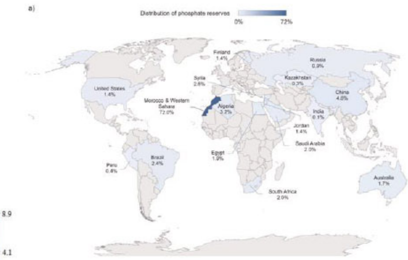
Photo: Gypstack Florida (2019)

- Florida → more than 1 billion (!) tonnes.
- 5.2 tons of phosphogypsum are produced for every ton of phosphoric acid.



Total Uranium [8 mg · kg^{-1} dry wt.] in agricultural soils close to the "stack"

http://dx.doi.org/10.1016/j.gloenvcha.2013.09.002



DOI: https://doi-org.ez.statsbiblioteket.dk:12048/10.1039/C3EM00118K

- ✓ Considering 70 bn tons of Phosphate globally (Marroco & Western Sahara have 50 bn ton!)
- ✓ 0.1 % India

❖ Phosphorus is a bio essential element of life and a necessity for food production.

- ✓ From 22 M ton of P fertilizer (mineral + organic), only 6 M ton is consumed by humans and livestock → the rest is a loss and call for P-recycling!
- ✓ Eutrophication!
- ✓ 2.3–4.5 kg CO_2,eq./kg for Mineral P fertilizer
- ✓ 2.1 or 2.8 M ton of P per year could be recovered from wastewater ☺

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Part I
Part II
Part III
Introduction
Challenges
Concepts
Hypothesis
Research questions
Constructed Wetland [CW]?
Engineered wetland system [EWS] are intentionally constructed to optimize conditions for biological, chemical, and physical processes that improve water quality.
Free-Water Surface Flow (FWS)
Horizontal Subsurface Flow (HSSF)
Free-Floating Macrophyte system
Vertical Flow (VF)
System in India 300 m³/d
DBFZ / DOC
25TH SEPT 2024
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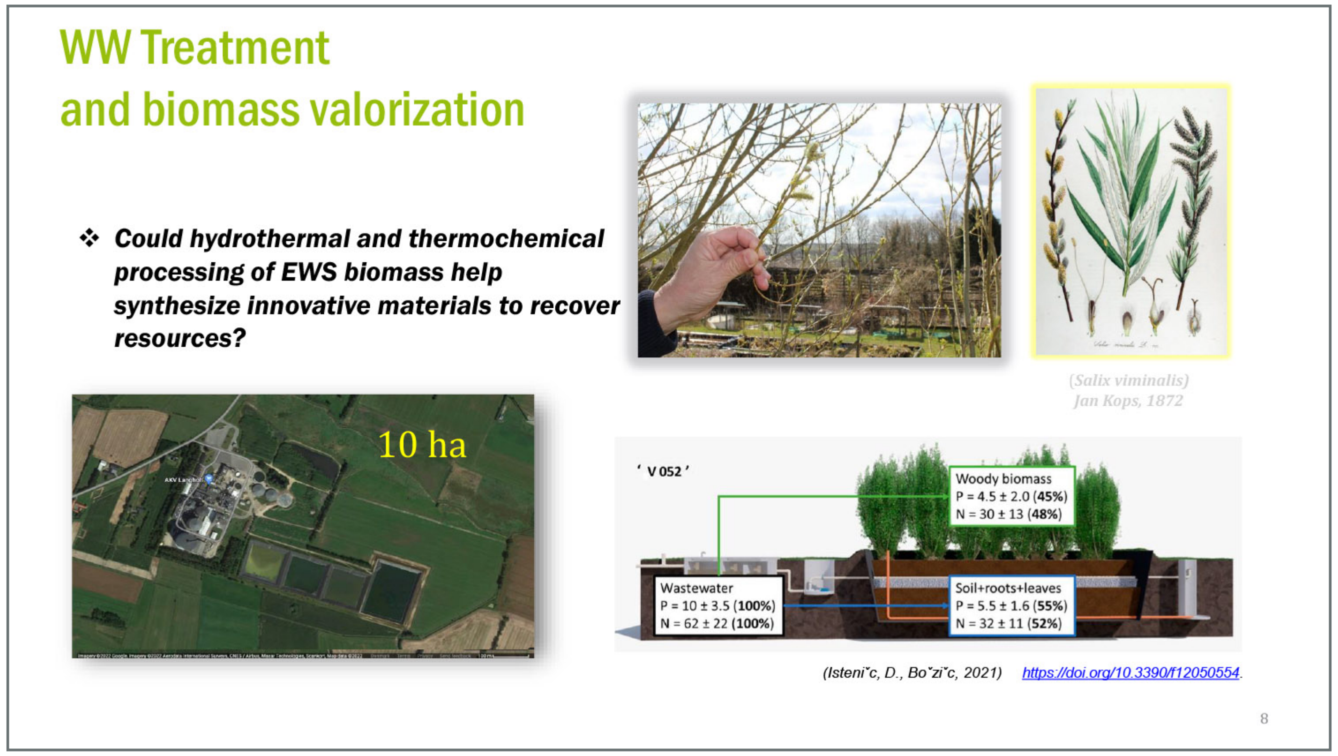

WW Treatment
and biomass valorization
❖ Could hydrothermal and thermochemical processing of EWS biomass help synthesize innovative materials to recover resources?
(Salix viminalis)
Jan Kops, 1872
10 ha
' V 052 '
Woody biomass
P = 4.5 ± 2.0 (45%)
N = 30 ± 13 (48%)
Wastewater
P = 10 ± 3.5 (100%)
N = 62 ± 22 (100%)
Soil+roots+leaves
P = 5.5 ± 1.6 (55%)
N = 32 ± 11 (52%)
(Isteni˜c, D., Bo˜zi˜c, 2021) https://doi.org/10.3390/f12050554
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Willow: Salix viminalix Bjørn. E.Wolf
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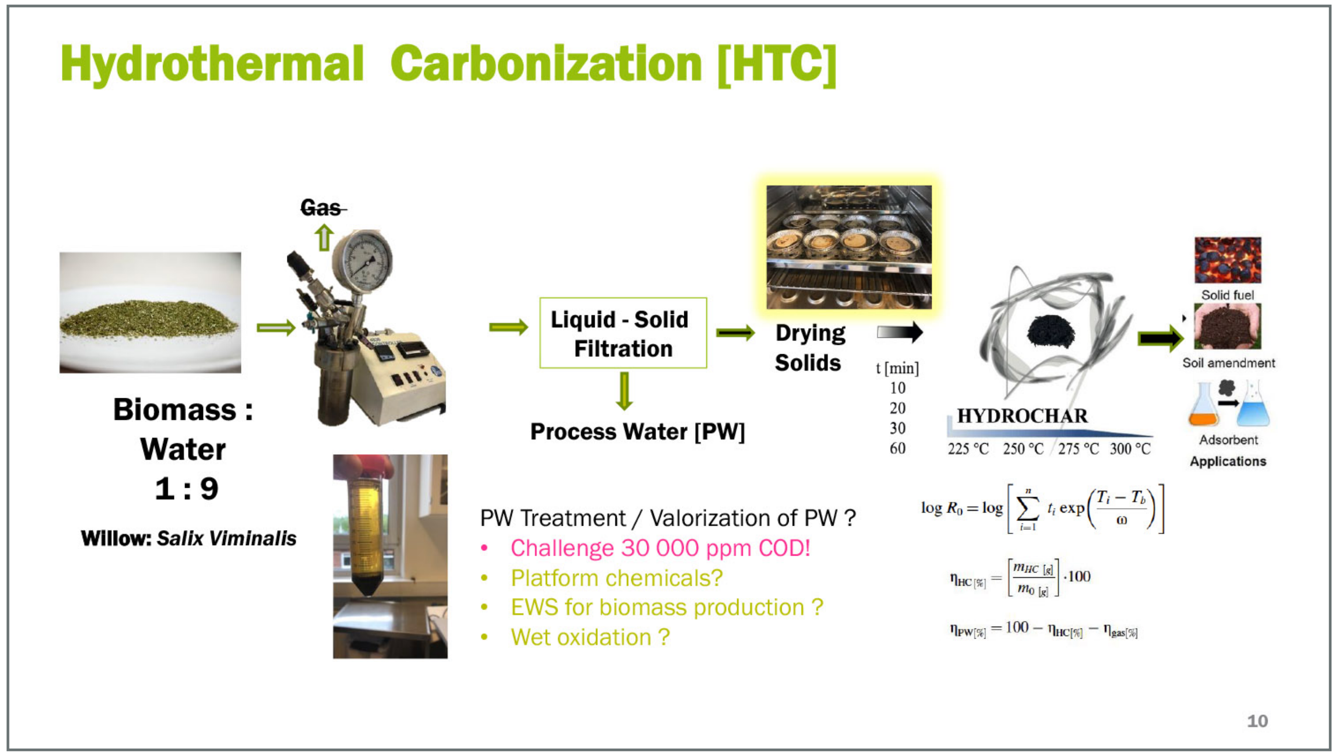
Yield annual:
Biomass DM → 31 t/ha
Wastewater is treatment ☺
N, P, K from wastewater are used by plants to grow.
The end-use of this biomass is often a simple:
→ incineration for heat and power ☹.
→ woodchips for soil amendment
→ could HTC or Pyrolysis be a better option? ☺
9



Hydrothermal Carbonization [HTC]
Gas
Biomass : Water 1 : 9
Willow: Salix Viminalis
Liquid - Solid Filtration
Drying Solids
Process Water [PW]
t [min]
10
20
30
60
HYDROCHAR
225 °C 250 °C 275 °C 300 °C
Solid fuel
Soil amendment
Adsorbent
Applications
PW Treatment / Valorization of PW ?
• Challenge 30 000 ppm COD!
• Platform chemicals?
• EWS for biomass production ?
• Wet oxidation ?
$\log R_0 = \log\left[\sum_{i=1}^{n} t_i \exp\left(\frac{T_i - T_b}{\omega}\right)\right]$
$\eta_{HC[\%]} = \left[\frac{m_{HC[g]}}{m_{0[g]}}\right] \cdot 100$
$\eta_{PW[\%]} = 100 - \eta_{HC[\%]} - \eta_{gas[\%]}$
10

Hydrothermal Carbonization [HTC]

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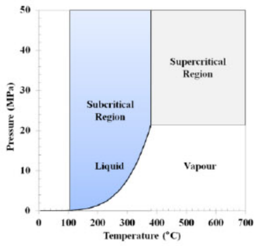
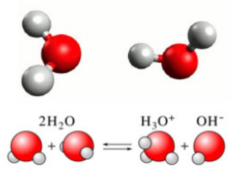
- The carbonization degree increases due to the constant removal of oxygen and hydrogen and the parallel rise in carbon content.
- HTC is dictated by the simultaneous physicochemical reactions that include hydrolysis, dehydration, decarboxylation, decarbonylation, aromatization, condensation, and polymerization.
- Chemical dehydration—which removes hydroxyl groups—significantly carbonizes biomass by lowering oxygen-to-carbon (O/C) and hydrogen-to-carbon (H/C) molar ratios (Li et al., 2020).
- Decarboxylation and decarbonylation reactions, which generate gas—CO_2 and CO—by partially degrading carboxyl and carbonyl groups, also contribute to the carbonization but to a lesser extent during HTC (Funke and Ziegler, 2010).



Self ionization



Tc = 374 °C
Pc = 22.1 MPa

https://doi.org/10.1016/j.jaap.2020.104771.
https://doi.org/10.1002/bbb.198

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Part I | Introduction | Hypothesis | Research questions
Part II | Materials and Methods | Results and Discussion
Part III

ψ **Published in ELSEVIER – Chemical Engineering Journal.**

—Hydrothermal carbonization and pyrolysis in wetland engineering: Carbon sequestration, phosphorus recovery, and structural characterization of willow-based chars with X-ray μ-computed tomography.

Paper I | Paper II | Paper III

H:
Pyrochars produced from the slow pyrolysis of EWS-willows will be more effective than hydrochars in retaining carbon and nutrients and can be used for soil amendment and carbon sequestration schemes.

DBFZ / DOC | 25TH SEPT 2024

Hydrothermal Carbonization

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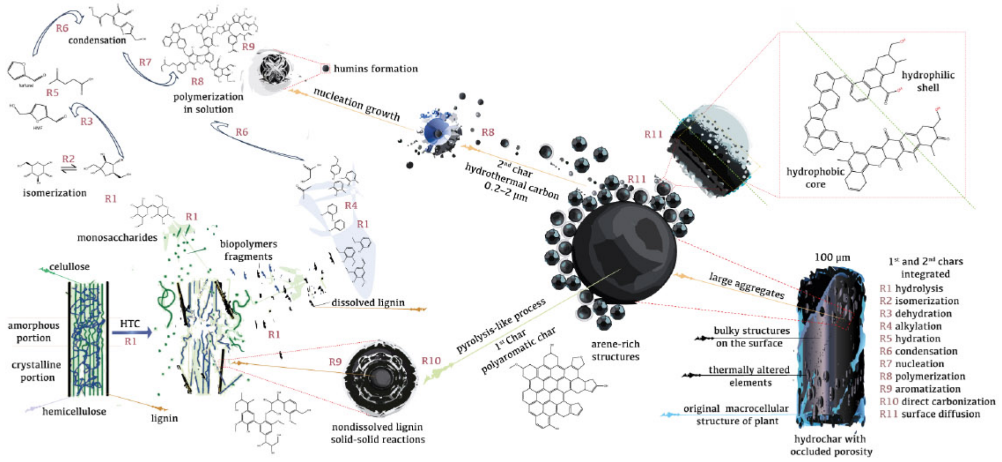

(A.Acosta et al. 2024)
https://doi.org/10.1016/j.cej.2024.151916

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Water reclamation and biomass conversion

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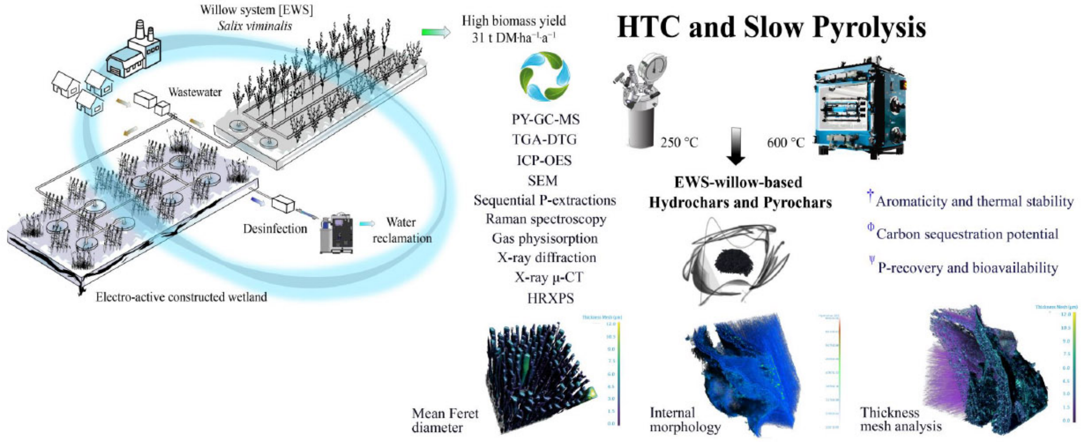

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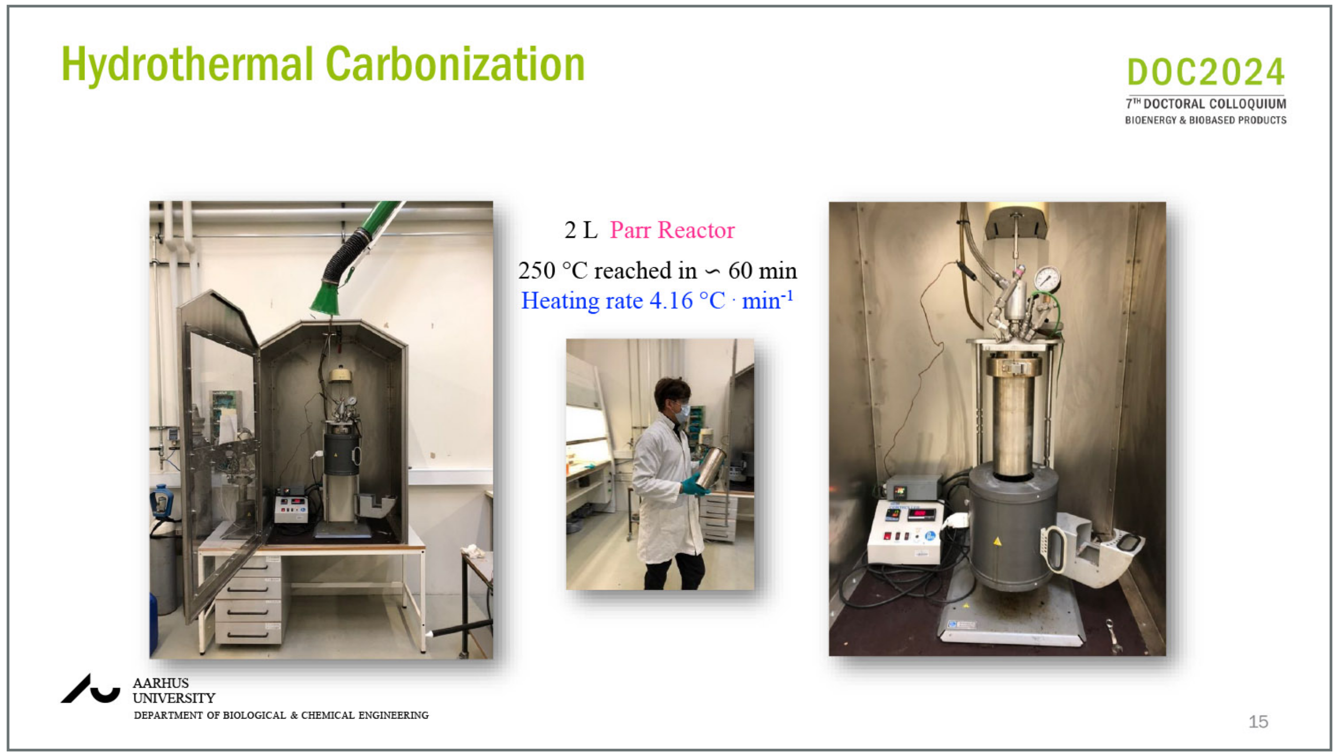
Hydrothermal Carbonization
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2 L Parr Reactor
250 °C reached in ~ 60 min
Heating rate 4.16 °C · min-1
AARHUS UNIVERSITY
DEPARTMENT OF BIOLOGICAL & CHEMICAL ENGINEERING
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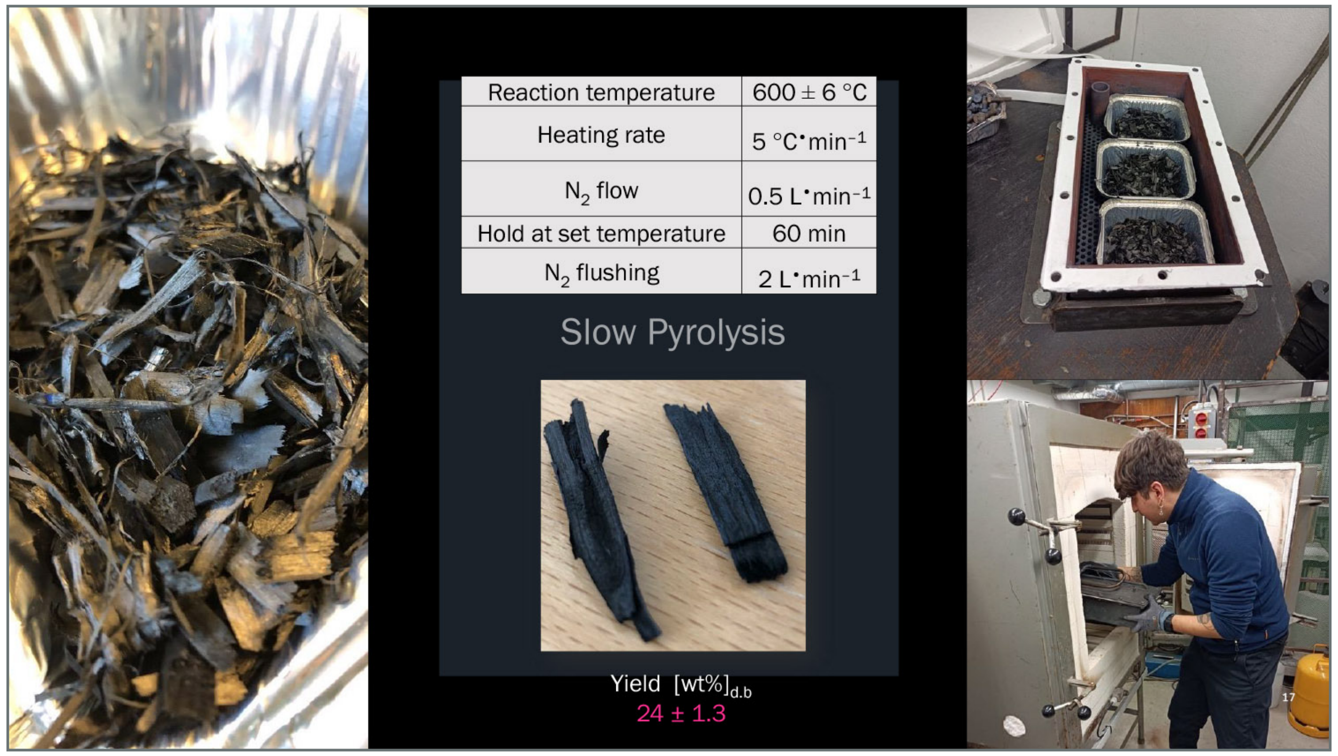
Reaction temperature 600 ± 6 °C
Heating rate 5 °C·min-1
N2 flow 0.5 L·min-1
Hold at set temperature 60 min
N2 flushing 2 L·min-1
Slow Pyrolysis
Yield [wt%]d.b
24 ± 1.3


Slow Pyrolysis
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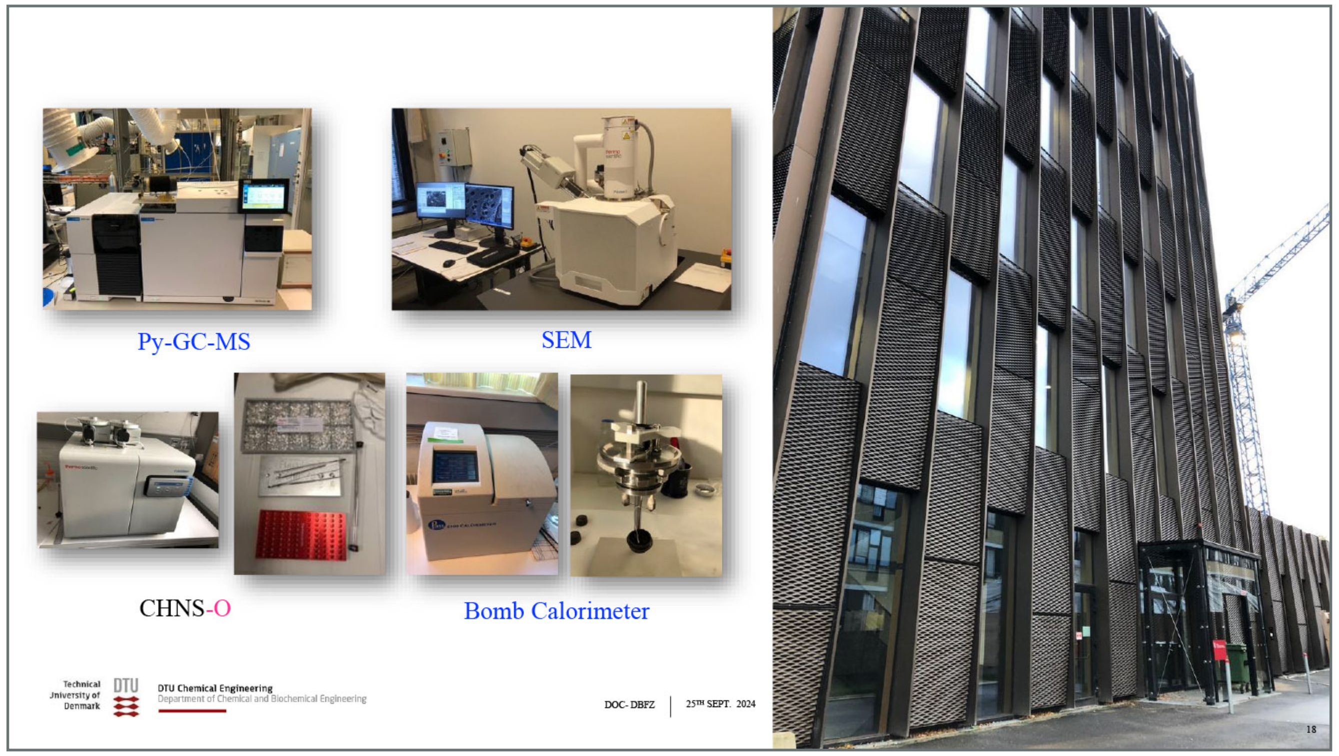
Py-GC-MS
SEM
CHNS-O
Bomb Calorimeter

ICP-OES

Agilent Technologies 5100

Hedley´s Extraction

FIAstar™ 5000
FOSS Analytical AB

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Carbonization

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Thermochemical properties
EWS-Derived woodchips and chars—hydrochar [HC] and pyrochar [PY] derivatives.
(wt.% dry basis); [mean ± std, n = 3].

Sample	Char Yield $[wt\%]_{d.b}$	Ultimate Analysis $[wt\%]_{d.b}$ C	H	N	S	O	Proximate Analysis† $[wt\%]_{d.b}$ VM	FC	Ash	Molar Ratio H/C	O/C	HHV MJ·kg^{-1}
S.v - Wolf [A]		46.9 ± 0.4	5.8 ± 0.1	1.6 ± 0.4	0.1 ± 0.0	41.9 ± 0.2	84.2 ± 0.9	12.1 ± 0.9	3.7 ± 0.0	1.46 ± 0.03	0.67 ± 0.00	19.5 ± 0.2
HC│250	35 ± 6	73.4 ± 0.4	5.5 ± 0.1	1.3 ± 0.2	0.1 ± 0.0	18.5 ± 0.1	57.3 ± 0.0	41.5 ± 0.1	1.2 ± 0.1	0.90 ± 0.01	0.19 ± 0.01	26.6 ± 0.1
PY│600	23 ± 1	83.5 ± 0.1	1.8 ± 0.1	1.9 ± 0.0	0.1 ± 0.0	7.9 ± 0.3	12.1 ± 0.3	82.5 ± 0.4	5.4 ± 0.1	0.25 ± 0.01	0.07 ± 0.00	32.1 ± 0.0

†volatile matter (VM), fixed carbon (FC)

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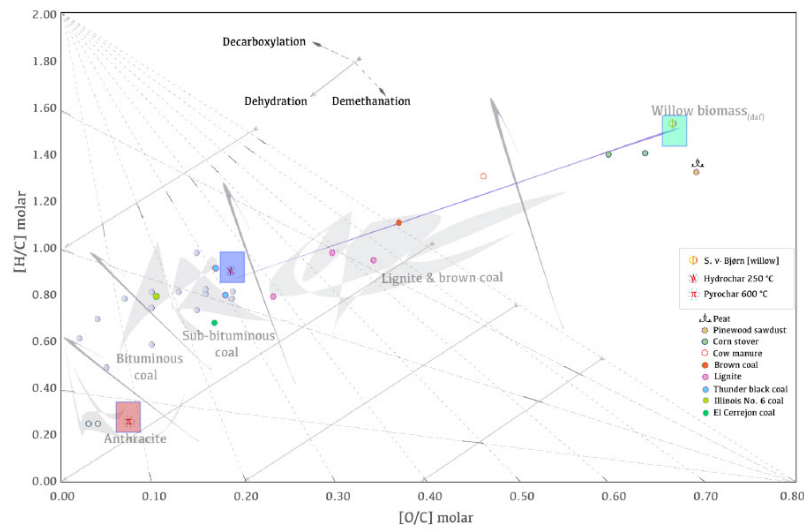

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Inductively Coupled Plasma Optical Emission spectroscopy [ICP-OES]

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[mean ± std, n = 3]

	Elemental content (mg·kg^{-1}) P	Fe	Ca	Mn	Na	K	Mg	Molar ratio†
S.v - Wolf [A]	1078 ± 27	166 ± 10	5210 ± 174	202 ± 37	405 ± 3	1470 ± 37	534 ± 16	4.5
HC│250	3365 ± 137	263 ± 6	16234 ± 152	813 ± 167	1371 ± 24	5097 ± 216	1774 ± 15	4.5
PY│600	4178 ± 714	1118 ± 872	15665 ± 2815	355 ± 202	1279 ± 303	4235 ± 1129	1968 ± 853	3.8
	Heavy metals (mg·kg^{-1}) Zn	Cd	Cr	Cu	Ni	Pb	Al	
S.v - Wolf [A]	143 ± 9	BDL	1 ± 0	4 ± 0	BDL*	BDL	24 ± 4	
HC│250	387 ± 7	BDL	29 ± 2	14 ± 0	BDL	BDL	58 ± 0	
PY│600	367 ± 52	BDL	28 ± 7	18 ± 3	BDL	BDL	401 ± 365	

†[Mg + Ca + Fe +Al] / P ; * Below detection limit

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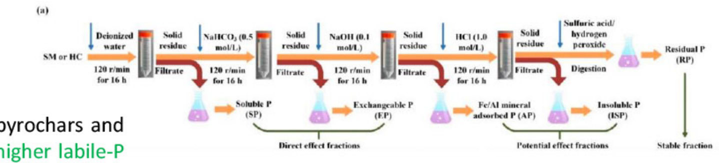
Sequential P-Extractions

[mean ± std, n = 3]

Sample	Pt† [mg·kg⁻¹]	P_E* [mg·kg⁻¹]	H_2O-P	$NaHCO_3$-P	NaOH-P	HCl-P	Res-PΨ [mg·kg⁻¹]	Pt Recovery [%]
			Extractable-P [mg·kg⁻¹]					
S.v - Wolf [A]	1078 ± 27	615 ± 30	456 ± 27	135 ± 6	14 ± 2	11 ± 1	472 ± 30	
HC | 250	3365 ± 137	1788 ± 188	595 ± 16	95 ± 5	136 ± 15	962 ± 213	1577 ± 188	109 ± 4
PY | 600	4178 ± 714	1522 ± 91	43 ± 3	172 ± 15	126 ± 4	1182 ± 74	2656 ± 91	91 ± 16

†Total P [ICP-OES];
*Extracted P [molybdenum blue method];
Ψ Residual-P = Total P – Extracted P



- High P-bioavailability in the willow-woodchips
- Significant P-retention in EWS-chars—up to 92 % in pyrochars and near-complete retention in hydrochars along with a higher labile-P fraction of 21 % in hydrochars than 5 % in pyrochars.

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X-Ray μ-CT

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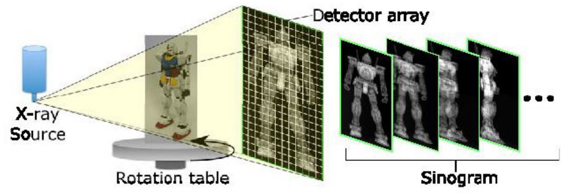
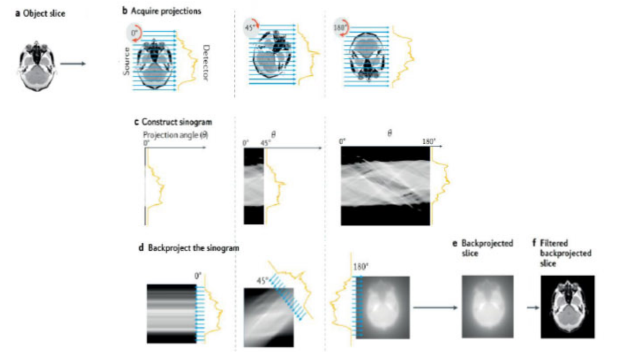


Ymanaka et. al (DOI:10.1109/TVCG.2013.87)



Back projection reconstruction method for a single slice obtained by parallel beam computed tomography.
(Withers et al. 2021)

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X-Ray μ-Computed Tomography [X-Ray μ-CT]

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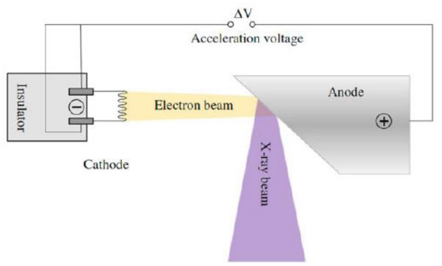
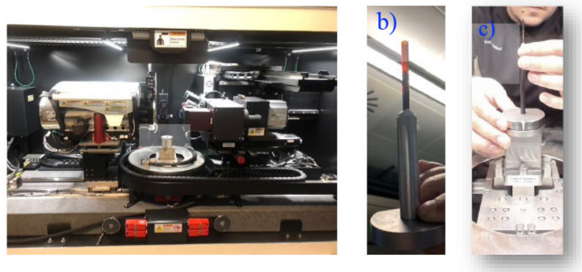


Schematic X-ray tube

AXIA iNANO



a) Zeiss Xradia 620 Versa; b) Hydrochar sample; c) Pyrochar sample

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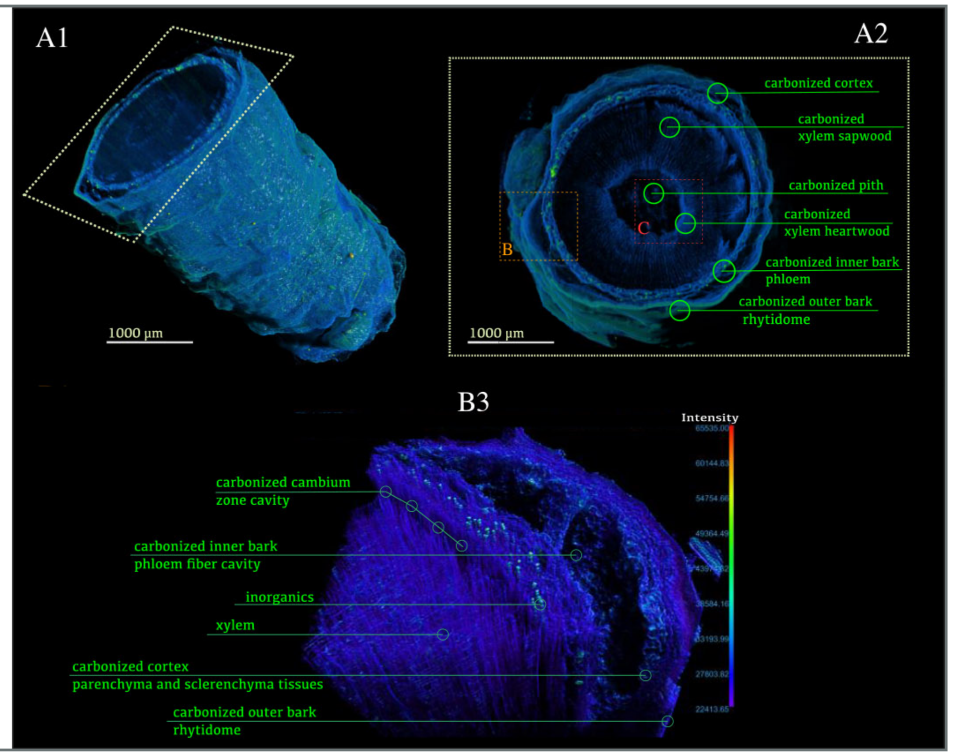
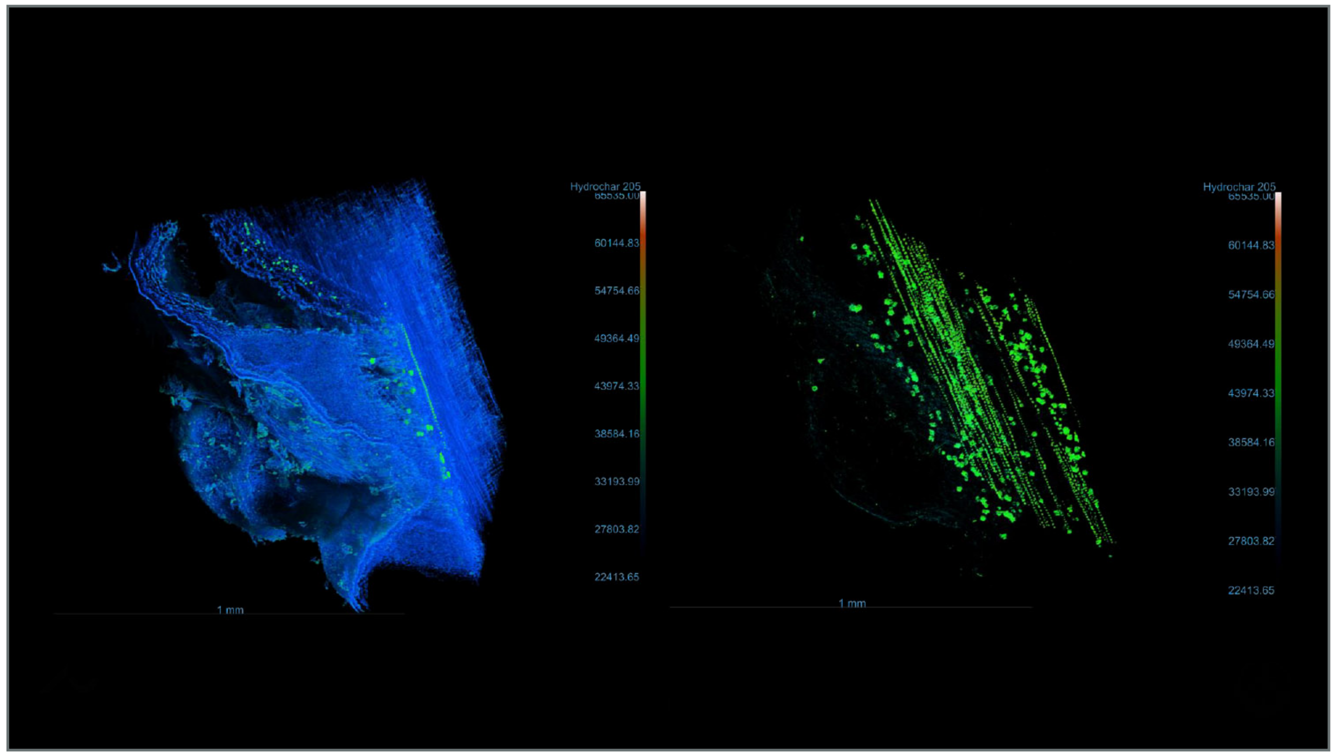
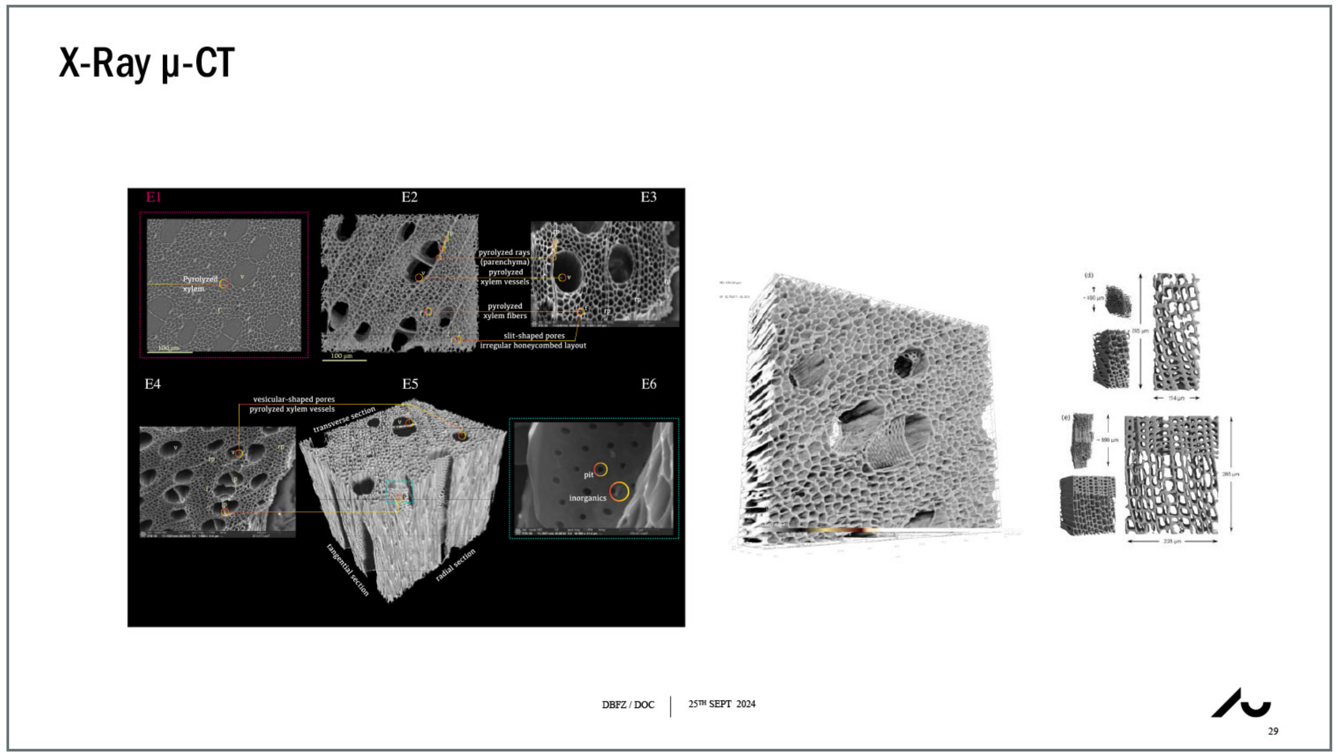
X-Ray μ-CT




Hydrochar 205
1 mm
1 mm


X-Ray µ-CT
E1
E2
E3
E4
E5
E6
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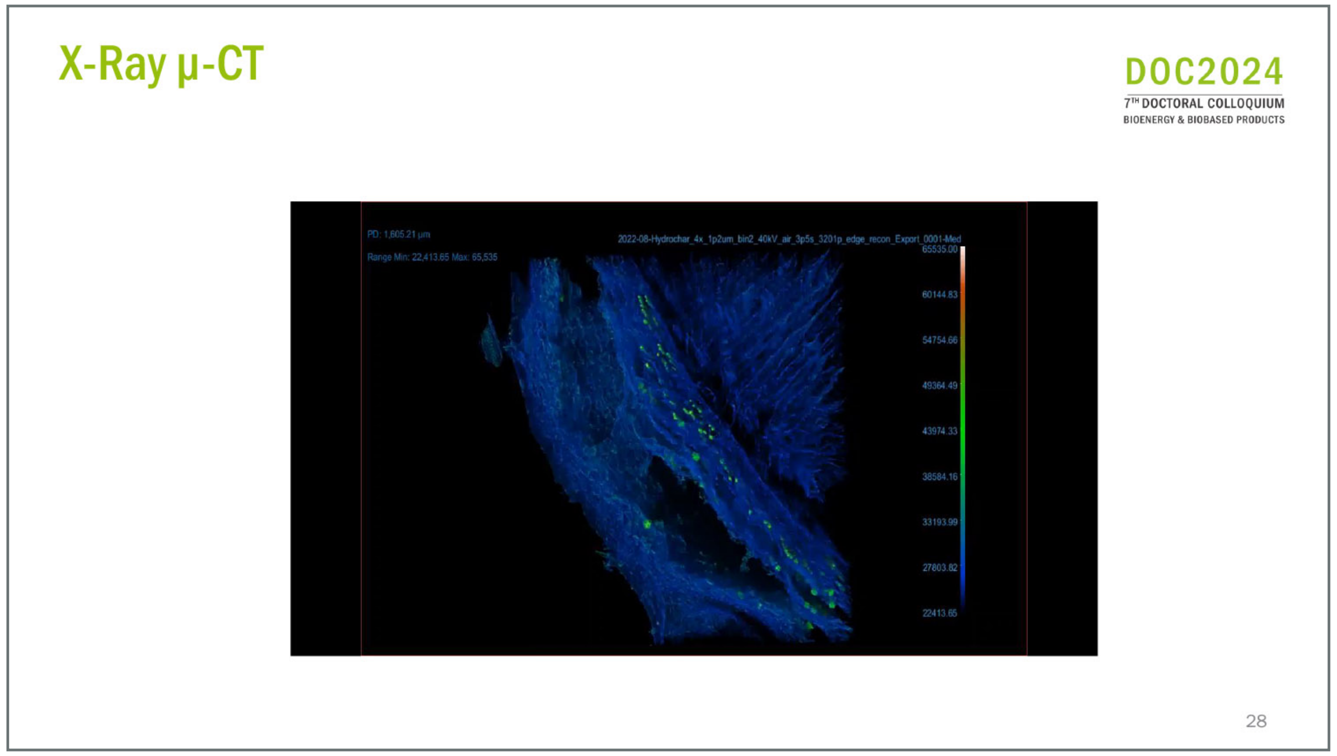
X-Ray µ-CT
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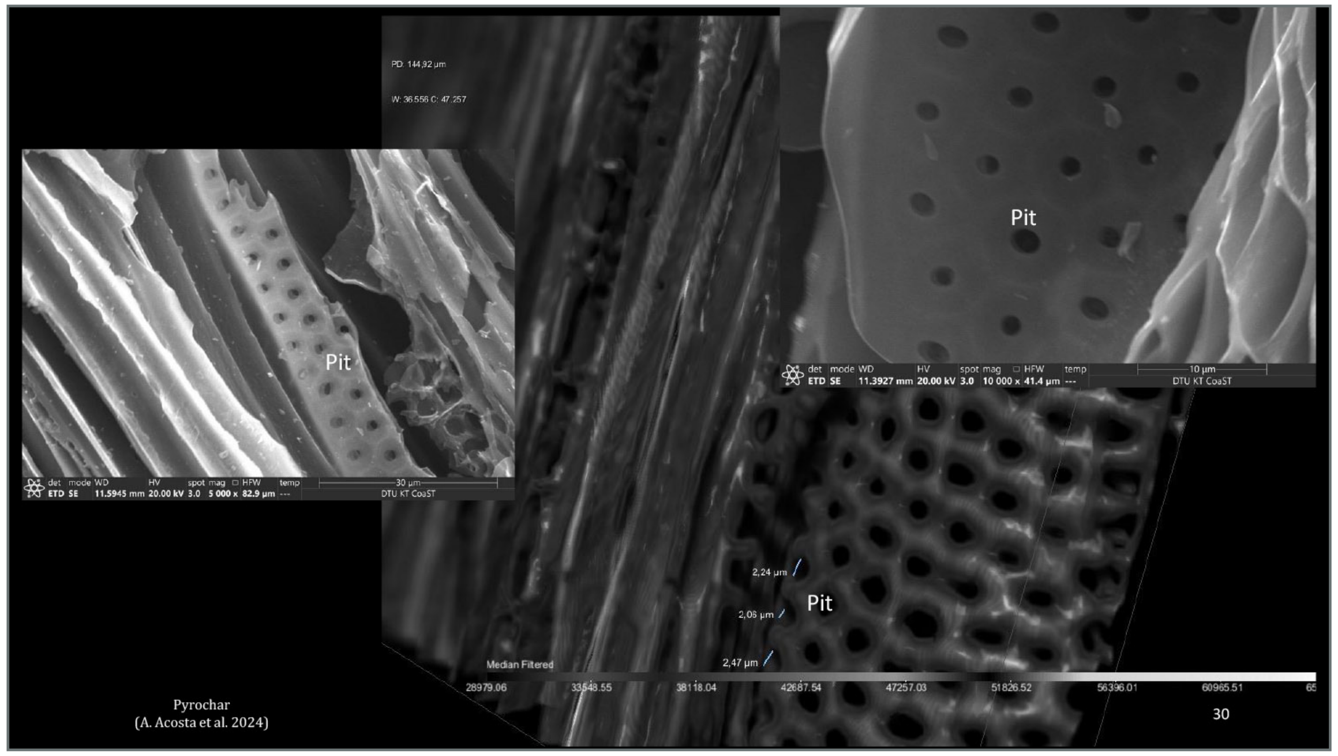
Pit
Pit
Pit
Pyrochar
(A. Acosta et al. 2024)
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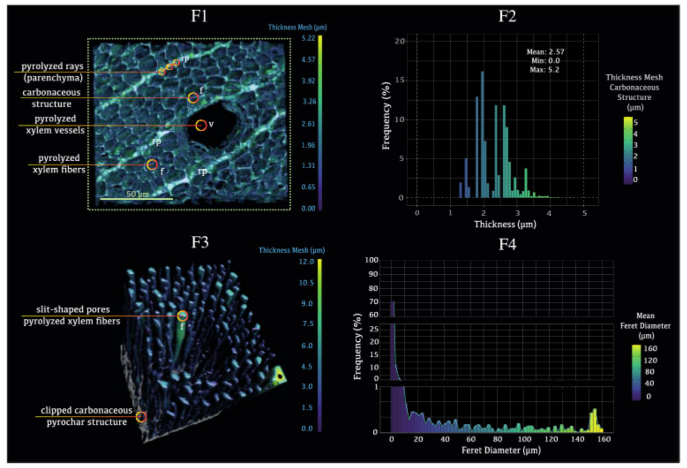
Thickness of the carbonaceous structure. X-Ray μ-CT



Water storage-like pores (0.5–50 μm) constitute about 92 % of the macropores in the EWS-willow pyrochar. ☺

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Nanometric physisorption

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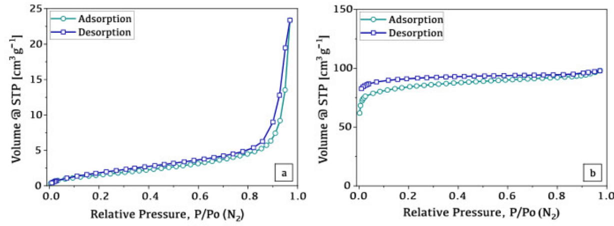
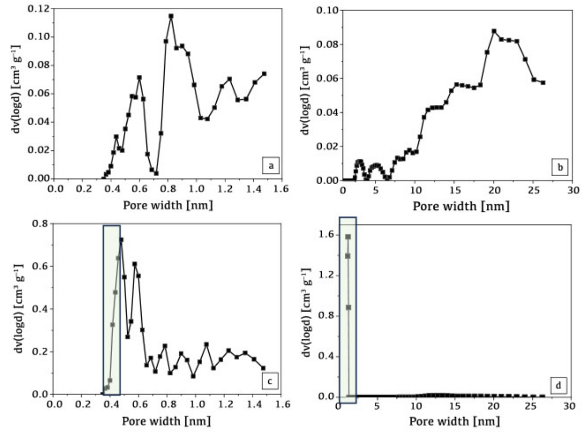
Nanometric physisorption

Sample	Specific surface area [$m^2 \cdot g^{-1}$] BET		GCMS	Pore volume [$cm^3 \cdot g^{-1}$] BET		GCMS
	N_2	CO_2	CO_2	N_2	CO_2	CO_2
HC|250	5±1	106±6	67±9	0.04±0.00	0.01±0.01	0.03±0.00
PY|600	317±13	384±54	506±71	0.37±0.03	0.11±0.01	0.15±0.00



The evolution of BET-N_2-isotherms at 77 K: (a) hydrochar and (b) pyrochar



Pore size distribution of willow-based chars as analyzed by Grand Canonical Monte Carlo (GCMC) and Non-Local Density Functional Theory (NL-DFT); upper panels (a and b) represent the hydrochar [HC|250] while lower panels (c and d) display pyrochar [PY|600]

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XRD and HR-XPS

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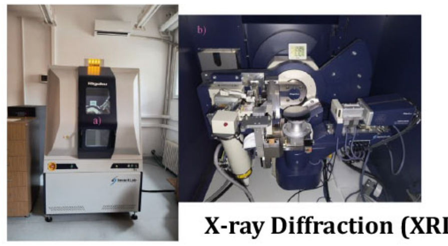
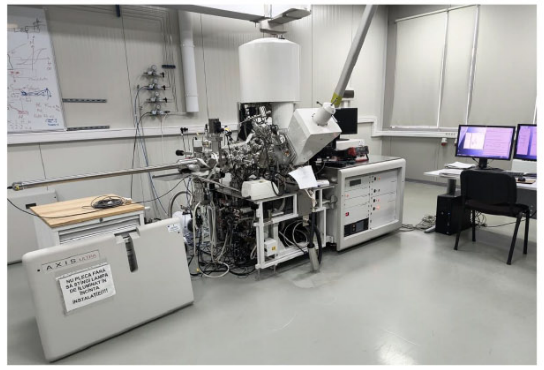


X-ray Diffraction (XRD)

Raman spectroscopy



High Resolution X-ray Photoelectron Spectroscopy (XPS)

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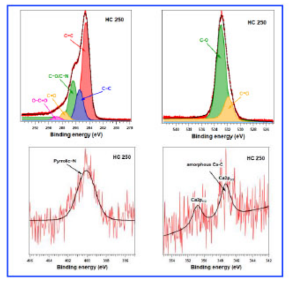
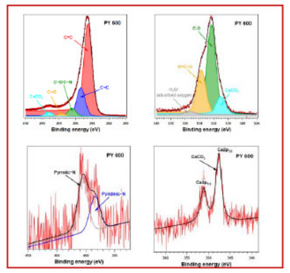
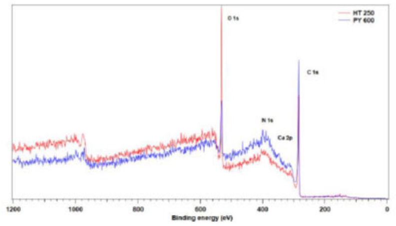
High Resolution X-ray Photoelectron Spectroscopy (XPS)





Chemical composition in surface max 10 nm

Atomic percentages (at.%)				
Sample	C 1s	O 1s	N 1s	Ca 2p
HC│250	79.08	20.39	0.45	0.08
PY│600	89.28	9.70	0.57	0.44



The C 1s, O 1s, N 1s and Ca 2p peak positions, the total atomic percentages (at.%) of various functional groups of each sample.

Sample	C 1s	C 1s	C 1s	C1s	C1s	O 1s	O 1s	O 1s	O1s	N 1s	N 1s	Ca 2p
HC│250	C-sp²	C-sp³	C–O/ C–N	C=O	O–C=O	C=O	C–O			pyrrolic-N		amorphous C-Ca
BE (eV)	284.5	285.4	286.4	287.6	288.8	531.8	532.9			400.01		347.3
at.%	42.79	13.65	17.02	3.87	1.76	3.98	16.41			0.45		0.08
PY│600	C-sp²	C-sp³	C-O/ C-N	C=O	$CaCO_3$	$CaCO_3$	C–O	O=C–O	adsorbed O_2/ H_2O	pyridinic-N	pyrrolic-N	$CaCO_3$
BE (eV)	284.5	285.4	286.4	287.6	289.2	531.01	532.3	533.7	535.3	398.4	400.5	347.6
at.%	60.22	19.12	5.40	1.88	2.67	1.11	5.66	2.75	0.19	0.22	0.35	0.44

EWS-pyrochars exhibit remarkable aromaticity with a higher concentration of overall sp^2 C-atoms at 63 % vs. 43 % in hydrocars.

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Py-GC-MS

Pyrola® 2000 connected to an Agilent 8890 gas chromatograph coupled to an Agilent 5977 Inert Plus mass spectrometer.

- ✓ *200 µg sample*
- ✓ *Pyrolysis time: 2 seconds*
- ✓ *Reaction temp: 600 °C*
- ✓ *Carrier gas: He 1.1 mL·min⁻¹*

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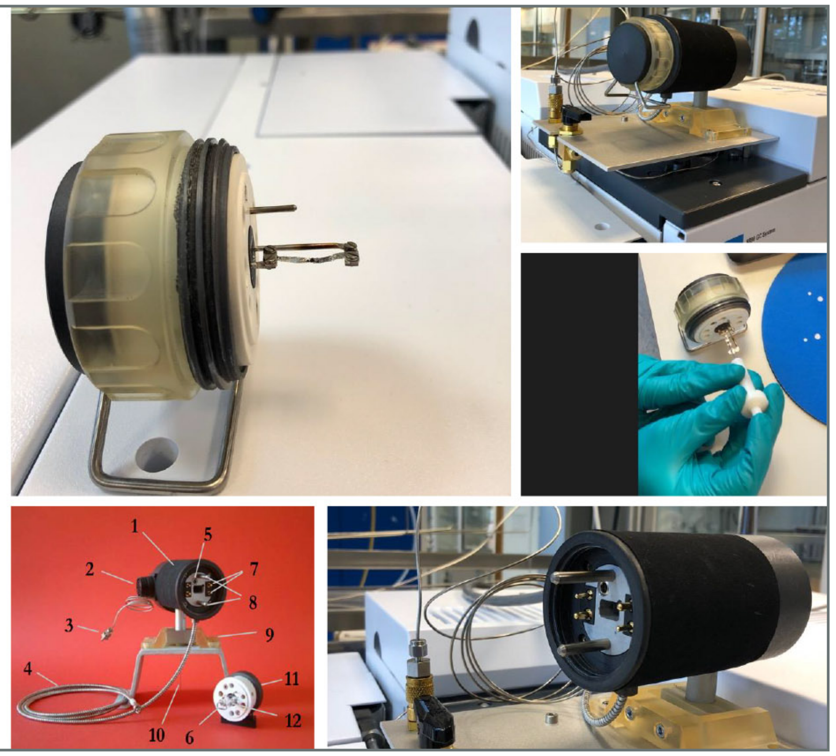
Department of Chemical and Biochemical Engineering



X-ray diffraction (XRD)

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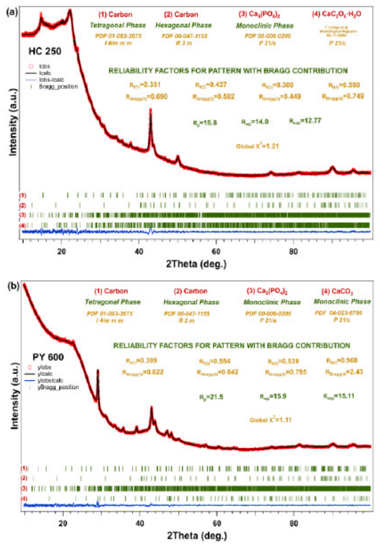
The broad XRD (002) peak in hydrochar at 2θ = 22.5° indicates amorphous carbon. The (100) peak at 2θ = 44° reflects graphite structures. Pyrochar only shows the (100) peak, indicating a more ordered, aromatic carbon matrix.

❖ Hydrochar identified crystalline phases:
$Ca_3(PO_4)_2$, and whewellite [calcium oxalate, $Ca(C_2O_4)·H_2O$].

❖ Pyrochar identified crystalline phases:
$Ca_3(PO_4)_2$ and $CaCO_3$
The transformation of whewellite $Ca(C_2O_4)·H_2O$.
in hydrochar to calcite ($CaCO_3$) in pyrochar occurs at 600 °C



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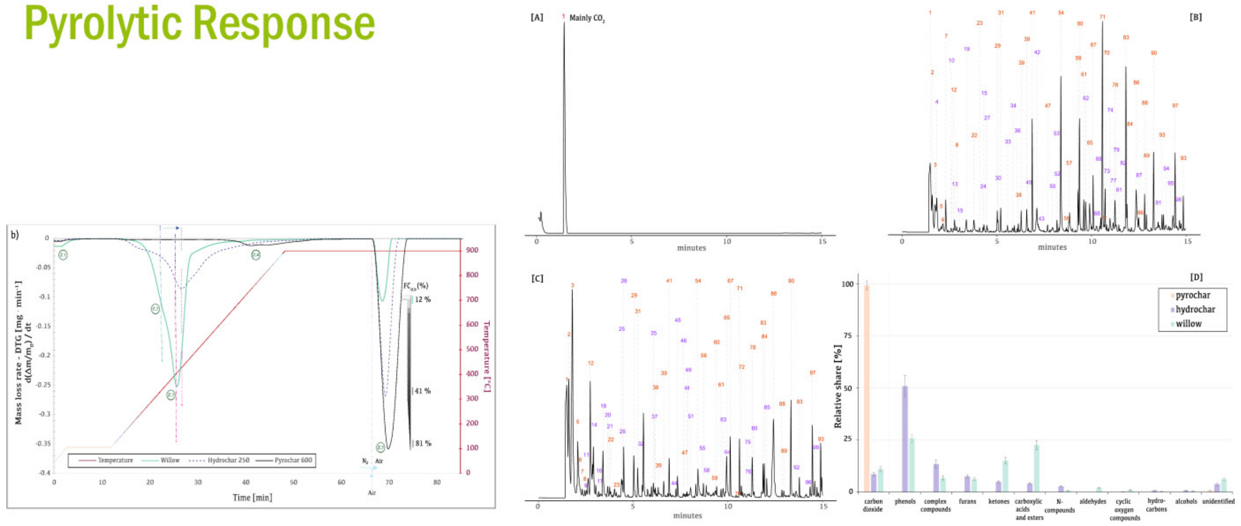
Pyrolytic Response



PY-GC-MS Ion chromatograms of pyrochar [A], hydrochar [B], and willow [C] with red peaks marking the same compounds found among the samples; Panel D compares the compound class with their relative share.

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Part I | Introduction | Hypothesis | Materials and Methods
Part II | Results and Discussion | Outlook
Part III

- **Soil Amendment Potential**: EWS-pyrochars are stable and free of harmful compounds, ideal for soil amendment.
- **Phosphorus Bioavailability**: EWS-chars show high P-retention—up to 92 % in pyrochars and nearly complete in hydrochars.
- **Innovative 3D-Visualizations**: New insights into chars' internal porosity and structural thickness.
- **Aromaticity**: EWS-pyrochars have higher sp^2 C-atoms (63 %) compared to hydrocars (43 %).
- **Water Storage Pores**: EWS-pyrochars have 92 % water storage-like pores.
- EWS-pyrochars exhibit high thermal stability, aromaticity, and low heavy metal content, providing significant synergistic benefits. *On a 10-hectare scale, hydrochars offer higher carbon retention and phosphorus recovery, with annual benefits of 80 tons of carbon sequestration (lasting decades to centuries) and 334 kg of phosphorus recovery. In comparison, EWS-pyrochars sequester 60 tons of carbon (lasting centuries to millennia) and recover 298 kg of phosphorus annually.*

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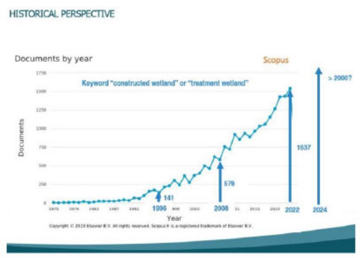
Part III | Conclusion | Outlook

- **EWS Efficiency**: EWS (Engineered Wetland Systems) effectively treat wastewater and recover resources like water, nutrients, materials, and energy.
- **Innovative EWS-Willow Chars**: EWS-willow-based chars, especially from hydrothermal carbonization (HTC) and slow pyrolysis, show great potential for resource recovery and soil amendment.
- **Pioneering Study**: Our research uniquely focuses on EWS-willows for HTC and pyrolysis, enhancing the understanding of EWS applications.
- **High Biomass Yield**: EWS-willow systems yield high biomass (31 t DM·ha^{-1}·a^{-1}) with significant nutrients, ideal for nutrient retention and carbon sequestration.



Research field that should continue ☺

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THANK YOU


Hans Brix
Professor
Head of Department


Carlos Arias
Senior Researcher


Patrick Biller
Associate Professor


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PhD

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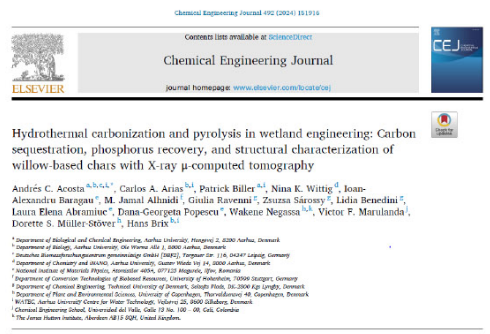
THANK YOU


Chemical Engineering Journal 492 (2024) 151916

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Hydrothermal carbonization and pyrolysis in wetland engineering: Carbon sequestration, phosphorus recovery, and structural characterization of willow-based chars with X-ray µ-computed tomography

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[i] WATEC, Aarhus University Centre for Water Technology, Vejlsøvej 25, 8600 Silkeborg, Denmark
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[k] The James Hutton Institute, Aberdeen AB15 8QH, United Kingdom.

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Janet Osei, University Rostock

Comparative Studies of Conventional and Biofuels for Sustainable Mobility using a Mathematical Model - A case of Ghana

Janet Osei, Prof. Dr. Rabani Adamou, Prof. Dr. Amos Kabo-Bah, Prof. Dr. Satyanarayana Narra
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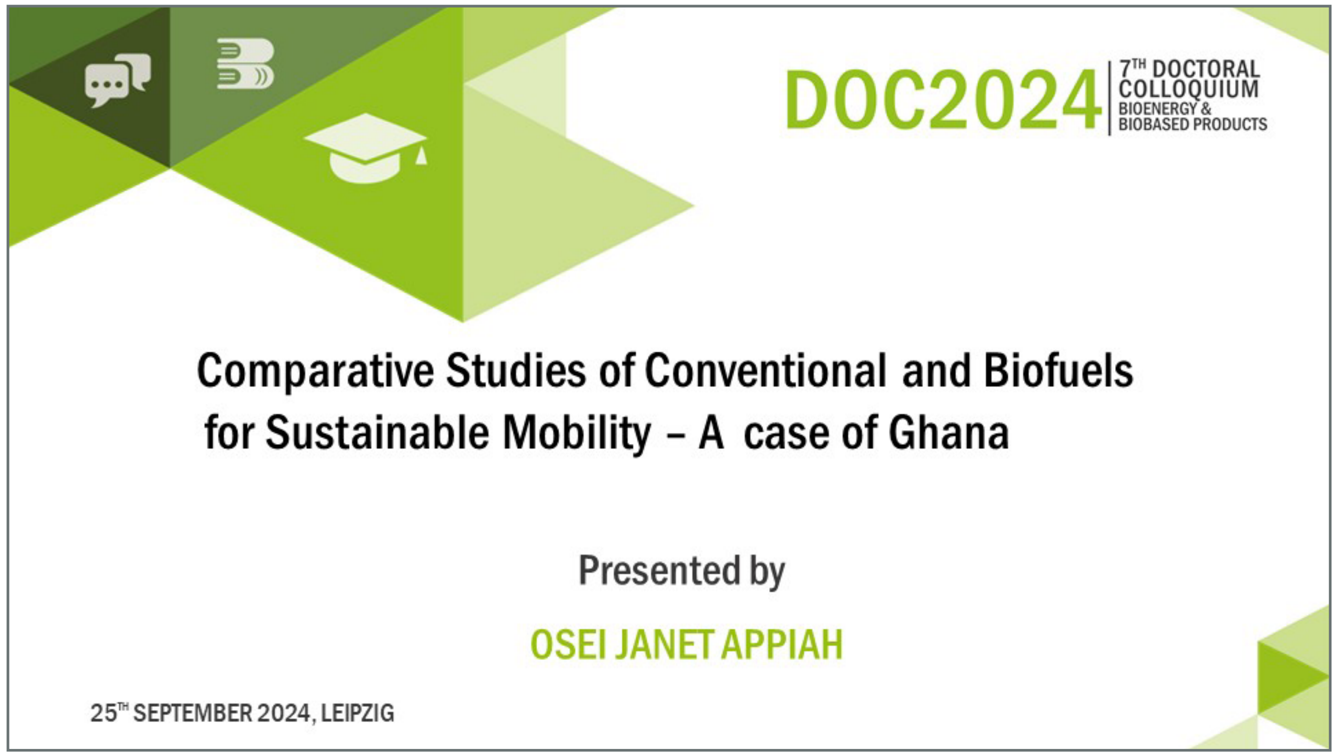
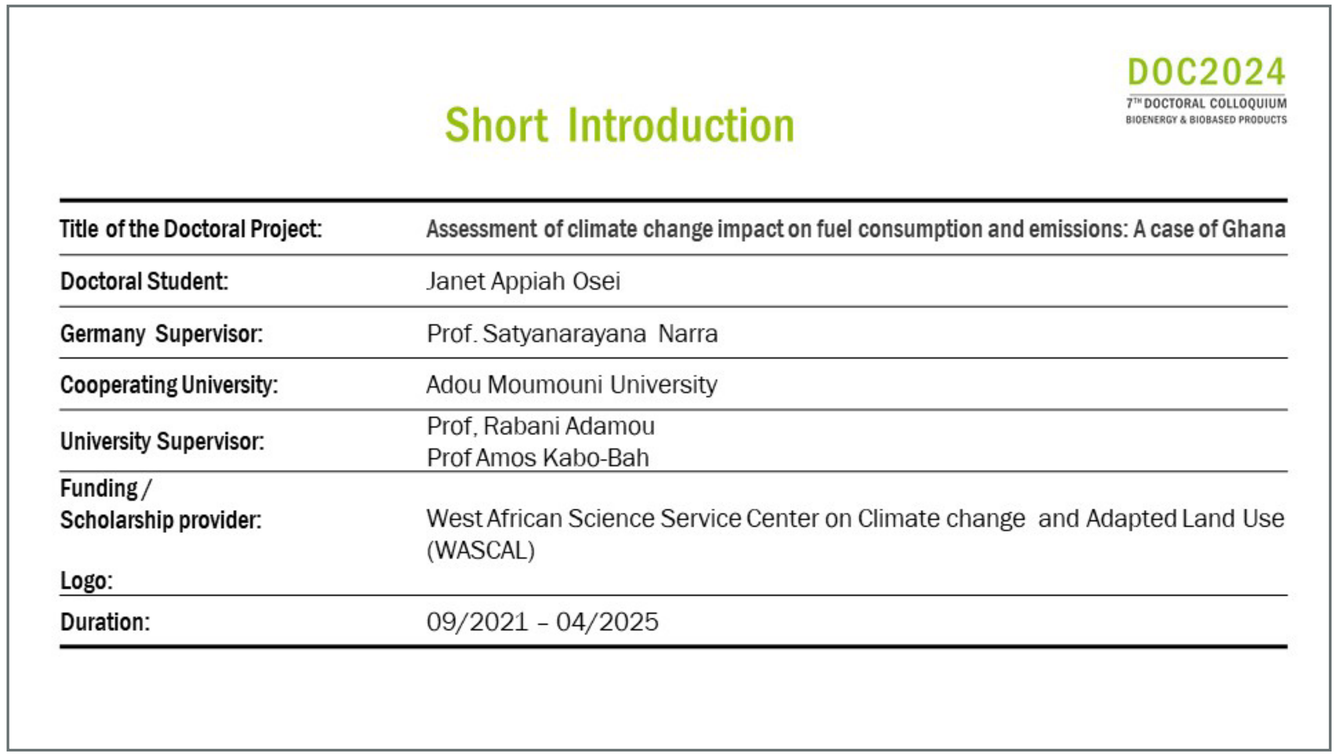
Keywords: Biofuels, emission savings, fuel consumption savings, sustainable transportation

Energy is principal to economic development due to the positive correlation between its consumption and living standards. It is pivotal to the human needs because it is required for mobility, lighting, heating and cooling. Mobility is one of the fundamental conditions for sustainable development in Africa. Hence, in actualizing SDGs which most African leaders have ratified and vowed to achieve, sustainable mobility cannot be overemphasized. Ghana is confronted with unsustainable transport system due to the high use of fossil fuels. The transport sector in Ghana is the largest emission sector within the energy sector with about 43 %. Based on the demands from the Paris Agreement, many developed countries have committed to over 50 % GHG emission reduction by 2030. The determined contribution of Ghana is to lower its GHG emissions by 15 % (11.1 $MtCO_2e$) base on Business-as-usual scenario emission of 73.95 $MtCO_2e$ by 2030 and additionally lower emissions by 30 % if there is availability of extrinsic support. To facilitate the process of reducing emissions, sustainable transport actions by the use of biofuels will enhance safe, efficient and green transport in Ghana which can spur healthy and livable living mostly in cities. According to the report by National Energy Statistics 2021, the importation of gasoline and gasoil have augmented at annual growth rate of 7.4 % and 8.7 % respectively from 2000 to 2020. The total amount of petroleum products imported in 2020 was 3,965 kilo tonnes representing a 385.9 % increase over the amount in 2000. The absolute dependence on imported fuels threatens energy security, devaluate the Ghana cedis currency and also deteriorate the balance payment and the country's foreign currencies reserves. Replacement of gasoline and diesel fuels with ethanol and biodiesel generated in Ghana will reduce the import bills and inject the amount saved into the domestic economy to ameliorate GDP of the country.

The study aims to curb GHG emissions by utilizing biofuels (bioethanol and biodiesel) generated from renewable energy sources as optimal alternative fuels for road vehicles. The study answers the question of how biofuel integration can be an efficient mitigation alternative in Ghana. A comparative test between conventional fuels and biofuels was conducted by employing a physical model to predict the amount of fuel consumption and emissions that will be generated from each fuel type. This will enhance the deduction of the total emission and fuel savings derived from biofuels relative to the conventional fuels. Based on author's knowledge, this is the first study to predict biofuel and conventional fuels consumption and emissions in Ghana using a mathematical model. A research gap that the study fills.





Scientific Background

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- Mobility is a fundamental tool for sustainable development
- Ghana is confronted with unsustainable transport system
  - ✓ Heavy reliance on fossil fuel
  - ✓ Traffic congestion
  - ✓ Old and inefficient vehicles
  - ✓ Poor road infrastructure
- This increase pollution, suppress market growth, hamper the movement of people etc.

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Problem Statement

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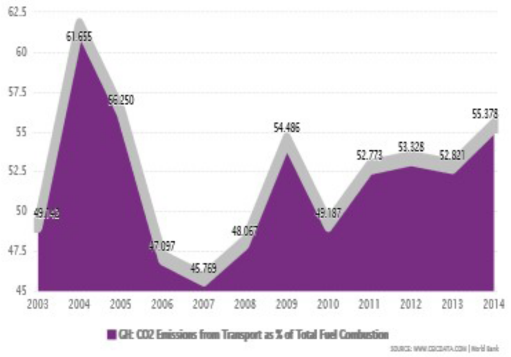
- High importation of petroleum products
- Highest emission sector



Adoption of green fuel (biofuel)

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Problem Statement

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- Plethora of studies on biofuel potential from organic wastes etc.
- Lack of empirical studies on potential vehicle fuel consumption and emissions from biofuels
- Available data are based on research from other regions

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Study Aim

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To ascertain the rate of fuel consumption and emissions from biofuels based on the environmental conditions in Ghana using analytical model

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Approach / Methods

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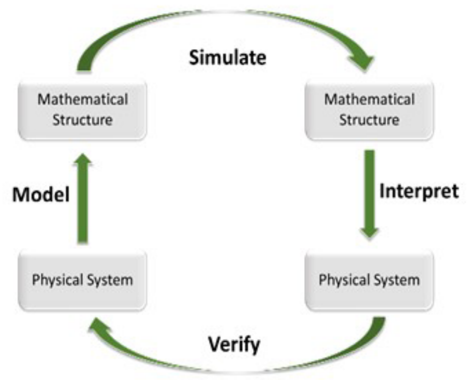

Vehicle Make	Model	Engine capacity (l)	Mass (kg)	Frontal area (m^2)	Aerodynamic drag (kW)	maximum power (kW)	acceleration (m/s^2)
Chevrolet	Matiz	0.8	775	1.91	0.34	38	1.63
Toyota	Yaris	1.5	1000	2.09	0.29	64	2.12
Toyota	Matrix	1.8	1300	2.24	0.33	99	2.79
Hyundai	Grace	2.5	1604	2.82	0.35	59	2.36
Toyota	HiAce	3	1780	2.846	0.36	96.5	2.525
Mercedes	Sprinter	3.5	2546	4.46	0.43	115	2.314

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Approach/Method

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- Three scenarios were employed- Business as Usual (BAU), Alternative and Extreme Analytical model
- $Q = bsf * 10^{-2} [\frac{F_{roll} * F_{inertia} * F_{drag} * v}{\eta T \rho f}]$
  - $F_{roll} = f \langle 1 + \frac{v}{147} \rangle mg$
  - $F_{drag} = 0.5 * d * A * \rho a * v^2$
  - $F_{inertia} = ma$
  - $\eta T = \frac{F_{inertia} v}{h}$
- $CO_2 = F_f \times NCV \times E_F$

F_{roll}= rolling resistance force
$F_{inertia}$=Force of inertia acceleration
F_{drag}= Force of aerodynamic drag
Bsf =brake specific fuel consumption
ηT= efficiency of transmission
ρf= fuel density
v=vehicle velocity
h= horsepower
d= air drag
A= frontal area
a= acceleration=mass
g= gravity
ρa= air density
E_F = emission factor
NCV=net calorific value

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Results

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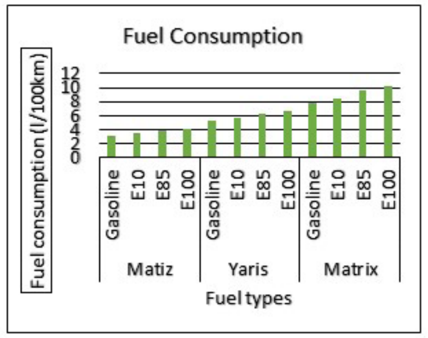

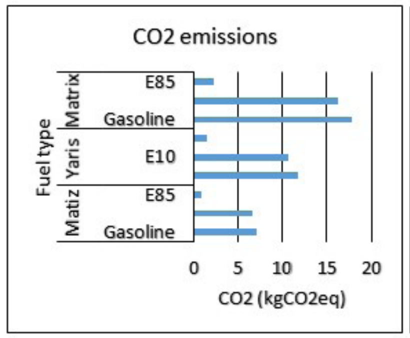

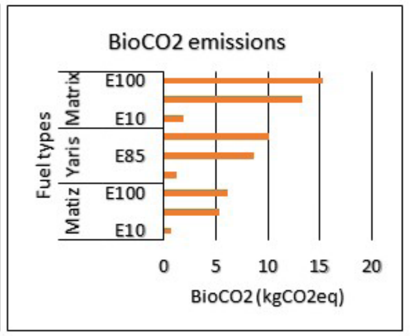

Bioethanol	Fuel Increase(%C)	CO2 saving (%)
E10	7.14	-8.22
E85	22.12	-87.09
E100	28.78	-100

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Results

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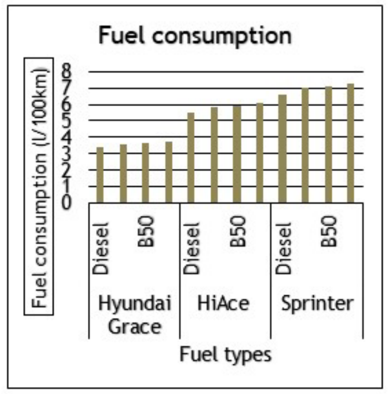

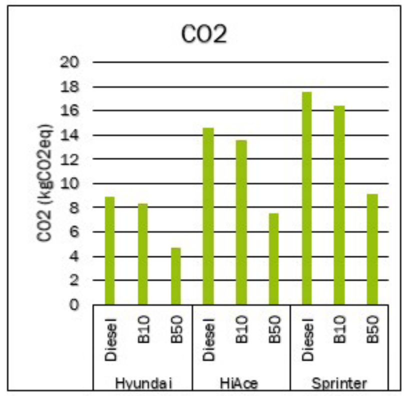

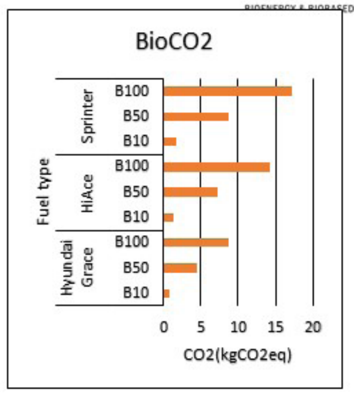

Biodiesel	Fuel increase (%)	CO2 saving (%)
B10	6.5	-6.35
B50	7.82	-48.23
B100	10.43	-100

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Results

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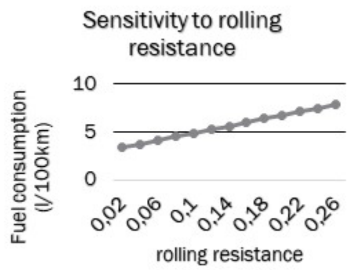
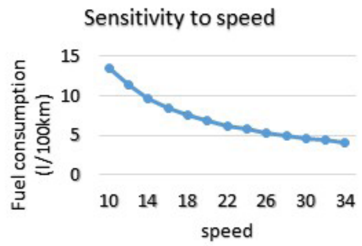
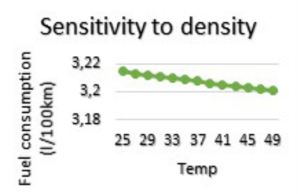
Uncertainty analysis







Density
MoE: 0.0021
CI: 3.1810 to 3.1851
SRC: -0.999

Rolling resistance
MoE: 0.9925
CI: 6.1465 to 8.1316
SRC: 1

Speed
MoE: 1.2580
CI: 4.4117 to 6.9278
SRC: 0.957

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Summary of results

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- Fuel consumption is dependent on fuel type
- Higher consumption in biofuels relative to conventional fuels
- Lower emissions in biofuels relative to conventional fuels
- Higher consumption and emissions in vehicles with larger engine capacity
- Analytical model was effective in predicting fuel consumption

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Conclusion

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- This study aimed to elucidate the impacts of biofuel in the transport sector of Ghana
- By using modeling and simulation, the study was able to determine ;
  - fuel consumption of biofuels
    - CO2 emissions of biofuels
- The results showed reduction in CO2 emissions in biofuels compared to gasoline fuel
- The study has helped to better understand the benefits of integrating biofuels in the transport sector of Ghana
- Therefore, with resounding policies bioethanol and biodiesel can be promising green transport fuels for decarbonization in Ghana

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