ISSN 2004-2965 Energy Proceedings, Vol. 24, 2021

International Conference on Applied Energy 2021
Nov. 29 - Dec. 5, 2021, Thailand/Virtual
Paper ID: 529

The Doctoral School Closed Carbon Cycle Economy: An interdisciplinary concept to promote the necessary understanding for a sustainable energy and structural transformation

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ABSTRACT

In order to meet global climate goals and to reduce CO_2 emissions, Germany is gradually decarbonizing not only the energy industry but also other sectors such as the chemical and steel industries. To this end, Germany will, e.g., completely phase out coal-fired power generation by 2038. This will inevitably lead to an energy and structural transformation that must be ecologically and economically sustainable. Making this change sustainable necessitates an interdisciplinary approach and understanding for the problems and issues to be solved. Against the background of the coal phase-out in the lignite mining region of the Rhenish region, the Doctoral School Closed Carbon Cycle Economy (DS CCCE) of the Ruhr-Universität Bochum focuses on research on topics related to the necessary energy and structural change and thus trains experts at graduate level. The involved disciplines are Applied Energy, Humanities, Natural Science and Social Science. The PhD projects are largely disciplinary in order to train specialists in the respective fields. At the same time, the DS CCCE offers interdisciplinary networking formats, in order to promote the necessary interdisciplinary understanding and to develop a common language in between disciplines. The DS CCCE is presented in this paper and the PhD projects funded by the DS CCCE are briefly outlined.

Keywords: interdisciplinary qualification, sustainable energy and structural transformation, decarbonization, coal phase-out, closed carbon cycle

NOMENCLATURE

Abbreviations

ABM	Agent-Based Network Model
CAP	Climate Action Plan
DS CCCE	Doctoral School Closed Carbon Cycle Economy
IPCC	Intergovernmental Panel on Climate Change
ITZ CC	Virtual Innovation and Technology Center Carbon Conversion
NDCs	Nationally Determined Contributions
RR	Rhenish lignite mining region
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

1. INTRODUCTION

In order to achieve global climate goals and to reduce global greenhouse gas emissions, the member states of the United Nations Framework Convention on Climate Change (UNFCCC) committed themselves to the Paris Agreement in 2015. They agreed to define, plan and regularly report on their nationally determined contributions (NDCs) – thus, to set up action plans for reducing their emissions. The overall goal of the Paris Agreement is to keep the rise in mean global temperature to well below 2 °C above pre-industrial levels, and preferably limit the increase to 1.5 °C [1]. According to the Intergovernmental Panel on Climate Change (IPCC), global net human-caused emissions of carbon dioxide would need to be approximately halved by 2030, reaching 'net zero' around 2050 in order to

Selection and peer-review under responsibility of the scientific committee of the 13th Int. Conf. on Applied Energy (ICAE2021).

meet the Paris climate goals [2]. To this end, the EU aims to reduce greenhouse gas emissions by 80-95% by 2050 compared with 1990 levels. In order to meet this target, a national Climate Action Plan 2050 (CAP) was adopted in 2016 in Germany setting out the required reduction steps. These include a reduction in greenhouse gas emissions of 40% by 2020, 55% by 2030, 70% by 2040 and ultimately a reduction of around 85% in 2050 compared to 1990, whereby the 2030 target also reflects the NDCs for Germany in accordance with the Paris Agreement. The CAP assorts five main areas of action: energy sector, industry, buildings, transport, agriculture. Figure 1 provides an overview of the emissions generated in 1990 and 2014 by these areas and the interim targets by 2030 according to the CAP [3].

As can be seen, the energy sector plays a central role

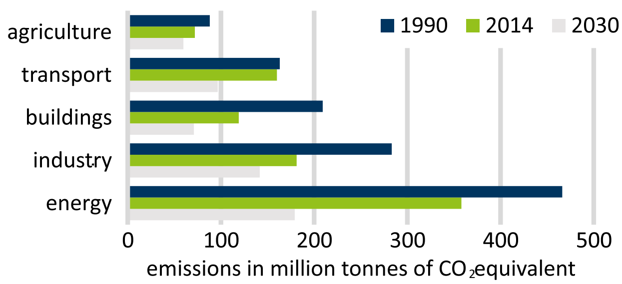

Fig. 1. Greenhouse gas emissions of the five main areas assorted within the CAP generated in 1990 and 2014 and

making its restructuring inevitable in order to reduce emissions. Important steps have already been taken and initiated as part of the *Energiewende*, so that emissions are to be reduced by 61 - 62 % by 2030 compared with 1990 levels through the further expansion of renewable energies and the gradual phase-out of fossil fuels [3]. Germany's complete phase-out of coal-fired power generation is scheduled for 2038 [4]. Nevertheless, coal currently still is the most important energy source in electricity production in Germany alongside renewable energies. In 2018, around 35 percent of gross electricity generation came from coal (22.5% lignite, 12.9% hard coal), as much as from renewables [5]. While hard coal production in Germany ceased in 2018, lignite currently remains the most important domestic fossil energy feedstock. In Germany, lignite is mined exclusively near the surface, i.e. in opencast mines, which are spread over three mining areas: the Rhenish lignite mining region (RR), the Lusatian mining area, and the Central German region, which are shown in Figure 2.

Due to the local availability of lignite as a favorable source of energy, typical industrial structures along the value chains around lignite mining, refining and power generation have developed in the lignite regions. In addition, branches of energy-intensive industries, such as the chemical, cement and steel industry, whose production structures have so far been essentially based on the processing of fossil carbon compounds, settled down in the region. The imminent phase-out of coal-fired power generation and the "zero emissions" target therefore require a system change in both the energy industry and the energy-intensive industries, which must incorporate a fundamentally different management of carbon-based raw materials. For the regions affected by the coal phase-out, it is therefore important not only to develop alternatives to the previous jobs in lignite supply and utilization, but also to design the structural change in such a way that the conventional carbon economy is replaced by a new, more sustainable carbon economy. The upcoming energy and structural transformations thus offer the opportunity, and the regions the potential, for a successful transition to sustainable energy supply and generation. Moreover, the upcoming structural change in the lignite mining regions can also make important contributions to a sustainable carbon economy if future-proof successor technologies for industrial jobs are established in the regions in a cooperative manner based on research and development in synchronization with the planned decline in lignite-based power generation.

However, the development of sustainable structures, value chains and ultimately a model region requires not only appropriate technologies, but also

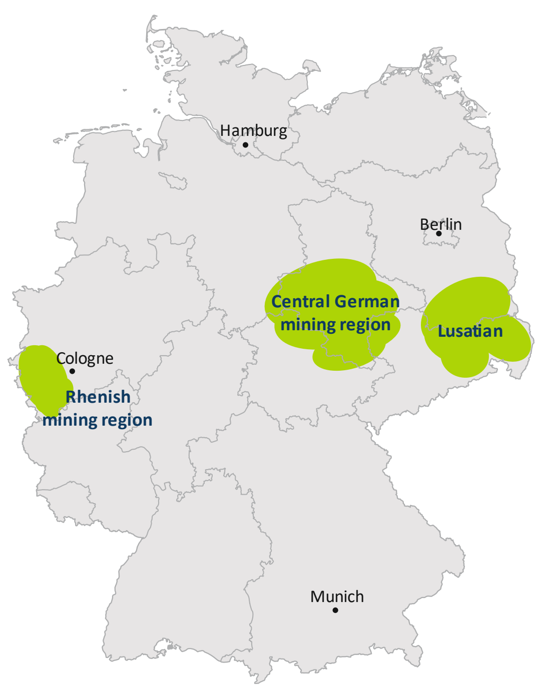

Fig. 2. Liginite mining areas in Germany based on [6]

social and ethical acceptance and suitable economic and legal framework conditions. An energy and structural change on the technical level alone is not target-oriented and sustainable, since the change ultimately affects the living and working environment of each individual; social acceptance thus is a success-defining factor. For instance, developing the most efficient electric car to substitute combustion engines would ultimately contribute nothing to achieving climate targets if it is not used nationwide due to a lack of acceptance. The overall transformation process to a sustainable model region must therefore inevitably be interdisciplinary.

In order to promote the necessary interdisciplinary understanding of the required topics at an early stage and to develop a common language, the Doctoral School Closed Carbon Cycle Economy (DS CCCE) at the Ruhr University Bochum deals, among other things, with questions concerning the material use of carbons, sustainable carbon cycles, energy supply, the development of new economic clusters, and aspects of the upcoming structural change in the RR, and at the same time offers an accompanying interdisciplinary training and further education program for the doctoral students.

2. DS CCCE

The DS CCCE is a project funded by the state of North Rhine-Westphalia and is part of the Virtual Innovation and Technology Center Carbon Conversion (ITZ CC), which, together with the joint project partners Fraunhofer UMSICHT and RWE Power AG, brings together know-how, plants and components as well as research and development work on centralized and decentralized carbon conversion and utilization, and makes it applicable for industry and the RR. The DS CCCE studies, among other things, fundamentals in the scientific/technical field that are relevant for the technology development but are not directly in the application-oriented focus of the other projects of the ITZ CC. Moreover, these projects are also embedded in a much broader, interdisciplinary framework through the work of the DS CCCE. The DS CCCE deals with humanities and social science issues, which can contribute to the development of a model region using the example of the RR and can be transferred to other affected regions in the further course.

The DS CCCE thus forms the basis for an interdisciplinary education of doctoral students in topics relevant to the transformation towards closed carbon cycles. At the same time, the actual scientific training will remain disciplinary - even the best interdisciplinary approach initially needs scientifically excellently trained experts for diverse issues. However, the structure of the DS CCCE will ensure through interdisciplinary activities (e.g., lecture series, doctoral seminars, workshops, and retreats) that its members, in addition to working on their actual doctoral topics, simultaneously develop the necessary interdisciplinary understanding of the relevant issues. These accompanying activities promote the exchange between the PhD students of the different disciplines and thus contribute to the development of a common language and a common understanding of the problems to be solved in order to master the transition to closed carbon cycles in the long run.

While many interdisciplinary graduate programs span across multiple departments and fields of study, the involved disciplines mostly still belong to the same superordinate department (e.g., Chemistry and Biology both belonging to Natural Sciences). In this respect, the DS CCCE takes a largely new approach, combining expertise from four overarching disciplines in its work. The departments currently participating in the DS CCCE belong to the academic disciplines Applied Sciences, Humanities, Natural Sciences and Social Sciences (in alphabetical order). Currently, 17 PhD positions are funded by the DS CCCE, and 8 additional doctoral students participate in the DS CCCE program. The specific field of studies and associated research areas investigated within the DS CCCE by the funded PhD students are outlined in the following sections.

2.1 Applied Science

Within the DS CCCE, the Applied Sciences area primarily considers topics regarding generation, storage, and supply of energy and corresponding energy systems. These topics directly aim at the restructuring of the energy industry and can help regions affected by the coal phase-out, such as the RR, to develop into model regions with a sustainable energy supply. The participating disciplines include mechanical engineering, thermodynamics, cross energy systems, energy systems and energy economics.

Particularly with regard to renewable electricity, power grids can be subject to fluctuations that can occur due to weather conditions as a result of fluctuations in wind and solar energy production. One possibility for balancing these fluctuations is the use of energy storage systems. One doctoral project, e.g., is concerned with the development of a material flow model and a suitable methodology that will enable the life cycle assessment of energy storage systems in the energy system, using the German energy system as an example. In addition to a life-cycle analysis, a social-ethical stakeholder analysis is carried out using the example of the RR, thus adding interdisciplinary aspects to the energy system analysis of grid-connected energy storage systems.

As an alternative to energy storage systems, the demand-oriented operation of biogas plants can be considered, so that the production and conversion of biogas can be used as flexibly as possible to compensate for fluctuations in the power grid. The medium-term flexibilization of biogas production through systematic intervention in the actual biogas formation process is being investigated in another doctoral project, while a further project is analyzing the effects of lignite from the RR and of biocoal as an additive in the biogas formation process.

In addition to biogas plants, photovoltaic and wind plants, e.g., are suitable renewable energy producers that can be integrated into the energy system. However, the volatility of these renewable energies must be taken into account, as well as their decentralized nature. For these reasons, the substitution of large conventional power plants by renewable plants must follow an overall concept that considers the characteristics of the respective systems. This requires, among other things, the spatial as well as temporal analysis of electricity distribution, considering power grid routes, grid load profiles and intermediate storage, which is being researched in another PhD project of the DS CCCE.

In addition to the decentralization of the (German) energy system with respect to generation and demand-driven supply of energy, the complexity of the energy system will increase more and more in the future. In addition to the actual power supply, the gas, heat and transport sectors will also undergo an energy system transformation, whereby their energy supply will be increasingly electricity-based using renewable energy sources. As a result of the increasing complexity, the challenge for future energy supply structures is to ensure the necessary resilience, i.e., the system's ability to fully or at least partially maintain system stability in the event of disruptions, errors or special situations, or to automatically restore it as quickly as possible through system-immanent processes. The resilience of future energy supply systems and infrastructures is another topic of a PhD within the DS CCCE. With regard to future energy supply systems and infrastructures, H_2- and CO_2-rich gas flows (e.g. from large-scale processes) will play an increasingly important role. These gas flows must be adequately handled, transported and accounted for, which poses significant measurement challenges that cannot be readily addressed with the methods and equipment currently available for natural gases. As part of another PhD project, the scientific foundations are established for extending the scope of application of modern gas measurement technology methods to H_2-enriched natural gas.

2.2 Humanities

The disciplines law and ethics, respectively mining and energy law, sectoral and spatial planning, environmental law and applied ethics, which belong to the Humanities, participate in the DS CCCE.

The two doctoral projects belonging to the overarching field of law focus on the investigation of the legal possibilities and limits with regard to possible after- and follow-up uses of former lignite mining areas, which is exemplarily investigated for the RR. The first doctoral project focuses on aspects of spatial planning and urban land-use planning with the aim of developing scenarios and procedural models that enable coordinated regional planning for the lignite mining areas. These scenarios and models must be precisely tailored to the challenges of the coal phase-out and must be implementable in a timely manner while ensuring a high degree of legal security. The second PhD project focuses on sectoral planning and approval in order to explore separate mechanisms for accelerating procedures with regard to possible after- and follow-up uses in the RR and to develop legal policy recommendations.

In the scope of an ethical analysis, the normative goal conflicts of the *Energiewende* and especially of the coal phase-out in Germany are investigated in another PhD project. From an ethical point of view, aspects of environmental protection, economic interests, the rights of future and present generations, and the question of security of supply are contradictory. The aim of the research is to develop an approach that can be used to resolve conflicting goals or to justify a ranking of different moral claims. In addition, proposals are to be developed as to what possibilities exist for former coalfields such as the RR to make structural change ethically justified as well as politically, technically and legally feasible.

2.3 Natural Science

Within the DS CCCE the Natural Science includes PhD projects from the departments of industrial chemistry and inorganic chemistry and earth science, namely applied physical geography, soil science and soil economy.

Both chemical centered PhD projects deal with the electrocatalytic production of synthesis gas on the one hand and the production of short-chain olefins from these synthesis gases on the other hand. The production of synthesis gases by electrocatalysis uses CO_2 as a raw material, which is typically converted electrochemically on Cu-catalysts to hydrocarbons and other basic chemicals, which in turn can be used as source for specialty chemicals and fuels or fuel additives. Preliminary studies showed that the composition of the synthesis gas can be selectively controlled by the proportion of water in the electrolysis cell if sulfidic materials are used as electrocatalysts instead of conventional Cu-based materials. The integration of sulfidic materials in gas diffusion electrodes with a focus on the parameterization of the process parameters for the production and application of these electrodes in synthesis gas production is therefore the central topic of a PhD project. From the electrocatalytically obtained synthesis gas, short-chain olefins such as ethylene and propylene can be further produced as the simplest unsaturated hydrocarbons and the most widely produced basic chemicals. Under the right conditions, special catalysts allow the selective formation of these short-chain olefins, although both the mode of action and the exact composition of the catalysts are not yet understood. This is being systematically investigated as part of another PhD project.

The PhD project thematically based within Earth Science deals with the use of lignite from the RR for soil improvement and thus investigates a possibility for the, as far as possible, sustainable utilization of lignite after the end of coal-fired power generation. Within the project, the soil chemical composition of various lignite-based soil improvers (i.e. humic acid) and their effect on key yield-determining factors are being investigated. Products already available on the market as well as specially prepared products are being tested here, which also include mixing with residues from agricultural animal production (slurry) and biogas production (digestate). The latter is closely interlinked with one PhD project from the biogas sector (sec. 2.1).

2.4 Social Science

Further PhD projects within the DS CCCE are assigned to the disciplines labor and economic sociology, macroeconomics and comparative politics. In the last mentioned, the assigned PhD project deals with the formal and informal information flows between experts, interest groups and politicians, assessing the importance of this information exchange for the policy process of structural change and developing proposals for the reasonable enhancement of these information channels. In the context of the DS CCCE, structural change in the RR and closed carbon cycles, it thus analyzes an essential procedural and substantive aspect of the short- and long-term policy-making of structural transformation processes.

Two further PhD projects, which are closely interlinked, are located in the field of macroeconomics. With the help of both projects, an agent-based network model (ABM) of the RR innovation system is being designed. With the help of model simulations, statements are to be made about the effects of external influences (e.g. political decisions) or endogenous developments (e.g. the disappearance of an actor) on the RR innovation system and thus on the regional economic performance. In the context of the first PhD project, inhibiting and supporting factors of structural change will be incorporated into the model. For this purpose, existing innovation networks in the RR will be analyzed quantitatively and the diffusion of knowledge within the group of innovators and imitators will be investigated. The second doctoral project deals with the qualitative analysis of innovation networks involving stakeholders of the RR and thus provides insights to implement concrete technologies and industries in the ABM.

The PhD projects thematically related to labor and economic sociology deal with the social acceptance and attitudes of citizens in the RR towards structural change and lignite (utilization) and with the influence of public media and digital communication reporting on lignite, structural change and the energy transition on these very points of view. The population in the affected regions is characterized by employees who are/were active in lignite production and opencast mining as well as in the upstream and downstream sectors, and for whom the lignite industry is important as an economic sector and employer for the region. On the other hand, there are, e.g., citizens whose residences are/were affected by resettlement, as well as environmental activists and coal opponents. However, so far there are no scientific results on the citizens' point of view that show how they evaluate the current developments, what hopes and concerns they have, what opportunities and challenges they see ahead of them and how they view lignite and its use. Using the example of the Rhenish mining area, the attitudes and acceptance of the local citizens will therefore be examined and analyzed in a differentiated manner on a scientific basis. In a further PhD project, the various perspectives of communication and reporting in the field of structural change associated with the energy transition will be investigated and evaluated with a special focus on the RR using Big Data analyses. This will highlight the respective narratives around the relevant topics that are strategically used to achieve different goals by different social groups and examine their social impact. By specifically highlighting these aspects, strategies and recommendations for action can be developed, e.g., to reduce prejudices against the general carbon-based economy caused by media coverage.

3. CONCLUSION

The energy and structural change required to achieve global climate targets must be designed in such a way that it is ecologically, economically and socially sustainable. The regions affected by the coal phase-out or rather the phase-out of fossil energy supply - not only in Germany, but in the long term worldwide - can already become pioneers and model regions for a transition to sustainable structures with closed carbon cycles and hubs for the future supply of renewable energy, basic chemicals and steel. However, this development requires not only appropriate technologies, but also social acceptance and suitable economic and legal framework conditions. In order to promote the necessary interdisciplinary understanding at an early stage and to develop a common language for the problems and issues to be solved, accompanying doctoral programs and interdisciplinary concepts combining the expertise of several superordinate academic disciplines like Applied Sciences, Humanities, Natural Sciences, and Social Sciences can be established to train experts at graduate level. The general scientific education can continue to be disciplinary, yet with a common thematic background, on which the interdisciplinary programs, such as the Doctoral School Closed Carbon Cycle Economy, are built.

ACKNOWLEDGEMENT

The projects Doctoral School Closed Carbon Cycle Economy (DS CCCE) and the ITZ CC are funded by the State of North Rhine-Westphalia through the Ministry of Economic Affairs, Innovation, Digitalization and Energy of the State of North Rhine-Westphalia (MWIDE NRW).

The authors appreciate the contributions from the colleagues within the DS CCCE and acknowledge (in alphabetical order) Ulf-Peter Apfel, Valentin Bertsch, Christian Dötsch, Rainer Eising, Mandy Gerber, Klaus Joachim Grigoleit, Rolf Heinze, Bernd Marschner, Martin Muhler, Christian Pielow, Julian Röder, Michael Roos, Anna-Lena Schönauer, Klaus Steigleder and Harald Zepp, who also supervise the PhD projects.

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