NEFI
NEW ENERGY FOR INDUSTRY

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24.10.24 – 25.10.24

NEFI CONFERENCE 2024

Innovating Together: Paving the Path to Climate Neutrality

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VIENNA, AUSTRIA

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NEFI+ is the new innovation laboratory of the Climate and Energy Fund's RTI initiative for the transformation of industry. Important practical research and demonstration projects for a climate neutral industry are being developed in six hubs. The innovation network NEFI - New Energy for Industry (AIT Austrian Institute of Technology, Montanuniversität Leoben, OÖ Energiesparverband, Business Upper Austria) supports the development of the innovation hubs with its infrastructure, expertise and existing networks. Significant funding comes from the two strong industrial federal provinces of Upper Austria and Styria. The Climate and Energy Fund's RTI initiative for the transformation of industry is part of the Climate Protection Ministry's overarching climate and transformation campaign "Transformation of Industry".

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CONFERENCE PROCEEDINGS

NEW ENERGY FOR INDUSTRY 2024

3rd Conference of the Innovation Network

October 24-25, 2024 in Vienna, Austria

The NEFI innovation network of science, technology providers and companies demonstrates a pathway towards climate neutrality of industry and acts as the contact point for R&I solutions "Made in Austria"

Climate neutrality in industrial energy systems
Through 100 % renewable energy supply at selected locations

Value creation & location security
through technology development and export "Made in Austria"

Resilience
of industry in Austria in energy supply, processes and infrastructure

Publisher:

NEFI
NEW ENERGY FOR INDUSTRY

self-published

DOI: 10.5281/zenodo.13985900

IMPRINT

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FOREWORD NEFI INNOVATION NETWORK

INNOVATING TOGETHER: PAVING THE PATH TO CLIMATE NEUTRALITY

The path to achieving a climate neutral industry in Austria by 2040 is ambitious: it necessitates a transformative approach to the industrial energy system, interdisciplinary research & technology development and innovative policies aligned with both national and European climate objectives. Reaching this transition presents significant challenges, particularly given the limited timeframe to implement the necessary societal, political, and technological changes. However, these challenges also present a unique opportunity to reshape the industrial energy landscape of the future.

In this context, the 3rd NEFI Conference serves as a vital platform for dialogue and exchange among stakeholders from academia, research, industry, policy and politics. This year's conference not only showcases recent advancements in the transformation of the industrial energy system, but also addresses the critical societal, political, and technological challenges – both nationally and internationally – that must be addressed to realise our shared vision of a climate neutral future.

The innovation network NEFI New Energy for Industry, funded by the Austrian Climate and Energy Fund in collaboration with the regions of Styria and Upper Austria, stands as a beacon of applied research and development of practical solutions in addressing the complexities of realizing climate neutrality within the industrial sector. By providing practical and scalable solutions, NEFI demonstrates how climate action can not only reinforce Austria's long-term position as a robust industrial location, but also demonstrate the global applicability of comprehensive technologies developed under the "Made in Austria" brand.

Over the past six years, NEFI has successfully fostered a robust innovation ecosystem comprising approx. 120 partners from industry, research and public institutions, in 24 sub-projects. This collaborative effort has led to the successful initiation and execution of numerous research and innovation initiatives, catalysing an impressive investment volume of approximately €95 million.

Building upon this momentum, NEFI has now initiated the NEFI+ Innovation Laboratory. It is funded by the RTI Initiative for Transforming Industry of the Climate and Energy Fund and the regions of Styria and Upper Austria, thereby enabling NEFI to pursue its mission towards a climate neutral industry. NEFI+ acts as a catalyst for the development of cutting-edge prototype applications that will demonstrate measurable impacts on the climate neutrality of the industrial sector. NEFI+ connects key stakeholders along critical technology pathways and focuses its work in six thematic innovation hubs: Electrification and Energy Efficiency, Flexibilization, CO_2-Neutral Gases and Hydrogen, Carbon Capture and Storage, Circular Economy, and Industrial Symbiosis.

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ACKNOWLEDGEMENT NATIONAL RESEARCH FUNDING

"The transformation of industry is a challenge that can only be solved by joint efforts of key players from industry, research and policy.
NEFI has successfully built an innovation network with key stakeholders and contributes to advancing and accelerating technology development and demonstration in Austria. Net-zero solutions 'made in Austria' are already recognised globally by the 'Net-zero Industries Mission' of the Mission Innovation Initiative.
Looking forward, the Ministry for Climate Action will continue to support the path towards climate neutrality in Austria by providing more than 3 billion Euro for industrial transformation until 2030, thereby ensuring competitiveness and climate protection."

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LEONORE GEWESSLER

Federal Minister for Climate Action, Environment, Energy, Mobility, Innovation and Technology

"The Climate and Energy Fund of the Austrian government supports RD&D projects to accelerate the market implementation of innovative solutions. With the RTI initiative for transforming industry we are offering integrated funding to maximise the impact of applied research and demonstration with a total budget of around EUR 320 million up to 2027. The NEFI+ innovation lab will act as a catalyst for net-zero technologies and will present pathways for a climate neutral industry."

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BERND VOGL

CEO, Climate and Energy Fund, Austria

Over the past years NEFI has made an essential contribution to pathing the way towards a climate neutral industry. For this reason, we as Styria - a research and developing region - are pleased to continue supporting this program of accelerating decarbonization of the domestic industry and making it fit for the future.

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URSULA LACKNER

Regional Minister for Environment, Climate Protection, Energy, Regional Development and Spatial Planning, Federal State of Styria

The NEFI innovation network contributes due its prospective work significantly to the goal of decarbonizing the domestic industry and thus making our position as an industrial location more attractive. In addition, NEFI is another example of the outstanding cooperation between science and industry in Styria.

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BARBARA EIBINGER-MIEDL

Regional Minister for Economy, Tourism, Regions, Science and Research, Federal State of Styria

NEW ENERGY FOR INDUSTRY

"The transformation of the energy system poses a major challenge for the manufacturing and energy-intensive industries. At the same time, it offers technology providers a great opportunity to expand their market position worldwide. Upper Austrian technology innovations can make a significant contribution to securing the industrial location.
With NEFI+, we will accompany and support the development of energy technologies that contribute to climate protection and sustainability and increase the competiti-veness of the Upper Austrian economy."

MARKUS ACHLEITNER

Regional Minister for Economy and Energy,
Federal State Upper Austria

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I. Session: Advances in CCU and/or CCS technologies

This session focuses on cutting-edge technologies and processes for capturing, utilising, and storing CO_2 emissions, particularly from hard-to-abate industrial sectors. Presentations in this session will explore the application of CCU/CCS technologies in industries like cement, investigate catalytic processes for CO_2 conversion, and introduce innovative methods for characterising materials used in CO_2 methanation, considering both economic and ecological impacts.

A TIME-EFFICIENT CHARACTERIZATION METHOD FOR SORBENT MATERIALS USED FOR METHANATION

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Abstract: This work proposes a time-efficient adsorption characterization method for various sorbents for gas treatment and methanation. The developed method accompanied with the corresponding setup, where the sorption properties of solid samples are measured, is presented. Therefore, the collected data of zeolite samples is analyses and validated with literature.

Keywords: vapor sorption; zeolites; methanation.

1 INTRODUCTION

The ambitious goals of the EU and national states to increase the share of renewable energies and reduce climate-damaging gases require fast, regional and financially viable solutions. In this context, hydrogen (H_2) is seen as a high-quality energy carrier of the future and an essential building block for the decarbonization of industry. In addition to the major challenges of expanding the production capacities of "green H_2", further considerations of hydrogen utilization chain are also necessary. The use of H_2 in the existing gas network is associated with several challenges (safety precautions, special components, etc.). Methane (bio-CH_4, syn-CH_4) offers advantages due to its higher volumetric storage density, easier handling, and drop-in capability for natural gas. This work reports a step towards utilization of hydrogen and carbon chain by deploying sorption enhanced methanation (SEM) processes, where the reaction catalysts are embedded in porous zeolites, which selectively seal off the interfering reaction product water in the pores [1]. For this purpose, the water vapor sorption capacities of different sorbents are tested and evaluated for SEM-process by developing a time-efficient characterization method.

2 MATERIALS AND METHODS

2.1 Materials

The sorbents used in this study for dual purpose of water adsorption and future catalyst impregnation are 4A, 13X and Y type zeolites and commercial desiccants. Some zeolite granules are manufactured "binder less" (BF), which means that the binder is converted into a porous structure upon calcination and contributes to the adsorption process. According to the International Zeolite Assassination [5], 4A zeolites belongs to the LTA (Linde Type A) framework with pore sizes around 4 Å and 13X and Y zeolites are both FAU (Faujaste) type, differing only in their Si/Al content with larger pore sizes of around 9 Å.

2.2 Dubinin´s Adsorption Theory and Experimental Setup

One way of representing a sorption cycle, which has been proposed several times is the Dubinin adsorption potential [2]. The main consequence of this theory is the "temperature invariant characteristic curve", which describes the ratio of the change in Gibbs free energy ΔF in J/g to the amount of pore filling W in cm3/g or g/g of sorbent-adsorbate pair.

$$W = W(\Delta F) \quad \text{with} \quad \Delta F = -RT \cdot \ln(\, p/p0\,) \tag{2-1}$$

The reported setup consists of two chambers, each can be operated separately or be combined [3], one for high temperatures 25 to 250°C corresponding to the ΔF range from 300 to 2500 J/g (HT chamber), the second one an evacuated chamber for 25 to 150°C (VAC-chamber) with a temperature-controlled adsorbent reservoir that covers a measuring range of ΔF from 0 to 600 J/g. The HT chamber uses room humidity as an adsorptive, while the VAC chamber can be operated with various adsorbates. The sorption process in the HT chamber is controlled exclusively by varying the temperature of the sorbent and is therefore isobaric. The sorbent condition in the VAC chamber can be controlled by sorbent temperature and vapor pressure that is determined by the adsorptive temperature. The measurement can be made isobaric, isothermal, or mixed. The setup does not utilize closed-loop control technology but rather ramp controlled temperature and humidity programs. In practice, a lower limit of ΔF_{min} = 20 J/g has proven to be favorable in order to avoid the risk of condensation on the chamber walls. The load cell of both chambers are designed for 50 g of sorbent material, which means that a number of 50 - 100 zeolite grains can be used.

3 RESULTS

The basic principle of the method is to scan the relevant range of the adsorption potential ΔF and to detect the corresponding change in mass of the sorption material. Sorbent mass, temperature, and humidity data were recorded and ΔF and W values were calculated. In general, it´s meaningful to use a separate testing methods to determine the dry mass (ΔF ≈ 2500 J/g) and the maximum saturation (ΔF ≈ 0 J/g) of a sorbent as reference points.

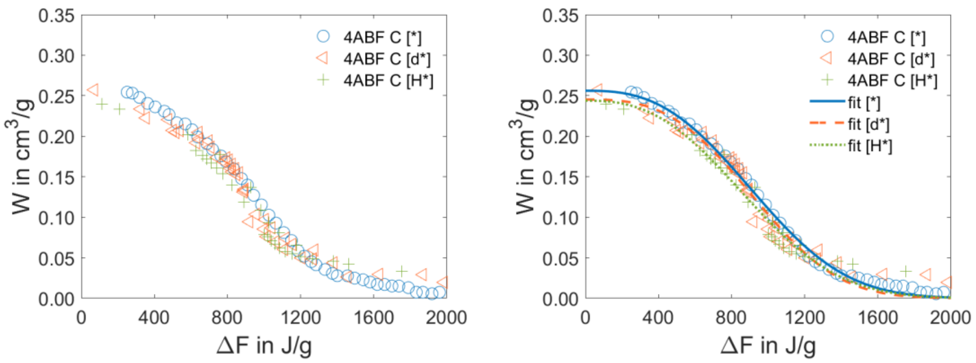

Figure 3-1: Results of 4ABF zeolite from own measurements and literature.

In Fig. 3-1, own measurement results for zeolite 4ABF samples were compared to data provided by the manufacturer and the literature data from [4]. The adsorption equilibrium data from literature is most commonly available as isotherms. For evaluation and comparison these data was redrawn as W(ΔF) diagrams together with own data. The data of the different sources will be further fitted with the three parameter Dubinin-Astakhov approximation and presented.

4 DISCUSSION AND CONCLUSION

The characterization of the sorption properties of porous materials in literature is mainly conducted using standardized equipment and techniques (TGA, DSC), which are time-consuming procedures and limited to rather small, powdery samples in the milligram range in general.

Dubinin´s adsorption theory, originally developed for activated carbon, also applies to molecular sieves such as zeolite and to desiccants such as silica gel, as already demonstrated in literature. The described measurement method proposed in this study uses the concept of the adsorption potential and is suitable to larger sample size than standard methods (10 − 50 g in powdered or granulated form). With the utilization of an open and closed adsorption chambers, a wide range of the Dubinin adsorption potential from 20 − 2500 J/g was covered without complex measurement controls and compensation technology. The setup can easily be reproduced in research facilities for rapid material characterization. The comparison of the measurement data with results from the literature shows that the accuracy and reproducibility of the method are in a satisfactory range. The deviations are explained by the different material quality and pre-treatment.

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CCU IMPLEMENTED IN THE CEMENT INDUSTRY: PROJECT ZEUS

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Abstract: Since the chemical reaction necessary for producing cement inherently leads to the emission of CO_2, the cement industry counts as one of the hard-to-abate sectors. The Net Zero Emission team works on several projects aiming at the decarbonization of cement. A new project that started in October 2023 is ZEUS (Zero Emissions through Sector Coupling), a joint research project involving renowned representatives from several branches of Austria's energy-intensive industries [1]. Its aim is to develop cross-sector, climate-neutral process chains, including the recovery of CO_2 from industrial waste gases and its conversion into valuable industrial chemicals. Our contribution to ZEUS is to set up a new type of demonstration plant for CO_2 separation from the flue gas via membrane technology combined with a CO_2 electrolysis process developed and patented by the Net Zero Emission team [2]. Formic acid obtained from CO_2 is a valuable and versatile product for construction chemicals, agriculture and cleaning and hygiene products. It is a platform chemical for the chemical and pharmaceutical industries. The ZEUS pilot plant enables testing in real operation and optimization as a basis to later scale it up for large-scale industrial applications.

Keywords: Cement industry; Carbon capture and utilization; Membrane technology; CO_2 electrolyser; Formic acid

1 INTRODUCTION

Carbon capture and utilization (CCU) are at the center of interest for unavoidable CO_2 process emissions from the production of cement, lime, refractory materials, and waste incineration. The CO_2 emissions from cement production mainly (2/3) result from the so-called "deacidification" of the limestone used ($CaCO_3$). A smaller proportion (1/3) of CO_2 emissions originates from firing. The so-called (cement) clinker, as the preliminary product for the actual cement, is produced from the input materials only at sintering temperatures of 1,450 °C, accounting for around 780 kg of CO_2 equivalents per ton of clinker.

Our decarbonization path (depicted in Figure 1-1) envisions to avoid 60% of CO_2 emissions through elaborate process engineering measures along the entire production chain. Such measures concern raw materials, fuels, cement composition and all concrete formulations. These include:

- Partial replacement of limestone as the main raw material by already deacidified calcium carriers (e.g., slags).
- Shifting fuels towards renewables such as green hydrogen and waste-derived biomass.
- Reducing the proportion of clinker in cement types and using tempered clays.
- Saving cement in concrete and at the same time using concrete in construction more efficiently.

The remaining 40% of emissions, primarily process emissions from limestone, cannot be avoided and must be treated using CCS or CCU.

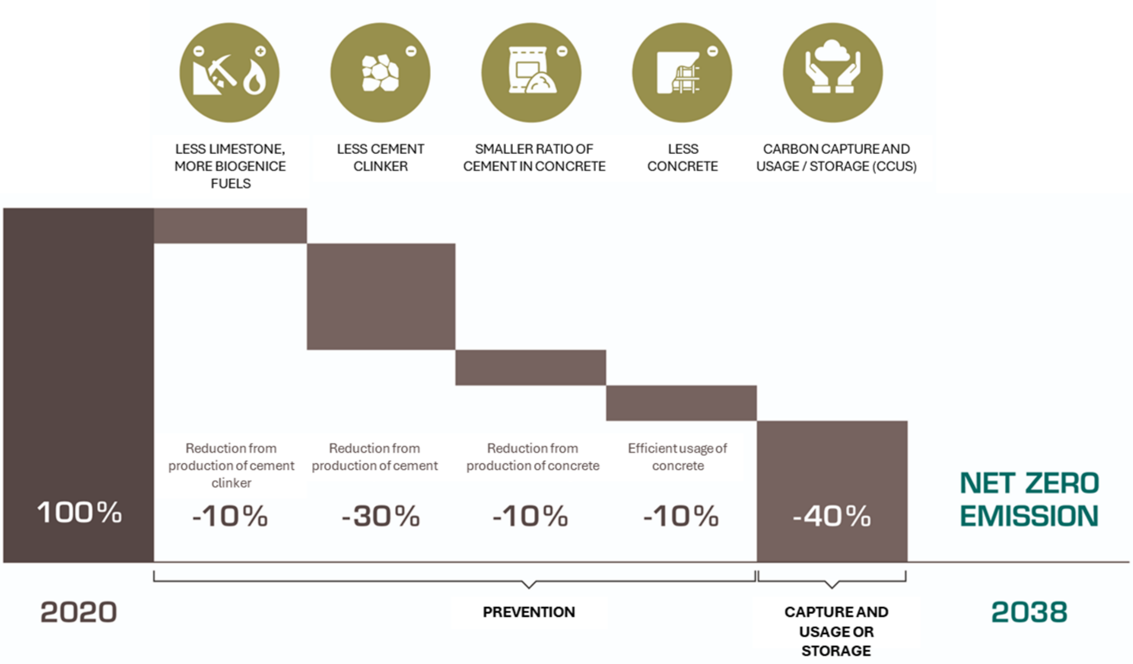

Figure 1-1: Decarbonization strategy with the goal to achieve net zero emission in 2038.

2 MATERIALS AND METHODS

Cement plants produce flue gas with an average CO_2 ratio of 15-20%. Post-combustion carbon capture can be used to recover ultra-pure CO_2 from this point source. Fluctuations in flue gas composition from the various operating modes, weather influences and processes must be considered.

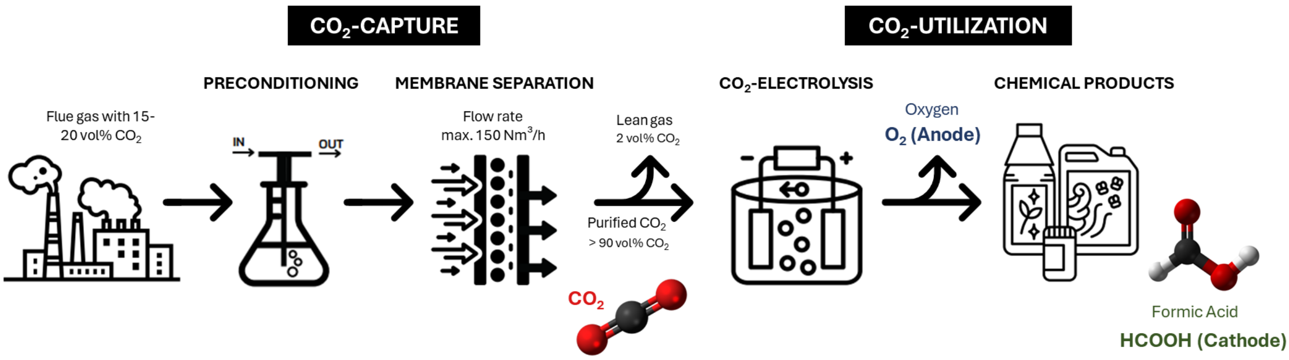

Figure 2-1: Overview of the CCU demonstration plant being built in Gmunden in 2024.

First, the flue gas produced is dedusted and treated through selective catalytic reduction (SCR) to reduce NO_x. It then passes through a scrubber to remove SO_x. This creates good conditions for a post-combustion carbon capture plant. Such a demonstration plant is built in Gmunden in 2024, whose principle is illustrated in Figure 2-1. The aim of this system is to generate know-how from real operations to further design the industrial-scale technology required for net-zero cement production.

3 RESULTS

The demonstration plant will go into operation by late 2024/early 2025 and recover up to 500 kg of carbon dioxide per day, which will be purified and electrochemically synthesized into basic chemicals. Optimization of operational parameters supported by process simulations will be essential to enhance the performance and to make reliable prognoses for large-scale applications. Electrochemical synthesis of up to 5 kg/h formic acid will be possible by using an electrolysis stack [2]. The robustness of the plants must be guaranteed under the given real flue gas conditions. In addition to the operational guarantees, the purity of the captured CO_2 must also be ensured. In the end, the pilot plant should provide the necessary real parameters for continuous operation.

4 DISCUSSION

CCU is an essential component of climate-neutral cement production, which requires both investments at production sites and supra-regional infrastructure measures. The electricity consumption for capture, liquefaction, and compression is a major cost driver for CO_2 capture. The electricity requirements of a cement plant will at least quadruple because of CO_2 capture alone. Thus, the electricity grids must be quickly adapted to the new power requirements.

CO_2 utilization concepts - are being developed rapidly - with the availability of pure CO_2 as a raw material, a circular carbon economy is attractive and can be accelerated by appropriate innovations. In this scenario, CO_2 will be the carbon source of the future, from which all products such as polymers, basic chemicals as well as pharmaceutical and biotechnological products will be synthesized [3]. Calculations of carbon demand in the future assume that, in addition to industrial, unavoidable CO_2 emissions, biogenic and atmospheric CO_2 will also be used as carbon sources [4].

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INVESTIGATING THE REVERSE WATER GAS SHIFT REACTION ON NICKEL- AND PEROVSKITE-BASED CATALYSTS

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Abstract: In terms of the utilization of CO_2, the reverse water-gas shift (rWGS) reaction represents a key technology to convert CO_2 with H_2 catalytically to syngas (H_2 and CO). The present work compares the performance of a commercially available nickel catalyst and a novel perovskite catalyst in a laboratory-scale experimental setup with operating conditions between 550 and 950 °C and 1 to 8 bara. The results show that the perovskite catalyst exhibits high selectivity for the rWGS reaction and suppresses methane formation, which is favorable for downstream power-to-liquid processes. The catalyst is effectively used at temperatures between 550 and 650 °C up to a maximum pressure of 6 bara, which nearly suppresses CH_4 formation and primarily facilitates the rWGS reaction. Consequently, the CO content in the product gas is significantly higher compared to the nickel catalyst. However, to fully understand the complexity of the heterogeneous catalytic systems of the rWGS, further development of the kinetics needs to be examined and will be presented in an upcoming full paper.

Keywords: CO_2 utilization; rWGS; catalyst performance; rWGS operation conditions; low-temperature catalysis

1 INTRODUCTION

In a power-to-liquid plant for the production of renewable fuels with e.g., a Fischer-Tropsch synthesis, the reverse water-gas shift (rWGS) reaction acts as a pre-conversion step and converts CO_2 and H_2 into synthesis gas. The reaction is thermodynamically favoured at high temperatures and low pressures, although undesired side reactions like methanation and carbon formation can occur at lower temperatures and reduce the entire process efficiency [1]. Operating the rWGS reactor at lower temperatures reduces energy demand and costs due to simpler reactor design, requiring innovative catalyst development and process engineering. In the present work, the performance of a commercially available Ni/Al_2O_3 catalyst is compared with that of a novel perovskite catalyst for low-temperature catalysis, as identified by Lindenthal et al. [2].

2 MATERIALS AND METHODS

The experimental setup consists of a gas mixing station (CO_2, H_2), a quartz glass tube reactor, a cooler, and a gas analysis. The heterogenous catalytic reaction takes place in a quartz glass reactor, which is positioned in a tubular furnace and allows a catalyst bed inlet temperature up to 950 °C. In the laboratory-scale rWGS reactor, the impact of various operating conditions (temperatures between 550 and 950 °C and pressures up to 8 bara) on the product composition are investigated on a nickel and perovskite-based catalysts. A feed gas is mixed with an H_2:CO_2 ratio of 3:1. A gas hourly space velocity (GHSV) of 8000 h^{-1} is used in the experimental tests.

3 RESULTS

The experimental results obtained with the nickel-based catalyst (Figure 3-1) and the perovskite-based catalyst (Figure 3-2) are presented in this section.

The dry product gas composition is shown as data points, while the corresponding theoretical thermodynamic composition is represented by lines. The graphs illustrate the results for a gas hourly space velocity (GHSV) of 8000 h^{-1}, and a temperature range of 550 to 950 °C and 1, 3, 6 bara, and additional for 550 and 650 °C at 8 bara.

Results of the Ni/Al_2O_3 catalyst show, that thermodynamic equilibrium is achieved, favoring high CO selectivity at 950°C and ambient pressure. Methanation occurs notably at low temperatures (up to 650°C) and 1 bara, whereby methane content increases with elevated pressure. The perovskite catalyst reaches thermodynamic equilibrium at 750 and 850°C across all pressures, with maximum CO production at 650°C and pressures above 1 bara. Methanation is suppressed on the perovskite catalyst, producing only 2.7 vol.-% methane at 8 bara and 550°C, compared to 28 vol.-% with Ni/Al_2O_3.

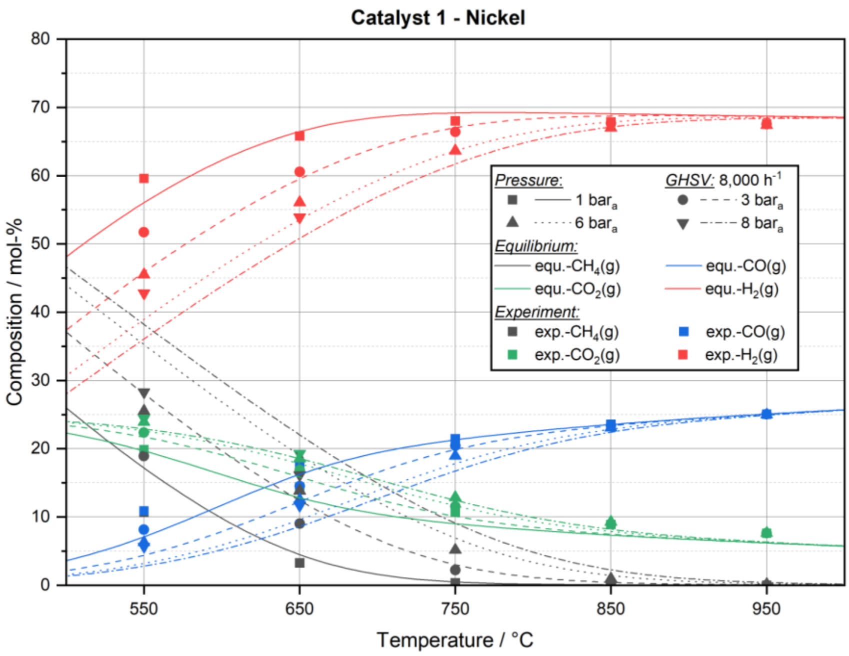

Figure 3-1: Product composition and thermodynamic equilibrium for catalyst 1 (Ni/Al_2O_3-based)

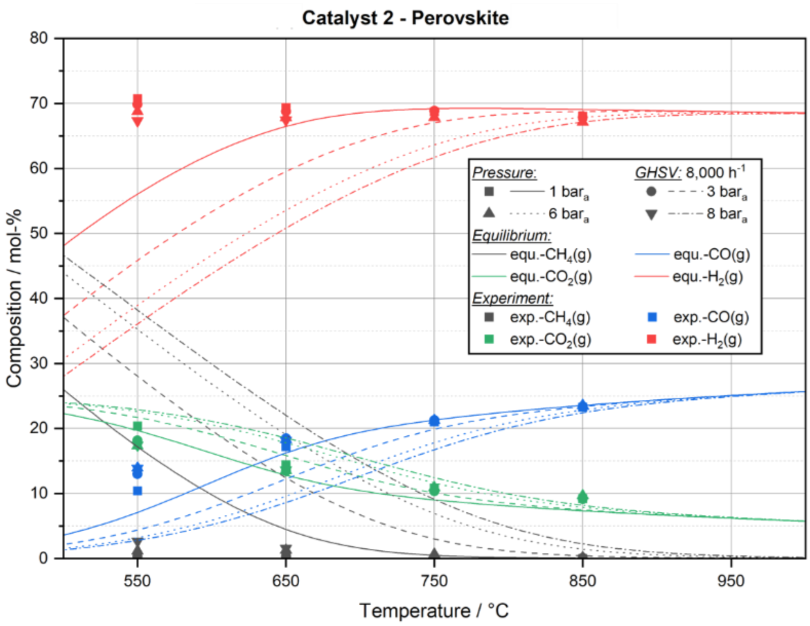

Figure 3-2: Product composition and thermodynamic equilibrium for catalyst 2 (perovskite-based catalyst)

4 DISCUSSION

The rWGS reaction is crucial in PtL processes, converting CO_2 and H_2 to syngas. This study compares the influence of operating conditions on product gas composition and CO selectivity for Ni/Al_2O_3 and perovskite catalysts. Results show that the perovskite catalyst can be operated at moderate temperatures (650 °C) with high CO selectivity and mostly suppress CH_4 formation. This novel perovskite catalyst has a significant potential for PtL processes, but it requires further investigation in terms of coke formation and long-term stability. The investigation of kinetics is part of additional studies and mandatory for modelling at operation condition where no equilibrium is achieved, as well as to address the effect of hindering CH_4 formation and possible coke formation.

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II. Session: CO_2-neutral Gases & Green Hydrogen: Modeling and Optimization

This session focuses on the development, generation, and application of CO_2-neutral gases, particularly green hydrogen, as sustainable alternatives to fossil fuels. Emphasizing scientific approaches, the session will delve into modeling and optimization strategies for the effective utilization of hydrogen.

GREEN HYDROGEN FROM SOLAR: IDENTIFYING EFFECTIVE DOPANTS AND DEPOSITION METHODS FOR HEMATITE PHOTOELECTRODES

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Keywords: photoelectrochemical water splitting; green hydrogen production; doped hematite photoelectrode; photocurrent; doping element; deposition method

Abstract: Photoelectrochemical water splitting is a promising method for green hydrogen production using sunlight. Hematite photoelectrodes present a sustainable option due to their high crustal abundance and a suitable band gap energy, enabling sunlight harvesting with a theoretical Solar to Hydrogen efficiency of 16.8 % and a photocurrent density of 12.4mA/cm² [1]. However, the inappropriate band edge alignment of hematite, the energy needed for water splitting cannot be generated solely by light, requiring additional external voltage to facilitate the process.

The misaligned band edge position can be directly adjusted through quantum confinement or indirectly modified by the use of doping elements. In addition to doping techniques, appropriate preparation and deposition methods of photoelectrodes play a crucial role in achieving the highest possible photocurrent. The right choice of doping element(s) and photoelectrode preparation method is key to advancing research progress.

This work analyses and identifies the most effective doping elements for hematite photoelectrodes and their respective deposition methods that yield significant increases in photocurrent density. The results from 125 doping experiments involving 44 doping elements or combinations show that the six most effective single dopants for homojunction hematite photoelectrodes are Gd, H, Ti, Ag, Pt, and Ta. Machine learning encoding techniques establish the numerical significance of the photoelectrode deposition method, indicating that Hydrothermal, Spray Pyrolysis, Chemical Bath Deposition,

Anodization, and Simple Solution Methods are the most effective ones. Additionally, co-doping hematite with Ti and Al clearly outperforms singly Ti-doped hematite.

1 INTRODUCTION

Currently, dominant hydrogen production pathways are fossil-based and carbon-intensive, exceeding the EU's Do Not Significant Harm (DNSH) threshold of 3 kg CO_2/kg H_2. Low-carbon electrolytic green hydrogen is expensive, with 71% of its production cost attributed to electrical energy consumption. The photoelectrochemical (PEC) water-splitting method bypasses these bottlenecks, offering a promising, low-cost, emission-free hydrogen production method using hematite (α-Fe_2O_3) as photoelectrode [2, 3].

However, laboratory results fall short of the ambitious targets in StH efficiency and photocurrent density due to hematite's poor conduction band edge position, which is more positive than the water reduction potential, preventing hydrogen reduction without external bias [4].

To address this, quantum confinement and doping techniques can improve the band-edge position of hematite [5]. Additionally, the deposition method significantly influences the photoelectrode's performance, as it affects the material's morphological and crystallographic properties. Highly crystalline photoelectrodes demonstrate superior photoactivity compared to amorphous films [6, 7]. An investigation of all possible doping elements and/or electrode deposition methods comes with enormous costs of material and time. Therefore, various photoelectrode preparation techniques have been analysed in terms of their photocurrent and deposition form.

2 MATERIALS AND METHODS

The data used for the analysis of hematite photoelectrode dopant were extracted from a broad variety of research papers with a key interest in the following features, being the most relevant parameters of photoelectrode activity:

- Used doping element
- Doping concentrations [%], directly measured or analysed and reported via X-ray diffraction
- Photoelectrode preparation and deposition method
- Device architecture of the PEC cell: homo or heterojunction
- Reported photocurrent
- Valence electrons, ionization energies, electronegativities and -positivities are also included

From the 45 doping elements/combinations on hematite from 125 experimental results, eleven features were used for the analysis. A correlation analysis was carried out on the numerical features to establish a significancy between positive or negative linear/quadratic relation with the target variable. The correlation matrix is plotted using the heatmap function from Python.

3 RESULTS

A first correlation analysis of numerical features of interest demonstrated no significant correlation between photocurrent and other parameters. Since the “Deposition Method” of the photoelectrode was initially a categorial variable, it was converted (encoded) into a numerical variable to assess its impact on photocurrent in the correlation analysis. The results revealed different performance levels of electrode preparation methods and doping elements. The hematite photocurrent performance by doping elements were sorted by high performing deposition methods and equally analysed along with their doping elements used, as visualized in Figure 3-2.

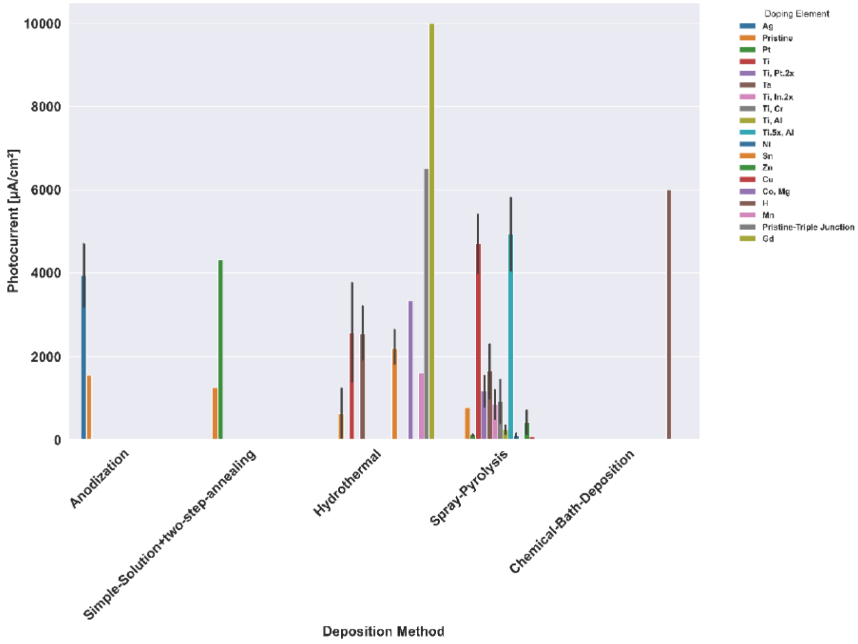

Figure 3-2: high-performing doping elements and deposition methods for hematite photoelectrode

4 DISCUSSION AND CONCLUSION

From the correlation and exploratory data analysis, the preferential single doping elements for high photocurrents in homojunction hematite photoelectrode are Gd, H, Ti, Ag, Pt and Ta with the highest correlation index on Hydrothermal deposition method. Despite the relatively high significance of this deposition method, it is not superior in all cases and its effectiveness depends on the used doping element. Pristine and Ti-doped hematite yield more photocurrents with respectively Anodization and Spray-Pyrolysis than the Hydrothermal deposition method. Even though the Hydrothermal method seems to be an effective way, its efficacy on hematite is based on the doping element employed. By the identification of key dopants in combination with optimized deposition methods, the minimum benchmark of STH efficiency of 10 % is feasible, providing a great potential for revolutionizing green hydrogen production by paving the way towards an elevated efficiency from a materials perspective.

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ON THE ADVANTAGES OF DYNAMIC SIMULATIONS WHEN MODELLING MULTI-NODE BLENDING OF GREEN HYDROGEN

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Abstract: Current advances and ongoing efforts towards reaching Austria's decarbonisation goals increasingly rely on an efficient integration of renewable hydrogen into the energy system. Besides its suitability for long-term energy storage, and potentials to directly convert (excess) renewable electricity into hydrogen, one of its most crucial roles as energy carrier lies in replacing natural gas where applicable. Especially for energy-intensive sectors, like industry and heavy-duty transport, this offers opportunities and flexibilities that are not achievable with electrification alone. However, this substitution relies on a sufficient hydrogen infrastructure. Until a dedicated hydrogen pipeline grid is in place, blending hydrogen into the existing gas grid can play a crucial role for its system integration. Further, injecting green hydrogen into the gas grid reduces CO_2 emissions of all connected demands, including industrial processes such as refineries, and large-scale heating systems. This work discusses the importance of accurate modelling approaches, capturing important real-world effects of the varying properties of a gas-mix under a wide range of hydrogen injection modes, resulting from the intermittent nature of renewable energy generation. First results show that a steady-state approach is insufficient to accurately represent hydrogen concentrations in dynamic scenarios, highlighting the need for a dynamic model to ensure effective gas network management and compliance with hydrogen concentration limits.

Keywords: green hydrogen; hydrogen blending; integrated energy system; hydrogen infrastructure

1 INTRODUCTION

Achieving climate neutrality by 2040 requires reductions in CO_2 emissions across all sectors. Green hydrogen, produced via electrolysis, can be used to decarbonise heavy-duty transport and industry, and further constitutes a flexible sink for excess renewable electricity. While large-scale infrastructure, such as hydrogen pipelines, is essential to supply various demands, injecting hydrogen into the existing natural gas grid can play a crucial role when ensuring sufficient and efficient hydrogen distribution. However, hydrogen injection affects fluid dynamic properties, which has implications for gas network management and energy flows within the system. In addition, the availability of green hydrogen and the regulatory feasible hydrogen injection rates vary dynamically, requiring detailed system analyses, especially for a network with multiple injection nodes.

The project *"Hydrogen Region East Austria goes Live"* (H2REAL) [1] aims to further develop hydrogen as a technology and its applications in the region of Eastern Austria. As part of H2REAL, this work contributes to the quantitative modelling tasks, by accurately modelling fluid dynamic properties in a network with multiple injection nodes. The following sections showcase insights and first results of the ongoing development of a dynamic simulation tool that is used to study the effects of different injection scenarios and supports determining an optimal integration strategy.

2 METHODS

Multi-node hydrogen injection requires a dynamic model of the physical gas flow. Existing literature on blending focuses on the analysis of the gas network under steady flow conditions [2], on dynamic quality tracking [3], or on the response to network operations [4]. However, there is a lack of focus on multi-node hydrogen injection and inherent interdependencies, highlighting the need for a dynamic investigation of multi-node hydrogen injection. The developed tool consists of gas network components (e.g., pipes, junctions, gas sources) which are implemented in Julia-programming language using *modelingtoolkit.jl* [5]. To model the physical gas flow in the components, the fluid dynamic balance equations are used with a finite volumes approach. In each volume, a set of three differential equations is solved, accounting for pressure, mass flow and hydrogen concentration. Therefore, the numerical effort of the dynamic simulation increases with the number of volumes within the grid. This tool allows constructing a large network, while accounting for various boundary conditions and scenarios. Especially for systems with multi-node hydrogen injection, important factors like limits on hydrogen-injection and choice of injection points (e.g., related to branches of lower grid-levels) require a comprehensive analysis. Furthermore, time-depending supply and demand profiles, which are subject to temporal (non-)simultaneity, may induce con-/destructive interference of the properties of the considered gas-mix.

3 RESULTS

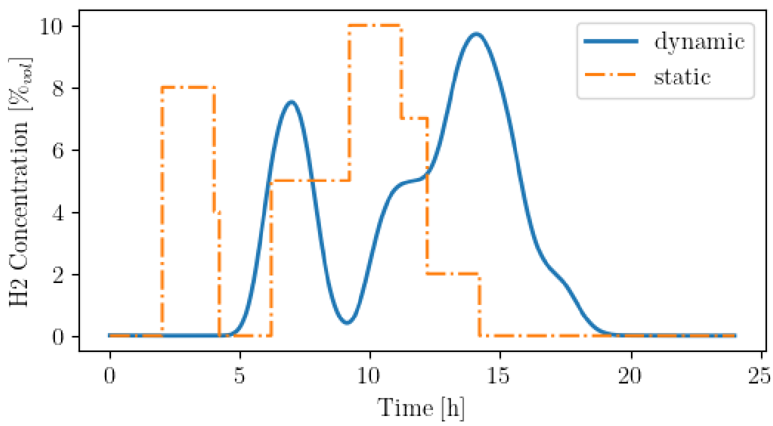

Figure 3-1: Comparison of hydrogen concentration from a static and dynamic simulation at the end of a 50 km pipe with inlet pressure of 55 bar, varying hydrogen concentration and a constant supply of 1 GW.

A comparison was conducted between the outlet hydrogen concentration of a gas pipe within the dynamic model and the steady flow approach. The presented example comprises a gas source with a fixed pressure of 55 bar, a sink with a demand of 1 GW, which equates to a methane flow of 18 kg/s, and a 50 km pipe with a diameter of 0.4 m. The inlet gas mixture is a time varying step function of hydrogen concentrations between 0 and 0.1 (dotted line). In the case of steady flow, the hydrogen concentration is identical at the inlet and outlet. However, the dynamic simulation shows a delayed and “smoothed” curve at the end of the pipe (Figure 3-1), resulting from the slow gas flow compared to the immediate change in hydrogen concentration at the inlet of the pipe.

4 DISCUSSION

Results show that the static approach is sufficient to ensure compliance with hydrogen concentration limits for a single injection point or constant injection rates. However, if there are multiple blending nodes along the pipeline, the inert flow may cause injection peaks of different suppliers to overlap, possibly exceeding the maximum hydrogen concentration limits. This issue becomes even more complex for large and interlinked network sections. Further investigations show that parameters such as pressure and density are similarly affected by the impact of a realistic model of a hydrogen-enriched gas, which further supports this modelling approach. Nevertheless, the dynamic model is constrained by the number of discretisation volumes, which concomitantly increases the numerical effort. Consequently, this limits the precision, especially of the hydrogen concentration, which is strongly affected by numerical diffusion.

Funding information. *This project is funded by the Austrian “Klima- und Energiefonds” and runs within the scope of the program „Vorzeigeregion Energie“.*

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OPTIMIZING LARGE-SCALE PEM ELECTROLYSIS FOR GREEN HYDROGEN PRODUCTION: A COMPREHENSIVE TECHNO-ECONOMIC CASE STUDY

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Abstract: As global energy generation shifts towards renewable sources, hydrogen is increasingly vital for mitigating the intermittency of wind and solar power. Proton exchange membrane (PEM) electrolysis, with its rapid dynamic response, is well-suited for green hydrogen production, though it generates waste heat.

This study assesses the techno-economic potential of a large-scale PEM electrolysis system powered by renewable energy. Electrolyser, wind, and solar capacities are varied, furthermore the system includes a compressor for hydrogen pipeline integration. The feasibility of utilising excess heat for district heating is additionally explored to enhance system efficiency. For simulation purposes a comprehensive PEM electrolysis model is integrated into an existing renewable energy simulation framework.

Results are expected to indicate that repurposing waste heat for district heating can improve overall system efficiency. The Levelized Cost of Hydrogen is anticipated to decrease with higher electrolyser utilization, affected by full load hours and heat sales.

This study aims to demonstrate the potential of integrating proton exchange membrane electrolysis with renewable energy to produce hydrogen and heat efficiently in future energy systems.

Keywords: Proton Exchange Membrane Electrolysis; Techno-Economic Analysis; Green Hydrogen; Waste Heat Recovery; Renewable Energy System; Modelling

1 INTRODUCTION

Renewable energy sources are paramount in achieving a sustainable energy system of the future. However, the volatility of wind and solar energy production present significant challenges. To address these issues, hydrogen has gained considerable attention in recent years for its service as an energy carrier in the energy transition. One possibility to manufacture green hydrogen is PEM electrolysis, during which water is split into hydrogen and oxygen. As this technology is ideally suited to utilise renewable energy and provide balance to the grid, it has large potential and is closely investigated during this work. [1–4].

However, since the electrolyser has a limited efficiency, a considerable part of input energy is lost as heat. Consequently, there is also a growing interest in extracting and recycling the waste heat and subsequently achieving a higher system efficiency. [5, 6]

The aim of this research paper is to conduct a techno-economic analysis of a renewable energy system that is centered around a large-scale PEM electrolyser and geographically located in the east of Austria, Burgenland. The system is displayed in Figure 1-1. As a first step it includes renewable energy sources, namely wind and PV capacities, which supply the electrolyser with electricity and are varied throughout the simulation to determine their impact. Further, converters are needed before the electricity reaches the PEM electrolyser itself, which is additionally flexible in size. The produced hydrogen is then compressed and supplied to a hydrogen collector that connects the rural area of production with the city of Vienna, where the hydrogen is ultimately consumed. Additionally, a goal of this work is to analyze the potential of re-purposing the generated waste heat as a supply source for a local district heating network.

Throughout the system analysis technical and economic key performance indicators (KPIs) are investigated. The focus is on the system efficiency and the Levelized Cost of Hydrogen (LCOH) as well as Heat (LCOHeat) and how those parameters are affected by various system configurations.

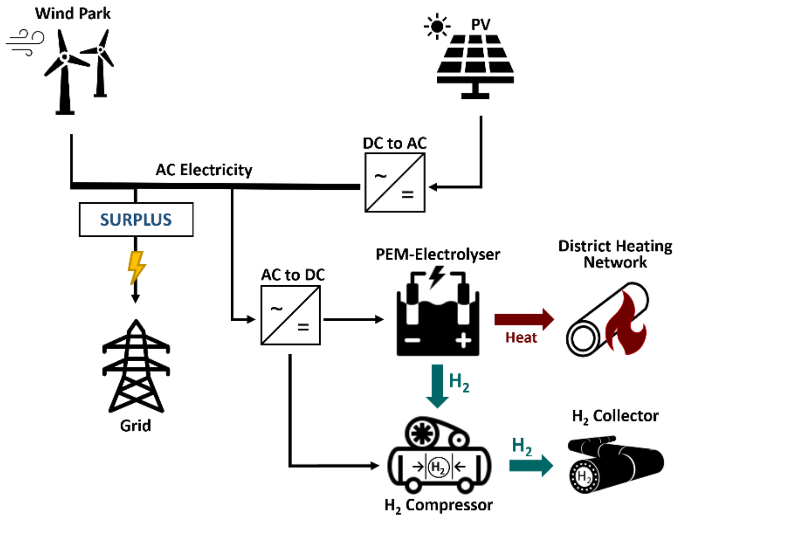

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Figure 1-1: System Boundaries and Visualisation

2 MATERIALS AND METHODS

For the evaluation of the described system, a semi-empirical PEM electrolysis model is implemented into an existing simulation framework designed for analysing renewable energy systems. The electrolyser model represents one component of the system and consists of a hierarchy of stacks and cells. Within the model the cell is characterised based on electrochemical and empirical correlations and, further the thermal behaviour of the stack is depicted and a cooling mechanism for the electrolyser is integrated.

To investigate the techno-economic performance of the system, a number of KPIs are determined. The overall system efficiency – especially including waste heat - is arguably the most important technical aspect, while the LCOH and its potential improvement by utilising waste heat is crucial for the economic analysis. Additionally, the LCOHeat is calculated to verify a viable heat recycling process.

3 RESULTS

Results are expected to indicate an improved system efficiency when re-purposing electrolysis waste heat as a supply source for a district heating system. Depending on the similarity of the DH demand and surplus heat generation, this enhancement is predicted to vary. Furthermore, the LCOH will be correlated with the resulting full load hours of the electrolyser. As far as the viability of heat extraction is concerned, it is assumed that for a good enhancement of overall efficiency, the connected LCOHeat will be sufficiently low.

4 DISCUSSION

To sum up, findings are anticipated to highlight the potential of coupling PEM electrolysis and renewable energy to produce hydrogen and heat simultaneously in future energy systems.

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III. Session: CO_2-neutral Gases & Green Hydrogen: System Integration

This session focuses on the advancement, production, and integration of CO_2-neutral gases such as green hydrogen, bio-CH_4, and Syn-CH_4, serving as sustainable alternatives to fossil fuels. The session will highlight scientific strategies for optimising and integrating these gases into existing and future energy systems.

ELECTROLYSIS IN DISTRIBUTION GRIDS: A REGULATORY VALUATION ON GRID-SUPPORTIVE OPERATION

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Abstract: The massive deployment of renewable electricity generation technologies requires significant electricity grid expansion and enforcement measures. Grid- supportive operation of electrolysis may act as an alternative to overcome grid constraints in a timely and effective manner. However, in liberalised markets, grid operators are not allowed to own and operate storage assets. This work investigates the regulatory feasibility on the basis of the draft of the new Austrian Electricity Act (Begutachtungsentwurf des Elektrizitätswirtschaftsgesetzes, ElWG draft). In fact, there is only one feasible option which allows DSOs to own and operate electrolysis: An exceptional permission from the regulatory authority following a negative tender and the check of alternatives. Only then, the DSO is allowed to operate the facility in a grid-supportive way. Any other market-based operation is ruled out.

Keywords: Distribution grid; Electrolysis; Grid-supportive operation; Regulatory analysis

1 INTRODUCTION

The strong expansion of wind power and photovoltaics leads to a significant additional burden on the electrical networks at all voltage levels, which in turn requires enforcement of the electricity grid. A potential alternative to conventional grid enforcement measures is the operation of electrolysis in a grid-supportive manner. However, the ownership and operation by distribution system operators (DSO) faces a significant regulatory hurdle, as grid operators are not permitted to operate any type of storage or generation assets, except in defined exceptional cases. According to the definition in the ElWG draft [1], electrolysis is considered an energy storage system. § 72 of the ElWG draft states that network operators are not allowed to own energy storage systems or to build, manage or operate these systems. However, exceptions to this are also given. The key question of this work is to investigate potential operating strategies for electrolysis with regards to their legal feasibility in relation to the ElWG draft as well as economic performance compared to conventional grid expansion measures.

2 MATERIALS AND METHODS

In the following, a list of potential operation strategies is provided. All operating strategies must contribute to maintaining secure, efficient network operations (referred to here as "grid-supportive").

Operation strategy 1a – Grid supportive operation by the DSO

- Smoothing of renewable production peaks plus eventually a certain baseload

Operation strategy 1b – Grid supportive and market-based operation by the DSO

- In addition, market-based operation is done depending on hydrogen/electricity prices

Operation strategy 2 – Grid supportive by the DSO, market-based operation by a third party

- A certain capacity is rented to a third party
- Third party operates the facility in a market-based manner

Operation strategy 3 – Grid supportive and market-based operation by a third party

- Full capacity is rented to a third party
- Third party operates the facility in a market-based manner

3 RESULTS

There are two cases under which DSOs can become owners and operators of electrolysis: The first option is the direct approval through the regulatory authority. The second is obtaining an 'exceptional permission' from the regulatory authority, following a negative tender.

Deployment option 1: direct approval through the regulatory authority. For this option, the electrolysis needs to qualify as a fully integrated network component (FINC). The ElWG draft introduces a definition of a ‚FINC': It means components, (including storages), „which are integrated in the transmission or distribution grid, contributing exclusively on the secure and reliable network operation, not contributing to system balancing or congestion management and typical charging/discharging intervals are significantly below the market time unit." (§ 6 para. 1 ElWG draft). In the annotations on the ElWG draft, it is stated that the market interval amounts to 15 minutes according to Regulation (EU) 2017/2195 [2].

Deployment option 2: Exceptional permission following a negative tender: This case requires an exceptional permission, presuming a negative tender result. A further requirement is the examination of alternatives according to §72 para. 3, which are available in a more cost-effective or more timely manner than the deployment of energy storages. As an option of more effective or more timely alternatives, the market-based procurement of flexibility services according to §120 needs to be checked.

A valuation of combinations of operation and deployment options regarding their regulatory feasibility is illustrated in Figure 3-1. Under deployment option 1, it is not possible to operate the facility grid-supportive, since (dis-)charging intervals will typically lie above 15 minutes for the purpose of smoothing wind power and photovoltaic peaks. This also holds for the case in which a third-party acts as the operator. . In addition, market-based operation under deployment option_1 is definitely excluded, as the unit may be used exclusively for secure network operation. In fact, there is only one feasible option for DSOs to own and operate electrolysis as an alternative to conventional grid expansion measures: Presuming a negative tender result, DSOs are allowed to operate the unit for grid-supportive purposes only (deployment option 2, operating Strategy 1a). The facility is not allowed to buy and sell electricity on markets.

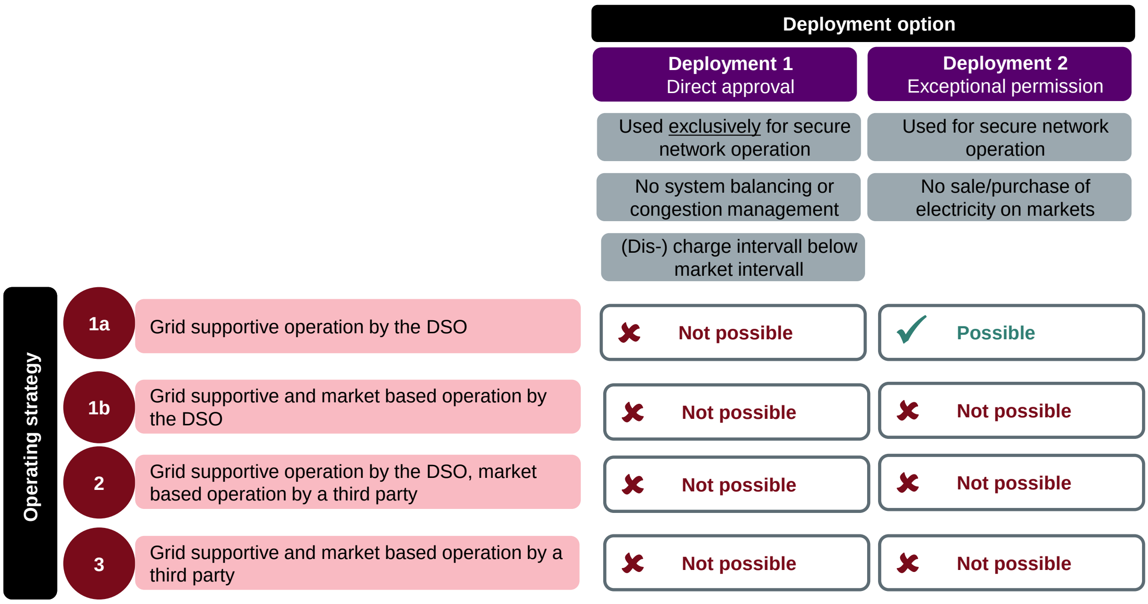

Figure 3-1: Feasible operation strategies of electrolysis under §72 ElWG

4 DISCUSSION

It is very likely that the only feasible operating strategy does not enable economic viability and comes as a very expensive option compared to conventional grid enforcement measures, since the load factor for the electrolysis might be very low. The Austrian law is stricter than required by the EU Directive 2019/944 [3] due to the inclusion of the 15-minutes-constraint into the definition of a FINC. This leaves virtually no room for DSOs to run energy storage facilities like electrolysis, despite it might be a more efficient measure compared to conventional grid expansion.

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INDUSTRIAL HYDROGEN IN EUROPE: PRODUCTION, INFRASTRUCTURE, AND APPLICATIONS

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Abstract: 38 partners around Europe work together on different innovations to boost the production, transport and use of green hydrogen. Under the project Hy2Market (HYdrogen TO enter MARKets reducing carbon Emissions footprinT in Europe) partners from Northern Netherlands, Upper-Austria, Rhone-Alpes, Asturias, Aragon, Castilla y Leon, Medió Tejo, Sicily, Western Macedonia and Constanta work together to realize a more mature hydrogen value chain across Europe. Through this interregional access, the exchange of knowledge can take place at a lower threshold and therefore more quickly. This allows new insights into the field of hydrogen production and use to be gained and a robust and innovative hydrogen value chain can be installed. Each step on the hydrogen value chain has another specific focus. At the hydrogen production the management systems are examined in more detail, at the transport existing and new infrastructure are taken into account and at the offtake of green hydrogen industry and mobility applications are involved. The Austrian partners of the project focus on the industrial use of hydrogen as feedstock and for energetic use. In particular it involved an upgrade from the 6 MW PEM electrolyser of the H2Future facility and from a mobile methanation container with 20 kW up to 100 kW.

Keywords: Hydrogen; Methanation; Electrolyser; industrial use; European cooperation;

1 INTRODUCTION

The Hydrogen strategy for a climate-neutral Europe of the EU commission names hydrogen as a ‘key priority to achieve the European Green Deal and Europe’s clean energy transition’. Further the strategy identifies investments, regulatory frameworks, new lead markets, research, innovation and a large-scale infrastructure network as requirements for the further use of hydrogen. It is clear from the strategy that cost reduction has a key role in further stimulating demand. For this to be possible, upscaling must take place, which can only be achieved if innovations take place along the entire value chain [1].

To reach these objectives knowledge exchange between different regions all over Europe is necessary. To achieve this knowledge exchange variety of companies, including SMEs from all the regions participate in collaboration with regional entities that are focused on enhancing the Hydrogen eco-system in their region, and throughout Europe. Based on already existing project from the Hy2Market region as for example HEAVENN [2], ITEG [3] and Green Hysland [4] the consortium identified their most close to market investments along the hydrogen value chain and the barriers they still facing: 1.

Economic barriers: most projects deliver expensive green H2 that is not economically competitive; 2. Technical barriers: operational optimisation of hydrogen production and scale up, lack of permanent infrastructure for transport and storage of pure hydrogen at low costs and large scale. Lack of experience with hydrogen in industrial applications and power production and heavy mobility; 3. Legislative and normative barriers: non-adapted legislation and/or standard framework or a lack thereof which prevents and seriously hinders projects.

2 METHODES AND GOALS

The collaboration of the different companies all over Europe aims to achieve the following goals 1. Transition towards a sustainable and green energy system based on carbon neutral fuels; 2. Economic development by SMEs and other partners in the quadruple helix; 3. Strengthening the competitiveness of European regions and companies on the global hydrogen market.

The Austrian contribution to achieving these goals are demonstrate hydrogen application in industrial processes, where hydrogen will be used as a feedstock and an energy carrier in an efficient way. Over the last five years several projects in Austria showed that need of green hydrogen in the different industrial sectors (chemistry, cement, steel). Some of the sectors already use hydrogen and want to go from green-to-grey [5], others are hard-to-abate applications [6]. At Hy2Market Austria improve already existing pilots further by scaling them up and expand them with new skills.

3 RESULTS FROM THE AUSTRIAN PROJECT SIDE

3.1 Hydrogen as Feedstock

Since 2019 the H2Future plant with the 6 MW PEM electrolyser is in operation, production hydrogen with a quality of 99.98 Vol-% hydrogen. The operation pressure is around 100 mbar. The use of the produced hydrogen is so fare on a low value, since the plant was used in test operation until end of 2021 and the use-cases are successfully executed since then. At the moment it is running in cost optimized mode providing grid services.

The project partners work on the design, installation and operation of a compression and purification system for the produced hydrogen in order to produce a hydrogen which is suitable for demanding applications. A large factor in contamination comes from the increased moisture content of the hydrogen. The purification gives the opportunity to produced hydrogen with a quality of 5.0 (99.999 Vol-% hydrogen), which fulfil the ISO 14687:2019 requirements. The compression works gradually and produces a pressure up to 500 bar, which gives the possibility that trailers and bottle can be filled and the hydrogen can be transported to other regions.

3.2 Hydrogen for Energetic Use

For the energetic use of hydrogen, a catalytic methanation pilot plant in the steel industry next to an amine scrubber pilot plant will be built in Austria. For the amine scrubber, the commissioning has been accomplished by the end of 2022. With the amine scrubber up to 800 kg CO_2 per day can be captures and compress. The other part of the pilot plant is the mobile catalytic methanation container. So fare the containers works with 20 kW_{sng} and was placed in Leoben. Now the container has been moved to Linz and will get an upgrade to 100 kW_{sng}. The planning and basic engineering has been finished and so that the tender process is going on right now.

4 DISCUSSION AND CONCLUSION

The project is still ongoing. As soon as all pilot systems are put into operation, operational data will be collected and evaluated for further improvement. The data can be shared in knowledge exchange with project partners across Europe, thereby increasing the impact of the results a valuable contribution is made to the further development of a hydrogen economy system.

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Funded by the
European Union

MODELLING THE FUTURE HYDROGEN SYSTEM: INSIGHTS FROM THE HYDROGEN VALLEY "EAST AUSTRIA"

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Abstract: The ongoing project H2REAL, "*Hydrogen Region East Austria goes Live*", aims to combine domain knowledge, existing assets, infrastructure, and real-world demonstrators, with scientific support to further develop the hydrogen infrastructure of Eastern Austria during the upcoming years. This work introduces the systemic modelling approach, undertaken as part of the project, that is used to analyse the emergence, transition, and to-be-achieved ideal design of the Austrian hydrogen infrastructure, that is indispensable to support imports, production, and transportation of hydrogen to wide range of customers. As part of the ongoing decarbonization of the industrial sector, the substitution of fossil energy carriers – especially natural gas – through renewable hydrogen is expected to play a major role in the upcoming years. The presented work applies a two-stage modelling approach, using the IESopt framework, to combine influential externalities derived from a global hydrogen model, with an energy system and infrastructure model featuring a high spatial resolution of depicted possible options of the East Austrian hydrogen system. This model is embedded into a European modelling region, and covers the sectors electricity, heat, and hydrogen. Further, accounting for climate change related effects and considering (besides other important factors) supply- and demand-side flexibilities, allows for a high explanatory power.

Keywords: Hydrogen Valleys, Infrastructure Modelling, Energy System Modelling, Optimization

1 INTRODUCTION

During recent years, hydrogen has emerged as a pivotal element in the energy transition, gathering significant attention in both political and scientific spheres. Despite its growing importance, the hydrogen sector remains underdeveloped in terms of existing infrastructure, especially when compared to other energy sectors. The H2REAL project [1] seeks to address this shortfall by encompassing nearly twenty partners such as energy providers, grid operators, logistics and distribution firms, alongside prospective consumers. It aims to establish a comprehensive hydrogen infrastructure in the newly formed East Austrian hydrogen valley, which will feature large-scale demonstrators[1] as well as in-depth system modelling.

To accurately model Austria's energy system, the fully sector coupled IESopt energy system optimization framework [2] is employed. It features, i.a.: Various hydrogen (and its derivatives) production and transportation options (H2-pipelines, blending, trailers, as well as trains and ships) on a global scope, storage solutions, and flexible hydrogen demands. It is incorporated into a broader European model context, accurately depicting the influence of climate change.

1 Including electrolysis sites of up to 300 MW, or the utilization of hydrogen as fuel for power plants.

2 MATERIALS AND METHODS

A realistic modelling of the future Austrian hydrogen infrastructure requires different levels of detail. In contrast to electricity, hydrogen or a derivative can be transported over long distances (e.g., using ships). Hence, studying hydrogen requires a broad geographical scope (c.f. 2.1). On the flipside, almost all future hydrogen infrastructure options are “to-be-invested-in": Currently, no notable infrastructure exists, and must therefore either be repurposed from existing natural gas (methane) infrastructure or be built from the ground up. Such a greenfield situation may allow for extremely diverse, and still comparably “optimal” options, which requires capturing as much detail as feasible to not involuntarily overlook important decisions, which is briefly discussed in 2.2.

2.1 Embedding Austria into a global scope

To account for global effects, we employ a two-stage approach: The first stage constructs a global hydrogen model[2], that considers world-wide transport routes for hydrogen (and derivatives), based on monthly time-periods. It allows quickly incorporating different assumptions on costs, available production/transport capacities, as well as timings (e.g., varying times for the availability of impactful projects like the “SoutH2 Corridor” [4]). The second stage then uses the results obtained from the first stage as boundary conditions for a European sector-coupled energy system model run, that explicitly considers interactions between electricity, heat, and hydrogen sectors.

2.2 High spatial resolution for the H2REAL valley

While the exact spatial design of the hydrogen system in countries “far” from Austria may have a vanishing importance on the Austrian infrastructure, detailed information for neighbouring

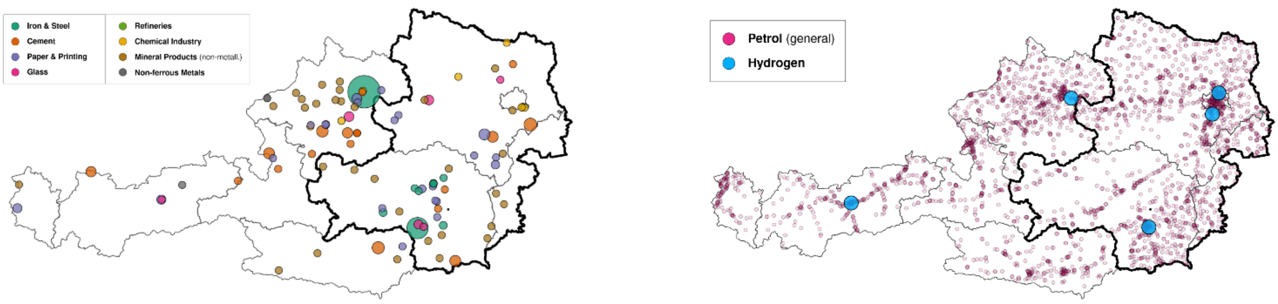

Figure 2-2: (left) Industry sites [5] across Austria, highlighting (black border) the H2REAL modelling region, sized proportional to annual fuel demand. (right) Current state of petrol/hydrogen filling stations across Austria [6].

countries, the whole of Austria, and especially the Eastern hydrogen valley, are crucial to identify and demonstrate the effects of different infrastructure-design decisions. As an example, Figure 2-2 showcases two of the many required (spatially) detailed input datasets.

[2] First results are published in [3], while a comprehensive version has been accepted for presentation at the *“20th International Conference on the European Energy Market”* and will be published in proceedings.

3 RESULTS

First results of the global hydrogen model (for 2030), based on a total amount of 40 Mt_{H2} of annual production capacities for renewable hydrogen (out of those, 19 Mt_{H2} in Europe), with 2.8 to 5.2 EUR_{2030}/kg_{H2} of levelized costs of production, showcase a high potential for continental autarky. Due to the comparatively low amount of 6.3 Mt_{H2} annual demand[3] in the "transition year 2030", and long-distance transportation suffering from high costs, Europe almost entirely covers its demand for hydrogen "locally" (with the main producers being the BE, NL, DK, DE, and the UK). On the Austrian level, first results suggest that investments connecting high-demand industrial sites to the emerging hydrogen backbone present no-regret decisions, while distributed low-volume demands are either covered by decentral small-scale electrolysis plants or through the supply of hydrogen via trailers.

4 DISCUSSION

While a diverse set of measures, across all sectors, will be necessary to achieve current decarbonization goals, renewable hydrogen can be expected to play a major role in the transition to a CO_2 neutral industrial sector. Using the comprehensive energy system modelling framework IESopt, we will further discover, analyse, and present increasingly detailed options and decisions for the 2030-to-2050 transition path of (Eastern) Austria's hydrogen system.

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Funding information. *This project is funded by the Austrian "Klima- und Energiefonds" and runs within the scope of the program „Vorzeigeregion Energie".*

[3] Assuming 42% of industrial (excl. refineries) demand covered by RFNBOs, in accordance with RED III, a 1% quota in the transport sector, the historical energy demand of 2022 translates to 4.4 MtH2. Additional 1.7+0.2 MtH2 for additional decarbonization measures (optimistic case) in the "steel industry" + "heating/other" sectors, result in 6.3 MtH2 of annual demand.

STRATEGIC ANALYSIS OF REGIONAL BIOMETHANE INJECTION POTENTIAL FROM AGRICULTURAL RESIDUES: LEVERAGING LP OPTIMIZATION FOR ECONOMIC ASSESSMENT

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Abstract: Biomethane, a green gas, represents a rapidly scalable Green Gas technology for short-term implementation. This paper introduces a Linear Programming-based methodology for estimating the economic potential from a previously derived technical potential, while concurrently devising the optimal distribution of the plant network. The LP-based model was developed based on various assumptions concerning revenue, investment and operating costs, substrate processing characteristics, substrate pricing, and transportation. The derived method is demonstrated using the example of the "Lower Austria" region in Austria. Different agricultural residues were considered as potential substrates. A base-case scenario was set up and investigated to demonstrate the model's characteristics and limitations. In this scenario, realizing the full economic biomethane potential identified would result in a theoretical green gas quota of 14 $\%_{TWh}$ for the Lower Austria region, assuming gas consumption from 2021. Additionally, a detailed sensitivity analysis was conducted to demonstrate how different model parameters affect the results. It was observed that the utilization yields of plant residues were higher than for animal manure, making plant residues more economically feasible within this model. Furthermore, this study presents the optimized plant network and the geographic distribution of the assessed biomethane potential for the base-case scenario.

Keywords: Biomethane Injection, Linear Optimization, Green Gas, Process Systems Engineering

1 INTRODUCTION

Biomethane holds significant potential for short- and mid-term Green Gas goals due to it being an already well-established and well understood digestion technology. Recently, biomethane has also become crucial for Austria's energy diversification, especially in consideration of the intended exit from Russian gas. [1] However, development has stagnated or even declined within the last years. [2] It is crucial to assess and understand the biomethane injection potential to maximize substrate utilization. Linear Programming (LP) has been used in previous attempts to investigate systematic biomethane utilization. [3] [4] While several estimations for the biomethane potential in Austria have been published, none have employed an LP model for their top-down assessment of this potential. [5] [6] This study aims to develop an LP model to estimate the economic potential for the region "Lower Austria" from a previously derived technical potential while also optimizing the plant network for maximum biomethane production.

2 MATERIALS AND METHODS

The LP model is built on various assumptions to characterize the system. It uses a previously derived technical biomethane injection potential and several technical or economic model parameters as input. Its objective function aims to maximize total biomethane production across all municipalities. The decision variables x_{ijk} represent the quantity of raw material *k* from municipality *i* utilized in municipality *j*, with a non-negativity constraint applied. A "Substrate Abundance-Constraint" ensures that the total use of each substrate *k* from municipality *i* does not exceed the physically available raw material. Economic feasibility is maintained through a constraint that requires the Net Present Value (NPV) of each biomethane injection plant to be non-negative. An equality constraint restricts the processing of raw materials in municipalities without access to the gas grid. An iterative solving procedure is implemented to ensure that plant sizes in the model are realistic.

3 RESULTS

In the base-case scenario, an economic biomethane injection potential from agricultural residues of just under 1.9 TWh per year was identified for the region Lower Austria. The injection potential consists of 95 $\%_{TWh}$ plant residues and 5 $\%_{TWh}$ farm manure. The distribution of this potential and injection plant is displayed in Figure 4-1. It may also be noted here that the iterative solving procedure imposed within this LP model has a substantial impact on the number of plants and their distribution in the beginning of the iterative solving procedure.

4 DISCUSSION

Realizing the full economic biomethane potential identified in the base-case scenario would result in a theoretical green gas quota of 14 $\%_{TWh}$ for the Lower Austria region, assuming natural gas consumption from 2021. The high proportion of plant-based agricultural residues in the substrate mix appears somewhat unrealistic for practical implementation. Nonetheless, this finding highlights the critical role that plant-based agricultural residues must play in the development of a Green Gas network. To increase the utilization of animal-based agricultural residues, higher biomethane revenues than those considered in the base-case scenario would be necessary. From Figure 4-1, It can be seen that the assessed biomethane injection potential is higher near injection plant locations. Access to the gas grid is crucial for harnessing a region's biomethane potential, as large areas without grid access have low utilization. Sensitivity analysis showed that biomethane revenue, CAPEX, and OPEX significantly influence the model, while transportation has minimal impact. This study primarily introduces the LP-based methodology for addressing this problem. The base-case model parameters were chosen for demonstration purposes and may differ in other contexts. As with all LP models, the assumptions and linearization affect result accuracy, highlighting trends rather than achieving a practical optimum.

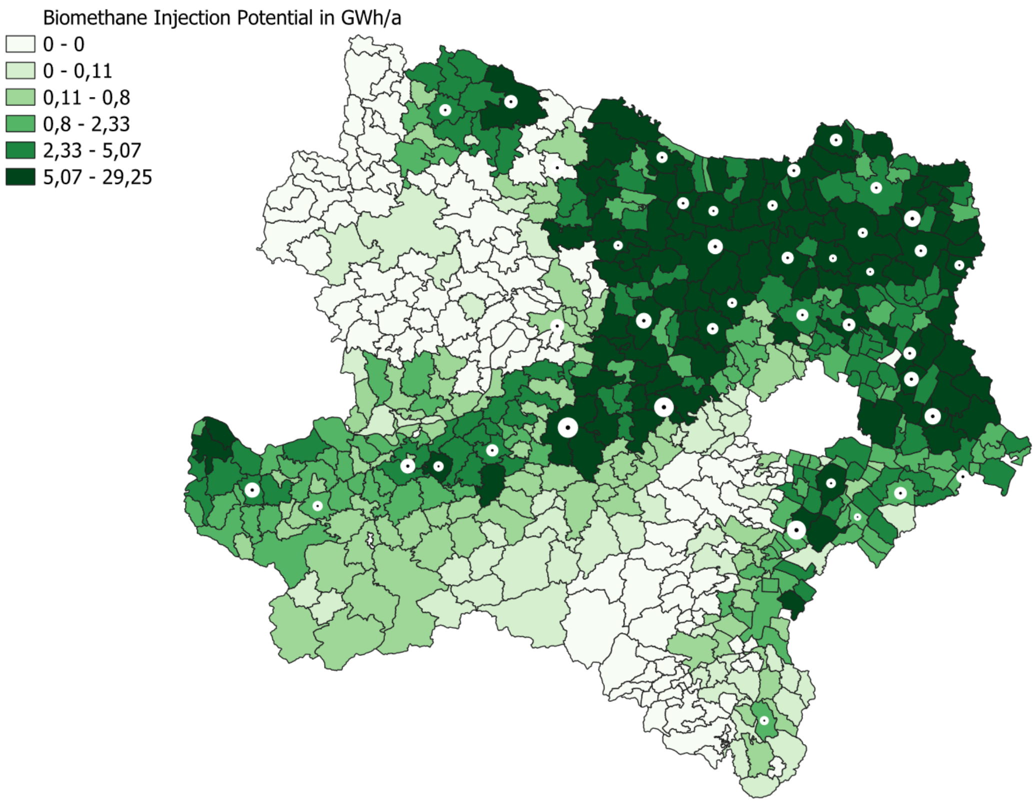

Figure 4-1: Geographical Distribution of the Economic Biomethane Injection Potential and optimized Locations of Injection Plants (Centroid Size corresponds to Injection Plant Capacity)

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IV. Session: Strategies for Industrial Demand Response

This session explores innovative solutions for managing volatile energy generation through enhanced demand-response approaches in industry and the efficient design of production processes. Contributions will focus on optimising production scheduling, cross-factory energy and production integration, and demand response strategies to improve flexibility in various industrial contexts.

CROSS-FACTORY PRODUCTION AND ENERGY OPTIMIZATION

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Abstract: The energy transformation to an electricity-based system to reduce greenhouse gas emissions creates challenges for companies in energy-intensive manufacturing sectors, i.e. increasingly volatile energy prices and at times the danger of power outages or compulsory measures to maintain grid stability are two major concerns. While approaches for optimized demand side management and utilizing energy flexibility via optimized planning and control are emerging for the factory level, the considerable potential for cross-factory optimization of energy use to improve grid stabilization and cost-effectiveness is still untapped. This paper proposes a concept for cross-factory energy optimization, featuring a simulation-based optimization of the manufacturing process along with the associated energy consumption. Special emphasis is put on developing methods to achieve cross-factory optimization while preserving the data confidentiality of all participating companies. The paper presents the preliminary findings from a use case in the energy-intensive Austrian steel industry.

Keywords: sustainable production; flexible energy systems; production planning and control; simulation-based optimization; cross-factory optimization

1 INTRODUCTION

The shift towards a carbon-neutral energy system, based on renewable energy sources, is pivotal for mitigating greenhouse gas emissions and addressing climate change [1]. Industrial production, responsible for a substantial share of energy consumption [2], is integral to this transition. The integration of variable renewable energy sources into the grid presents challenges, particularly in maintaining grid stability. Grid stabilization through optimized energy flexibility within the distribution grid is critical for managing these challenges [3]. In previous work, the authors of this manuscript developed and evaluated a digital twin-based optimized planning and control to achieve industrial energy flexibility for single factories [4]. However, there is considerable potential for cross-factory and distribution-grid-wide energy flexibility optimization, for which solutions are yet to be developed.

Currently, there are first concepts for taking the optimization approach to a cross-factory level in the energy-intensive steel for process industry [5] – while the manuscript at hand aims at steel processes in the logistically more complex discrete steel goods manufacturing. Key questions about cross-factory production and energy optimization remain unresolved, including the mechanisms for grid stability enhancement, data confidentiality methods, efficient integration of production and energy planning, and the potential benefits' scalability [5].

2 SUGGESTED APPROACH

Two basic options to achieve grid-serving energy flexibility on the distribution system level have been identified: **1. Collaborative synchronization**: This option (Figure 2-1) is based on joint optimization of energy flexibility measures between factories and their (distribution) system provider.

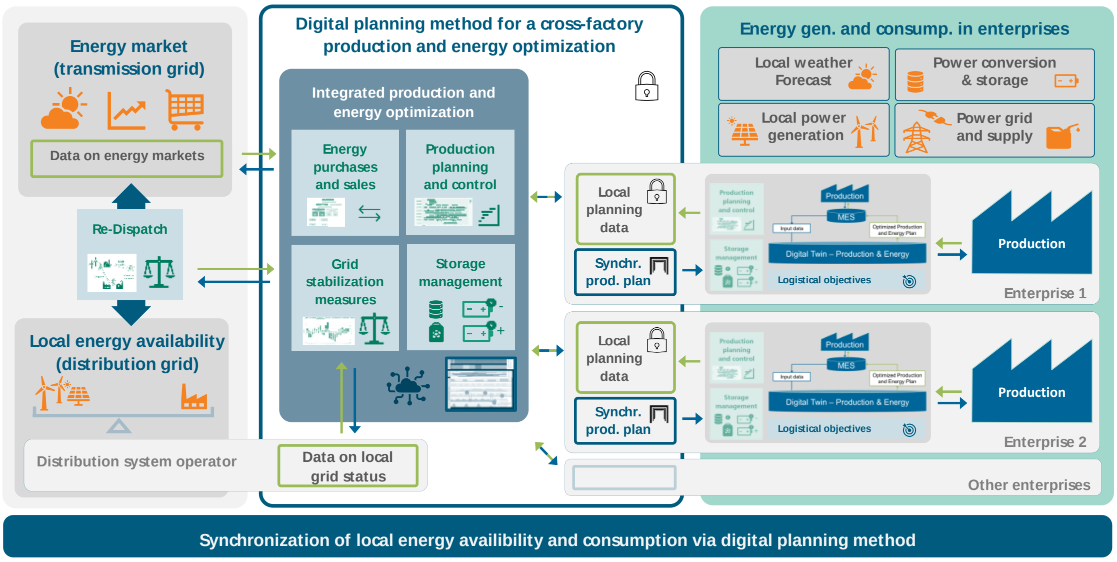

Figure 2-1: Preliminary concept of digital planning method for a collaborative synchronization

2. Market-based synchronization: In this option (Figure 2-2) grid-serving flexibility is traded on an energy flexibility synchronization market [6]. This energy flexibility market would enable companies to offer flexibility according to current (production) conditions.

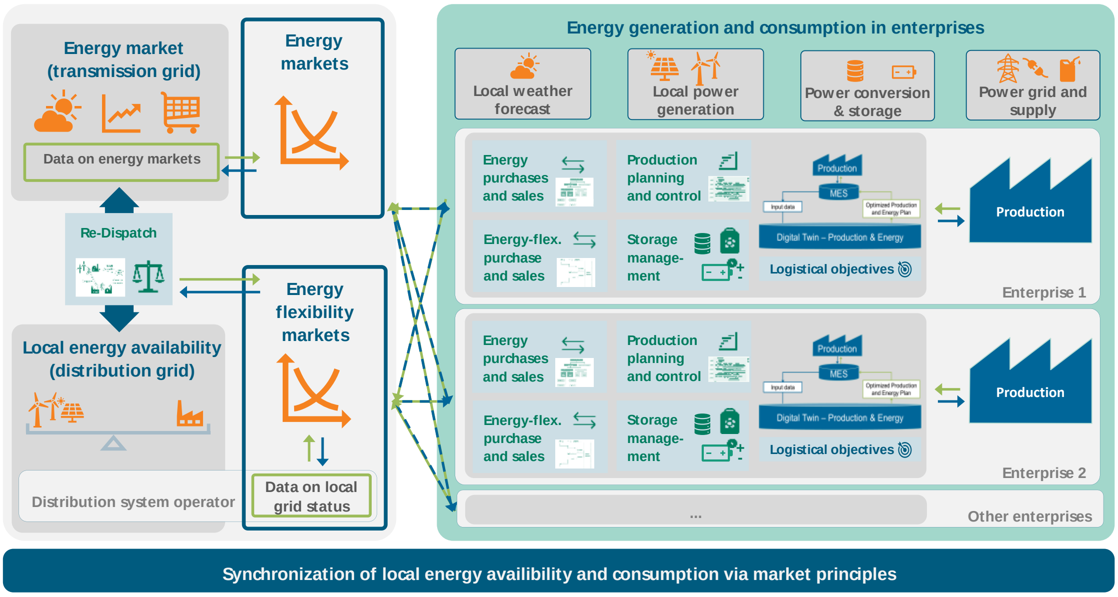

Figure 2-2: Comparative concept of market-based synchronization

3 RESULTS

In this paper, the initial concept stage of the approach will be presented. Starting from a requirements analysis among stakeholders in the use-case, three energy-intensive manufacturers, an energy supplier and a distribution system operator, and a literature analysis of existing approaches and theoretical background, the two basic concept options introduced in section 2 are developed. The optimization development starts from the already demonstrated optimization at the factory level, which utilizes a rolling-horizon simulation-based optimization for the production planning (i.e. order sequencing, scheduling and machine allocation) and equipment control (e.g. managing energy storage) while considering flexible energy market prices via a day-ahead forecast, to pursue a multi-criteria objective function, containing logistical production goals as well as energy cost and CO_2 optimization goals. The planning optimization utilizes flexibility, e.g. shifting energy-intensive orders and optimizing the use of local storage options in the process, first on the factory level before gathering the resulting energy consumption plans of multiple factories in the vicinity and comparing this to the energy availability and grid status at the distribution grid layer. A meta-optimization then tries to optimize the flexibility utilization of the three factories to achieve an optimal energy price for the participants as well as a grid balancing, resulting in lower grid stabilization costs. One major requirement in the development is the data confidentiality between the participating factories, while still considering all available flexibility potential. Here, the alternative option of a local market for flexibility measures is considered, which could also be used complementary to the collaborative optimization approach, e.g. depending on the grid stability and urgency for balancing.

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FLEXIBILIZATION OF INDUSTRIAL ENERGY SYSTEMS BY OPTIMIZATION-BASED DEMAND RESPONSE

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Abstract: The increasing share of volatile energy sources as well as variable demands provide challenges for the electrical power grid. To counteract these instabilities a balance between supply and demand needs to be established. In industrial processes, this can be achieved by coordinating the energy production with local storage and demand. Specifically, the optimized scheduling of batch production processes can avoid peak loads. A holistic approach for the control of industrial energy systems and production processes is needed to use this flexibility. This contribution presents an extension to a modular framework for optimization-based, predictive supervisory control of multi-energy systems providing the possibility to incorporate batch production processes, and a first study showing that shifting production processes can result in a more resource- and cost-efficient process.

Keywords: Industrial energy systems; Optimization; Sector coupling; Flexibility; Demand response

1 INTRODUCTION

In recent years, the effort and costs for balancing demand and supply in the electrical energy supply network have increased due to the increasing share of renewable electricity from volatile sources. Österreichs E-Wirtschaft [1] estimates that the demand for control energy in Austria will be around 4 TWh by 2030, while central power plants or storage facilities can only provide up to 2.7 TWh of electricity [1]. To achieve the required supply with electricity from renewable sources, an additional 1.3 TWh must be made available, which highlights the need for flexible consumers.

Especially the production sector, holding a share of 29% of the gross energy consumption (2022: approx. 305 TWh) [2], needs to identify flexibility options in the production process and make them accessible. In *Renewables4Industries* [3] the Demand Side Management potentials in spot and tertiary control energy market of the Austrian industry was estimated to be 500 MW [3]. Assuming an average availability of 24 hours, this results in a daily usable flexibility band of 12 GWh.

A holistic approach for the operation of industrial energy systems, using intelligent supervisory control strategies, can make this flexibility available to the electrical grid while still being resource- and cost-efficient. Such strategies must be able to simultaneously handle forecasts of energy production, energy demand and electricity prices, and must coordinate production, storage, and demand to utilize available flexibilities. Usually, the production schedule is planned ahead, while the control of the energy systems is done on an ad hoc basis. To treat both aspects of industrial processes on an equal footing, we present an extension of a framework for optimization-based, predictive supervisory control of multi-energy systems [4] which incorporates the scheduling of batch production processes, including material flows and electricity consumption.

2 MATERIALS AND METHODS

The foundation of this work is a framework where energy production, storage and consumption units can be defined and connected in a modular fashion to represent a multi-energy system [4]. Each component, such as gas boilers, thermal storage or photovoltaic cells, is represented by a mixed-integer linear program (MILP) considering operating constraints, dynamics, and control decisions. Sources of energy or resources assign costs to imports, and sinks provide reward for exporting energy or products, thus forming an objective function. Through the connections between the components, balancing equations are added and a single optimization problem is generated which can be solved by, e.g., commercially available solvers. The result is the optimal operating schedule of energy production and storage. Optimization is performed over a prediction horizon of at least one day and repeated every, e.g., 15 min to always consider the most recent information.

Consumers or renewable energy sources are typically represented by data-driven prediction algorithms which forecast the demand or yield based on historic data. Batch industrial processes differ from ordinary demand because their energy and resource requirements, as well as the product output, are known beforehand. They typically have a specific runtime and need to be scheduled in accordance with source product availability and output product demand. In the extension to the framework, they are represented by a convolution sum of process-specific energy and resource profiles with a binary start-up signal. Constraints guarantee that no second start-up can be scheduled during the runtime of an already triggered process. The model further includes constraints for the maximum electrical peak load and the minimum production aim.

3 RESULTS

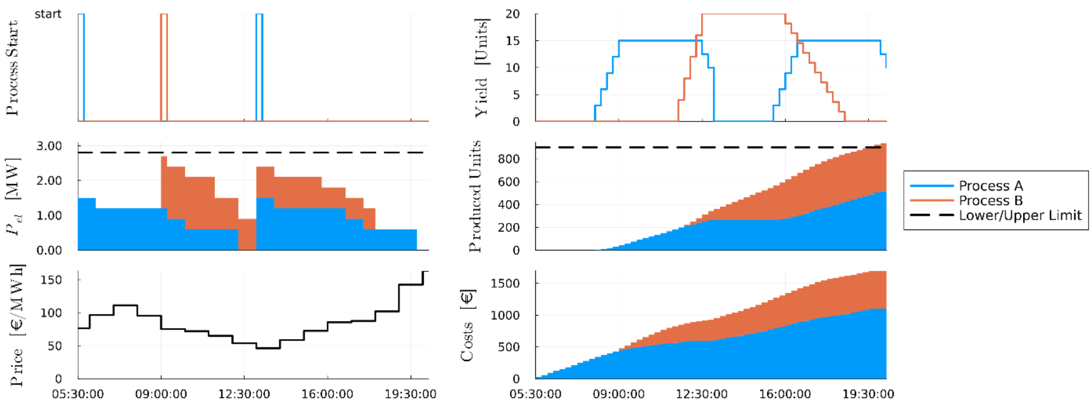

Figure 3-1: Optimized production schedule and resulting electricity demand considering a flexible energy tariff

We show the results of an exemplary production process consisting of two production units for the same product. We use an electricity price profile from the day-ahead market in Austria (EXAA 12:00 Market Coupling Auction for 23.05.2024) [5], a production demand of at least 900 units and a maximum peak load of 2.8 MW, two process profiles with respective process durations of 7.5 h and 9.75, and a sampling time of 15 min. The optimization results and the profiles are shown in Figure 3-1. The results show that shifting the start of process B to a later point (i.e., 9:00 a.m.) avoids violating the maximum peak load, while still satisfying the daily production goal.

4 DISCUSSION

This paper provides an insight in combining supervisory control methods for multi-energy systems with production scheduling. Taking these schedules into account allows for a more reliable forecasting of the energy demand, and thus leads to an increased efficiency in the control of the industrial energy system. Furthermore, the proposed supervisory controller allows to derive optimal operation schedules based on variable energy prices, while considering on-site energy production and demand. Additional goals and constraints such as power prices, limits on the power supply as well as operational constraints can be easily considered. Therefore, this holistic approach to the control and scheduling of the energy and production system reduces the stress on the electrical grid and provides a resource- and cost-efficient production schedule. A more detailed analysis including additional energy prosumers in the system will be presented in a follow-up publication.

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OPTIMIZED PRODUCTION SCHEDULING: A CASE STUDY ON FOOD AND STEEL INDUSTRY

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Abstract: As renewable energy sources expand, the need for providing system flexibility from end-users from all sectors grows. This contribution explores optimization approaches for scheduling problems in the food and steel industry. Applying integer linear programming, the study focuses on two use cases: baking ovens in an industry scale bakery and a rolling mill in an electric steel plant. By optimizing production schedules, the research aims for minimizing energy consumption and energy costs. The expected results highlight the potential of demand side management, contributing to decarbonization and sustainable industrial practices.

Keywords: Energy-intensive Industry; Iron and Steel Industry; Food Industry; Optimal Scheduling; Operation Optimization; Demand Side Management

1 INTRODUCTION

In a future climate-neutral energy system, flexibility will play a decisive role in both energy generation and demand as renewable energy sources expand, maximizing the benefits of decarbonization and economics [1]. Furthermore, it is expected that end-users from all sectors will participate in providing system flexibility, driving interest in demand side management (DSM) [2]. This is especially important for energy-intensive industrial sectors, which account for around a third of total energy demand in Austria [3].

Since the scheduling of activities is a problem most organizations must solve, this is of particular interest for the future design and understanding of industrial energy systems [4]. Tested on two representative use cases – baking ovens of an industrial scale bakery and a rolling mill of an electric steel plant – it is determined how DSM can be utilized to improve energy efficiency, and reduce energy costs. In general, DSM includes various measures, which influence type and level of energy demand and can be roughly distinguished into energy efficiency (EE), and demand response (DR). While EE aims to reduce energy consumption, DR refers to load profile adjustment (load shifting or shedding) driven by market incentives [5]. Load profile adjustments can be realized through flexible production planning. Especially for process industries this is relevant, as they operate in an environment characterized by increasing competitiveness and narrow profit margins. In most industrial facilities, schedules are manually generated based on multiyear experience and understanding of the production process. Challenges to optimal production pose the strongly different properties which are found in different industries [6].

2 MATERIALS AND METHODS

The scheduling problems are formulated as integer linear programming (ILP) problems, distributing jobs among production units and determining the optimal production sequence for each unit targeting energy efficiency in one use case and energy cost reduction in the other. The ILP is solved using the Python library PuLP (Python Linear Programming) [7].

2.1 Use case: Baking ovens in an industrial scale bakery

In the bakery six baking ovens are available and the production volume of the bakery can vary significantly due to holidays, production of seasonal baked goods or non-scheduled orders for events. The baking process itself is affected by many factors like product type (product-ID), state of the final product (pre-baked, frozen, etc.), oven pre-heating and baking duration. The goods are produced based on a list of baking jobs that is issued every day for the following day. By distributing the baking jobs in an optimal fashion among the available ovens while also optimizing the baking sequence for every oven, the aim is to minimize the used energy for heating up and standby mode between the baking jobs (Figure 2-1). The available prototype of the optimizer considers realistic heat-up rates, using a machine learning model based on measured production data, and different baking recipes.

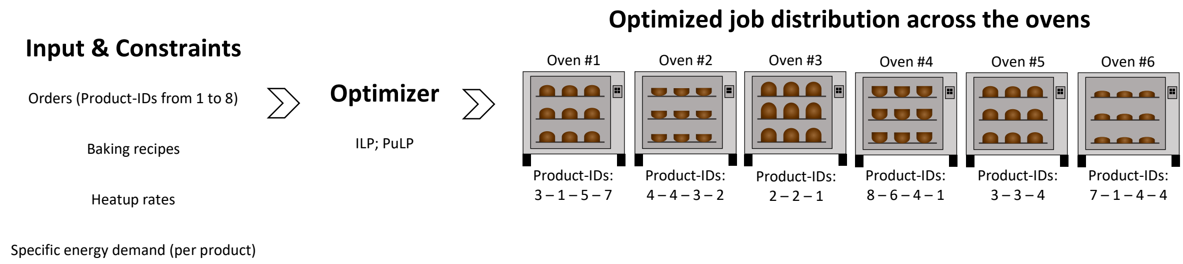

Figure 2-1: Example of optimized process flow sheet for use case 1

2.2 Use case: Rolling mill in an electric steel plant

The rolling mill operates on a list of orders (jobs) covering a time horizon of multiple weeks. Each job is specified by product type, quality, diameter, length, quantity and delivery date. Notably, the diameter of the product correlates directly with specific energy consumption, with smaller diameters requiring more rolling work and, consequently, greater energy usage. As constraints the changeover times for the different products and delivery dates are considered. By integrating future electricity prices of short-term markets, the approach enables the DSM mechanism of price-based demand response, optimizing the production schedule according to pricing fluctuations. The logic of the optimization is displayed in Figure 2-2.

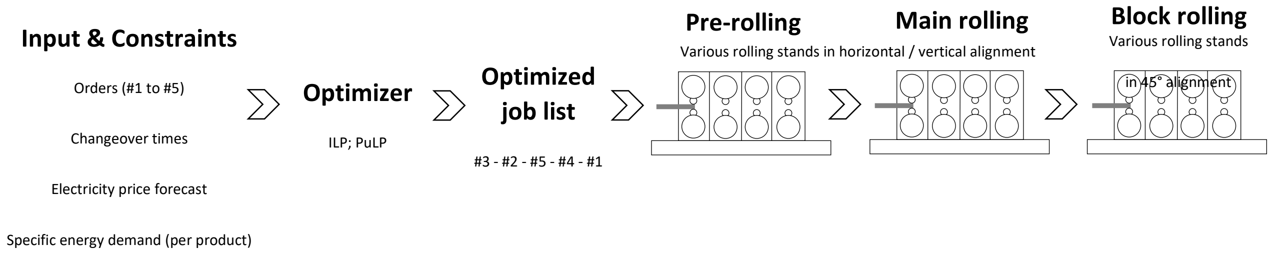

Figure 2-2: Example of optimized process flow sheet for use case 2

3 EXPECTED RESULTS

In the bakery use case, the optimizer is expected to reduce total energy consumption, and in the electric steel mill use case, to shift energy-intensive rolling tasks to periods with lower electricity prices. This shift would occur during times with a higher share of renewables in the grid, thereby reducing CO_2 emissions associated with production. To evaluate the results, the energy consumption and costs of the real production plans are compared with the optimized production plans. Furthermore, attention will be paid to the differences between the production processes (serial vs. parallel production lines; one day vs. multiple days optimizing horizon). Calculation times, robustness and applicability of the results will also be checked. The results of this ongoing research will be presented at the NEFI conference.

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V. Session: Techno- and/or Economic Approaches to Maximizing Industrial Flexibility

This session will focus on techno-economic approaches that maximise industrial flexibility, including innovative solutions for energy-based industrial redispatch provision, and the cost-benefit analysis of flexible systems. Contributions will examine how technological innovations and optimisation strategies can enhance flexibility in various industrial contexts, covering both technical and economic considerations.

A COST-BENEFIT ANALYSIS OF INDUSTRIAL FLEXIBILITY FOR AUSTRIAN REDISPATCH PROVISION

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Abstract: As part of the *NEFI* project *Industry4Redispatch*, a cost-benefit analysis to evaluate the impact of integrating industrial flexibility into the Austrian redispatch process is conducted. This work summarizes the chosen approach and highlights different assessments made for the involved assets/parties: Industrial sites offering flexibility, flexibility service providers aggregating those, and distribution and transmission system operators making sure that resulting activations for redispatch are feasible for the overall grid. The cost-benefit analysis compares the status quo, which relies solely on conventional dispatchable power plants, with a scenario incorporating industrial flexibility. The analysis utilizes a two-stage modelling approach to estimate redispatch activations and economic outcomes, involving detailed electricity market data and simulated redispatch information from industrial sites. Results indicate that incorporating industrial flexibility could lead to reduced redispatch costs and enhanced grid stability, though ongoing model improvements are essential for more precise validation. The ongoing modelling process highlights the importance of high-resolution input data.

Keywords: Cost-benefit Analysis, Industry Flexibility, Redispatch, Power Systems

1 INTRODUCTION

As part of the ongoing project *Industry4Redispatch* (I4RD), a cost-benefit analysis (CBA) is implemented [1], that focuses on evaluating the impact of integrating industrial flexibility in the Austrian redispatch (RD) provision process. It aims to determine resulting individual costs and benefits for different providers of RD, as well as analysing different measures for the distribution and transmission system operators (DSOs, respectively TSO), and flexibility service providers (FSPs). Since absolute values in themselves may – depending on the field of application or recommendations to be derived – not support meaningful interpretations, the CBA is conducted in comparison to a defined baseline, namely the current status quo: A system where RD procurement only makes use of conventional large-scale power plants, using a purely cost-based remuneration scheme. The following section give an overview of the CBA process and required data quality.

2 MATERIALS AND METHODS

While historic data of today's electricity market operation are increasingly available in a transparent and public manner (e.g., APG's "Markttransparenz"), operational details on transmission line loading factors, critical congestions, activated remedial actions, and especially any resulting redispatch of power plants are not readily available.

2.1 Virtual redispatch as basis of the calculations

Before being able to estimate the effect of changes in RD procurement on the system, and its economic outcomes, solid information of RD activations is necessary. This is based on an optimisation model of the Austrian energy system including grid data. Specifically, a two-stage modelling approach is used: First, the *market-stage* employs a standard fundamental electricity market model, based on highly detailed data made available by project SECURES [2]. This data reflects the distribution of demand across various regions, considering weather-related effects on demand and supply, as projected under expected climate-change impacts. Additionally, the spatial distribution of industry sites is informed by previous work from the project I4RD. The following *redispatch-stage* considers the chosen power-plant dispatch, and day-ahead electricity prices, as market-based inputs. General electricity demand within a zone is distributed based on population density. At the same time, Congestions, arising from the non-grid-aware zonal market operation are then resolved by activating redispatch *"bids"*, using a DC-OPF[1] that minimized total redispatch costs, while having access to costly (e.g., change in dispatch) and non-costly (e.g., change in HVDC operation) remedial actions. For each asset, a *"bid"* contains the maximum available volume for a positive or negative change of the planned dispatch, during a specific time period, including an attached cost estimation[2].

2.2 CBA from different perspectives

The following paragraphs provide a high-level summary of the applied CBA methodology, for different perspectives of the parties involved when activating an industrial flexibility for RD.

[1] While the optimal power flow considers the whole market region, grid capacity constraints are only enforced for Austria and neighbouring countries. Therefore, no remedial actions are activated in other zones (due to unlimited lines), preventing possible distortions due to limited quality of high-resolution data. However, this allows the implicit depiction of cross-zonal power flows, without which proper line loadings could not be determined.

[2] Estimations, including their derivation from various sources and assumptions, for different industry types as well as conventional power plants, are mostly based on energy (electricity and gas) prices, variable and fixed costs, and potential catch-up effects. These are explained in detail in an accepted entry to the EEM24 conference and will be published in proceedings.

Industry. For a considered industrial asset, the baseline scenario is based on measured data, scaled and/or resampled onto the model year (here: 2030). The electricity demand is assumed to be purchased at quarter-hourly day-ahead spot market prices or produced on-site, e.g., in hydropower plants or thermal conversion units (e.g., turbines or gas engines) - accounting for gas prices, CO_2 emission-related costs, as well as (grid) taxes and fees. Based on bid acceptance derived from 2.1, the CBA then derives amortisation, total revenues, energy costs, and resulting overall cost reductions per industrial site.

Transmission System Operator. The CBA from the TSO's perspective aims to analyse the total Austrian redispatch costs, and potential improvements after the involvement of industrial flexibilities, compared to the status quo. Possible advantages may not only materialize in monetary improvements, but also in the overall number of hours where a change of dispatch[3] was necessary, or an overall reduced amount of activated energy.

Distribution System Operator. As part of I4RD a custom bid-filter algorithm has been developed, that allows a DSO to prevent certain activation combinations that would lead to infeasible states in the distribution grid. The CBA compares such a system against otherwise necessary grid reinforcements.

Flexibility Service Provider. The CBA for a FSP's potential business case has high co-dependence with those of the, by the FSP, aggregated industry sites, and will therefore not be discussed in more detail here, c.f. [1] for more information.

3 RESULTS

Reliable results for the CBA depend entirely on accurate projections of future RD demand. While the transmission grid model can be constructed from publicly available data sources, which also include – even if not in the highest quality – extensive power plant lists, the accurate distribution of demand plays a crucial role. This is further aggravated when considering RD activations of industry sites, a level of detail that vanishes in most studies since these can otherwise be aggregated with other types of demands. Figure 3-1 shows first outcomes of the data processing necessary for the calculations of future RD demand.

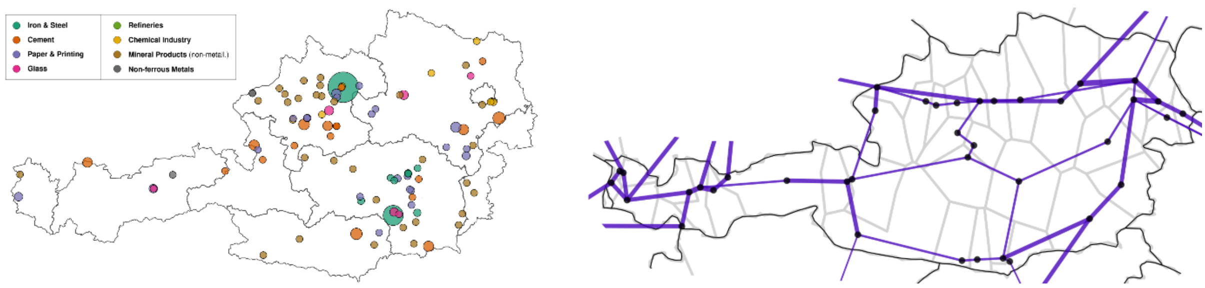

Figure 3-1: (left) Industry sites [3] across Austria, with depicted sizes proportional to annual fuel demand, and (right) Austrian transmission grid, with respective areas to be that aggregate onto each node.

4 DISCUSSION

[3] A "change of dispatch" may be required for periods longer than an actual need for redispatch exists, due to accounting for must-run conditions, startup, shutdown, or minimum on/off constraints.

Ongoing improvements to the model are still necessary to achieve better validation results compared to real-world data. Even though the modelling region of interest is confined to Austria, high data quality for neighbouring countries is crucial, since power flows and resulting congestions are often caused by specific cross-border flow situations, or by congestions on foreign grid elements close to the border. Finally, correctly accounting for a N-1 secure operation, instead of the commonly chosen assumption of a 30% security margin on each element, is expected to further improve modelling accuracy. In the future, the introduced CBA can be used to support further discussions on regulatory requirements, potential financial incentives, and other systemic questions.

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Funding information. *This project is supported with the funds from the Climate and Energy Fund and implemented in the framework of the RTI-initiative "Flagship region Energy".*

ENERGY-BASED INDUSTRIAL SYMBIOSIS IN CLIMATE NEUTRAL INDUSTRIAL ENERGY SYSTEMS: THE INFLUENCE OF TECHNOLOGICAL INNOVATION

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Abstract: The Austrian industrial sector is a significant contributor to the national greenhouse gas emissions and energy consumption, making its transformation towards climate neutrality by 2040 essential. A promising strategy to reduce environmental impact and energy use is energy-based industrial symbiosis. This work explores how energy-based industrial symbiosis potentials will evolve in climate-neutral industrial energy systems, considering the introduction of new technologies for example to integrate renewables or facilitate electrification. A sector-specific technology map to design a generic industrial symbiosis network, a comprehensive framework for synthetic industrial load-, generation-, and waste heat profile generation, as well as system modelling and optimization methods provide the methodological background of the work. Expected results include quantifiable reductions in CO_2 emissions and exergy demand by industrial symbiosis.

Keywords: Industrial symbiosis; Energy-based industrial symbiosis; Climate neutral industrial energy systems; Industrial transformation; Exergy-based optimisation

1 INTRODUCTION

The Austrian industrial sector accounted for 26 million tonnes of CO_{2eq}, representing approximately 34 % of Austria's total greenhouse gas emissions in 2021 [1]. It also accounted with 88 TWh for around 28% of Austria's end energy demand in 2021 [2]. Austria aims to achieve climate neutrality by 2040 and become a European leader in energy transition. This goal is embedded in national acts [3, 4], striving to shift the energy system entirely to renewable sources. Transforming industry towards climate neutrality is crucial to maintaining Austria's economic competitiveness.

One key strategy to address the high environmental impact and intensive energy use of the industrial sector is industrial symbiosis (IS). Especially the energy-based industrial symbiosis (eIS) is recognized as an effective strategy to reduce the use of conventional fuels in energy production. eIS aims to substitute conventional inputs to industrial processes by reusing waste materials and waste energy (especially waste heat) from a different process, whether they are within the same company or span different companies. [5]

eIS goes hand in hand with the introduction of novel technologies and processes. To achieve climate neutral industry up to 6 main technological levers are crucial [6, 7]: (i) renewable energy sources, (ii) energy efficiency, (iii) electrification of end-use sectors, (iv) green hydrogen and its derivatives, (v) bioenergy coupled with carbon capture & storage (CCS) and (vi) CCS. Especially electrifying processes and integrating renewables introduce volatility in the dynamic relationship between manufacturing industries and energy markets and, thus, will have an influence on eIS potentials. This paper explores how eIS will evolve within climate-neutral industrial energy systems. Using a sector-specific technology map for industrial symbiosis and a generic IS network, it will be analysed how the shift towards climate-neutral industry impacts eIS potentials.

2 METHODS

Based on an industry sub-sector specific technology map for IS and a generic, adaptable IS network, this study analyses how eIS potentials change when industries transition towards climate neutrality. To facilitate this analysis, the software "Ganymed", will be adapted to generate synthetic load and generation profiles (LPs), as well as waste heat profiles (WHPs) for climate-neutral industrial energy systems [8]. In an ongoing research, methods will be employed to maximize the eIS potential within the IS network. The scientific approach involves developing a network model and creating linearized or surrogate models for the conversion units, focusing on units connecting companies. Subsequently, an exergy-based system optimisation is applied in the ongoing research.

2.1 Industry sub-sector specific technology map

The aim is to review sector-specific technological strategies for climate neutral industries to identify key process routes and key technologies for maximizing synergies for eIS [6, 7]. To evaluate the technologies and their contribution to synergies, KPIs (e.g., specific CO_2 emissions, energy intensity, etc.) will be collected to develop a sector-specific technology map. The technology-related data will be used for designing a generic IS network.

2.2 Energy-based industrial symbiosis potential

The generic IS network is the framework for extracting the changes in the time-resolved LPs and WHPs for the integrated industrial sectors when adapting to the previously identified key process routes and technologies in the context of a climate-neutral industry. Furthermore, the models of the conversion units will provide initial operating profiles. Based on the profiles, and under consideration of electricity price and renewable generation profiles an exergy-based system optimisation (e.g., using OEMOF) to minimize costs or exergy demand will offer operating profiles for the conversion units and corresponding eIS potentials, which can be discussed through sensitivity analyses.

3 EXPECTED RESULTS

The sector-specific technology map and generic industrial symbiosis network will illustrate the dynamic interactions between various industries, highlighting pathways to increased efficiency and reduced CO_2 emissions. Therefore, expected results include quantifiable reductions in emissions and exergy demand in investigated industrial sectors. Furthermore, time-resolved operating profiles for key conversion units facilitating transition to climate neutrality, as well as corresponding time-resolved eIS potentials will be provided. Hereby, a focus will be to quantify the eIS potentials and derive the sensitivities of the potentials due to the industrial transition. For example, an increase of the potentials is expected by. e.g. fostering energy cascades through the integration of low and high temperature heat pumps or material and energy storages. The results of this ongoing research will be presented at the NEFI conference.

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FINDING A NEW BALANCE – VALID INDICATORS FOR TECHNO-ECONOMIC ENERGETIC FLEXIBILITIES

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Abstract: Industry is not only a big primary emitter of CO_2 itself, but also a big consumer of electricity with a share of about 43% of electricity consumption in Austria in 2023. Therefore, providing the future electrical grid with storage capacities will be a big opportunity for industrial facilities, as industry has a unique capability of load management due to its diversity compared to households or other services. While major scientific projects have investigated this potential, there is a lack of incentives for industrial plants at various levels to foster the balancing of electricity supply.

In this paper we provide an overview regarding the state of research and the obstacles we need to overcome to close the implementation gap. We expand the state-of-the-art approach of assessing flexibility potentials by not only incorporating technical but also economic and organizational key performance indicators. With the proposed novel assessment strategy, we bridge the gap between top-down and bottom-up approaches, aiming to facilitate practical and economically viable demand response measures in energy-intensive industrial processes. Our methodology is demonstrated through a case study based on real life industry application, with results validated against literature and expert discussions.

1 INTRODUCTION AND MOTIVATION

The increased volatility of renewable electricity production is widely recognized as one of the biggest challenges for decarbonisation of the power sector. The manufacturing sector, with its heterogeneous consumption profiles and high loads, is in a unique position to adapt to this new electricity landscape. Various publications have highlighted the sector's potential for significant demand-side management (DSM) [2]. Despite this, there remains a considerable implementation gap that we target to help overcoming. In a first step we present a method for a high-level assessment of energetic flexibility potentials matching technical possibilities with economic target orientation and organisational practicality.

2 MATERIALS AND METHODS: STATE-OF-THE-ART ASSESSMENT METHODS IN LITERATURE

With the term flexibility potential, we refer to the capacity of industrial processes to adjust their energy consumption patterns in response to external signals, such as price changes or grid demands, to optimize economic benefits. The quantification of flexibility potentials on network level is highly dependent on anticipations and method, such as the allowance of reduced production volume or organizational factors like work shifts. This gets evident in publications that start assessing the potential top down on industrial network level.

On the other end of the spectrum sophisticated methods are developed bottom up with the target of sorting out realizable potentials starting from production station level, and aggregating to production system levels [5]. Leinauer et al. as well as Richter et al. independently find an objective system with a target conflict as depicted in Figure 2-1 [1, 4]. We conclude that these competing targets must be considered and balanced to find valid potentials for demand response measures. While the targets “Efficiency”, “Price” and “Peak Load” can be considered in an optimization, the balancing against the target of “Throughput” is more complex to consider and cannot be calculated as precise as peak power or efficiency losses. To be able to sort out only economically viable energetic flexibility potentials an upper estimation of opportunity cost for the considered process must be found.

For our flexibility assessment we choose a higher-level approach by not assessing technical feasibility in detail, but only determining basic parameters of applicability. With this approach we can more easily build understanding on the industry partners side and get more rewarding boundaries for optimization. The preliminary technical parameters we will consider for our assessment together with industry partners can be found in Table 2-1.

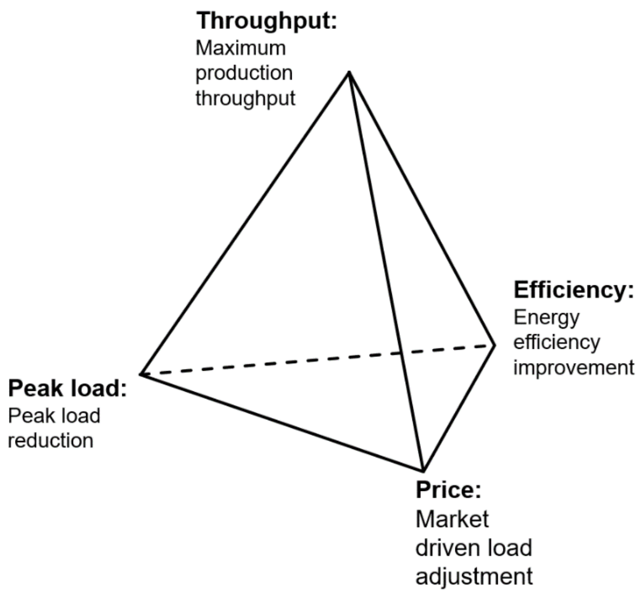

Figure 2-1: Targets and conflict area for the application of energetic flexibility (own illustration based on results from [1] and [4])

Table 2-1: Technical description parameters for flexibility potentials

Parameter	Unit	Definition
Activation time	[h]	Time between the activation of a flexibility and completed adoption of the power demand
Activation duration	[h]	Maximum time the activation can be upheld in the process before return to load as planned
Power potential	[MW]	Mean difference of power between load profile with and without activated flexibility potential
Temporal availability	[h/a]	Sum of timespans the flexibility potential can be activated throughout the year. This heavily depends on capacity utilization.

The technical parameters we consider together with the economic and organizational key parameters for the production step considered for flexibilization:

- Opportunity cost [€/h]
- Labor intensity [number of operators]

We will demonstrate this assessment approach based on a real-life industry facility application. The potentials will be validated by an optimization that we plan to apply onto the most promising flexibility options in further publications.

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INDUSTRIAL FLEXIBILITY FOR REDISPATCH PROVISION - AN OPTIMIZATION-BASED APPROACH FOR BID GENERATION

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Abstract: The industry as a flexibility provider will play a more important role in future energy systems, e.g. for redispatch provision. This work proposes a method to derive industrial flexibility as bids for a redispatch clearing process using Mixed Integer Linear Programming. The presented approach is applied to determine the flexibility potential of a baking factory by shifting the cleaning hours of each of their production lines, which leads to a temporary decrease in electricity consumption. Firstly, we formulate an optimization problem for the optimal cleaning period of each line, considering operational constraints, such as working hours, and minimum time between cleaning of the same production line. Secondly, we derive possible bids that can be offered to system operators for the redispatch process. Each bid corresponds to a shift in the planned cleaning hours. We compare a reference use case without flexibility with two further use cases, which differ in terms of operational constraints and electricity price assumptions. The results show that smaller industrial plants can offer flexibility by shifting demands. However, the overall impact on industrial energy savings might be very small depending on the actual production scheme and energy supply system.

Keywords: Industrial flexibility; Optimization; Mixed Integer Linear Programming; Redispatch

1 INTRODUCTION

A side effect of the ongoing transition of the energy sector and the respective decommissioning of conventional thermal power plants in Austria is an increased need for new flexibility sources in power grids [1]. Also, challenges coming along with climate change and related changes in weather conditions make new flexibility sources necessary [2]. When speaking about new flexibility sources, several candidates pose an interesting option. From the perspective of flexibility suppliers, there are different ways to (financially) benefit from flexibility provision. An overview of possible suppliers and consumers for flexibility is shown in Esterl et al. [1].

The research project "Industry4Redispatch", aims to set up frame conditions, interfaces, and process flows for all involved stakeholders to involve the Austrian industry in future redispatch (RD) provision by offering flexibility with its different technical assets. Thus, the remainder of this paper will address the provision of industrial flexibility for RD, the tasks involved and present an approach to derive optimal operation and flexible bids for a production site in the food processing industry.

2 MATERIALS AND METHODS

2.1 Industrial Redispatch Provision and Mathematical Programming as Enabler

The following prerequisites need to be fulfilled when providing industrial flexibility. First, a baseline for the planned operation and planned consumption of electricity from the grid needs to be derived. In a second step, possible bids are derived and – in combination with the corresponding baseline - submitted to the system operators. When deriving bids, compensation effects (anticipatory or catch-up effects) must be considered. After an RD clearing process, the operational trajectories - defined by the baseline and the accepted bids - need to be executed. Mathematical programming has been applied to realize optimal planning and – combined with model predictive control – the realization of optimal operation. Fuhrmann et al. [3] presented optimal planning with mixed-integer linear programming and model predictive control for a lab system. The present paper extends their formulation to derive industrial flexibility bids.

2.2 Industrial Site

For the analyzed site, the flexibility offered is provided by the interplay of production processes and its energy-consuming machines. Flexibility is offered by shifting the cleaning procedure of two production lines listing six hours. During cleaning of the respective line, energy-intensive processes, e.g., shaping, fermenting, and freezing, must be stopped, resulting in a reduction in the electricity demand. To fulfill the RD prerequisite, first, the energy demand and energy-related costs for the non-flexible operation were determined as a *reference use case (RUC)*. The two considered production lines are cleaned every Thursday and Friday (9 a.m - 3 p.m). In two further use cases (UC), different assumptions are made for the time constraints of the cleaning as well as for the electricity prices –UC1: cleaning times: 8 a.m. to 8 p.m., fixed prices, and *UC2*: no time constraints, prices from the day-ahead market.

3 RESULTS

The proposed adaption of the optimization model can integrate flexibility from scheduling processes with catch-up effects as shown in Figure 3-1. For an annual simulation, the following results are achieved: In UC 1 and UC 2, 616 and 2142 bids are generated, respectively. The difference in the number of possible bids can be explained by the higher degree of freedom to shift cleaning time slots in UC 2. Nevertheless, only a maximum of one bid per day can be accepted by the system operator, since the cleaning can only be shifted once per week. For both UCs, average bid power, bid duration, and bid costs are determined. Optimal starting times differ strongly in both UCs: In UC 1, starting times are more common during lunchtime since the energy demand is higher due to higher outside temperatures. In contrast, for UC 2 starting times are more common in the morning or in the afternoon. This is because the spot market prices are often lower during lunchtime. The overall energy savings in the operation of the production lines are marginal for both UCs compared to the RUC. For UC 2 longer average bid durations are possible due to more shift options. The bid costs are, in general, lower, which can be explained by a comparison of day-head prices (lower) to fixed prices (higher). The same effect leads to overall cost savings mainly in UC2.

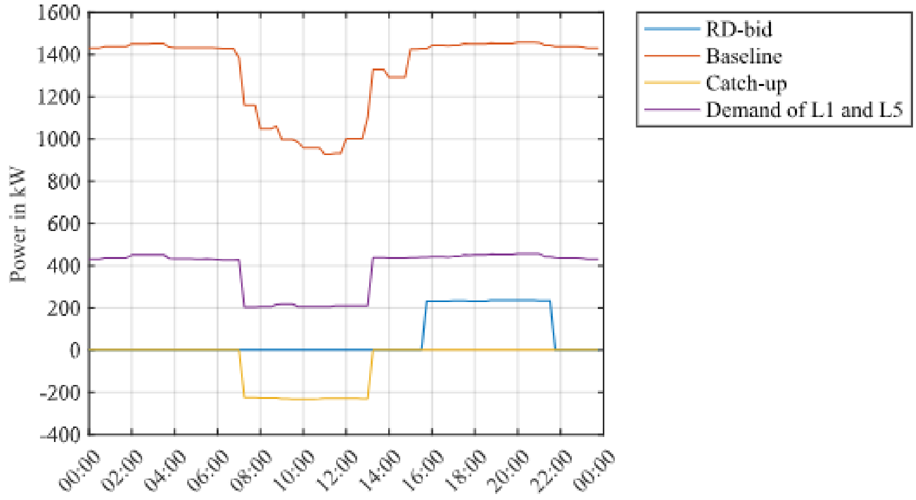

Figure 3-1 – Visualization of RD-bid, baseline including the demand of the two considered production lines (L1 and L5), and catch-up of one specific bid starting at 15:45

4 DISCUSSION

This work presents an adapted formulation to consider flexibility bid derivation in optimal planning models for industrial energy system operation. The formulation can derive a baseline and flexibility bids under consideration of necessary catch-up effects. Optimal planning of the cleaning times in UC 1&2 can only save about 0.1 % compared to the RUC. This means, on the other hand, that shifting the cleaning time slots - and hereby offering RD bids - can be done with low additional energy costs. For factories and processes with higher degrees of freedom in their energy systems, the economic impact may be significantly higher.

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VI. Session: Industrial symbiosis and energy efficiency

This session will focus on industrial symbiosis highlighting how collaborative strategies in energy and material exchange can enhance energy efficiency and reduce material and energy consumption. The session focuses on innovative approaches to waste heat recovery, the optimisation of thermo-chemical processes, and the decarbonisation of energy-intensive industries like steel processing.

DECARBONIZATION OF STEEL PROCESSING

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Abstract: Steel industry is one of the main industrial sectors in Austria, but also accounts for approximately 15% of Austrians CO2-emissions. [1] However, steel production and processing are one of the most difficult sectors to decarbonize, as they still rely on fossil energy carriers (coke, coal, natural gas). Thus, decarbonizing this sector is crucial to achieve net-zero targets. This requires the decarbonization of steel production but also steel processing. While research focuses on the decarbonization of steel production, hardly any research has been conducted on the decarbonization of steel processing. Subsequently, a suitable method is developed to design and evaluate different decarbonisation pathways for steel processing both technically and economically. This involves the investigation of carbon neutral energy carriers such as electricity, hydrogen, synthetic natural gas, biogas, syngas, etc..

Keywords: steel industry, steel processing, alternative fuels, electrification, green chemicals, hydrogen, renewable energy

1 INTRODUCTION

Energy-intensive processes, high temperature requirements and quality standards are among the reasons why steel industry is so difficult to decarbonize and still relies on fossil energy carriers. Even though, both steel production and processing must be considered to fully decarbonize this sector, there are only various approaches to decarbonize steel production, but hardly any for steel processing. Steel is processed, for example, by forging, hot rolling or press hardening and requires high temperatures to produce goods with the desired shape and with required material properties. Therefore, the workpieces need to be heated, which requires a considerable amount of natural gas. To replace natural gas with alternatives and thus decarbonize steel processing, different decarbonization pathways are available, which are shown in Figure 1-1.

There are two major options which are the electrification and the use of alternative fuels. Electrification requires green electricity from PV and wind power plants. Electricity from the grid is considered to compensate peaks in the production of renewables. Hydrogen is produced via electrolysis with green electricity and water and can be used directly as fuel for an industrial furnace or is further processed into synthetic natural gas. In addition to hydrogen, CO2 is required to produce synthetic natural gas. CO2 can be captured from the industrial furnace, allowing the CO2 to recirculate in the process. A more detailed study on the concept of the roundtrip-methanation is provided by [2]. Synthetic natural gas can also be produced with syngas from biomass gasification. However, syngas could also be used directly as fuel under certain conditions. Another alternative fuel is biomethane produced via fermentation in a biogas plant. Biogas can either be directly used in the industrial furnace or purified to biomethane via CO2 capture.

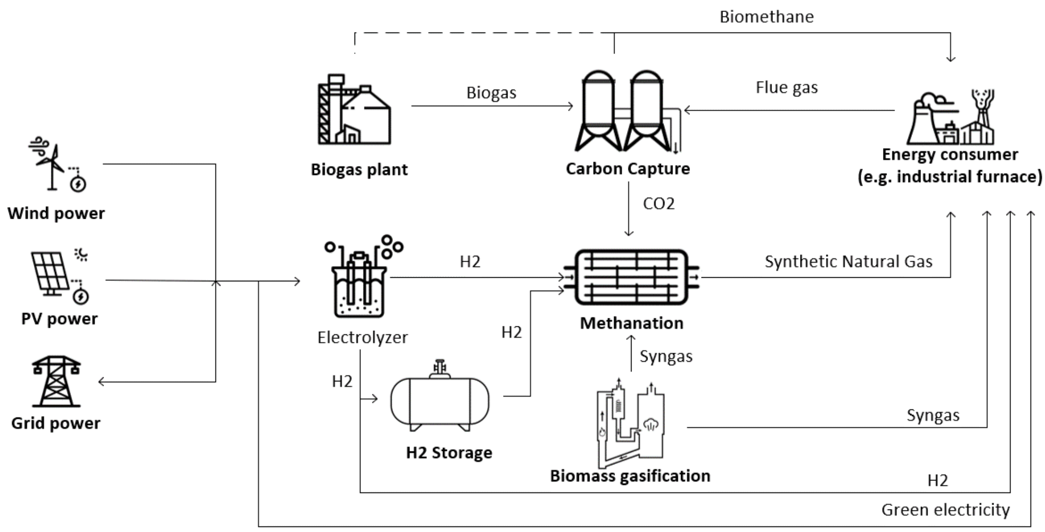

Figure 1-1 Possible decarbonization pathways

However, the suitable decarbonization pathway for a steel processing site must be analysed individually, as various requirements must be considered. These include space requirements/constraints, the compatibility of alternative fuels, especially hydrogen, with existing facilities, and the influence of alternative fuels, in particular hydrogen, on products.

2 MATERIALS AND METHODS

Firstly, a feasibility study of all options for decarbonizing steel processing, which mainly comprises the electrification and the use of alternative fuels is conducted.

Based on this, the most viable options are selected and further analysed with simulations using IPSE Pro and/or Dymola/Modelica. Static simulations provide a thorough understanding of the process chain while dynamic simulations enable to consider fluctuations of the production of renewables as well as varying energy consumption profiles of different energy consumers. Subsequently, a profound techno-economic analysis is conducted.

3 RESULTS

The most feasible options to decarbonize steel processing is the electrification and the use of hydrogen or SNG. Biogas/biomethane from biomass fermentation and syngas/SNG from biomass gasification are excluded after initial analysis. The main reasons are uncertainties regarding the regulatory framework and limited availability of substrates.

Electricity from wind and PV can be produced locally. In Figure 3-1-1 the profile of the power generated from a wind and PV park at a location in Austria is shown. A more profound analysis show that wind and PV power production complement each other very well, as PV dominates during summer and wind during winter.

Based on this renewable power production, hydrogen can be produced via electrolysis. Thereby, the electrolysis has a lower and an upper limit as shown in the detail of Figure 3-1-1.

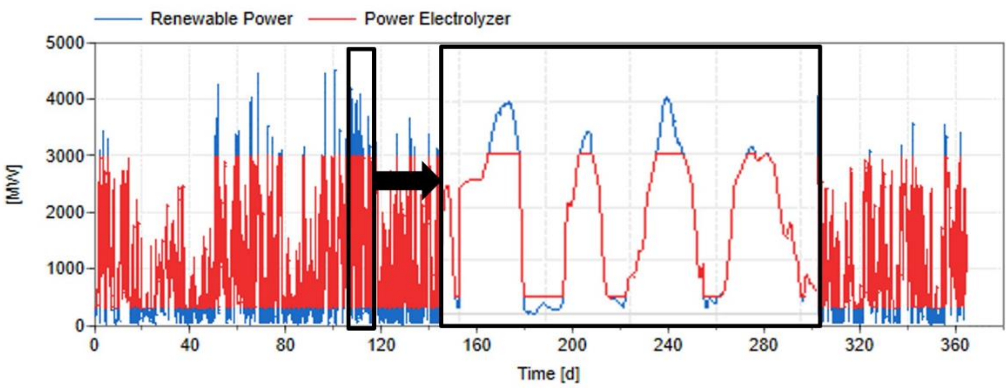

Figure 3-1 Renewable power production vs. hydrogen production

4 DISCUSSION

There is no decarbonization pathway suitable for all steel processing sites, requiring an individual analysis for each site. Most likely, a combination of different approaches must be applied to achieve full decarbonization. The method developed in this study allows to design and evaluate the most techno-economic options for different steel processing sites.

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MODELING OF A BIDIRECTIONAL CHARGING SYSTEM IN AN INDUSTRIAL DC MICROGRID

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Abstract: To achieve international climate neutrality goals, reducing energy consumption and emissions is essential. This necessitates the adoption of renewable energy sources, which require greater flexibility to balance generation and consumption. Direct Current Microgrids (DC MGs) are particularly effective in enhancing energy flexibility and savings, as they improve grid efficiency, flexibility, and reduce voltage converter losses by enabling the integration of renewable, self-produced energy from sources like photovoltaic (PV) systems. Bidirectional charging further contributes to this flexibility by allowing electric vehicles to act as temporary energy storage systems, providing decentralized battery storage to the microgrid. The combination of DC MGs and electric vehicles (EVs) with bidirectional charging systems shows great potential for saving costs, energy, and supporting the energy sector through their significant flexibility. Since research in this area is still limited, further investigation into the interaction and integration of these two key technologies is highly demanded. Therefore, this paper analyzes a modeling approach of an electrical vehicle supply equipment (EVSE) connected to a DC MG to examine this. Modeling this type of device is a crucial first step to investigate the interactions of DC MGs and EVs with bidirectional charging systems, future control techniques, energy management systems, and potential stability issues.

Keywords: bidirectional charging; electric vehicle; modeling; direct current; microgrid; flexibilization; electrification.

1 INTRODUCTION

Through use of DC power systems, it is possible to revise the actual supply of industrial production systems, seeing that it shows potential on power loss reduction and enhancement of power flexibility and quality [1]. The German research project “DC-INDUSTRIE” addressed this topic, elaborated a concept of a non-proprietary industrial DC MG and published a document with a complete description of an open system for an industrial DC MG system [2]. The concept consists of multiple sources such as renewable energy sources, the supply from alternate current distribution grid and energy storage systems [3]. Industrial power loads draw power directly from the DC MG and can feed braking energy in it, instead of wasting it in braking resistors, while a DC MG droop control based on voltage ensures power balance and ensures suitable power supply to those loads [3].

The research project "DCI4CHARGE" aims to the integration of EVSE and EV into DC MG, since the EV's battery could be used as a quasi-stationary storage device for various power flow purposes within a DC MG [4] – similar as in a vehicle-to-grid (V2G) scenario [5]. For this to be possible, bidirectional charging together with smart strategies must be employed [5]. Thus, the further investigation and progress of the functionalities of bidirectional charging technologies is indispensable. Modeling such systems is the first step to the exploration and the ongoing development of bidirectional charging systems in a DC MG context.

2 MATERIALS AND METHODS

The "DC-INDUSTRIE" *OpenModelica* library, which was developed and validated during the research project and already comprises various industrial DC MG components, was extended to meet the needs of future investigations of the possible behavior and scenarios resulting out of the integration of EVs and DC MG. The first step was to analyze how the other DC MG components were modeled, for the purpose of developing a matching model of a bidirectional charging system, which shall merge the behavior of an EVSE and an EV system. Secondly, a simple bidirectional charging system model was developed and implemented based on the simple behavior of a current source, considering that a current source acts inherently bidirectional. After successfully testing its functional aspects through simulations while integrating it to a DC MG model, an additional feature was implemented in the model: a droop control which adapts its response depending on the state of charge (SoC) of the EV's battery and on the DC MG voltage. Additionally, it can receive external regulation of an energy management system (EMS), i.e. the DC MG's tertiary control based on the definitions of [3].

3 RESULTS

The result of the work, illustrated in Figure 3-1 below, is a bidirectional charging system model, that allows the execution of a charging process in dynamic mode, which is the charging control mode defined in [6]. The dynamic mode's main prerequisite is the possibility of an intervention from a secondary actor, in that case the EMS of the DC MG. Through the offset of a current flow ($i_{off_{EMS}}$ in Figure 3-1), the EMS controls directly the power flow and thus accomplish its purpose of fulfilling the user's mobility needs and the DC MG operator's goals by acting externally. The added feature allows the model to reproduce smart charging processes in future simulations.

Additionally, the voltage-based droop control dependent on the EV's SoC allows a better and smoother current and power flow variation in the whole system by switching the acting droop curve according to the SoC value.

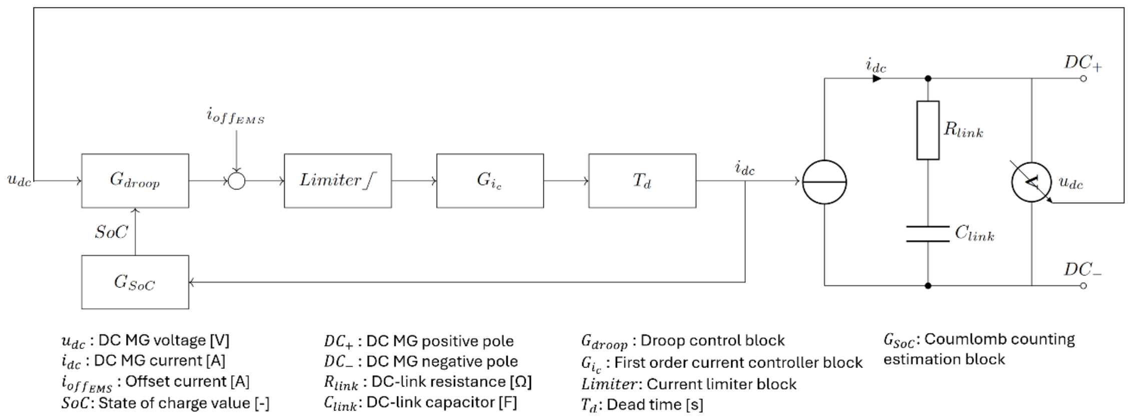

Figure 3-1: Simplified model depiction of the bidirectional charging system

4 DISCUSSION

As the adoption of EVs keeps increasing, industrial DC MG also can expand its potentials by exploring the benefits of V2G with EVs. Through future simulations and tests, the model will allow studies about possible stability issues of DC MGs with integrated EVSEs and EVs in different scenarios and perform first tests of control techniques of bidirectional systems integrated into DC MGs. Such model will also facilitate the investigation of DC MG EMSs in scenarios in which bidirectional charging plays an important role, such as supporting grid stabilization, increasing renewable energy utilization and saving costs for the EV owners. Such simulations enabled by this model can be validated in the future in real industrial facilities within the scope of “DCI4CHARGE”.

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ON THE POTENTIAL OF WASTE HEAT RECOVERY BY MEANS OF THERMOELECTRICITY

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Abstract: Waste heat is a by-product of every power generation and industrial process and is one of the largest sources of inexpensive, clean, and fuel-free energy available. Thermoelectric generators have been demonstrated to be a promising technique that can convert any form of waste heat directly into higher-value electrical energy. They offer several advantages: no moving parts, no working fluids, easy scalability, low maintenance costs, the ability to operate under non-continuous conditions, and a long lifespan.

This paper introduces a newly developed system for radiant waste heat recovery utilizing a bismuth-telluride based thermoelectric generator. Experiments conducted on a high-temperature test stand under laboratory conditions successfully achieved a maximum power density of 4 kW/m² at a temperature difference of approx. 280°C. A special focus has been placed on the design of the energy recovery system, ensuring it can withstand the harsh conditions typical for applications in the energy-intensive industry such as steel industry, glass industry, etc.

Keywords: thermoelectricity, thermoelectric generator, TEG, thermoelectric module, energy recovery system, energy harvesting

1 INTRODUCTION

The global demand for energy has undergone significant transformations in recent years, driven by a combination of economic growth, technological advancements, and the policy shifts aimed at sustainability. This transition is accompanied by a growing emphasis on energy efficiency. A study of Papapetrou et. al. showed the waste heat potential in various industrial sectors in the EU is about 304.13 TWh/year. [1] Therefore, the implementation of thermoelectric generators (TEGs) in these industries to convert unused waste heat into electrical energy is crucial for enhancing energy efficiency, reducing operational costs, and improving overall sustainability.

TEGs have proven to be a promising technique that utilizes the Seebeck effect to convert various forms of waste heat into valuable electrical energy. Various materials are used in the production of TEGs, which differ in their composition and applicable temperature ranges. Currently, the most important thermoelectric materials are IV-VI mixed crystals, Half-Heusler compounds and the well known bismuth telluride (Bi_2Te_3) based materials. However, since the first two options are unavailable or special order only, Bi_2Te_3 is the primary choice for its availability and cost efficiency. The drawback is its 300 °C maximum temperature limit compared to the other options.

2 MATERIALS AND METHODS

Figure 2-1 (left) shows the prototype of an energy conversion system for recovering unused radiant waste heat in the energy-intensive industry. Therefore, the system has been designed to operate in harsh environmental conditions such as fluctuating temperature and humidity, parasitic incident heat radiation, dusty environments, etc.

The main parts are a commercially available, low-cost TEG (Bi_2Te_3, TEP1-142T300, T_{max} = 300°C), a hot side to absorb the heat radiation, a cold side for heat dissipation to generate the temperature difference and a data acquisition system. The hot side is made of a stainless steel plate covered with paint to increase the infrared absorptivity. The aluminum-based cold side with water-filled channels effectively dissipates the heat from the TEG and additionally cools down the electronics. For high conversion efficiency a perfect thermal insulation between hot- and cold side is essential. This insulation is achieved by using MONOLUX-500, a high-temperature-resistant and mechanically processable silicate plate (> 900°C). Spring washers are installed beneath the cable suspensions to mitigate mechanical stress from temperature changes and ensure consistent mechanical loading on the TEG. A high temperature silicon oil (T_{max} = 315°C for closed systems) was used as thermal interface between TEG, hot- and cold-side. An additional stainless steel heat shield protects the cold side and electronics from radiation.

The data acquisition system operates autonomously and transmits the measurement data wirelessly (2.4 GHz WiFi) to a PC. It is designed to simultaneously generate electrical energy from the TEG and measure its electrical parameters, including open-circuit voltage, short-circuit current, and internal resistance, as well as the temperatures of the hot side, cold side and heat shield. Additionally, it measures humidity, ambient temperature, and air pressure to assess the environmental conditions. The energy harvesting electronics using a LTC3129 to increase the low thermoelectric voltage (> 1.8 V) to the minimum supply voltage (3.3 V) required by the ESP32 microprocessor used in the system and to charge a Li-ion cell to power the electronics even when no heat source is available.

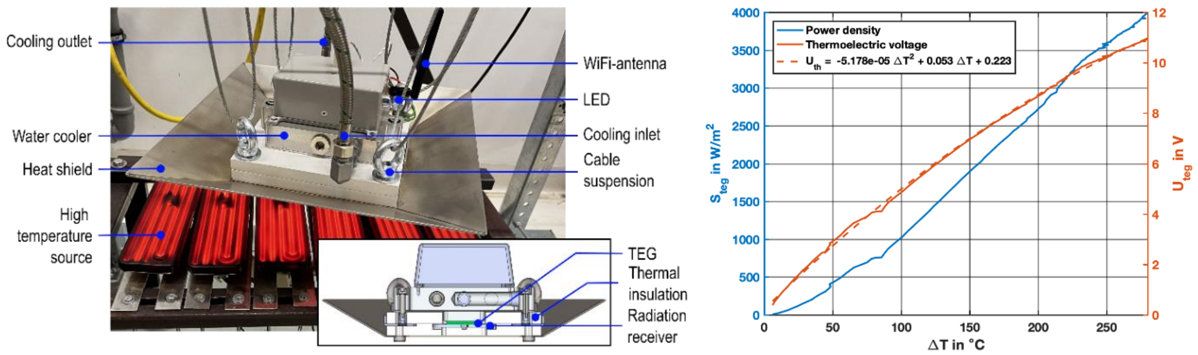

Figure 2-1: Left: Assembly of the energy recovery prototype and cutting plane; Right: Measurement results: power density S_{teg} vs. temperature difference ΔT and thermoelectric voltage U_{teg} vs. ΔT

3 RESULTS

To test the energy conversion system in the lab, a high-temperature test stand was designed and built. It consists of six heating elements, each with an electrical power of 1.2 kW and a surface area of 0.09 m². The TEG-system was mounted approximately 5 cm above the heating elements using steel cables (see Figure 2-1, left) and connected to a cooling device with a cold side temperature of 18°C.

Figure 2-1 (right) shows the measurement results of the power density (blue line) and open-circuit voltage of the TEG (red line) vs. temperature difference $\Delta T = T_{hot} - T_{cold}$. As shown, a maximum power density S_{teg} of 4 kW/m² at matched power can be achieved at a temperature difference ΔT of 280°C. In scaled-up systems, a fill factor will reduce this performance. The open-circuit voltage U_{teg} is 11.1 V, which aligns nearly the theoretical voltage

$$U_{th} = (\alpha_p - \alpha_n)\,\Delta T\, n = 11.4\,V, \tag{3-1}$$

where n = 127 leg pairs, α_p = 145 µV/K and α_n = -175 µV/K (values from [2]).

4 DISCUSSION

This paper presents an advanced thermoelectric system for recovering waste radiant heat, achieving an electrical power density of 4 kW/m². However, experimental results obtained in the high-temperature test stand showed that this power output is close to the theoretical limit.

Our approach focused on developing a small-scale system to ensure reliability, durability, and cost efficiency — as these are key factors for industrial implementation — and to avoid performance issues as reported in [2], [3]. Furthermore, the system is designed to work autonomously and is equipped with a data acquisition system to monitor the behavior during the experiments. Based on the successful demonstration of the small system, the next step is to design and develop a fault-tolerant energy recovery system, ensuring that one or more TEG degradation or failures do not lead to total inoperability, with an output power of 1 kW.

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VII. Session: Legislation, Politics and Business Models

The industrial energy transition depends on regulatory, legal, and policy frameworks that drive the transformation of energy markets and infrastructure. Consequently, this session explores the latest developments in decarbonisation policy challenges, the impact of RED III on third-party access, and the economic effects of digitalisation in energy-intensive industries.

A SURVEY ON DRIVERS, OBSTACLES AND ECONOMIC EFFECTS OF DIGITALIZATION IN THE ENERGY-INTENSIVE INDUSTRY

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Abstract: In today's rapidly evolving technological landscape, the energy-intensive industry is at a critical point of innovation and change. Technologies like artificial intelligence, the Internet of Things, and advanced data analytics are transforming industrial processes and resource use. This research explores the key drivers, obstacles, and economic impacts of digitalization and energy efficiency in the energy-intensive industry. It offers a detailed understanding of its journey toward digitalization by highlighting current efforts, challenges, and future directions for improving energy efficiency and sustainable practices. Further, it aims to uncover the forces behind digital transformation in the energy-intensive industry, identifying important drivers and examining barriers to digital technology adoption. A survey of industry professionals provides insights into the current state of digitalization, its effects on energy demand, primary drivers, obstacles, and future trends. Results show a strong push towards digitalization, especially in the steel and manufacturing sectors, driven by internal strategies and external support. Key drivers include better productivity, cost reduction, and increased competitiveness. Major obstacles are high initial costs, the need for skilled workers, leadership gaps, and outdated machinery. There is a clear link between digitalization and energy efficiency, with companies reporting financial savings and expecting more improvements through innovation.

Keywords: Digitalization; Energy Efficiency; Energy-Intensive Industry; Technological Transformation; Industrial Innovation

1 INTRODUCTION

The energy-intensive industry urgently needs innovation and transformation for sustainable growth. Digitalization - through technologies like artificial intelligence (AI), the Internet of Things (IoT), and data analytics - transforms industrial processes and resource use, making the sector crucial for sustainable development [1, 2]. The research aimed to examine digitalization's drivers, barriers, and economic impacts in the energy-intensive industry. While offering productivity, cost, and energy efficiency benefits, digitalization faces challenges such as high initial investments and the need for skilled workers. The identification of forces driving digital transformation in the energy-intensive industry and the obstacles hindering it were among the main targets. An empirical survey of industry professionals provides valuable insights into the current state of digitalization, its impact on energy demand, and future trends, focusing on how digitalization can enhance energy efficiency and sustainability in this sector.

2 MATERIAL AND METHODS

The research comprises a comprehensive literature review on digitalization in the energy-intensive industry. This review defined digitalization and identified key technologies that drive Industry 4.0. It explored the impact of digitalization on energy management and efficiency and analyzed its implementation's primary drivers and challenges [3, 4].

An empirical survey titled "Digitalization, Energy Efficiency, and their Drivers and Obstacles in the Energy-Intensive Industry" was conducted to validate the literature findings. The survey included 31 questions, differentiated into four categories: General Questions, Digitalization, Energy Efficiency and Sustainability, and Drivers and Obstacles to Digitalization.

The survey targeted professionals in energy-intensive industries, ensuring diverse representation. General questions gathered information about respondents' companies, roles, and sectors. Energy efficiency questions explored the relationship between digitalization and energy efficiency measures. The drivers and obstacles question stream identified key factors promoting or hindering digitalization. Responses were analyzed to identify trends and insights into digitalization's impact on energy efficiency, the drivers and obstacles to transformation, and the industry’s readiness for Industry 4.0. Combining the literature review with empirical data, this research provides a comprehensive understanding of the digitalization landscape in energy-intensive industries, highlighting key innovation drivers and challenges.

3 RESULTS

The response of 41 participants (return rate of approximately ten percent) from the energy-intensive industry who completed the full survey and eight others who completed it partly, aimed to ensure the sample's representativeness for differentiated conclusions. According to [5], the survey required a sample size of 44 responses from an assumed number of 348.000 leaders in Austria’s industrial sector with a 95% confidence interval and 15% margin of error. The survey, reflecting the target population's characteristics, revealed a strong tendency toward steel and manufacturing (32 responses) and significant representation from large enterprises (82%), validating its applicability to the energy-intensive industry despite a more miniature representation from chemical, pulp and paper, food and beverage, and pharmaceutical industries.

The analyzed results show a significant trend in digitalization initiatives in conjunction with the impact on energy demand and energy efficiency. As a complete representation of our findings would be out of scope, a representative finding is the results of decision criteria for investment in digitalization (see Figure 3-1). The most important criteria for investment decisions in digitalization are the payback period, investment amount, energy savings (both absolute and relative), and life cycle costs. The results for other criteria, such as net present value and digitalization as a means of climate protection, are more balanced. These findings suggest that economic considerations outweigh non-financial concerns (such as ecological or social ones) and strongly influence the decision to undertake a digitalization initiative.

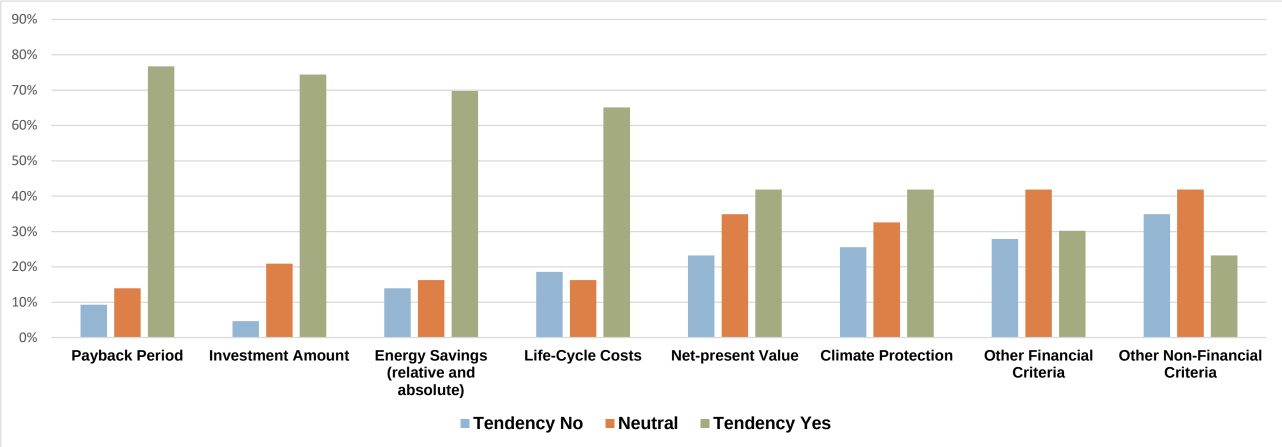

Figure 3-1: Decision Criteria for Investments in Digitalization

4 DISCUSSION

The findings indicate a strong push towards digitalization in energy-intensive industries, driven by the need for increased productivity, cost reduction, and competitiveness, alongside internal strategies and external financial support. While digitalization correlates with reduced energy consumption and improved efficiency, it faces challenges such as high investment costs, aging infrastructure, workforce qualifications, and technical issues with outdated machinery. Despite these obstacles, the industry recognizes the importance of energy efficiency and is forecasted to continue investing in research and development, workforce development, and cultural shifts toward sustainability. Ultimately, the human factor remains indispensable, guiding toward a more modern, flexible, and competitive production system.

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POLICY CHALLENGES IN INDUSTRIAL DECARBONISATION: NEXT STEPS FOR THE UK'S CLUSTER-BASED APPROACH

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Abstract: The transition to a net-zero economy requires policy innovation and effective implementation, especially in the industrial sector, a major greenhouse gas emitter. This paper critically examines the UK's approach to tackling the complex policy challenges associated with transforming its industrial manufacturing sector. The UK’s pioneering Industrial Decarbonisation Strategy in 2021 took a novel place-based, rather than sector- or technology-led approach to industrial decarbonisation seeking to capitalise on synergies within clusters of co-located industries. However, practical difficulties in implementing this approach may be putting the UK’s progress in creating sustainable industries at risk. Drawing on insights from IDRIC’s research and industry dialogue, this paper assesses the key challenges for advancing industrial deep decarbonisation, infrastructure development, and achieving a just transition, through a cluster-based approach.

Keywords: Industrial Decarbonisation; Policy; United Kingdom; Fuel Switching; Industrial Clusters; CCUS; Electrification; Business models; Infrastructure; Just Transition; Collaboration.

1 INTRODUCTION

Greenhouse gas emissions from industry accounted for 14% of UK’s territorial emissions in 2022 [1]. Approximately half are emitted by six coastal industrial clusters, while the remainder come from less geographically concentrated ‘dispersed’ sites. The ambition of establishing net zero industrial clusters has become a core pillar of UK’s journey to net zero emissions. The *Industrial Decarbonisation Strategy*, 2021 [2] placed CCUS and hydrogen at the centre of these plans. The cluster-led approach assumes that deploying low carbon infrastructure first into areas of energy intensive industry will reduce upfront investment in transmission and distribution infrastructure, mitigate development risks through providing a guaranteed customer base and leverage economies of scale to foster innovation [3]. Cluster-based activities were incentivised through two programs: The Industrial Decarbonisation Challenge (2021-24) focused on industry coordination and cross-cluster learning through funding of cluster-wide net zero roadmaps and FEED studies for shared infrastructure. In parallel, through competitive ‘cluster sequencing’, clusters deemed the most advanced for the deployment of carbon capture, transport and storage infrastructure are selected and given access to capital and revenue funding in the CCUS business models.

Three years on, the practical challenges of a cluster approach are becoming apparent. As the Climate Change Committee urges faster progress in industrial decarbonisation to reach the UK’s net zero target [1], this paper discusses the lessons emerging from the cluster approach.

2 MATERIALS AND METHODS

This paper synthesises key insights on the challenges presented by integrating sector-based, intervention-based, and place-based approaches to deliver industrial decarbonisation. It draws on findings from 34 IDRIC social science journal articles which incorporated expert interviews, document analysis and workshops, alongside policy analysis [4] complemented by insights from IDRIC's ongoing stakeholder dialogue, including seven cross-sectorial policy workshops with academic experts, industry cluster representatives and government representatives, undertaken between Jan 2022 and Oct 2023 [5].

3 CHALLENGE AREAS FOR INDUSTRIAL DECARBONISATION

Ensuring effective funding mechanisms for deep decarbonisation has remained a critical challenge. Despite the strong reliance on CCUS in all cluster roadmaps, a slow roll-out of the cluster sequencing process and a lack of plan to incentivise CCS and hydrogen development outside the designated 'Track 1' and 'Track 2' clusters are putting progress in meeting government targets at risk. Alternative decarbonisation pathways, particularly electrification, are crucial not only for sites within clusters but also for dispersed sites lacking access to future hydrogen and CCS networks. However, electrification has received less government attention to date and additional funding support is needed to cover both capital and operational expenses, similar to existing business models supporting CCS and hydrogen. The lack of a clear mechanism to support industrial electrification may push industries towards hydrogen as the default path.

A second challenge remains in effective energy system integration. Local cluster plans have proved useful in outlining ways of repurposing existing infrastructure (e.g. gas pipelines) and developing new shared infrastructure. A key challenge remains in integrating these hubs not just with wider local infrastructure (e.g. heat networks) but also in national energy systems. A new National Energy Systems Operator (NESO) is being established to deliver strategic energy plans for transforming the electricity and gas network into a whole energy system. Until a plan is in place, uncertainty over the speed, scale and location of developing hydrogen network remain an issue for decisions about fuel switching.

A third challenge remains in delivering a just transition. Optimism about the renewal of UK's former industrial areas co-exists with fears over job losses from decarbonisation and relocation and concerns that wider challenges facing industrial communities are not being addressed. The legacy of past deindustrialisation has led to a weak social security net, cuts to public service and fragile communities. While place-based investment and activities in clusters may address wider socio-economic needs, the risk of a piecemeal approach will not reach areas of highest need.

4 STRENGTHS AND CHALLENGES OF THE CLUSTER-BASED APPROACH

The UK's experience highlights the benefits of cluster decarbonisation for encouraging industry collaboration over sector-based strategies where companies are direct competitors. This approach aids in modelling decarbonisation options, planning shared infrastructure, and facilitating off-taker agreements. Coordination has been most effective where there is a history of previous collaboration between industry and with local governments and other stakeholders.

However, key challenges remain. Collaboration within and between clusters conflicts with the competitive nature of securing decarbonisation funding. Stakeholder coordination has remained difficult in clusters with more limited history of collaboration and where relationships between local industries and communities are historically strained. More broadly, there is a systemic challenge in integrating cluster plans effectively into national energy systems and a risk that the emphasis on CCS within cluster collaborations may lead to missed opportunities to explore and advocate for alternative decarbonisation options. This emphasis means that to date dispersed sites have received comparatively less policy focus.

While the UK has an Industrial Decarbonisation Strategy, it currently lacks an Industrial Strategy that outlines a clear, long-term vision for supporting a sustainable industrial sector, and integrates with other government strategies in energy, finance, infrastructure, and skills.

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RED III – WHAT IS NEW FOR THIRD PARTY ACCESS

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Abstract: Industrial waste heat utilization can significantly enhance primary energy efficiency, reduce emissions, and yield cost savings. A key method for leveraging this heat is by integrating it into district heating networks (DHNs). However, legal barriers present substantial challenges to such endeavours. Notably, at both the EU level and within most EU countries, there has been a lack of specific legislation governing market entry into existing DHNs. The Renewable Energies Directive 2018/2001/EU (RED II) aimed to establish a legal framework to facilitate access for third-party renewable or waste heat generators to feed into DHN. However, these provisions have been changed with the directive 2023/2413 (RED III). The findings of this paper indicate that the (new) legislation has the potential to significantly alter the dynamics between parties; however, DHN operators can still reject feed-in requests on economic and technical grounds. Furthermore, RED III mandates that DHN operators increase the proportion of energy derived from waste heat or renewables, thus promoting greater collaboration with third-party waste heat generators.

Keywords: District heating, Renewable Energy Directive, industry, waste heat, feed-in, access rights

1 INTRODUCTION

Before RED II, there was no European legal standard requiring district heating network operators to accept feed-in from third-party renewable energy sources (RES) or waste heat generators. This lack of obligation also applied to individual EU Member States. While bilateral private agreements were possible and often used, they required the network operator's explicit consent. Without such consent, third parties could only seek access through antitrust law, applicable if the operator held a dominant market position. District heating networks generally have monopoly-like structures due to high investment costs and geographical restrictions, which make parallel networks economically unviable. Although dominant operators are generally not obligated to contract with third parties, antitrust laws prevent the abuse of a dominant position, such as unjustified refusal of access, especially when competition is excluded. However, network operators are only required to allow access if it is technically feasible and does not unfairly disadvantage them.

2 RESULTS

RED III introduces binding renewable energy targets for the heating sector for the first time, ensuring renewable energy use beyond the electricity sector.

Table 2-1: Increasing targets

Building Sector (Art. 15a)	• 2030 min. 49% own supply from RES • MS defines indicative nationale share (INS)	• Waste heat max. 20% creditable • Increase INS by ½ of the waste heat %
Industry Sector (Art. 22a)	• Increase in RES for final energy consumption and non-energy purposes by 1.6% annual average calculated for 2021-2025 abd 2026-2030 • INS of waste heat max. 0.4 % creditable to average annual increase	• Supply via efficient district heating; networks that supply a building or if thermal energy is only consumed on site and is not sold excluded. • Increase in the average annual increase by ½ of the waste heat %
Heating and Cooling (Art. 23)	• Increase in RES share by min. 0.8% as annual • average calculated for 2021-2025 and by at least 1,1% points as annual average calculated for 2026-2030 • MS select at least 2 measures from catalogue	• Waste heat max. 0.4% creditable to average annual increase • Increase of average annual increase by ½ of the waste heat consumed up to max. 1.0% for 2021-2025 and 1.3% for 2026-2030. • Evaluation of waste heat utilisation • Catalogue of measures: physical admixture of waste heat // Waste heat for industrial heating processes
District heating (Art. 24)	• MS aim to increase the share of RES and waste heat compared to 2020 • INS of 2.2% as average annual increase for 2021-2030 • Crediting options for MS with already high RE/waste heat share	• Equalisation of RE and waste heat

3 DISCUSSION

One important aspect of RED III is Art 24 (4b) on third-party access to district heating networks. Article 24 (4b) RED III stipulates that district heating systems with a capacity of more than 25 MWh must grant third-party suppliers of energy from renewable sources and waste heat access to the grid, or offer third-party suppliers the option of purchasing their heat from renewable sources or waste heat and feeding it into the grid. Accordingly, RED III provides for two models, the single buyer model and the pass-through model.

Third-party access to the district heating system is therefore only to be granted if one of the following conditions is met: firstly, there is additional demand for heat from new customers; secondly, the existing heat generation capacities are to be replaced; or thirdly, an expansion of the existing heat generation capacities is required. This limitation ensures that access to the district heating networks is non-discriminatory, but at the same time purpose-orientated and takes into account the technical and economic framework conditions. This ensures security of supply on the one hand and supports the efficient use of existing resources and the promotion of renewable energy sources on the other.

Art. 24 para. 5 RED III allows district heating system operators to refuse access or purchase of heat if a) the system does not have the necessary capacity due to other supplies of heat from renewable energy sources or waste heat, b) the heat supplied by the third-party supplier does not fulfil the technical requirements for a safe and reliable supply, c) the costs for end customers would increase disproportionately if access were granted compared to the costs for the main source of heat or cooling supply on site, or d) the operator's system is an efficient district heating system.

The last paragraph of Art 24(5) RED III sets out the obligations of the Member States and the operators of district heating systems in the event of a refusal to feed-in and how legal remedies against an unjustified refusal are to be ensured. The interpretation of the paragraph can be divided into two main aspects: (i) The operator's duty to inform the competent authority and (ii) the creation of an appeal procedure against unjustified refusals. Therefore, it obliges the operators of district heating systems to be transparent when refusing to supply and requires Member States to provide procedures to ensure that unjustified refusals can be challenged. This strengthens the legal position of third-party suppliers and promotes fair, non-discriminatory access to the energy markets.

RED III, in Article 10, provides exemptions for Member States (MS) that allow them to bypass certain obligations in the district heating and cooling sector under specific conditions. One exemption applies if the share of district heating and cooling was less than 2% of the gross final energy consumption in the heating and cooling sector as of 2018, which does not apply to Austria. Another exemption is possible if a Member State increases the share to over 2% and demonstrates this by developing new efficient district heating and cooling systems according to national energy and climate plans. This could apply to Austria, depending on implementation and planned investments. Additionally, an exemption is granted if 90% of the gross final energy consumption in district heating and cooling systems comes from efficient systems, which requires a thorough review of the energy sources used. Whether Austria meets this requirement depends on its current systems and their efficiency.

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VIII. Session: Systemic Innovations: Scenarios and Efficiency Potentials

Achieving climate neutrality in industry requires systemic innovations, future scenarios, and strategies that unlock efficiency potentials, provide actionable recommendations, and scale net-zero technologies across various sectors. This session explores the transformation towards a climate-neutral industry, including the integration of geothermal energy, cascading heat utilisation, and the impact of innovative heat pricing on district heating networks.

EXAMINATION OF THE SUITABILITY OF INDUSTRIES FOR THE INTEGRATION OF GEOTHERMAL ENERGY AND CASCADING UTILISATION OF HEAT USING THE EXAMPLE OF GMUNDEN

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Abstract: The energy demand of industry accounts in Austria for around 30 % of final energy demand, with process heat demand being the largest share of industrial energy consumption. In order to successfully decarbonise the industry, geothermal energy with its diverse possibilities such as heating, cooling, power generation and storage must also be integrated into industrial processes. As part of the CASCADE project, industrial plants in the Gmunden region are being analysed for their suitability for the potential supply for geothermal energy. The Gmunden dairy is the main focus of the investigations. Analyses of measurement data from the various processes will provide information on necessary temperature levels, energy quantities and changes in energy requirements over time. The work also focuses on the excess heat potential of industrial and trade companies. At the Gmunden dairy, all relevant excess heat flows are analysed in order to assess the potential for further cascading use in the district heating network or in other companies. For all other companies the top-down approach via specific key numbers is applied to determine the excess heat streams.

Keywords: Industry, excess heat, geothermal energy, cascading energy use

1 INTRODUCTION

The project CASCADE is part of the NEFI – New Energy for Industry model region which places the decarbonisation of industry in the centre of a long-term innovation process to foster technological development. The CASCADE project aims to assess deep and shallow geothermal resources in three areas in Upper Austria – Steyr, Gmunden, and St. Martin im Mühlkreis - in order to investigate the feasibility of providing heat for the involved partners, i.e. industrial partners – Gmundner dairy plant as well as the district heating grids of the two municipalities Steyr and Gmunden. Key element is the elaboration of a concept for cascaded heat use: high-temperature deep geothermal resources for industry and the district heating grids, followed by use of the middle- to low-temperature residual heat for housing and commercial purposes, thus creating regional synergies and at the same time significantly boosting the economic efficiency of the system.

Industrial energy use accounts for approx. 29 % of the final energy use in Austria [1]. Process heat demand is the largest fraction of industrial energy use. In accordance with the Paris agreement, this on-site demand need to be supplied by carbon neutral energy carriers. In order to achieve a successful long-term transformation of the energy supply structure in course of the energy transition, in particular the heat sectors must be included in addition to the current strong focus on the electricity sector: In Austria, the heat supply is responsible for more than half of the final energy demand (Fig. 1-1), low-temperature heat <100 °C for space heating and water heating takes a share of approx. 64 %, the rest is accounted for medium- and high-temperature heat used in the industry and service sectors [2].

Figure 1-1: Final energy consumption in Austria 2022 and share of renewable energy divided between heat, electricity and fuels (own illustration, data from Statistics Austria [2])

In the supply of medium- and high-temperature process heat in industry and trade, excess heat is inevitably generated as a by-product either in process equipment (dryers, ovens, boilers etc.) or in the form of wastewater (washing, dyeing and cooling processes) for example. It describes the losses of a process and can be reduced by efficiency measures, but not completely avoided [3]. The reason why excess heat can often no longer be used directly in the process is that the quality or useful work potential of the excess heat (exergy) is already too low for the relevant processes in operation and can therefore no longer be used economically.

In terms of cascading energy use, however, this part of the excess heat can be used to cover heat requirements outside the plant to supply private buildings, other industrial plants or greenhouses for instance. Energy cascades also refer to a special form of connecting customers to DH networks enabling lower return temperatures and higher transport capacities. Here, suitable customers draw their heat demand from the return line of the main DH networks. [4]

Geothermal heat is available 24/7 and should be used as best as possible due to the high investment costs. However, existing studies on geothermal use in Austria were mostly limited to the geothermal heat supply of private and public buildings. Regarding the industrial use of geothermal energy, the examples might be fewer but show high potential.

2 METHODOLOGY

In addition to other objectives in the CASCADE project, the authors' first objective is to verify the suitability of the Gmunden dairy for the integration of geothermal energy for the supply of the processes (this applies also for other industries). The second objective is to determine the available excess heat potential (on all investigated temperature levels) from the plants for further cascade utilisation in the existing district heating network of the city of Gmunden as well as a possible supply to other companies, but perhaps for internal use. To analyse the energy flows in the plants, a distinction is made between bottom-up and top-down approaches. In the case of the Gmunden dairy, the bottom-up method is used to analyse all energy streams using time-resolved measurement data and thus identify energy consumption as well as possible excess heat streams. For the other companies the top-down approach is applied. In this case key figures from literature or derived from statistical data (e.g. energy consumption per employee) are used to determine the overall energy consumption of the companies. Key figures from the literature or from our own calculations of similar industrial sectors are used to determine excess heat. [5]

3 RESULTS AND DISCUSSION

The work on the energy situation of the plants has not yet been finalised. The analysis of the Gmunden dairy includes different parts of the plant. To date, the CIP system (cleaning in place), VTIS installation for continuous UHT treatment with direct steam injection, the two cheese dairies and the thickening of whey have been analysed. Other systems to be analysed are the steam generation, the air compressors, the refrigeration systems and the wastewater flows.

In addition to the dairy, further 10 industrial and trade companies with more than 20 employees were identified and analysed on the basis of the top-down approach. Energy demand and excess heat potentials are calculated using the top-down approach described above based on the available number of employees. The excess heat can also be categorised into temperature classes by comparing it with similar companies that have already been analysed.

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THE IMPACT OF A NOVEL HEAT PRICING METHOD ON A SUPRA-REGIONAL DISTRICT HEATING NETWORK

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Abstract: In literature, much research focuses on pricing heat in a district heating network, often assuming the network to be a natural monopoly. These price models often come with either disadvantages for consumers or drawbacks for heat suppliers. Less research is devoted to the analysis of pricing models for supra-regional district heating networks, which can connect existing district heating networks and heat generation units. Consequently, the integration of such a network presents economic consequences that are not yet fully understood. This article aims to close this research gap by providing insights into an innovative heat pricing model, highlighting its impact on heat prices and the levelized costs of heat for heat providers. To achieve realistic results, the described price model is used to simulate and analyse a supra-regional district heating network using a dynamic load flow calculation over the course of an entire year.

Keywords: Supra Regional District Heating Network; Heat Price; Styria, Load Flow Calculation, Industrial Waste Heat; Primary Energy Savings

1 INTRODUCTION

Pricing heat in a district heating network (DHN) is a highly debated topic, both scientifically and socially. Today, heat prices are very often non-transparent leaving end customers with no alternatives once they have opted for a district heating connection. In many cases, this issue arises because the heat provider in a DHN has a natural monopoly [1]. The reasons for this situation can also be traced back to the high investment costs of the heat generation units (HGU). To ensure that these investments are profitable, providers need to set high heat prices, especially when full load hours are low. To address this, regulating the heating market is a potential solution. Some of such models could be the true cost [1] or the true cost plus [2] model. While regulation could satisfy consumers by ensuring transparency and, thus, fair prices, it may also deter companies from investing in efficiency improvements or even entering the market. This is particularly true for companies whose primary business is not heat production, such as those generating industrial waste heat (IWH), which is a secondary product. In contrast to regulated heat price markets, deregulated markets provide e.g. IWH heat suppliers a greater room for manoeuvre, but this can lead to incomprehensible heat prices due to the frequent occurrence of monopoly heat generation lots. Some models could be pricing based on marginal costs, incremental costs or on shadow prices [2]. Even though heat producers often claim their prices follow this scheme, this is not always guaranteed due to a lack of competitive pressure in their monopoly position [3]. A similar approach could be to price heat based on a specific energy carrier price, such as a natural gas-based substitution price [1]. However, such pricing models could lead to over- or underprice the heat and often offers no incentives to become more energy efficient. This leads to the conclusion that a system, balancing consumer protection with incentives for companies to participate and invest in the heating market is strongly needed. One approach to archive this, is described in [4]. The authors propose a transparent pricing system that incentivizes heat providers to improve their efficiency. However, the described system may seem overly complex to operate. The method described in [3] offers a solution for pricing heat with their levelized costs of heat (LCOH). This method simultaneously allows actual costs to be passed on and provides a transparent approach. However, this model assumes there is only one heat supplier company, so the generation units are not in competition among each other. Otherwise, the proposed method would tempt participants to distort LCOHs to gain market advantages. To address the issue of fair and competitive heat pricing for heating networks with multiple suppliers, this article presents a novel approach by using a LCOH based bid pricing system for supra-regional district heating networks (SRDHN). To analyse its effects, the approach is applied to a SRDHN in Austria.

2 METHOD

SRDHNs offers the possibility for multiple heat providers with different types of HGUs to integrate in a deregulated heat market. This leads to the positive outcome that improving energy efficiency becomes key for participating in the market, and overpricing can be avoided. Therefore, a heat merit order(Figure 2-1) needs to be implemented. To avoid low or negative prices, which would deter companies, especially IWH, from entering the market, the prices in the merit order should follow LCOH rather than marginal costs. Since it must always be assumed in a merit order system that the bid prices (BP) do not correspond to the actual LCOH, additional rules must be implemented.

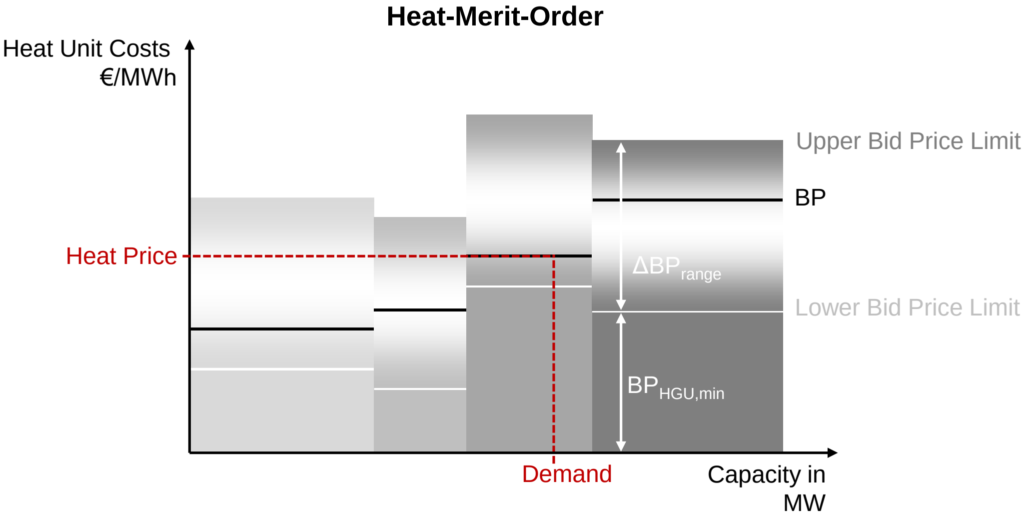

Figure 2-1 Final Heat Price based on a Merit Order System

Lower and upper bid price limits are introduced to ensure that heat providers submit bids for their HGUs that closely align with their actual LCOH, while still allowing for some flexibility. The lower limit should be based on the most efficient HGU of each type in the SRDHN area. This lower limit should be based on the specific investment and operation costs, excluding fuel costs, like the LCOH without fuel costs. To calculate these specific costs the amount of the generated heat for each year should be chosen based on the maximum achievable full load hours in the considered SRDHN, assuming the HGU would be the sole heat provider.

3 RESULTS AND CONCLUSTION

The paper analyzes the influence of the proposed method on the development of the heat-price in comparison to a conventional approach. Additionally, there is a discussion on how the new method impacts the cash flow and, consequently, the net present value of the most important HGU types. This can be achieved by comparing the costs or the net present value of the non-connected grids with those when connecting these grids with the SRDHN.

The novel heat pricing approach enables transparent heat pricing within a free market context. This system creates incentives to encourage improvements in plant efficiency to ascend in the merit order sequence. This approach is facilitated by the innovative concept of an interconnected, supra regional heat transmission network, whose technical feasibility has already been confirmed in an initial study. The price model is tested using a load flow calculation [5] that realistically simulates daily operations, leading to comprehensible and realistic results. Hence, the results can be regarded as a valuable initial assessment of the actual costs associated with a SRDHN.

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TRANSFORM.INDUSTRY
TOWARD CARBON NEUTRALITY IN AUSTRIAN INDUSTRIES

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Abstract: Domestic industry is a cornerstone of Austrian prosperity, as is an intact environment and a climate that is conducive to life. The Austrian government has committed for the country to become climate-neutral by 2040; this cannot happen without substantial efforts in all CO_2-intensive areas. To preserve the industry and environment, a transformative approach is necessary. Within the present study we investigated how this approach could look like for the diverse, technologically complex industrial landscape - and with maximum preservation of domestic value creation. It also discusses, which of the many potential technologies are the most promising and are worth the investments from a macroeconomic perspective. To encompass a comprehensive solution space, four extreme scenarios were formulated and modelled. 17 key technologies and their individual applications were evaluated for all 13 industrial subsectors, with a macroeconomic analysis yielding holistic recommendations. Main results are the importance of using domestically available energy carriers to maximize added value (especially electricity and biomass), the doubling of the industrial electricity demand until 2040, and the reduction of primary energy demand through intensified sector coupling. The most economic approach is a joint effort of industry and the energy supply sector.

Keywords: industrial climate neutrality; decarbonisation pathways; clean manufacturing; scenario modelling; macroeconomic analysis; integrated energy systems

1 INTRODUCTION

At the heart of sustaining prosperity and achieving climate policy objectives lies value-added activity and innovation. This work aims to model the impact of 17 technologies on 13 sectors of the Austrian manufacturing industry on energy balance, GHG emissions and economic output and aims to provide clarity regarding the technologies to be further developed and deployed, presenting fundamental pathways for industrial transformation.

2 MATERIALS AND METHODS

The status quo of economic activity, energy-use, and emissions based on the national accounts and energy accounts [1] together with the values from the *NEFI* decarbonisation pathways [2] form a basis for the future energy demand in Austrian industry. To cover a large solution space and provide robust results, four extreme scenarios were set up and modelled:

- **"Renewable gases" (RG)**: Provision of renewable energies by energy suppliers and continuing use of existing technologies by substituting fossil fuels by renewable gases.
- **"Circular economy" (CE)**: Increased material efficiency and higher recycling rates enable a substantial reduction in the energy-intensive production of raw materials.
- **"Innovation" (IN)**: Best-available and breakthrough technologies are used to a large extent, which is achieved through a high level of integration of the value chains.
- **"Sector coupling" (SC)**: An optimization approach is pursued in which domestic primary energy consumption is minimized as energy is used optimally for this purpose.

All scenarios are consistent in the sense that they reach climate neutrality by 2040 but differ in the way they reach this goal. Eight technologies for process transformation and nine technologies for heat provision were analysed together with their potential usage in 13 industrial sectors. A bottom-up analysis of the applicability of these technologies yielded future energy demand, GHG emissions, and investment needs.

3 RESULTS

Looking at all scenarios, the energy demand of the industry will increase by 15-24 % to 132-144 TWh by 2040. From the total energy demand, 55-60 % are ascribed to the same energy carriers in every scenario and are therefore found as no-regret options, that is: 39 TWh electricity (27.0-29.5% of total energy demand), 23 TWh renewable gases (16.0-17.4%), 10 TWh solid biomass (6.9-7.6%), 5 TWh waste heat (3.5-3.8%) and 2 TWh district heating (1.4-1.5%). Investigating further the different scenarios apart from the common demands, the *renewable gases* as well as *circular economy* scenarios rely additionally to 27.1-32.4% on renewable gases (47 TWh in RG and 36 TWh in CE), while the *innovation* scenario uses 16.7% hydrogen (22 TWh) and additional 6.3% electricity (8 TWh), and the *sector coupling* scenario utilises 16.7% hydrogen (22 TWh) and 11.7% waste heat (16 TWh).

From screening the best applicable technologies for each sector, the following provide in total the largest GHG reduction potential:

- Direct reduction with methane or hydrogen in the primary steel production together with electric arc furnaces in the secondary steel production
- Carbon capture with amine scrubbing or oxyfuel combustion in the cement production
- Renewable gas-fired boilers
- Heat pumps using ambient heat or waste heat
- Direct waste heat utilisation for processes and amine scrubbing
- Ammonia and methanol production from hydrogen in the chemical industry

- Olefine production via methanol from hydrogen or biomass in the chemical industry

The cumulated investment requirements range from 17.4 billion Euros in the *circular economy* scenario to 24.4 billion Euros in *innovation* and *sector coupling* scenarios. By far the highest investment requirements were found for the *iron & steel* sector with 10-14 billion Euros, followed by the *minerals* sector with 2-4 billion Euros, *(petro-)chemical* industry with 1-3.9 billion Euros and *pulp and paper* with up to 3.8 billion Euros. From a macroeconomic perspective, all scenarios showed long-term growth of gross domestic product (GDP), but involving a decrease in net exports through increased imports of renewable energy carriers. The highest increase in GDP related to the required investments were found in the *circular economy* and *innovation* scenarios.

4 DISCUSSION

From the presented results, the following recommendations have been derived:

- Prioritising efforts to expand renewable generation and transport infrastructure in Austria is crucial as the industry's electricity demand will double by 2040 and local production of renewable energy carriers and feedstocks from electricity may reduce import demands.
- The non-energy-intensive sector must accelerate the adoption of already well-developed cross-sectoral technologies (e.g., heat pumps) to maintain competitiveness and achieve emission-reduction targets.
- Rapid development and deployment of production technologies in energy-intensive sectors is needed. Integration of renewable energies and corresponding technologies in mainly existing production processes need much higher R&D efforts.
- Austrian activities for industrial decarbonization should prioritise the use of domestic energy sources, particularly electricity and biomass, maximizing the added value by minimizing import demands.

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IX. Session: Circular Economy

This session focuses on innovative approaches in the circular economy, showcasing research on waste heat utilisation in thermo-chemical processes, life cycle assessment for sustainable steel industry transitions, and energy, water, and carbon flow optimisation in biopharmaceutical facilities. Presentations highlight key strategies for reducing environmental impact and enhancing resource efficiency.

DYNAMIC PROSPECTIVE LIFE CYCLE ASSESSMENT OF TRANSITION PATHS FOR THE STEEL INDUSTRY

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Abstract: Life cycle assessment as established method to assess the global warming potential of products and services is subject of research activities to improve the assessment of changing and emerging systems as part of transition paths towards climate neutrality. The novel tool *Prosperdyn* presented in this paper contributes to this research field by enabling dynamic prospective life cycle assessment of transition paths. The novelty compared to other available tools in this field is the approach for the calculation of different foreground technology and energy supply paths, combined with also changing global background systems resulting in significantly reduced computational time. *Prosperdyn* has been applied to the changing crude steel production from the blast furnace route today to direct iron reduction by hydrogen up to the year 2050. Moreover, a dynamic impact assessment to evaluate the effect of emission reduction measures results in the additional radiative forcing as complementary metric to the global warming potential.

Keywords: prospective life cycle assessment, dynamic life cycle assessment, steel production, climate neutrality, industry transition, emerging technologies

1 INTRODUCTION

The Emission Trading System requires the European industry to reduce greenhouse gas (GHG) emissions on a steep continuous path towards the target of net zero in 2050. The especially challenged primary steel industry can reach this target only by deploying emerging production technologies and efficient use of renewable energy carriers [1]. Knowing about the effect, which technology choice and timing of its deployment have on the path of GHG emissions, is currently of high importance to support investment decisions of the industry sector. Life cycle assessment (LCA) as a suitable method to assess emissions of industrial production was designed to evaluate present processes statically, it has however limitations when applied to changing and emerging systems [2].

Hitherto available tools for prospective or dynamic LCA have focussed either on the prospective modification of background data or on complex dynamics in a foreground system [3], [4]. In most cases, however, only the emissions of one foreground system at one or two time steps in future have been assessed. The presented tool *Prosperdyn* combines those approaches deliberately aiming for a novel dynamic-prospective tool that includes prospectively modified background data in temporally resolved scenarios for transition paths of the Austrian steel industry.

2 MATERIALS AND METHODS

Data of present and emerging steelmaking processes is combined to form a first transition path of a potential future integrated steel plant inventory. As novel dynamic inventory calculator for the *Brightway* package *premise* [3], *Prosperdyn* calculates first the demands for electricity and hydrogen for the transition path and creates a corresponding infrastructure inventory comprising the construction of power plants, electrolysers and other facilities. Then it calculates dynamic emissions for both these inventories drawing on background data from *premise*, which modified *ecoinvent* data according to integrated assessment models. The calculated course of dynamic emissions is the basis for static as well as dynamic impact assessment methods. Methods from *Brightway* calculate for each year global warming potentials. Moreover, a dynamic impact calculator computes the additional radiative forcing superimposing the dynamic behaviour of individual greenhouse gases with the dynamic emissions. Depending on the results, scenarios are rearranged with the targets climate neutrality in 2050 and minimisation of the emitted greenhouse gases until then.

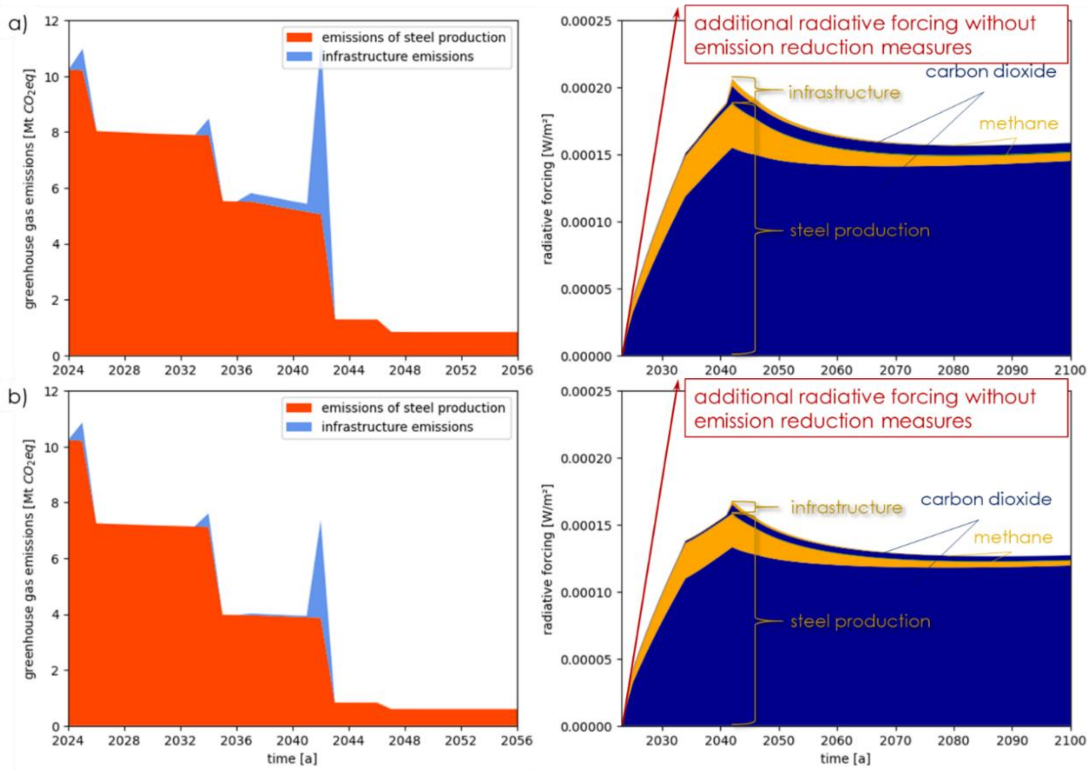

Figure 2-1: GHG emissions according to GWP100 (left) and additional radiative forcing due to carbon dioxide and methane emissions (right) of two preliminary scenarios for the transition path of a steel plant. Emissions during steel production and for the construction of plant infrastructure are considered separately. The red arrows elucidate, how radiative forcing would evolve without reduction measures

3 RESULTS

Figure 2-1 shows the greenhouse gas emissions as global warming potential and their related radiative forcing for two preliminary scenarios for a fictitious steel plant. Impacts arising during the construction of the infrastructure are shown separate from the emissions arising during steel production. Since these scenarios do not achieve climate neutrality the additional radiative forcing increases in distant future again, even though it is significantly lower than without reduction measures.

4 DISCUSSION

The novel tool *Prosperdyn* shows distinct advantages in its application to assess the effectiveness of transition paths of the steel industry towards climate neutrality. It expands the functionality of the tool *premise*, which considers prospective changes of the background, in two more aspects of the foreground inventory. Each scenario can describe process individual foreground dynamics with increased flexibility concerning their temporal resolution and the time correlation between processes. Due to its increased calculation performance, many scenarios can be modified iteratively and calculated subsequently in short time. Combined with advanced calculation methods for the dynamic assessment of climate impacts, it calculates consequences of emissions in a temporally exact manner and supports decisions when which steel making technology or energy carrier should be applied from an environmental perspective.

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OPTIMIZED USE OF WASTE HEAT IN THERMO-CHEMICAL PROCESSES FOR PROCESSING SECONDARY RAW MATERIALS

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Abstract: The use of waste heat has great potential for reducing CO_2 emissions, as around 90% of heat production worldwide comes from fossil sources. The processing of secondary raw materials is also becoming increasingly important. This is where the “TCP_to_industry” research project comes in, supporting the practical testing of seccon GmbH's patented thermo-chemical process by comprehensive energy system modelling. The regarding energy model is designed to depict the thermo-chemical process behind the seccon patents and determine the optimum for the processing of various recyclable materials. The aim of the optimization is to use as much waste heat as possible while reducing costs and electricity and/or gas consumption.

Keywords: processing secondary raw material; waste heat utilization; optimization

1 INTRODUCTION

The European CO_2 reduction targets require significant improvements in private and industrial applications and processes. The industrial heating sector plays a particularly important role, as around 90% of heat generation worldwide comes from fossil energy sources in 2018 [1]. Effective decarbonization can be driven by increasing process efficiency, the use of renewable energies or the use of waste heat. Although waste heat is already frequently used directly in industrial processes or in district heating grids, considerable quantities remain unused because either heat recovery in the company itself has already been exhausted or there are no customers to be supplied nearby. The use of this waste heat therefore represents huge potential for decarbonization.

Additionally circular economy approaches offer the potential for reducing both the use of primary energy and the associated emissions. By recovering raw materials, primary raw materials as well as primary energy can be saved if more energy is required to extract primary raw materials than to process secondary raw materials. Recyclable materials are processed using mechanical, chemical or thermal processes. Mechanical processes usually deliver products with a poor degree of purity, whereas chemical and thermal processes are energy-intensive and increase the process costs and emissions generated. Ideally, waste heat can be used for thermal processes. [2]

This is where the “TCP_to_Industry” research project comes in. In addition to the practical testing of seccon GmbH's patented process, the research project focuses on the development of a comprehensive energy model. The patent submitted by seccon for a “Process for recovering recyclable materials from recycling materials” describes a thermo-chemical process in which waste is thermally processed. The thermo-chemical process takes place in a rotary kiln. The heat required for this is obtained from a nearby industrial production plant that generates waste heat. This is intended to guarantee cost- and emission-efficient processing of recyclable materials using waste heat that would otherwise not be used. [3] The overall energy model is intended to represent the thermo-chemical process in the best possible way and determine the optimum for the preparation of different recyclable materials in combination with the waste heat from a nearby industrial plant.

2 METHODS

The overall energy system model consists of three main components as shown in Figure 2-1: (1) Aspen Plus model, (2) interface and neural network, (3) optimization model. The Software ASPEN Plus is used to model the chemical aspects of the thermo-chemical process. Since ASPEN Plus cannot perform optimization, an interface in combination with a neural network was developed to connect the ASPEN Plus models with the optimization model to determine the optimal operation of the thermo-chemical process in combination with a selected industrial plant. The aim of the neural network is to find relationships between the input variables (ASPEN Plus Model) and at the same time to make forecasts for the input variables of the optimization model. An LSTM RNN model was developed for this purpose. Energy flows are represented, waste heat is utilized and recycled, and the exhaust gas is used.

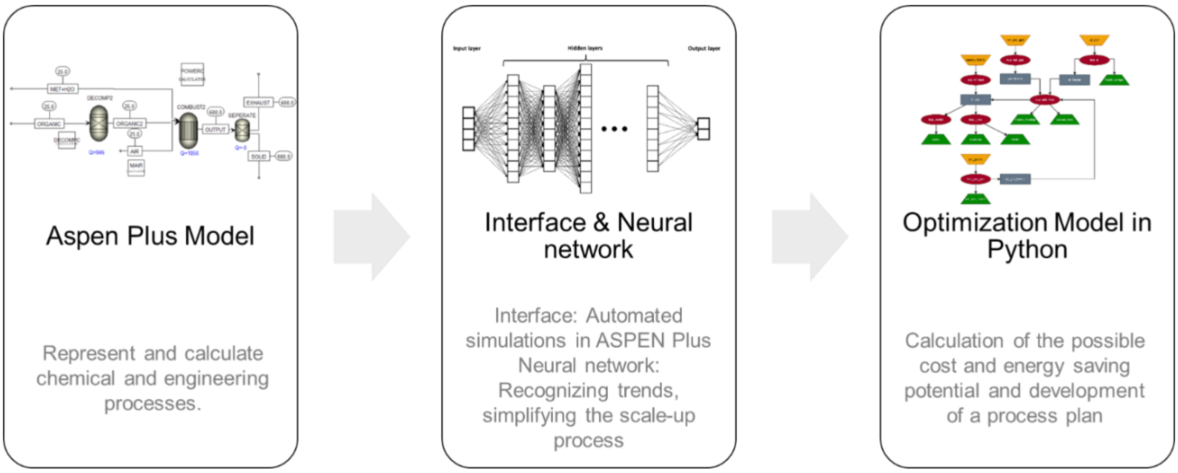

Figure 2-1: *Overview overall energy system model*

The optimization model was generically modeled with the Python library OEMOF. The aim of the optimization is to use as much waste heat as possible while reducing costs as well as the use of electricity and/or gas. The optimization model consists of several components (buses, transformers, sources and sinks) that are linked together with energy flows, and constraints, which describe the behavior of the energy system. Furthermore, the model is divided into four sections, each describing a specific part of the energy system. The first section contains the main components (rotary kiln, inlet of the process gas/waste heat, cooler component, unused energy and losses, sinks for the materials) and describes the thermal behavior of the thermo-chemical process and to account for temperature changes over time. The second section describes how to deal with the exhaust gases generated from the processed materials. The exhaust gases can either be sold to an external buyer, reused in a burner in the process itself or delivered to the nearby production plant, from which the waste heat is obtained. Depending on various input parameters, the optimizer decides which of the two purposes is most suitable in each point of time. The third section is responsible for the additional heat required to increase the process temperature. The additional heat can be generated by the exhaust gas burner, a natural gas burner and an electric heater. If too much heat is available, it can be fed into a district heating system or released into the atmosphere without further use. The fourth section describes the use of electrical energy for mechanical purposes. This energy is used, for example, for the rotational energy of the rotary kiln and for pumps or compressors to transport the process gas. The use of mechanical energy depends on various factors such as material and gas flow and is calculated during optimization.

3 RESULTS

In the proposed paper, a reference scenario is compared with an optimized scenario for one summer and one winter week each. To ensure that the use of waste heat is preferred, it is assumed that the waste heat is initially available free of charge. In all scenarios, four different materials (coffee capsules, biomass, printed circuit boards and fiber composites) are processed. In the reference scenario, the quantities of materials and the process plan (PP), i.e. the order in which the material is processed, are defined. As part of the optimization process (OPT), the optimizer decides when, how many and which materials can be processed based on a cost reduction and the available waste heat potential. It is possible that materials are only partially processed or not processed during optimization compared to the reference scenario. The total energy savings and profit increase potentials shown in Table 3-1 compare the resulting energy quantities and costs for the process plan with those for optimization. In the example shown, all materials from the reference scenario are fully processed in the optimized scenario.

Table 3-1: Overview results – Comparison of results according to process plan (PP) and with optimization (OPT)

scenario	Total amount of energy		Total energy savings	Profit increase potential	
	PP	OPT			
	[MWh]	[MWh]	[%]	[€]	[%]
Summer month	5.163	5.158	0,08	3.125	0,46
Winter month	5.349	5.341	0,14	2.726	0,39

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X. Session: Poster Presentation

ECONOMIC ANALYSIS ON A GREEN HYDROGEN ELECTROLYSIS POWER PLANT IN NORTHEAST OF BRAZIL

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Abstract: This study has the objective of answering the following question: Which renewable energy source will provide the lowest production cost of Hydrogen in an Electrolysis plant in Northeast of Brazil? For that, the production costs of Green Hydrogen from different Renewable Energy sources will be calculated and compared between each other, in order to comprehend which option is the most suited, in economic terms, for this specific case. The sources that will be analyzed are: Solar, Wind Onshore, Hydro and Biomass. Calculations will be made in order to find out the renewable energy source that will provide the lowest production cost for the Green Hydrogen produced in a plant in the Northeast of Brazil, in a city named Pecém. These estimations will be based on real data (except the CAPEX of the Electrolyzer, which in all 3 cases are based on estimates from literature) and parameters of the Hydrogen Plant, obtained through interview with a worker from EDP (public information). This study led to the conclusion that the Renewable Energy source that provides the lowest Green Hydrogen production cost for Brazil is Wind Onshore. A combination between Alkaline Electrolyzer and Wind Onshore provides the lowest production costs.

Keywords: Green Hydrogen; Production Costs; Brazil, Electrolyzer, Wind Onshore

1 INTRODUCTION

With the growth of the Renewable Energies Systems, it is faced an increase in the demand for Energy Storage Systems, since one of the main issues with the employment of “clean energy” is that most of the sources have high variability, meaning that it is only possible to generate electricity when there is sun or wind, if either Solar or Wind energy is employed, for instance. This is one of the challenges that nations need to overcome in order to become fully reliable on renewables energies. Therefore, if it is possible to store large amount of energy in a cost-efficient manner, then it will be easier for the countries to reach their decarbonization targets.

This way, since the Hydrogen can be used as Energy Storage/Transport medium, its relevance within the renewable energy sector is of enormous interest. Regarding its production, according to International Renewable Energy Agency (2021) [1], at the end of 2021, approximately 47% of the global Hydrogen production came from natural gas, and 27% came from coal.

Regarding the storage of Hydrogen, according to International Energy Agency (2019) [2], it can be done mainly in two ways: through the use of storage tanks or by employing the so called geological storage, which is the use of salt caverns, depleted natural gas or oil reservoirs and aquifers to store the H_2. Also according to the author, it can be transported through pipelines, shipping and using trucks, in the case of smaller distances.

Concerning the production of Hydrogen, regardless if renewable or not, it can be produced through many processes, which according to Silveira (2017) [3] are: Electrolysis, Thermolysis, Photolysis and Thermochemical. Regarding the “colour” of Hydrogen, Heliogen (2021) [4] explains there are several “colours” of hydrogen, such as: green, pink, white, blue, brown and gray hydrogen. Nevertheless, according to the author, the Green Hydrogen is the one produced through the electrolysis process, which has its necessary electricity fed by renewable sources with zero carbon emissions.

This way, since the production cost for the Green Hydrogen is directly influenced by the LCOE (Levelized Cost of Electricity) of the employed energy source, this study has the objective of answering the following question: **Which renewable energy source will provide the lowest production cost of Green Hydrogen in an Electrolysis plant in Northeast of Brazil ?**

2 MATERIALS AND METHODS

The current study presents the goal of applied research, a purpose of exploratory research and the methods to be employed are the bibliographic research and the case study. Regarding the approach, it can be considered as a qualitative-quantitative, mainly quantitative research.

Besides that, it is relevant to note that some data regarding the Green Hydrogen Plant in Brazil will be obtained through interview with worker from the usine and some other data will need to be estimated through existing literature. The main parameter based on the estimates from literature is the CAPEX of the Electrolyzer, which for all of the 3 cases is based on the information provided by studies (bibliography). Also, other information will be taken from IEA reports, for instance, the LCOEs and the WACC for Brazil. Once all of the data has been gathered, calculations and analysis were elaborated to be able to reach conclusions. Additionally, the software employed for making all of the necessary calculations and plotting charts is Microsoft Excel.

3 RESULTS

As mentioned, this study seeks to comprehend which of the renewable energy source will provide the lowest production cost of Green Hydrogen. This way, the production costs were estimated for different renewable energy sources and for different electrolyzer types. Due to the fact that the the Biomass, Hydro and Solar provide identical production costs and since Solar is the source employed by the Green Hydrogen Power Plant in Pecém, in the following chart (Chart 3-1), only the production costs considering Solar and Wind Onshore are shown.

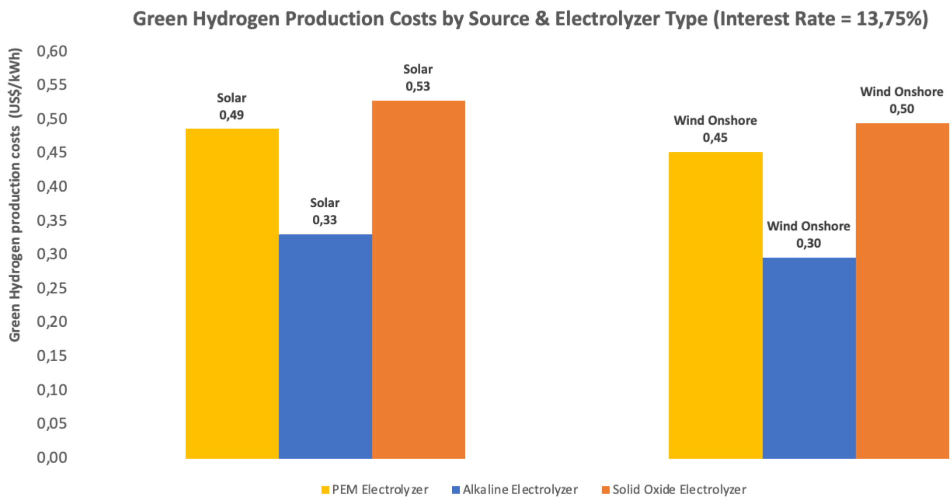

Chart 3-1: Green Hydrogen Production Costs by Source & Electrolyzer Type - Interest rate = 13,75%

In the chart, it is possible to note the differences in the production costs for each renewable energy source and each of the studied electrolyzer type (for all 3 of them, the CAPEX of Electrolyzer was calculated based on estimates from literature). In addition, it is possible to conclude that the option which provides the lowest production cost is the Alkaline Electrolyzer, having the electricity provided by Wind Onshore, since this electrolyzer type requires the lowest CAPEX and due to the fact that the Wind Onshore provides the smallest LCOE between the renewable energy sources that were analyzed.

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EMBRACING THE POTENTIAL OF OPEN STRATEGY IN ENERGY TRANSITION PLANNING: PARTNER SELECTION AND STAKEHOLDER ENGAGEMENT STRATEGIES FOR GRAND CHALLENGES

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Abstract: In the 21st century, urgent climate change effects have put energy policy into the forefront, necessitating a transition toward sustainable energy systems. At the same time, given the dynamic and complex corporate environments characterized by intensified competition and evolving consumer demands, the call to open up the strategy process through increased transparency and inclusion is on the rise. This paper studies a nation-wide initiative by an economic chamber in Central Europe, aiming to achieve green energy targets by 2030 and climate neutrality by 2040, thereby addressing the interplay of technological, social, and organizational innovations. Through a multi-faceted research approach encompassing interviews, meetings, and observations, the study investigates partner selection and stakeholder engagement dynamics in navigating energy transition challenges. Findings highlight the relevance of diverse partnerships to mitigate path dependence and industry-centric biases. It further reveals tensions between theoretical calls for cognitive diversity and the focus on energy sector stakeholders, potentially constraining transformative potentials. By shedding light on partner selection processes, this research contributes empirical insights with theoretical and practical implications for energy transition strategies and open strategy frameworks.

Keywords: Interorganizational Strategizing; Partner Selection; Stakeholder Engagement; Open Strategy; Energy Transition

1 INTRODUCTION

In the 21st century, the urgent need to address climate change, especially in energy policy, has become essential [9]. Current energy systems are unsustainable and require a transition involving technological, social, and organizational innovations [2, 10]. This transition is not just about technology but also about human decisions and actions [15]. Addressing energy transition within corporate strategy is challenging due to established paths and frames [17]. Such challenges often exceed individual organizational capabilities [16]. Opening up the strategy process can facilitate this transition [3, 12, 19], though there is limited knowledge on this approach for energy transition [4].

Partner selection is critical for successful collaboration [11, 14]. This paper aims to identify crucial selection criteria for strategizing across organizational boundaries, focusing on stakeholder engagement through increased levels of inclusion and transparency [5, 12] in energy industry [10].

2 MATERIALS AND METHODS

We study a nation-wide initiative by an economic chamber in Central Europe to achieve 100% green energy by 2030 and climate neutrality by 2040. This ‘energy masterplan’, running from the beginning of 2023 to mid of 2024, involves around 260 people from 200 organizations, participating in a four-stage workshop series. Our research analyzes how stakeholder groups are identified, selected, and motivated to continuously participate [11, 18]. Utilizing the case study method [6, 20], we employ a threefold and rich data collection approach including semi-structured interviews and meetings with energy experts and the economic chamber, while studying the open strategy process itself over time by participant observation, enriched by the analysis of internal archival data [8, 13].

3 PRELIMINARY RESULTS

This study examines participant selection, additional partners, and dropouts in an energy transition initiative. Interviews highlight the need for diverse strategy partners, based on stakeholder mapping and criteria like proximity, expertise, resources, legitimacy, and willingness to contribute. Cognitive diversity was prioritized to address the radical changes required, making proximity alone insufficient. Transparency and engagement strategies, such as open communication, ongoing interaction, and involving reputable figures, were crucial for building trust and commitment. The findings suggest that each context demands specific selection criteria, with cognitive diversity and effective communication being vital for achieving the initiative’s ambitious goals for energy transition.

4 DISCUSSION

Recent contributions suggest opening up the strategy process to find promising ways to manage the energy transition [3, 12, 19]. Our empirical findings highlight the necessity to collaborate with various stakeholders and to focus on partners with a greater diversity [4, 5] to overcome issues like the log-in problem or path dependence, which are seen as inhibiting factors for addressing the energy transition [1, 7] and being highly relevant for organizations in the energy industry. Further, theoretical perspectives emphasize cognitive distance among participants to overcome industry blindness, yet the initiator focused on energy sector organizations. This approach may hinder the necessary revolutionary transformation, suggesting the need for more diverse partners to tackle energy transition. Partner selection and stakeholder engagement is crucial for successful collaborations [11, 14]. While case studies can be limited in terms of generalizability our findings offer valuable theoretical and managerial insights on applying open strategy in the energy industry.

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ENERGY EFFICIENCY AS AN UNDERRATED KEY LEVER FOR INDUSTRIAL DECARBONIZATION DATA FROM 71 ON-SITE EFFICIENCY ASSESSMENTS IN THE NON-ENERGY-INTENSIVE MANUFACTURING INDUSTRY

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Abstract: Energy efficiency is recognised as a key lever for industrial decarbonisation. NEFI Lab estimated its overall potential in the Austrian manufacturing industry at 8.3% of total consumption, excluding growth and efficiency gains in core process technologies. This work shows that the actual potential in non-energy-intensive industries is much higher, at 17%, and analyses the structure of these potentials [1]. Most of them are found to be recurring across industries. The sample consists of 71 companies analysed on-site, of which 69% were assessed twice after a period of four years with an average of 20% of the potential having been implemented. The results are therefore considered to be robust.

Keywords: industrial carbon neutrality; decarbonisation pathways; clean manufacturing; scenario modelling; macroeconomic analysis; integrated energy systems

1 INTRODUCTION

Achieving climate neutrality by 2040 is a key objective for Austria, reflecting its commitment to the European Union's climate goals. The industrial sector, which accounts for 34% of Austria's greenhouse gas emissions, plays a crucial role in this transition. The New Energy for Industry (NEFI) initiative [2] is consistent with the literature in identifying energy efficiency as a key lever for industrial decarbonisation. The literature provides many examples where a single technology or a few sites are analysed in depth and / or comprehensively, as seen in [3]. In addition, [4] and [5] provide high-level assessments of energy efficiency potentials across industries, however without in-depth, on-site analysis or validation by providing implementation rates.

The NEFI scenarios assume that most technologies, in particular industrial boilers, will achieve higher efficiency levels and that the efficiency potential of the best available technologies will be fully realised by 2050. In addition, the use of heat pumps is expected to increase, largely replacing boilers in low temperature heat demand applications (< 200°C). According to the models, this shift will result in energy savings of 9.1 TWh, or 8.3% of the total industrial energy demand by 2050.

This article complements the literature and NEFI Lab assumptions with an on-site technology analysis that is both comprehensive in terms of installed equipment and detailed at the technological level. For all applications, the technology in use has been compared with known best practices and the state-of-the-art, and the business case for implementation has been assessed to provide a likelihood of implementation. To the best of our knowledge, this dataset is unique in the literature in that it provides a highly detailed and comprehensive analysis for a wide range of industries and a relatively large number of sites, including not only technical but also economic considerations.

2 MATERIALS AND METHODS

In addition to technology change and fuel switching, improvements in energy efficiency — including electrification of thermal energy demand (e.g., heat pumps) — have been identified by NEFI [2] and the literature [4] as key levers to achieve industrial decarbonization.

The data presented here cover assessments carried out between 2015 and 2023. 69% of the sites revisited after four years to assess the robustness of the identified potential by examining the proportion of realized savings. These potentials represent economically viable actions, where the return on investment (ROI) exceeds the weighted average cost of capital (WACC). The potentials are aggregated and categorized into ten sub-categories, following the approach of [3]. The potentials for each category are then derived and their economics compared.

For this study, 71 industrial sites with an annual energy demand ranging from 1.5 GWh to 60 GWh were assessed on site according to EN ISO 16247 (parts 1 to 5). 53.3% of the companies in the sample belong to manufacturing industries, 44.4% to services and 2.2% to construction. The identified energy efficiency potentials have been categorized into the following groups:

- Part renewal
- Automation and control
- Heat recovery
- Adaptation of heating and cooling concepts
- Adaptation of ventilation concepts
- Energy monitoring
- Adaptations of the pressurized air system
- Process changes
- Building measures
- Organizational measures

3 RESULTS

This study complements the conventional top-down approaches in the literature [5] with a detailed bottom-up, on-site analysis to assess the potential for energy efficiency improvements in the Austrian manufacturing industry. While NEFI used a bottom-up approach to assess the energy efficiency potential in energy-intensive industries, this work focuses on other manufacturing sectors.

The highest energy savings potential was identified in the heat recovery category, with an average savings potential of 6.4%. Overall, the assessments identified potential savings of 393 GWh out of a total energy consumption of 2,219 GWh, or 17%. These results indicate that there are larger economically viable efficiency potentials than those projected in the literature and in the NEFI scenarios. With continued technological progress and higher implementation rates of known efficiency measures, the industrial sector could potentially reduce its annual energy demand by 9.1 TWh.

4 DISCUSSION

Significant energy efficiency potential in the manufacturing industry has been identified in the literature, and this work has identified additional potential that exceeds these figures. The data presented here shows a significantly higher efficiency potential of 17.7% compared to the 8.3% reported in the literature for the entire manufacturing industry. It has been estimated that this additional potential could reduce industrial energy demand in 2040 by 9.1 TWh (or 5.4%) at no additional cost over ten years, even taking into account the moderate growth assumed by NEFI Lab. This potential was identified using only available, state-of-the-art technologies, suggesting that an even greater potential may be achievable with the development of new technologies.
Furthermore, as energy-intensive industrial processes were not covered in this study, it is recognised that there is likely to be more potential in these areas, as detailed in the NEFI Lab's analysis of the Austrian industry. The importance of in-depth bottom-up analysis and effective communication of known potentials was highlighted to ensure their implementation. These results represent significant progress towards a more accurate representation of state of the industry and the achievement of national policy goals, both in statistical projections and in policy making.
A limitation of this study is the relatively small sample size. However, the detailed bottom-up information provided by the NEFI work provides considerable support. Consequently, this study focusing on non-energy intensive industries, together with the work of NEFI Lab on energy intensive sectors, significantly enhances the explanatory power of energy scenarios within the industry.

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EVALUATION OF THE INDUSTRIAL SYNERGY POTENTIAL IN THE INDUSTRIAL ZONE OF CALLAO/PERU

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Abstract: This study analysed over 60 companies in Callao, Peru, focusing on renewable energies and industrial symbiosis, as the first of this kind project in the country. Data was collected from energy audits, ministry records, questionnaires, and direct communication, then mapped using QGIS. A workshop with industry and government stakeholders identified regulatory, financial, and technological barriers. Three case studies were developed including operator and financing models, highlighting the potential for photovoltaic power, biogas production, and excess heat recovery. The most promising potential, excess heat recovery, could save 5.400 t/a CO2 and supply energy to nine companies but requires joint investment due to profitability issues. A demonstration project is recommended to overcome barriers and promote renewable energies and industrial symbiosis, which are largely unknown in Peru.

Keywords: Industrial Symbiosis; Emerging Markets; Excess Heat Extraction

1 INTRODUCTION

In the industrial zone of Callao in Lima/Peru more than 60 companies of several industrial sectors such as textile, foundry, metal work, and chemicals were analysed regarding the use of renewable energies (RE) and industrial symbiosis (IS) in the energy sector.

IS and RE in industrial applications are still not widely recognised in Peru which corresponds with the findings of Boom-Cárcamo and Peñabaena-Niebles [1]. In their work they undertook a comprehensive screening of research papers in the field of IS in emerging countries and frontier markets. For Peru no scientific publication on the topic is known. Outside the scientific context, there have been a few approaches on the topic like an evaluation project on material exchange for waste mitigation in the industrial zone of Villa El Salvador in Lima [2] or a strategic plan for circular economic development in the Piura region [3]. Nevertheless, these publications only refer to the material aspect not considering the possibility of shared energy usage including cross-company heat recovery or modern renewable energy technologies. The lack of examples has some structural reasons that do not only apply to Peru but also exist in other emerging markets as stated by Boom-Cárcamo and Peñabaena-Niebles. Their findings serve as reference for the findings of a stakeholder workshop conducted in the framework of this project.

2 MATERIALS AND METHODS

Data was collected from four sources: reports from energy audits by Peruvian energy efficiency experts, energy consumption lists from the energy ministry, questionnaires sent to companies, and direct communication with company representatives in Lima.

The localisation of all the companies with their attributes from the database was carried out using QGIS software. The visualisations for each company include their data source, natural gas and electricity consumption and CO2 emissions.

During a stay in Lima, a workshop in Callao was held with 90 participants including industry representatives, government officials, consulting firms and technology manufacturers. It included project related presentations and interactive sessions to jointly develop and discuss potentials, possible cooperation ideas and the identification of technological, legal, and financial barriers in Callao. Apart from the workshop, 7 site visits in selected companies of different industries with particularly high potential and interest were carried out.

3 RESULTS

Based on site visits in Callao, three case studies were chosen to conduct a techno-economic analysis and propose financing models by the Austrian project partner REENAG Holding GmbH:

1) Photovoltaic power generation and sharing in the premises of a shipyard.
2) Biogas production from wastewater in a cardboard factory.
3) **Excess heat extraction** from exhaust gases in a glass factory and an **industrial heat network** for neighboring companies.

A concept of case study 3 has the following impact:

- ~ 20.000 MWh/a of available excess heat, which is currently released to the environment at > 900 °C; 5.400 t/a of CO2 equivalent savings (replacing natural gas).
- 9 project companies in the vicinity that could be consumers of industrial heat.
- High profitability for waste heat consumers (reduced carbon footprint, price stability).
- Recommended form of implementation: Joint venture by the waste heat purchasing companies. For this, capital is raised jointly, and shareholder loans are provided to the joint venture with an interest rate of 9 % and a repayment term of 13 years. Dividends could be distributed from the equity investment, leading to a return of 11 %.

The workshop in Callao provided valuable insights into the state of the art in the Peruvian industry and the legal framework. The identified barriers from the interactive sessions can be summarised in three main points:

1) Lack/barrier of regulatory framework and political support.
2) Too high costs/long amortisation periods.
3) Lack of local technological know-how, e.g. system suppliers, planning offices.

4 DISCUSSION

A large-scale demonstration project to implement one of the proposed concepts, with an extensive training program and the involvement of the authorities, would counteract all three barriers. Case study 3 is the most suitable option due to its financial viability and innovation content in the region.

District or industrial heating networks are widely unknown in Peru with no such project in place and missing knowledge among the stakeholders as could be observed at the workshop. It has the highest industrial relevance as most energy consumption in the area is related to heat demand. Additionally, it exemplifies IS, which could highlight this topic in the regional industry.

Such a demonstration project, with special authorisations, would allow authorities to learn and develop appropriate regulations and administrative processes. Within the capacity-building program, necessary policy objectives, regulatory guidelines, and funding models would be developed in stakeholder workshops, addressing the criticism of high costs (barrier 2). As technology becomes established, costs decrease, making political support crucial through guiding legislation and financial incentives.

To initiate competence building (barrier 3), the topic of industrial synergies and renewable energy technologies should be included in educational curricula and adult education programs imparting theoretical and practical knowledge through technical visits at the demonstrator. An existing plant generates more attention and conviction that it is feasible. Increasing visibility among companies could be achieved by integrating this issue into mandatory energy audits. Awareness in politics could be achieved by introducing the topic through a business association that represents the interests of many companies as an important part of the national economy. As soon as demand increases, specialised companies will also enter the Peruvian market.

An international knowledge transfer project (e.g. also with South American countries such as Brazil, which are already more advanced in the field of IS and RE [1]) could also contribute to capacity building for legislation and incentives.

5 REFERENCES

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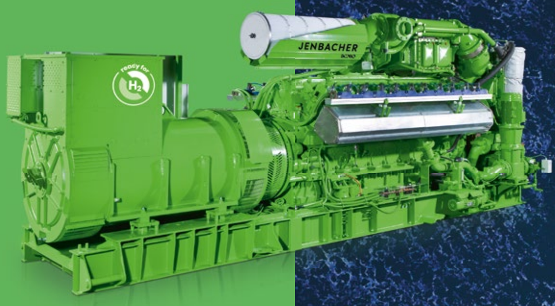

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