Technical University of Leoben

Science 4 Technology – Poster Exhibition 2026

Department: Environmental and Energy Process Engineering

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Flexibilizing Electric Steelmaking
Demand Side Management for an Electric Arc Furnace

Optimizing Cost and Emissions within an Environmental & Economic Dispatch Framework

Why Flexibility in Electric Arc Furnaces Matters for the Energy Transition and This Study's Aim

In the context of the energy transition, the energy-intensive iron and steel industry is undergoing a fundamental transformation that requires flexible, cost-effective and environmentally friendly operating practices. [1]

Figure 1: Working Electric Arc Furnace (EAF) [2]

In principle, electric arc furnaces (EAFs) offer considerable flexibility potential for market-oriented operation. This study investigates how targeted demand side management measures can dynamically adapt EAF operation to fluctuating electricity and gas prices. Unlike traditional unit commitment approaches that simply shut down when prices are high, this work varies the proportions of the two energy sources, electricity and natural gas, within an environmental and economic dispatch model. This makes it possible to quantify cost savings and emission reduction potential, as well as to assess how the trade-off between economic and environmental objectives shapes EAF operation.

Multiobjective Dispatch Optimization

An integer linear programming (ILP) formulation of furnace operation was implemented in Python. In the optimization model, the electricity-to-gas ratio is dynamically adjusted in response to market signals, subject to technical constraints. In the ILP, batch scheduling and the electricity-to-gas mix are represented by binary variables $z_{i,r,s} \in \{0,1\}$ indicating that batch i starts at time s with ratio option r, with a unique start. Costs and emissions are accumulated as $K_{tot} = \sum_{i,r,s} K_{i,r,s} \cdot z_{i,r,s}$ and $E_{tot} = \sum_{i,r,s} E_{i,r,s} \cdot z_{i,r,s}$ and a weighted-sum objective balances both:

$$min\ Z = \alpha \cdot K_{tot} + (1-\alpha) \cdot E_{tot}$$

Here, α ∈ $[0,1]$ controls the trade-off: larger α places more weight on cost, smaller α places more weight on emissions. A mixed integer linear program (MILP) with a continuous electricity share was also tested. Althrough more detailed, led to weaker relaxations and markedly longer solve times. The ILP was therefore selected for robustness, speed, and comparable objective quality.

References

[1] PAULIUK, Stefan ; MILFORD, Rachel L. ; MÜLLER, Daniel B. ; ALLWOOD, Julian M.: The steel scrap age. In: Environmental science & technology 47 (2013), Nr. 7, S. 3448–3454

[2] https://www.istockphoto.com/photo/electroarc-furnace-at-metallurgical-plant-gm997123048-269800241

Results on Utilization Driven Flexibility and Outlook for Practical Scalable Deployment

Across real price scenarios, measurable cost and emissions effects were obtained.

At full utilization, energy costs fall by up to **6.4 %** and CO_2 by up to 0.9 %, at 85 % utilization, cost savings rise to **11.5 %** due to greater temporal flexibility.

Lower utilization expand opportunities to avoid peaks and exploit cheaper or lower-emission windows. A clear trade-off emerge: substantial CO_2 cuts generally require higher energy costs, while cost-optimal operation could raise emissions. Sensitivity results shows electricity price as the dominant cost driver, natural gas and CO_2 certificates are secondary.

Under a renewable electricity mix, potential CO_2 reductions reach approximately **89 %**.

Figure 2 illustrates market-responsive dispatch as the electricity-gas mix shifts over time under different α weights.

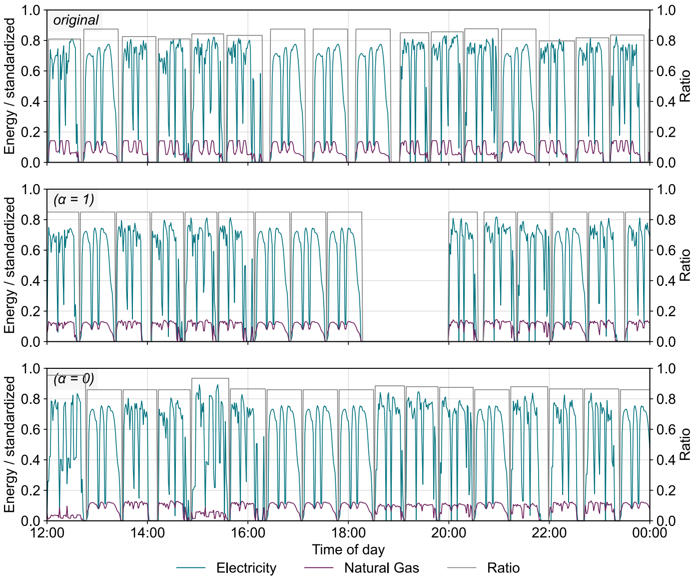

Figure 2: Market-responsive dispatch over time

Looking ahead, increasing renewable penetration and stronger CO_2 price signals would enhance the environmental benefits of flexible, market responsive operation. In a more decarbonized system, the load shifting capability of EAFs is expected to become more valuable, positioning the steel sector as a significant contributor to industrial demand side management and power system flexibility. Stronger Sector coupling and demand response would further raise flexible EAF value.

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Investigating the influence of a booking system based on dynamic forecasting and pricing on power flow reliability

Importance and Aim

- In the future, energy management will be one of the main topics based on the growing population and the increasing number of EV implementations.
- Reducing the grid stress is of actual value in this area.
- Reducing the grid Stress.
- Increase the number of EV charging stations by using a booking system and dynamic pricing.

Background & Research Gap

- Different forecasting models, such as deep learning models, were used to forecast day-ahead power load.
- Dynamic pricing for day-ahead improved power consumption during off-peak consumption.
- By charging several EVs during off-peak hours, the possibility of overload increases. A booking system with flexible pricing(hourly) would overcome this problem.

Methodology

In this study, a Long-Short-Term-Memory (LSTM) model for forecasting was used with the following properties after the hyperparameter optimization. Table 1 shows these properties as well as evaluation metrics.

For the optimization study, Pyomo was used to reduce the charging cost and enhance the grid stability. For the tested grid, the EV-excluded data frame for the testing period is shown in Figure 1. Table 2 shows the properties of the EVs used in this grid.

Table 1. The main properties of the LSTM model

Look-back no.	Neuron	Epochs	Early-Stopping	Evaluation Metrics	Training Period	Testing Period
24	100	50	Yes	MAPE, SMAPE	A year	A week

Figure 1. Demand and the maximum capacity of the tested grid at the local grid transformer

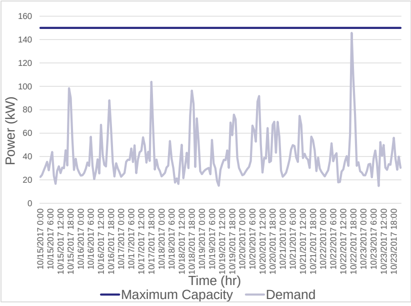

Table 2. The properties of the EVs used in the study

Number of cars	Charging time	Number of cars	Battery capacity	Required SoC	Current SoC	Bidirectional
4 cars	0-8AM	2	80 kWh	80%	25%	No
		2	75 kWh		25%	Yes
5 cars	8AM-4PM	2	80 kWh	80%	30%	Yes
		2	80 kWh		20%	No
		1	75 kWh		30%	Yes
9 cars	4PM-11PM	3	80 kWh	80%	35%	No
		3	80 kWh		30%	Yes
		1	70 kWh		30%	Yes
		2	70 kWh		30%	No

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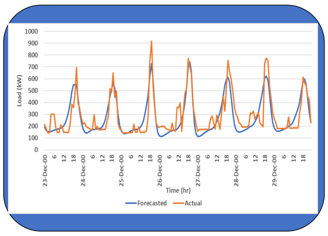
G. Alkhayat, R. Mehmood, A review and taxonomy of wind and solar energy forecasting methods based on deep learning, Energy and AI 4 (2021).
S. Saharan, S. Bawa, N. Kumar, Dynamic pricing techniques for Intelligent Transportation System in smart cities: A systematic review, Comput Commun 150 (2020) 603–625..
A. Fayyazbakhsh, T. Kienberger, J. Vopava-Wrienz, Comparative Analysis of Load Profile Forecasting: LSTM, SVR, and Ensemble Approaches for Singular and Cumulative Load Categories, Smart Cities 8 (2025).

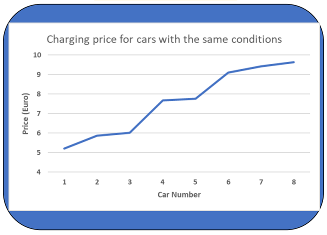
Results and Discussion

Forecasting with MAPE 12.6% and SMAPE 6.79% for on-peak demand and forecasting adjustment showed high robustness for the booking system. Moreover, more EVs can be charged with the booking system than without. By optimization, the grid stability will be guaranteed with the booking system and dynamic pricing. In this system, once a customer starts the booking, a charging schedule will be made, and then the available capacity will be updated for the new EV owner. As far as the available capacity defines the price, the early bookers get better prices.

Forecasting



Charging Price



Charging Schedules

Conclusions

The forecasting method showed promising robustness, which is one of the most important factors for the booking system. The booking system that is based on market- and grid- optimization improved the grid stability, and the number of EV charging increased, which is an important factor in the future due to high EV integration. This method can be improved to have a more reliable pricing methodology based on different available capacity levels. In addition, this method can help the energy suppliers with their future planning to make the energy supply for EV consumers available by making the demand optimum.

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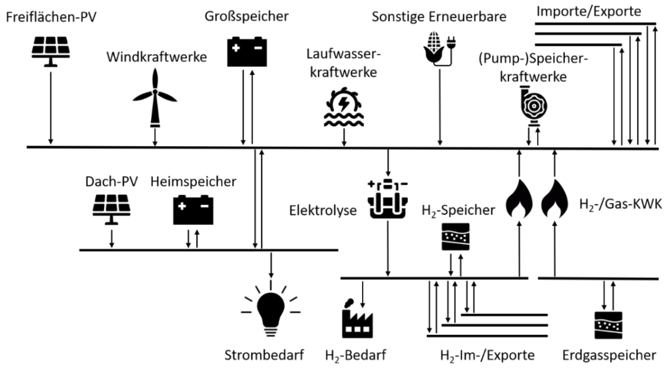
Europamodellierung

Anwendung und Integration des europäischen Energiesystems in bestehende Systeme

Strom wird in Europa über Nationalstaaten hinweg gehandelt. 2025 wurden 21,7 TWh an Strom nach Österreich importiert, 16,5 TWh wurden exportiert. Die Vorteile des internationalen Stromhandels liegen darin, dass Überschüsse in anderen Ländern Abnehmer finden und Unterdeckungen über Importe ausgeglichen werden können. [1]

Daraus folgend müssen auch Berechnungen des österreichischen Energiesystems das gesamte europäische Energiesystem abbilden. Am Lehrstuhl für Energieverbundtechnik werden daher bestehende Modelle immer weiter ausgebaut und verbessert, um den Einfluss Europas auf das Energiesystem Österreichs immer besser zu beschreiben. Dabei werden neben dem Stromsystem auch Sektorkopplungstechnologien inklusive Wasserstoffsystem auf Gebotszonenebene modelliert.



Schematische Darstellung einer Gebotszone mit 3 Knoten, Verbraucher, Erzeugungs-, Speicher- und Sektorenkopplungstechnologien

Grundlage für die Modellierung ist das Projekt Open TYNDP der Open Energy Transition, welches es sich zum Ziel gesetzt hat, den Ten Years Network Development Plan (TYNDP) der ENTSO-E und der ENSTOG nachzubilden. [2, 3]

Konkrete Anwendung findet das Modell im Projekt “Weiterentwicklung der Stromspeicherlandschaft”. In dieser Studie wird das Speicherzielbild für Österreich im Jahre 2030 errechnet. Dies erfolgt über die Eruierung der optimalen Batteriekapazität in Österreich in einer europäischen Marktmodellierung.

Ziel ist eine Vereinigung des Europamodells mit dem 400-Knoten-Modell HyFlow, um so in der Auflösung der Netzebene 4 Rückkopplungen mit Resteuropa zu berücksichtigen.

[1] Austrian Power Grid GmbH: Transparenzplattform. Wien 2026.
[2] Open Energy Transition: Open-TYNDP (Version v0.5.1)
[3] ENSTO-E, ENSTOG: Ten Years Network Development Plan 2024. Brüssel 2025.

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Energy analysis of different pathways to convert CO_2 to methanol

The development of Aspen plus simulation for converting CO_2 to methanol

Hard-to-abate industries, including cement, refinery, iron and steel, and limestone, need methods to capture CO_2 to reach low CO_2 emissions. Together with H_2, conversion reactors can transform this CO_2 into a value-added products, such as methanol. This utilization pathway is an alternative to long term underground storage, which requires a European transport infrastructure.

How to do it?

Our study investigates three different CO_2-to-methanol pathways using the Aspen Plus software. Where the main components are modeled as follows:

- Absorber: validated rate-based absorption column
- Synthetic gas production: nominal operation of electrochemical cells
- Methanol reactor: reactions occurred in the presence of a catalyst at constant pressure and temperature with different H/C ratios (see equation (2))
- Stripper: Validated rate-based CO_2 separation column
- Solvents: MEA for the indirect pathways and K_2CO_3
- Distillation column: Reaching pure methanol with 99% purity on a molar basis

The **energy efficiency** is obtained by considering all necessary input energy (electric, thermal) after thermal demands are met by matching internal heat sources (e.g., methanol reactor, electrolysis) and the energy content of the produced methanol (see equation (1)).

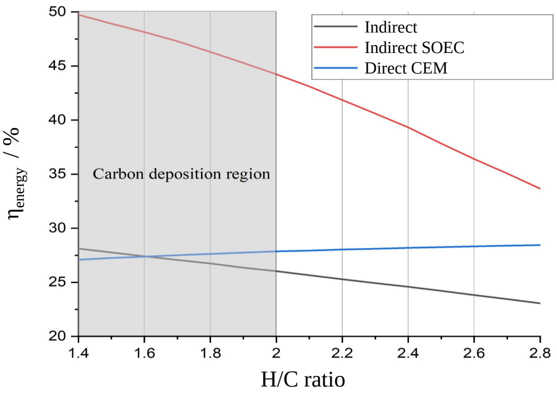
$$\eta_{energy} = \left(\frac{\dot{n}_{CH3OH} \cdot LHV_{CH3OH}}{\dot{Q}_{exernal\ source} + \dot{W}_{in}}\right) \quad (1)$$

$$H/C = \frac{H_2 - CO_2}{CO_2 + CO} \quad (2)$$

The three considered pathways are:

1. **Indirect:** The CO_2 is captured with an amine scrubber and thermally desorbed. A synthetic gas mixture suitable for methanol production is obtained by adding H_2 produced by PEM electrolysis.
2. **Indirect SOEC:** The CO_2 is captured with an amine scrubber and thermally desorbed. In the next step, the CO_2 is fed together with steam to the SOEC, which produces a H_2, CO_2, and CO gas mixture, ready for methanol production.
3. **Direct CEM:** The CO_2 is captured in a potassium absorber, and the enriched solution is recovered in a CEM cell [1], producing synthetic gas with 60% H_2 and 40% CO. This gas mixture can be directly converted in a methanol reactor. The H/C ratio is adjusted by adding H_2 from PEM electrolysis.

What are the takeaways?



A low content of H_2 **(H/C smaller than 2)** can lead to **depositions of solid carbon** in the methanol reactor and thus can deactivate catalytic surfaces.

High H/C ratios result in increased methanol production but also leakage of unused H_2.

The **energy efficiency** of the indirect SOEC pathway decreases strongly with increasing H/C ratio, which is caused by **less efficient water electrolysis.** While in direct CEM, efficiency increases due to a more beneficial gas mixture, which allows for a stronger **increase in methanol production.**

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[1] Yurou Celine Xiao et al., Direct carbonate electrolysis into pure syngas, RCS Publishing, EES Catalysis, DOI: 10.1039/D2EY00046F.

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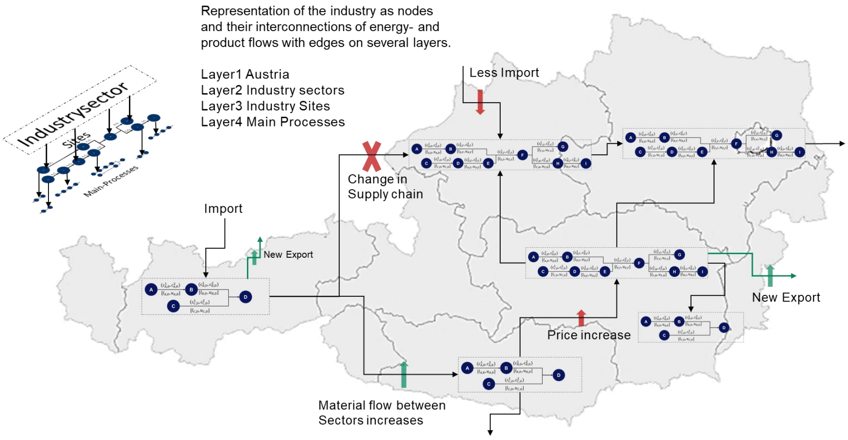
TECHNO-ECONOMIC OPTIMIZATION OF INDUSTRIAL MULTI-ENERGY SYSTEMS

Scenario Modelling of resilient transformation pathways towards climate neutrality

Introduction

The defossilisation of the industrial sector in Austria is essential for achieving the national climate neutrality targets by 2040 and the Clean Industrial Deal. The Austrian industry contributes to 44% (30.4 million t CO2e in 2023 [1]) of total Austrian greenhouse gas emissions. The most energy-intensive sectors include iron and steel production, processing of non-metallic minerals, the chemical and petrochemical industry, and the pulp and paper industry. Together, these sectors are responsible for 80% (24.4 million tonnes in 2023) of greenhouse gas emissions from the industrial sector [1]. Industry also plays an important role in ensuring the socio-economic development of the Austrian economy, generating 25% of national GDP (EUR 119.46 billion) and 24.9% (approx. 1.02 million) in 2023 full-time equivalents [2]. In order to support defossilization in the best possible way, a multi-energy system model is being developed taking into account technical, economical and resilience aspects as well as international trade.



Methodology and expected results

This model builds on the report of the NEFI Innovation Network [3], which assesses industrial production processes incorporating future technologies. The industrial sectors are depicted by the main industrial sites and their main processes. The energy requirements and the interconnection of the industrial sectors with each other on the basis of their product and material flows are modelled on a high resolution as schematically shown in Figure 1.

Based on this approach, which takes into account the material consumption and according energy demand for industrial production, national and international influences, industrial scenarios are developed up to 2050. These contribute to the analysis of defossilization measures and identify changes in the energy system and their infrastructure requirements. Through techno-economic optimization, climate-neutral transformation paths can be analyzed in order to identify fields of action and derive no-regret measures for industry. The international and national influences on Austrian industry, but also the changes caused by the transformation towards climate neutrality, provide a more detailed insight into the complex Austrian industrial sector, taking into account the topics of value creation, location security, resilience and climate neutrality from a more holistic perspective.

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[1] Michael Anderl et al., „Nahzeitprognose der österreichischen Treibhausgas-Emissionen für das Jahr 2023 (NowCast 2024),“ 2024.
[2] STATISTIK AUSTRIA, „Volkswirtschaftliche Gesamtrechnungen 1995–2023 Hauptergebnisse,“ 2024.
[3] V. Alton, P. Binderbauer, R. Cvetkovska, G. Drexler-Schmid, B. Gahleitner, R. Geyer, A. Hainoun, T. Kienberger, M. Rahnama-Mobarakeh, P. Nagovnak, C. Schützenhofer und S. Stortecky, „Pathway to Industrial Decarbonisation – Scenarios for the Development of the Industrial Sector in Austria,“ 2022.

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Multi-Energy-Systems-Optimization
Scenario-Modelling
Future Core-Technologies for Industry

NEFI NEW ENERGY FOR INDUSTRY

EVT ENERGIEVERBUNDTECHNIK