

Aalborg Universitet



Book of Abstracts 2025

11th International Conference on Smart Energy Systems

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Book of Abstracts 2025

11th International Conference on Smart Energy Systems



#SESAAU2025



11th International Conference on Smart Energy Systems
16-17 September 2025

Conference Booklet

Aalborg University
Department of Sustainability and Planning
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Preface and welcome

It is a great pleasure to welcome you to **SESAAU2025 - the 11th International Conference on Smart Energy Systems**, which takes place in Copenhagen on 16-17 September and with technical tours on 15 and 18 September 2025. The conference is organised by Aalborg University and Energy Cluster Denmark. We look forward to meeting participants from academia and industry from around the world in person. The conference this year is in CPH Conference in central Copenhagen with the conference dinner venue within walking distance.

We thank the sponsors for their contribution to this year's conference: Anedel, Grundfos, HOFOR, Kamstrup, Kingspan, CIP, EMD, Euroheat & Power, Gradyent, PlanEnergi, and Ørsted.

We have maintained the online conference platform from the virtual conferences. On the platform, you can find recorded presentations and slides, and you can communicate in writing with the session presenters. Further, you should remember to nominate candidates for the Best Presentation Award via the platform. The platform will be accessible from 12 to 19 September to all attendees, whether attending online or in person.

The ongoing war in Ukraine as well the political situation in the United States underline the value of strategic autonomy – particularly within energy supply. At the same time, the energy transition must push forward to limit global warming. Fortunately, the exploitation of locally available renewable energy sources go hand-in-hand with increasing self-reliance and thereby increasing strategic autonomy.

The conference targets smart energy systems, sustainable energy, electrification of the heat and transport sectors, electrofuels and energy efficiency. We aim to establish a forum for presenting and discussing scientific findings and industrial experiences related to the subject of smart energy systems based on renewable energy, 4th generation district heating technologies and systems, electrification of heating and transport sectors, electrofuels and energy efficiency. The Smart Energy System concept is essential for 100% renewable energy systems to harvest storage synergies and exploit low-value heat sources. The most effective and least-cost solutions are to be found when the electricity sector is combined with the heating and cooling sectors and/or the transport sector. Moreover, the combination of electricity and gas infrastructures may play an important role in the design of future renewable energy systems.

The 11th conference in the series cements it as a main venue for presenting subjects that are pertinent to the development and implementation of smart energy systems to fulfil national and international objectives. This year, we welcome a record-high number of participants - 425 participants from 30 countries around the world – to a programme with four strong keynote profiles and 270 session presentations as well as technical tours.

On the first day, the keynotes will focus on smart energy systems in cities - from global mitigation pathways to heating transitions. On the second day, focus will be on energy policy landscapes in the EU and the US.

All presentations, discussions, talks and debates during the conference contribute to the understanding and development of future energy systems. We thank everyone for your valuable contributions.

We wish you all a fruitful conference,

Henrik Lund, Brian Vad Mathiesen, Poul Alberg Østergaard
and Jakob Zinck Thellufsen, Aalborg University

Hans Jørgen Brodersen, Energy Cluster Denmark

CALL FOR ABSTRACTS

11th International Conference on Smart Energy Systems

4th Generation District Heating •
Electrification • Electrofuels • Energy Efficiency

Copenhagen 16-17 September 2025

Topics

Smart energy system analyses, tools and methodologies

Smart energy infrastructure and storage options

Integrated energy systems and smart grids

Institutional and organisational change for smart energy systems and radical technological change

Energy savings in the electricity sector, buildings, transport and industry

4th generation district heating concepts, future district heating production and systems

Electrification of transport, heating and industry

CCUS and PtX technologies and the production and use of electrofuels in future energy systems

Planning and organisational challenges for smart energy systems and district heating

Geographical information systems (GIS) for energy systems, heat planning and district heating

Components and systems for district heating, energy efficiency, electrification and electrofuels

Renewable energy sources and waste heat sources including PtX for district heating

Important dates 2025

22 Apr **Deadline abstract submission (optional upgrade to paper)**

1 May **Reply on acceptance of abstracts**

1 - 31 May **Early registration**

1 Jun - 20 Aug **Normal registration**

12 - 19 Sep **Virtual conference is open**

15 and 18 Sep **Technical tours**

16 - 17 Sep **Conference**

We invite researchers and experts from industry and business to contribute to further enhancing the knowledge of smart energy systems, 4th generation district heating, electrification, electrofuels, and energy efficiency.

The Smart Energy System concept is essential for cost-effective 100% renewable energy systems. The concept includes a focus on energy efficiency, end use savings and sector integration to establish energy system flexibility, harvest synergies by using all infrastructures, lower energy storage cost as well as to exploit low-value heat sources.

As opposed to, for instance, the smart grid concept, which takes a sole focus on the electricity sector, the smart energy system's approach includes the entire energy system in its identification of suitable energy infrastructure designs and operation strategies. Focusing solely on the smart electricity grid often leads to the definition of transmission lines, flexible electricity demands, and electricity storage as the primary means of dealing with the integration of fluctuating renewable sources. However, these measures are neither very effective nor cost-efficient considering the nature of wind power and similar sources. The most effective and least costly solutions are to be found when the electricity sector is combined with the heating and cooling sectors and/or the transport sector. Moreover, the combination of electricity and gas infrastructures may play an important role in the design of future renewable energy systems, and the electrification of heating and transport – possibly through electrofuels – can play a pivotal role in providing flexibility and ensuring renewable energy integration in all sectors.

In future energy systems, energy savings and 4th generation district heating can be combined, creating significant benefits. Low-temperature district heat sources, renewable energy heat sources combined with heat savings represent a promising pathway as opposed to individual heating solutions and passive or energy+ buildings in urban areas. Electrification in combination with district heat is a very important driver to eliminate fossil fuels. Heat pumps, PtX and utilisation of waste heat together with energy efficiency and 4th generation district heating create a flexible smart energy system. These changes towards integrated smart energy systems and 4th generation district heating also require institutional and organisational changes that address the implementation of new technologies and enable new markets to provide feasible solutions to society. Thus, the conference takes a holistic approach to the design of future energy systems.

Conference Chairs

Prof. Henrik Lund, Aalborg University

Prof. Brian Vad Mathiesen, Aalborg University

Prof. Poul Alberg Østergaard, Aalborg University

Ass. Prof. Jakob Zinck Thellufsen, Aalborg University

Hans Jørgen Brodersen, Senior Project Manager, Energy Cluster Denmark



**AALBORG
UNIVERSITY**



www.smartenergysystems.eu
#SESAAU2025

Aim and Organisers

Over its decade-long existence, the conference has become a significant venue for academia, industry, consultancy, and utilities to engage and discuss how to transition the energy system. Originally developed as a spin-off from the 4DH Research Centre targeting 4th Generation District Heating, the conference maintains a strong focus on district heating systems but also focuses on the integration with other sectors – electricity, cooling, industry, and transport in line with the sector integration core of the smart energy system concept. The aim of the conference is to establish a venue for presenting and discussing scientific findings and industrial experiences related to the subject of Smart Energy Systems based on renewable energy, 4th Generation District Heating Technologies and Systems, electrification of heating and transport sectors, electrofuels and energy efficiency. The conference is organised by Aalborg University and Energy Cluster Denmark.

Format

Again in 2025, we look forward to welcoming our participants to a hybrid conference with the possibility to attend either online or in person – this time at CPH Conference in central Copenhagen. In Copenhagen, you can attend the conference sessions in person, while the online conference platform enables you to watch recorded presentations; interact in writing with the presenters and nominate candidates for the Best Presentation Award. The online conference platform will be open to all attendees both before and after the conference in Copenhagen.

Submission Procedure

Both scientific and industrial contributions to the conference are most welcome. In general, we recommend to avoid presentations of planned research, but rather experiences and results.

To attend the conference as a presenter, you need to submit both an abstract and a recorded presentation. The recorded presentation must be prepared in the summer of 2025. Once your abstract is accepted for presentation, you will receive more information and a guideline to the recording of your presentation. Abstracts can be submitted via www.smartenergysystems.eu until 22 April 2025.

Authors of approved abstracts may be invited to submit papers to special issues of Energy, Smart Energy, Energies, and IJSEPM. Abstracts may be presented at the conference without uploading a full paper, as this is not a requirement.

Best Presentation Awards

Best Presentation Awards will be given to a selected number of presenters at the conference.



Conference fees

Early registration (1-31 May):

- 375 EUR (attendance in Copenhagen)
- 275 EUR (virtual attendance)

Normal fee (1 Jun - 20 Aug):

- 475 EUR (attendance in Copenhagen)
- 375 EUR (virtual attendance)

Conference dinner (Copenhagen):

- 110 EUR

International Scientific Committee

Prof. Alexandros Flamos, University of Piraeus, GR
Prof. Anna Volkova, Tallinn University of Technology, EE
Prof. Aoife Foley, University of Manchester, UK
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Morten J. Duedahl, Business Development Manager at DBDH, DK
Peter Jorsal, Product and Academy Manager at Kingspan, DK
Thomas Pauschinger, R&D international at AGFW, DE
Ulrik Stridbæk, Vice President at Ørsted, DK

Conference programme

On the following pages, you will find the conference programme, which consists of the programme for Copenhagen as well an overview of the recorded presentations which can be accessed via the online conference platform in the period 12-19 September 2025.

You can also see the updated programme here:



Access to online conference platform

For access to the online conference platform, please use link and personal credentials sent to you on 12 September 2025.

Via the conference platform you can:

- Watch a recording of the keynote speeches
- Watch all recorded session presentations and communicate in writing with the presenters
- Nominate your favorite candidate for the Best Presentation Award.

Best Presentation Awards will be announced and awarded a prize at the plenary closing session. You nominate the candidates via the online conference platform.

PROGRAMME COPENHAGEN TUESDAY 16 SEPTEMBER 2025

08:00-09:00 Registration and Breakfast

Main entrance

09:00-10:45 Plenary opening session

Ground floor - plenary room

Plenary opening session: Smart Energy Systems in Cities: From Global Mitigation Pathways to Heating Transitions

Chaired by Poul Alberg Østergaard

09:00-09:15 Henrik Lund and Glenda Napier: Opening and Welcome to SESAAU2025

09:20-09:50 Keynote ŞIIR KILKIŞ: Smart Energy Systems Targeted Mitigation in Urban Areas for Avoiding Increments of Global Warming

09:55-10:25 Keynote ASBJØRN HAUGSTRUP: Outlook: Why is the heating of our homes attracting increased political attention and what is its role in Smart Energy Systems if we are to meet political targets?

10:25-10:45 Debate

10:45-11:15 Coffee and networking in sponsor area

Ground floor

PROGRAMME COPENHAGEN

11:15-13:00

Parallel sessions 1-8

Ground floor
Sankt Hans Torv

Session 1: 4GDH
concepts, future district
heating production and
systems

Chair: Lieve Helsen

Session keynote Sven
Werner: Thermal lengths
in district heating systems

Naomi Adam:
Environmental Trade-
Offs in Collective
Heating Systems: A Life
Cycle Perspective on
Cluster Size

Nina Dungworth:
Practical considerations
and results of optimising
residential heat networks,
focusing on consumer
connection retrofit works

Stanislav Chicherin:
Design and Integration
of 5th Generation
District Heating and
Cooling Systems:
Economic Viability,
Technical Methodologies,
and Urban Applicability

Charlie Prétot:
Innovative architectures
of thermal source
networks

Esther Borkowski:
Enhancing Model
Accuracy in Grid-
Integrated Building
Control: A Semi-
Systematic Literature
Review of Hybrid
Modelling Approaches

Ground floor
Nørrebro Runddel

Session 2: Components
and systems for DH,
energy efficiency,
electrification and
electrofuels

Chair: Peter Jorsal

Session keynote
Jakob Nymann
Rud: Transition to an
Electrified and Low
Temperature Heat
Supply in Copenhagen

Pauli Hiltunen: District
heating providing
flexibility for the North
European electricity
system

Rasmus Frost Lund:
200 MW air source
heat pumps for district
heating: Challenges in
large-scale application

Davide Rizzi: High-
Temperature, Large-Scale
Heat Pumps: The Key to
Decarbonizing Energy
Systems

Abdulrahman Dahash:
Techno-economic
advantages of coupling
large-scale seasonal
thermal energy storage
with heat pumps in
district heating systems

Francesco Neirotti:
From waste to value:
Circular Thermal
systems and heat pumps
driving industrial
energy efficiency and
decarbonization

Ground floor
Spisehuset

Session 3: Planning
and organisational
challenges for smart
energy systems and
DH

Chair: Urban Persson

Session keynote Bent
Ole Gram Mortensen:
Price caps as part of the
green transition systems

Laura Kuper: Economic
Risk Assessment of
District Heating Network
Topologies: A Scenario-
Based Analysis of
Consumer Connection
Rate Uncertainties

Tim Mandel: Who pays,
who benefits? Multi-
stakeholder cost-benefit
analysis for strategic heat
planning in three German
neighbourhoods

Anna Lackner:
Decarbonization Pathway
Optimization and Risk
Assessment for District
Heating applied to a
Polish Case Study

Daniel Møller Sneum:
Financing district heating
investments

Jan Markowski:
Intelligent energy
management in
compressed air energy
systems on the base of
inverse problem solving

1st floor
Amager Strandpark

Session 4: 4GDH
concepts, future district
heating production and
systems

Chair: Anna Volkova

Session keynote Jan Eric
Thorsen: Reducing DH
return temperatures by
cascading concepts

Jerik Catal: Optimized
Buildings for
Decarbonized DH: A
Measures Catalogue for
Reducing Temperatures,
Enhancing Flexibility, and
Cutting Costs

Dabrel Prits: A Data-
Driven Framework
for Assessing Building
Readiness for Low-
Temperature DH

Simran Chaggar: A
data driven approach
within retrofit design to
reduce emitter upgrades
for commercial buildings
connecting to low-
temperature heat networks

Julian Plautz:
Thermohydraulic
Modeling and Simulation
of a DH Network for the
Optimization of Building
Refurbishment Strategies

Rahul M. Karuvinal:
Advanced Modeling
of DH Networks and
Analysis using uesgraphs
v2.0.0 Tool: A Case
Study...

13:00-14:15

Lunch and networking

1st floor
Kastrup Lufthavn

Session 5: Smart energy system analyses, tools and methodologies

Chair: Erik Ahlgren

Session keynote Jack M. Kristensen: Harnessing AI and IoT to Unlock Household Electricity Flexibility for a Smarter Energy Future

Antti Solonen: Demand Side Response in large scale: the Virtual Heat Storage concept

Axel Johansson: Exploring the Possibilities of Using Day-Ahead Environmental Impact Forecasts for Electricity Generation

Michael Krause: The impact of heat pumps on the electricity load: Evaluation of large sets of operational data including the simulation of future situations

Théo Balanza: The role of flexibility in a sector-coupled European energy system

Lorenzo Mario Pastore: On the role of hydrogen in 100% renewable energy systems: an assessment of applications, costs and infrastructure in Italy by 2050

2nd floor
Enghave Plads

Session 6: Planning and organisational challenges for smart energy systems and DH

Chair: Kristina Lygnerud

Session keynote Connie Ocando: Empowering the DHC Sector: Focus on Education and Skills

Marta Cavaleiro: Bridging the skills and competence gap in DHC: the DHC Academy Alliance

Jelena Ziemele: Achieving Carbon Neutrality in DH: Lessons Learned from the Climate City Contract of the City of Riga

Lennart Trentmann: Combining High Temporal and Spatial Resolution of DH Network Design – A Iterative Approach of DHN and Supply Structure Design

Jonathan Hachez: Methodology to develop an investment plan for heating and cooling systems under climate uncertainty

Verena Alton: Early-stage techno-economic assessment of DHC networks and individual systems - The FAST-DHC web-tool...

2nd floor
Vesterbro Torv

Session 7: Energy savings in the electricity sector, buildings, transport and industry

Chair: Morten Duedahl

Session keynote Lukas Kranzl: Implementing the EPBD: the impact of the policy settings on energy savings and heating system mix

Ece Özer: Bi-Level Optimization for Designing Subsidy Schemes for Staged Energy Retrofits in Residential Buildings

Lars Hellemo: Striving for realism in analyses of building retrofit potential for the green energy system transition with agent-based modelling

Astrid Leitner: Real-World Implementation of Residential Energy Management Systems: Balancing Thermal and Electrical Energy

Robert Puknat: Optimizing residential energy systems in low-energy houses in timber-frame construction using Smart EMS for dynamic electricity pricing

Jonas Hoppe: Renovation paths of single-family-houses and their impact on the heat transition in German districts

2nd floor
Hovedbanegården

Special session on Energy communities and positive energy districts

Chair: Mark Wiering

Session keynote Peter Sorknæs: North and South, what is the difference: Energy communities across the Europe

Jelena Nikolic: Energy Cooperatives legal framework: Differences and similarities in Denmark, the Netherlands, and Norway

Minh Thu Nguyen: Inclusive communication ecology for smart energy systems: Case studies from Positive Energy Districts across Europe

Martijn Gerritsen: Varieties of PEDs: Positive Energy Districts as building blocks for strategic energy planning at the local level

Annette Steingrube: A practical assessment method for Positive Energy Districts

Mario Mihetec: Energy Communities and Smart Systems: Catalysts for a Rapid Renewable Energy Transition

PROGRAMME COPENHAGEN

14:15-16:00

Parallel sessions 9-16

Ground floor
Sankt Hans Torv

Session 9: Institutional and organisational change for smart energy systems and radical technological change

Chair: Ruta Vanaga

Session keynote Kristina Lygnerud: The impact of social sustainability on district heating competitiveness

Frede Hvelplund: Fundamental policy changes in a transition from around 50% to around 100% Renewable Energy

Ruta Vanaga: Integrated Approach for Sustainable Urban Energy Transition: Citizen Engagement, System Dynamics Modeling, and Immersive VR Decision-Making Tools

Pascal Fröhlich: Historical Cost-Optimised Expansion of Renewable Energy Sources

Hironao Matsubara: Progress of Regional Decarbonization in Japan and Challenges to Realization

Alessandro Mati: Fueling sustainable aviation: prospects for electrofuels and policy frameworks

Ground floor
Nørrebro Runddel

Session 10: Smart energy system analyses, tools and methodologies

Chair: Marie Münster

Session keynote Mirko Morini: Predictive controller for optimal hydrogen generation and injection into the natural gas network

Dana Orsolits: Coupling Power System and Gas Grids Through Dynamic Hydrogen Injection: Enhancing Flexibility in Smart Energy Systems

Diamantis Almpantis: Smart Control Strategies for direct coupled PV-PEM Hydrogen Systems: Real-Time Optimization with Machine Learning Support

Bernd Riederer: Smart control of hydrogen-based multi-energy systems

Mathieu Patin: Benchmarking Control Strategies for Multi-Stack Electrolyser Systems under Renewable Energy Variability

Ruben van den Berg: Driving decarbonization: evaluation of a case study of green hydrogen-based transport in Nieuwegein, the Netherlands

Ground floor
Spisehuset

Session 11: Smart energy infrastructure and storage options

Chair: Dietrich Schmidt

Session keynote Ralf-Roman Schmidt: Risk Assessment for Seasonal Thermal Energy Storage in District Heating Networks

Jānis Narbutis: Optimization of Thermal Energy Storage in Building Facades Using Phase Change Materials and Accumulation Tanks

Martin Sollich: Optimal Heat Storage Sizing for District Heating Networks to Maximize Electricity Revenue from Combined Heat and Power Units

Benedict Brosius: Optimal real-time operation of smart energy systems with seasonal storage under uncertainty

Paul Volk: Renewable district heating systems in rural areas considering seasonal storage & decreasing use of biomass

Curtis Meister: Data-Driven Surrogate Models of Seasonal Thermal Energy Storage for MPC Applications – A Case Study on the Dronninglund Pit Storage

1st floor
Amager Strandpark

Session 12: Integrated energy systems and smart grids

Chair: Jan Eric Thorsen

Session keynote Isabelle Best: Dynamic supply temperature optimization of a complex nested district heating network

Jacobus van Rooyen: Operational strategy optimization under dynamic electricity prices; utilizing tank storages and high temperature seasonal storages

Oddgeir Gudmundsson: Revealing the Hidden Potential of Energy Efficiency in DH Networks

Marius Güths: Optimization of energy flows with differing optimization goals on quarter level

Jinze Li: Hybrid Renewable Energy Integration for Oil and Gas Power Supply: Optimization and Feasibility in China

Jihong Hang: Developing strategies for the electrification of Oil and Gas Industry in China

16:00-16:30

Coffee break

1st floor
Kastrup Lufthavn

Session 13: Smart energy system analyses, tools and methodologies

Chair: Ingo Leusbrock

Session keynote Carlos Santos Silva: Using ENERGYPLAN to model energy systems with high spatial resolution: the case study of mainland Portugal electrical system

Anders N. Andersen: The role of Non-Asset Traders in the European Day-ahead and Intraday electricity markets

Enno Wiebrow: Enhancing Flow-Based Market Coupling with Uncertainty and Forecast Integration for Renewable Energies

Mikkel Bue Lykkegaard: Data Compression for Time Series Modelling: A Case Study of Smart Grid Demand Forecasting

Ona Vassallo: From combustion to conversion: Impact of heating demand decrease on district heating systems

Abdul Azzam: A Model Predictive Control Framework for Integrated Thermal and Electric Systems in Multi-Energy Grids

2nd floor
Enghave Plads

Session 14: Planning and organisational challenges for smart energy systems and DH

Chair: Bent Ole Gram Mortensen

Session keynote Lisa Hjerrild: Regulatory challenges of energy communities

Viktoria Illyés: Adopting low-temperature heating and cooling networks in the core of sector-coupling energy communities: a multidisciplinary task

Saltanat Kuntuarova: Game-theoretic modeling of energy-sharing communities within integrated district heating and electricity systems

Eric Gonzalez Gonzalo: Key findings on organizational and planning challenges across different actors on PEDs

Fabian Ochs: Design Workflow for Optimized Heat Pump Systems for Positive Energy Districts

Katharina Esterl: Importance of integrating models within a broader systematic perspective when planning local energy systems

2nd floor
Vesterbro Torv

Special session on Power-to-heat and thermal energy storage for faster and more affordable decarbonization

Chair: Hanne Kauko

Session keynote S. Backe: Quantitative Impact of Flexible Thermal Energy Resources in Future European Energy System Pathway

T. Holmes: The role of thermal energy storage in providing flexibility for the decarbonization of industrial process heat and DH

S. Zwickl-Bernhard: Defining Flexibility: A Key Performance Indicator Framework for District Energy Systems under Uncertainty

L.M. Engan: Impact of Seasonal Thermal Energy Storage on the Power System at Different Latitudes

S. S. Foslie: Decarbonizing industrial process heat demands using hybrid solar thermal and photovoltaic systems in combination with thermal energy storages

W. Trainor-Guitton: Underground Thermal Energy Storage for Space Cooling...

H. Kauko: Reducing grid impact of zero-emission passenger ports through power-to-heat and thermal energy storage

2nd floor
Hovedbanegården

Special session on Energy transition and decarbonisation in the district heating sector

Chair: Mariusz Tańczuk

Session keynote J. Kalina: What can we do in Bucharest? The issues of decarbonising large DH systems

V. Lapinskienė: Decarbonizing the Vilnius DH System: Modernization of the Heat Source in Naujoji Vilnia

Ł. Jendryasek: Modernization of a Cogeneration-Based DH Network: Low-Temperature Heat Recovery and Dual Heat Pump Integration in Opole Poland

M. Tańczuk: Integration of distributed waste heat sources into second-generation DH systems – technical and economic challenge

A. Menapace: Unlocking Waste Heat Potential for DH Systems

P. A. Sørensen: Know-how package and toolkit for transition of DHC systems using low temperature sources and heat pumps

M. Barzantny: Cracking the code of PTES – the impact of atypical geological conditions on seasonal heat storage performance in Opole

16:30-18:15

Parallel sessions 17-24

Ground floor
Sankt Hans Torv

Session 17: 4GDH
concepts, future district heating production and systems

Chair: Carsten Ø. Pedersen

Session keynote Anna Cadenbach: Influence of sector coupling on a DH system in a German town: thermal simulation and comparison of different supply scenarios

Ina Herrmann: Analysis of peak load reduction with configuration of DH controllers and a newly developed optimization box

Anna Dell'Isola: Upgrade of a Virtual 5th Generation DHC Network through Optimal Control

Simon Müller: Optimizing the Operation of a Thermal Source Network Based on a Digital Twin Using Matlab/Simscape

Nermina

Abdurahmanovic: Simulation-based validation of an AI-supported operation strategy for sector-coupled district heating system

Theda Zoschke:

Demonstration of model predictive control for optimal power dispatch in a DH network with decentralized producers

Ground floor
Nørrebros Runddel

Session 18: 4GDH
concepts, future district heating production and systems

Chair: Gareth Jones

Session keynote Morten Karstoft Rasmussen: End-user installation monitoring, diagnosing, and optimization at a very large scale

Charlie Davies: Developing a heat loss key performance indicator for district heat networks

Avril Bullock: Achieving 4th-generation heat network performance by converting an existing UK communal heating system from a 4-pipe to a 2-pipe network

Lucrezia Manservigi: Diagnosis of faults in district heating network components

Sajedeh Roustaei: Data-driven approach for diagnosing inefficiencies and optimizing district heating networks

Alireza Etemad: A Multi-Scale Analytical Framework for Assessing Flexibility, Feasibility, and Performance of Decentralised 4th-Generation District Heating Systems

Ground floor
Spisehuset

Session 19: GIS for energy systems, heat planning and district heating

Chair: Andreas Müller

Session keynote Steffen Nielsen: High Resolution Spatial Mapping of Biogas Potentials and Site Selection – A Danish case study

Giulia Spirito: HeatNODE, a cost-optimized model for the creation of the Italian Atlas of potential district heating networks to recover industrial waste heat

Alejandro Zabala Figueroa: GIS-based data-driven simulation of load profiles in industrial and urban areas

Marina Georgati: A spatial assessment of the district heating potential in Europe

Alina Kerschbaum: Spatially-Explicit Technical Potential of Onshore Wind Energy in Germany: A Regulatory and Geographical Assessment

Anton Achhammer: The impact of hydrogen underground storage on fair partnerships: A GIS-based integration of salt caverns into PyPSA-Earth

1st floor
Amager Strandpark

Session 20: Renewable energy sources and waste heat sources including PtX for district heating

Chair: Ralf-Roman Schmidt

Session keynote Dagnija Blumberga: Gaseous Bioresources Towards Climate Neutrality

Sander Dijk: Balancing the energy system: a system-integrated approach to enlarge biomethane feed-in capacity into the gas infrastructure and reduce fossil fuels

Rikke C. Pedersen: A techno-economic analysis of infrastructure for CCS: Can biogas facilities benefit from a shared CO2 conditioning system?

Alisson Julio: From Carbon Neutrality to Negative Emissions: Evaluating the Impact of CCUS on Energy Systems and Power-to-X supply

Christian Schützenhofer: Excess heat availability from a net zero emissions industry: sector-specific potentials considering widespread electrification and carbon capture

Hrvoje Dorotić: Participation of district heating systems in balancing power markets via power-to-heat technologies

19:30

Conference dinner at Enghavevej 82B. Entrance via the backyard.

1st floor
Kastrup Lufthavn

Session 21: Energy savings in the electricity sector, buildings, transport and industry

Chair: Anders N. Andersen

Session keynote Leif Holm Tambjerg:
Renewable and Affordable Industrial Process Heat supplied from DH

Michał Majchrzyk:
Improving system efficiency using low temperature and latent waste heat

Valentin Kaisermayer:
Smart System Integration of Waste Heat Recovery, Heat Pumps and PV to Unlock the Energy Potential of Thermal Baths

Xin Bin: Cost-Effective Retrofit of Heat Exchanger Networks in Dairy Industry: Integrating CIP Scheduling and Multiple Utility Sources

Francesco Ghionda:
From Waste to Worth: Integrating a Double-Effect Heat Pump in a Pharmaceutical Industry for Process Cooling & DH

Rachel Parziale:
Monitoring the heat and electricity requirements in 4 northern German heat pump districts

2nd floor
Enghave Plads

Session 22: Smart energy system analyses, tools and methodologies

Chair: Matteo Giacomo Prina

Session keynote Erik Ahlgren: Modeling long-term sectoral integration in urban energy transitions

Yassine El Alali:
Comparison of community-based and individualized energy scenarios in the urban energy transition using multi-objective optimization

Martina Capone: A Simulation-Optimization Framework to Support the Transition of District Heating Systems

Paula Oberfeier: The role of reversible heat pumps in decarbonizing the heating sector under rising temperatures

Michel Noussan:
Evaluation of the hourly GHG intensity profiles of high-temperature heat pumps in industrial applications

Ivan Sukhanov: Adaptive demand-based logic for the Heat pump using supervised machine learning algorithms

2nd floor
Vesterbro Torv

Session 23: Smart energy system analyses, tools and methodologies

Chair: Carlos Santos Silva

Session keynote Wojciech Kostowski:
Beyond conventional cooling - investigation of the impact of RHVT implementation into the Linde refrigeration cycle

Nils Zimmerling:
Monitoring of district heating concrete ducts by measuring thermal parameters

Nicholas Tedjosantoso:
Tensor-Based Modeling Framework for District Heating Pipes

Ingeborg Treu Røe:
Smart integration of renewable energy technologies in heat- and power-intensive industries in Europe

Bram van der Heijde:
Energy flexibility from smart district heating and cooling control in smart energy systems: An updated review

Alejo Silvarrey Barruffa:
IIsim: an source to source compiler of industrial process simulation models

2nd floor
Hovedbanegården

Session 24: Planning and organisational challenges for smart energy systems and DH

Chair: Benedetto Nastasi

Session keynote Dietrich Schmidt:
Perspectives on the digitalization of the district heating systems

Johan Granberg:
Electricity grids in Energy Islands - A future scenario analysis with cyber security implications

Jakub Skórczynski:
Cyber Resilience Act and NIS2: Two legislative initiatives on cybersecurity that might change the way we work with smart energy systems

Marja Heikkinen:
Energy system modelling of urban infrastructures and energy storage – quantifying the impacts of policy (in)coherence

Eike Schuler: Do common multi-stage energy planning models underestimate regrets in the face of long-term uncertainties?

Théodore Fontenaille:
Rural Heating Networks: A Processual Approach for Overcoming Challenges and Identify Levers

09:00-10:45

Parallel sessions 25-31

Ground floor
Sankt Hans Torv

Session 25: Smart energy system analyses, tools and methodologies

Chair: Paula Ferreira

Session keynote Costanza Saletti: RECoS – An open-source tool for multi-energy system analysis

Gabriele Fambri: Deep reinforcement learning to explore multi-energy systems: a methodological approach

Gerrid Brockmann: Analysis of District Heating Network Configurations for a Suburban Region: a Sensitivity Study about the Heat Demand Density and Supply Temperature

Ethan St. Catherine: Heat Network Metering and Monitoring Standard: Regulating metering systems within UK heat networks

Tuomas Vanhanen: Comparison of carbon neutrality strategies on the peak power demand of a Nordic city

Budareld Mbumba: Challenges and prospects of electricity access in Angola

Ground floor
Nørrebros Runddel

Session 26: CCUS and PtX technologies and the production and use of electrofuels in future energy systems

Chair: Haoshui Yu

Session keynote Mehdi Savaghebi: Unlocking Frequency Ancillary Services Potential in Eco-Industrial Clusters

Hossein Nami: Grid Capacity-Aware Investment Roadmap for Sector-Coupled Industrial Clusters

Karl Vilén: Impacts of Capacity Pricing Mechanisms and Motivation Tariffs in District Heating

Falk Birett: Mapping the Gap: Analyzing the Status and Future Prospects of Power-to-X Deployment in Germany

Julian Straus: Modelling details matter – Representation of electrolysis in energy system models

Alexander Meisinger: Financing energy partnerships beyond Europe through H2Global: A case study on the way to a German-African energy transition

Ground floor
Spisehuset

Session 27: Electrification of transport, heating and industry

Chair: Dagnija Blumberga

Session keynote Andra Blumberga: Unintended long-term consequences of short-term climate and energy policy decisions: the case of diffusion of electric vehicles

Marko Starčević: The Role of Electric Vehicles as Flexible Consumers in Energy Communities

Arven Sylva: What is the interplay between smart charging, V2G and distributed charging infrastructure as flexibility options in the Swiss energy system?

Endeshaw Bekele: Optimal Strategies for a Zero-Emission Transport Sector in 100% RE Cities

Antonia Golab: Density and speed of public charging infrastructure rollout: Accelerating the electrification of the passenger car stock at the federal state level

Delight Ezeh: Techno-economic assessment of flexible electrification systems for heat decarbonization in hard-to-abate industries

1st floor
Kastrup Lufthavn

Session 28: 4GDH concepts, future district heating production and systems

Chair: Sven Werner

Session keynote Casper Hvilsted Nørgaard: A Regional Approach to Offshore Wind: The Key to a Cheaper & More Resilient European Power System

Shiyan Chang: Decarbonization of district heating in China

Dennis Lottis: Simulation Study on Optimizing Substations: Challenges and Solutions in the Transition to Fourth Generation District Heating Systems

Femke Janssen: Roll-Out Strategy Optimization for District Heating Networks

Andrea Franzoso: Multi-Agent Deep Reinforcement Learning for Optimized Operation of Industrial Energy Systems

Bart Homan: Exploring options for optimizing the energy consumption, production and storage of the Ecofactorij business park using HIL simulation

10:45-11:15

Coffee and networking in sponsor area

2nd floor
Enghave Plads

Session 29: Planning and organisational challenges for smart energy systems and district heating

Chair: Stefan Holler

Session keynote
Benedetto Nastasi: Renewable District Cooling by leveraging renewable energy sources via advanced energy storage systems

Jacob Estevam Schmiedt: Data for Optimizing Heat Supply Systems in Existing Districts

Daniel Zinsmeister: Transforming the Heating Sector: A Techno-economic Analysis of Munich's Local Heat Transition Planning

Lars Goray: F|Heat – An Open Software Ecosystem for Municipal Heat Planning

Abdulraheem Salaymeh: Techno-Spatial Evaluation of the Practical Usability of Industrial Waste Heat in Urban Heating Systems

Oskay Ozen: A Qualitative Investigation of German Manufacturing Companies' Efforts to Incorporate Sustainability Into Production Site Transformations

2nd floor
Vesterbro Torv

Special session on Nordic Hydrogen Valleys

Chair: Iva Ridjan Skov

Session keynote Anne Neumann: Analyzing Regulatory Instruments for Emerging European Hydrogen Markets

Rasmus Bramstoft: Nordic and European hydrogen production in an uncertain future

Frederik Dahl Nielsen: Nordic Hydrogen Hubs: A Multi-Model Framework for Regional Integration towards 2040

Marie Münster: Exploring the competition between e-fuels and negative emissions for decarbonizing international transport in the Nordics

Johannes Giehl: Power-to-X for Green Fuels: Techno-Economic Optimization of Energy Hubs Under Different Power Supply and Carbon Pricing Scenarios

Frederik Fristed: Hydrogen and CO2 infrastructures for Nordic maritime decarbonisation: a self-sufficiency perspective

Maria Grahn: Under what circumstances can hydrogen become a cost-effective fuel choice for a future global fleet of heavy-duty trucks

2nd floor
Hovedbanegården

Special session on Medium-duration thermal energy storage – Technologies, capacities and challenges - A Joint Workshop by IEA-ES Tasks 42, 44, 45

Chair: Peter Sorknæs

Jianhua Fan: Water pit thermal energy storage for district heating system

Gerald Englmaier: Latent thermal energy storage for data center application

Ming Chen: Potentials of molten salt for medium duration thermal energy storage

Annelies Vandersickel: Beyond Grid Flexibility: Power-to-Heat and Carnot Batteries for Zero-Carbon Industrial Heat and Power Supply

Adriano Sciacovelli: Carnot Batteries: Technological capabilities, challenges and emerging trends from IEA-ES task 44

Alice Tosatto: Optimizing large-scale Thermal Energy Storage Envelope Design for Enhanced Energy and Exergy Efficiency in District Heating Systems

11:15-13:00

Parallel sessions 32-38

Ground floor
Sankt Hans Torv

Session 32: Energy savings in the electricity sector, buildings, transport and industry

Chair: Mirko Morini

Session keynote Lieve Helsen:

A system of systems approach to decarbonize heating and cooling in the built environment

Jaap Neven: Evaluating Model Predictive Control Performance with Various Combinations of Building RC-Models and State Observers

Arttu Häkkinen: Bayesian LSTM for indoor temperature modeling

Karl Walther: The advantages of integrated versus non-integrated optimal control for district energy systems and buildings: Insights from four case studies

Jiyuan Cui: Optimizing the operation of an integrated energy system for a small district using a two-level control strategy

Steen Schelle Jensen: Potential of real-time end to end optimization of the full district heating system from heat source to distribution and demand

Ground floor
Nørrebros Runddel

Session 33: CCUS and PtX technologies and the production and use of electrofuels in future energy systems

Chair: Richard van Leeuwen

Session keynote Haoshui Yu: Exploring optimal Power-to-Methanol configuration with SOEC-based technologies

Hans Gelten: Power-to-Methanol: Techno-Economic Analysis of a regional, decentral case-study

Meng Yuan: European Energy Independence: Trade-offs in Domestic Production vs. Renewable Fuel Import

Leon Schumm: Green Steel: Integrated Modeling of Global Value and Supply Chain Configurations and Trade

Fabio Bozzolo Lueckel: Deployment of hydrogen in energy systems: finding the right policies to foster a nascent industry

Ramin Ghiami Sardroud: Detailed energy and techno-economic comparison of three CO₂-to-methanol integration pathways: Novel direct CO₂ capture and electrolysis

Ground floor
Spisehuset

Session 34: Smart energy system analyses, tools and methodologies

Chair: Jacek Kalina

Session keynote Leszek Pająk:

Utilization of a deep geothermal borehole heat exchanger HOCLOOP solution in cooperation with existing coal-fired district heating

Dmitry Romanov: Applicability of pygfunction for modelling deep coaxial borehole heat exchangers

Matthias Posch: Effect of hot air welding parameters on the ageing behaviour of polyethylene liners

Christoph Komanns: Evaluating Peak Shaving Potential with Open-Source Software

Niklas Denter: Modelling battery waste heat recovery for sector-coupled power-heat systems in district heating planning

Aleksandra Banasik: Experimental Investigation of a PCM Storage Unit with Process Visualization

1st floor
Kastrup Lufthavn

Session 35: 4GDH concepts, future district heating production and systems

Chair: Robin Wiltshire

Session keynote Tom Burton: An Overview of proposed Technical Assurance Requirements for Existing Heat Networks in the UK

Eoin O Broin: Heat Recovery from Wastewater Treatment Plants to Supply Existing Buildings with Low-Carbon Heat via District Heating

Milad Morid Zadeh: Smart waste heat recovery in a Danish supermarket refrigeration system

Nirav Patel: A techno-economic feasibility study of 5th generation district heating and cooling in Vienna

Jonathan Chambers: 5th Generation District Heating and Cooling with TESSA – pilot project in a UNESCO world heritage site

Sylvester Ofili: Feasibility Analysis of Geothermal Energy Integration in Ultra-Low Temperature District Heating Networks

13:00-14:00

Lunch and networking

2nd floor
Enghave Plads

Session 36: Planning and organisational challenges for smart energy systems and district heating

Chair: Lukas Kranzl

Session keynote Andreas Müller: The potential of local heat networks in the city of Vienna

Clara Büttner: Open source tools and data for cross-sectoral grid planning on all voltage levels

Ryoga Ono: Strategic planning for installation of district heating systems in Japan: Opportunities and Challenges

Thuvaraahen Nagendiram: Strategic Heat Planning for Decarbonisation: Insights from Denmark and Implications for China's Clean Heating Development

Wiebke Gerth: Automated planning of multiple-supply heating networks within the framework of greenfield planning

Giulia Anna Maria Castorino: Energy and economic analysis of technologies suitable for energy transition in the hospital sector

2nd floor
Vesterbro Torv

Session 37: Smart energy system analyses, tools and methodologies

Chair: Dirk Vanhoudt

Session keynote Matteo Giacomo Prina: Evaluating Machine Learning Robustness as an EnergyPLAN Surrogate Model for Uncertainty Analysis

Jonathan Sejdija: A Probabilistic Framework for Analyzing Uncertainty in Industrial Energy Supply and PPA Portfolios

Anna Billerbeck: Modelling climate-neutral district heating in energy system models – insights from an expert survey

Allan Iraqi: A generic substation heating power forecasting approach using machine learning

Jonne van Dreven: Generalising Fault Signatures for Robust District Heating Substation Monitoring

Philipp Herpich: Charting the EU Energy System Towards 2060 – Model results of the EU-EnVis-2060 scenarios

2nd floor
Hovedbanegården

Special session on Medium-duration thermal energy storage – System perspectives - A Joint Workshop by IEA-ES Tasks 42, 44, 45

Chair: Geoffroy Gauthier

Niels van der Veer: Cost-effective and low-carbon heat supply using medium duration molten salt energy storage in the industry

Frederick Stender: Effects of different uses of molten salt storages in the national energy system – A case study on Denmark

Silvia Trevisan: Heat integrated Carnot Batteries for Decarbonized Industries – System Opportunities Mapping

Wim van Helden: Accelerating the Role of Large Thermal Energy Storages as Elements for Medium and Long Duration Flexibility

Michael Bayer: Cascading of sTES for optimal operation of DHC networks – Case study on a cooling dominated grid

Morten Herget Christensen: Heat pump and e-boiler hybrid systems for charging of thermal energy storages – Techno-economic analysis of district heating and industry applications

14:00-16:15 Plenary closing session

Ground floor - plenary room

Plenary closing session: Diverging energy policy landscapes in the EU and the US?

Chaired by Brian Vad Mathiesen

14:15-14:45 Keynote PHILIP CHRISTIANI: Europe's Energy Pivot: A Strategic Blueprint for a Prosperous and Secure Energy Future

14:50-15:20 Keynote LILY BERMEL: The state of U.S. clean energy investment and policy

15:20-15:45 Debate

15:50-16:05 Best Presentation Award ceremony by Poul Alberg Østergaard

16:05-16:15 Henrik Lund and Hans Jørgen Brodersen: Closing

Technical Tour 15 September: Waste-to-energy plant with CO₂ capture

Monday 15 September 2025 at 14:30 - 17:30

ARC and the upgraded CCS project

ARC (Amager Resource Centre) is a waste treatment company owned by five municipalities in Copenhagen. ARC runs the waste-to-energy plant Amager Bakke, 10 recycling centres, plus 12 minor near/local recycling stations etc., and handles waste from 670,000 citizens and 68,000 companies. In 2024, ARC incinerated almost 610,000 tons of non-recyclable, residual waste and turned it into 198 GWh of electricity and 1,363 GWh of district heating. The vision of ARC is to make waste treatment and incineration net zero/carbon neutral. One step is by implementing an extra cleaning filter that captures CO₂ from the flue gas. In 2025, we established the CopenCaptrue project in collaboration with the German energy company E.ON. The partnership aims to capture 400,000 tons of CO₂ annually by 2030. A demonstration project began in 2021 and is now on its third demonstration unit. This is the first CCS project connected to a waste-to-energy plant in Denmark. The technology behind carbon capture is extremely energy intensive. By integrating CO₂ capture into the district heating system, ARC's demonstration project aims to show that CO₂ capture can be achieved with neutral energy consumption.

Technical Tour 18 September: Energy renovation of buildings

Thursday 18 September 2025 at 8:20 - 11:30

Introduction to building renovations and visit to renovated building

Building renovation plays a vital role in the green transition. With buildings responsible for nearly 40% of global energy consumption and a significant share of CO₂ emissions, energy-efficient building renovation is essential to meet climate targets. In Europe, up to 95% of the 2050 building stock already exists – making renovation, rather than new construction, the key to a sustainable future. During the tour of Industriens Hus, State of Green will first present their latest White Paper on “Building Renovations” in the “House of Green”, an interactive showroom and visitors' centre, followed by a tour of the “Confederation of Industry's” renovated building.

See www.smartenergysystems.eu for more information

4th Generation District Heating concepts, future district heating production and systems

Alireza Etemad: A Multi-Scale Analytical Framework for Assessing Flexibility, Feasibility, and Performance of Decentralised 4th-Generation District Heating Systems

Andrea Franzoso: Multi-Agent Deep Reinforcement Learning for Optimized Operation of Industrial Energy Systems

Anna Dell'Isola: Upgrade of a Virtual 5th Generation District Heating and Cooling Network through Optimal Control

Anna Cadenbach: Influence of sector coupling on a district heating system in a German town: thermal simulation and comparison of different supply scenarios

Asger Ulf Jensen: Improved District Heating Network Hydraulics for Enhanced Energy Distribution and Excess Heat Recovery

Avril Bullock: Achieving 4th-generation heat network performance by converting an existing UK communal heating system from a 4-pipe to a 2-pipe network

Bart Homan: Exploring options for optimizing the energy consumption, production and storage of the Ecofactorij business park using HIL simulation

Casper Hvilsted Nørgaard: A Regional Approach to Offshore Wind: The Key to a Cheaper & More Resilient European Power System

Charlie Prétot: Innovative architectures of thermal source networks

Charlie Davies: Developing a heat loss key performance indicator for district heat networks

Dabrel Prits: A Data-Driven Framework for Assessing Building Readiness for Low-Temperature District Heating

Dennis Lottis: Simulation Study on Optimizing Substations: Challenges and Solutions in the Transition to Fourth Generation District Heating Systems

Eoin O Broin: Heat Recovery from Wastewater Treatment Plants to Supply Existing Buildings with Low-Carbon Heat via District Heating

Esther Borkowski: Enhancing Model Accuracy in Grid-Integrated Building Control: A Semi-Systematic Literature Review of Hybrid Modelling Approaches

Femke Janssen: Roll-Out Strategy Optimization for District Heating Networks

Hasibuzzaman Mahmud: An automated framework to select the most profitable consumers for district heating network connections

Ina Herrmann: Analysis of peak load reduction with configuration of district heating controllers and a newly developed optimization box

- Jan Eric Thorsen: Reducing district heating return temperatures by cascading concepts
- Jerik Catal: Optimized Buildings for Decarbonized District Heating: A Measures Catalogue for Reducing Temperatures, Enhancing Flexibility, and Cutting Costs
- Jonathan Chambers: 5th Generation District Heating and Cooling with TESSA – pilot project in a UNESCO world heritage site
- Joseph Shanley: Equipment Condition and Resilience Requirements of UK Heat Networks
- Julian Plautz: Thermohydraulic Modeling and Simulation of a District Heating Network for the Optimization of Building Refurbishment Strategies
- Lucrezia Manservigi: Diagnosis of faults in district heating network components
- Milad Morid Zadeh: Smart waste heat recovery in a Danish supermarket refrigeration system
- Morten Karstoft Rasmussen: End-user installation monitoring, diagnosing, and optimization at a very large scale
- Naomi Adam: Environmental Trade-Offs in Collective Heating Systems: A Life Cycle Perspective on Cluster Size
- Nermina Abdurahmanovic: Simulation-based validation of an AI-supported operation strategy for sector-coupled district heating system
- Nina Dungworth: Practical considerations and results of optimising residential heat networks, focusing on consumer connection retrofit works.
- Nirav Patel: A techno-economic feasibility study of 5th generation district heating and cooling in Vienna
- Nyasha Grecu: The role of geothermal energy in decarbonizing district heating under future uncertainty: a techno economic analysis for an Austrian case study
- Philipp Gradl: Return-flow and bi-generation upgrades: Real-world results from an Austrian district heating network
- Rahul Mohandasan Karuvungal: Advanced Modeling of District Heating Networks and Analysis using uesgraphs v2.0.0 Tool: A Case Study from a German Living Lab Project
- Sajedeh Roustaei: Data-driven approach for diagnosing inefficiencies and optimizing district heating networks
- Shiyan Chang: Decarbonization of district heating in China
- Simon Müller: Optimizing the Operation of a Thermal Source Network Based on a Digital Twin Using Matlab/Simscape
- Simran Chaggar: A data driven approach within retrofit design to reduce emitter upgrades for commercial buildings connecting to low-temperature heat networks.
- Stanislav Chicherin: Design and Integration of 5th Generation District Heating and Cooling Systems: Economic Viability, Technical Methodologies, and Urban Applicability

4th Generation District Heating concepts, future district heating production and systems (continued)

Sven Werner: Thermal lengths in district heating systems

Sylvester Ofili: Feasibility Analysis of Geothermal Energy Integration in Ultra-Low Temperature District Heating Networks

Theda Zoschke: Demonstration of model predictive control for optimal power dispatch in a district heating network with decentralized producers

Tom Burton: An Overview of proposed Technical Assurance Requirements for Existing Heat Networks in the UK

CCUS and PtX technologies and the production and use of electrofuels in future energy systems

Alexander Meisinger: Financing energy partnerships beyond Europe through H2Global: A case study on the way to a German-African energy transition

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Ramin Ghiami Sardroud: Detailed energy and techno-economic comparison of three CO₂-to-methanol integration pathways: Novel direct CO₂ capture and electrolysis

Components and systems for district heating, energy efficiency, electrification and electrofuels

Abdulrahman Dahash: Techno-economic advantages of coupling large-scale seasonal thermal energy storage with heat pumps in district heating systems

Davide Rizzi: High-Temperature, Large-Scale Heat Pumps: The Key to Decarbonizing Energy Systems

Diego Alejandro Prieto Melo: From Shine to Decline: Analysis of Power Loss Rate of Photovoltaic Systems in Germany

Francesco Neirotti: From waste to value: Circular Thermal systems and heat pumps driving industrial energy efficiency and decarbonization

Jakob Nymann Rud: Transition to an Electrified and Low Temperature Heat Supply in Copenhagen

Meisam Sadi: Carbon dioxide-based district energy systems in heating and cooling applications

Pauli Hiltunen: District heating providing flexibility for the North European electricity system

Rasmus Frost Lund: 200 MW air source heat pumps for district heating: Challenges in large-scale application

Electrification of transport, heating and industry

Andra Blumberga: Unintended long-term consequences of short-term climate and energy policy decisions: the case of diffusion of electric vehicles

Antonia Golab: Density and speed of public charging infrastructure rollout: Accelerating the electrification of the passenger car stock at the federal state level

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Michael Krüger: Systematic Evaluation of Brayton Battery Concepts for Multi-Purpose Energy Applications

Energy savings in the electricity sector, buildings, transport and industry

Arttu Häkkinen: Bayesian LSTM for indoor temperature modeling

Astrid Leitner: Real-World Implementation of Residential Energy Management Systems: Balancing Thermal and Electrical Energy

Blanca L. Foliaco Romero: Comparative Analysis of Transcritical CO₂ and R410 Heat Pumps for Electrical Ferries: Simulation and Control Optimization

Constantin Völzel: 5GDHC networks in urban settlements - Barriers and technological prerequisites for applications in existing buildings

Ece Özer: Bi-Level Optimization for Designing Subsidy Schemes for Staged Energy Retrofits in Residential Buildings

Francesco Ghionda: From Waste to Worth: Integrating a Double-Effect Heat Pump in a Pharmaceutical Industry for Process Cooling & District Heating

Jiyuan Cui: Optimizing the operation of an integrated energy system for a small district using a two-level control strategy

Jonas Hoppe: Renovation paths of single-family-houses and their impact on the heat transition in German districts

Jaap Neven: Evaluating Model Predictive Control Performance with Various Combinations of Building RC-Models and State Observers

Karl Walther: The advantages of integrated versus non-integrated optimal control for district energy systems and buildings: Insights from four case studies

Lars Hellemo: Striving for realism in analyses of building retrofit potential for the green energy system transition with agent-based modelling

Leif Holm Tambjerg: Renewable and Affordable Industrial Process Heat supplied from District Heating

Lieve Helsen: A system of systems approach to decarbonize heating and cooling in the built environment

Lukas Kranzl: Implementing the EPBD: the impact of policy settings on energy savings and heating system mix

Michał Majchrzyk: Improving system efficiency using low temperature and latent waste heat

Rachel Parziale: Monitoring the heat and electricity requirements in 4 northern German heat pump districts

Robert Puknat: Optimizing residential energy systems in low-energy houses in timber-frame construction using Smart EMS for dynamic electricity pricing

Valentin Kaisermayer: Smart System Integration of Waste Heat Recovery, Heat Pumps and PV to Unlock the Energy Potential of Thermal Baths

Xin Bin: Cost-Effective Retrofit of Heat Exchanger Networks in Dairy Industry: Integrating CIP Scheduling and Multiple Utility Sources

GIS for energy systems, heat planning and district heating

Alejandro Zabala Figueroa: GIS-based data-driven simulation of load profiles in industrial and urban areas

Alina Kerschbaum: Spatially-Explicit Technical Potential of Onshore Wind Energy in Germany: A Regulatory and Geographical Assessment

Anton Achhammer: The impact of hydrogen underground storage on fair partnerships: A GIS-based integration of salt caverns into PyPSA-Earth

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Marina Georgati: A spatial assessment of the district heating potential in Europe

Steffen Nielsen: High Resolution Spatial Mapping of Biogas Potentials and Site Selection – A Danish case study

Ulrike Jordan: Potential of wastewater, rivers and residual material as heat sources for district heating in the German federal state of Hesse

Institutional and organisational change for smart energy systems and radical technological change

Alessandro Mati: Fueling sustainable aviation: prospects for electrofuels and policy frameworks

Frede Hvelplund: Fundamental policy changes in a transition from around 50% to around 100% Renewable Energy.

George Pickens: Structuring a technical assessment to support regulation of minimum heat network standards

Hironao Matsubara: Progress of Regional Decarbonization in Japan and Challenges to Realization

Kristina Lygnerud: The impact of social sustainability on district heating competitiveness

Pascal Fröhlich: Historical Cost-Optimised Expansion of Renewable Energy Sources

Ruta Vanaga: Integrated Approach for Sustainable Urban Energy Transition: Citizen Engagement, System Dynamics Modeling, and Immersive VR Decision-Making Tools

Aadit Malla: Assessing the Potential for Biomass Reduction Through Targeted Retrofitting of District Heating Systems in Austria

ONLINE PROGRAMME

Integrated energy systems and smart grids

Isabelle Best: Dynamic supply temperature optimization of a complex nested district heating network

Jacobus van Rooyen: Operational strategy optimization under dynamic electricity prices; utilizing tank storages and high temperature seasonal storages

Jihong Hang: Developing strategies for the electrification of Oil and Gas Industry in China

Jinze Li: Hybrid Renewable Energy Integration for Oil and Gas Power Supply: Optimization and Feasibility in China

Kristina Haaskjold: Hydrogen at sea: Evaluating offshore production for Europe's future demand

Marius Güths: Optimization of energy flows with differing optimization goals on quarter level

Matthias Brandes: Model-Predictive Power Control in Small-Scale Hydraulically Coupled District Heating Systems

Oddgeir Gudmundsson: Revealing the Hidden Potential of Energy Efficiency in DH Networks

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Paula Oberfeier: The role of reversible heat pumps in decarbonizing the heating sector under rising temperatures

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Anne Neumann: Analyzing Regulatory Instruments for Emerging European Hydrogen Markets

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Frederik Fristed: Hydrogen and CO2 infrastructures for Nordic maritime decarbonisation: a self-sufficiency perspective

Johannes Giehl: Power-to-X for Green Fuels: Techno-Economic Optimization of Energy Hubs Under Different Power Supply and Carbon Pricing Scenarios

Maria Grahn: Under what circumstances can hydrogen become a cost-effective fuel choice for a future global fleet of heavy-duty trucks

Marie Münster: Exploring the competition between e-fuels and negative emissions for decarbonizing international transport in the Nordics

Rasmus Bramstoft: Nordic and European hydrogen production in an uncertain future

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Annette Steingrube: A practical assessment method for Positive Energy Districts

Jelena Nikolic: Energy Cooperatives legal framework: Differences and similarities in Denmark, the Netherlands, and Norway

Mario Mihetec: Energy Communities and Smart Systems: Catalysts for a Rapid Renewable Energy Transition

Martijn Gerritsen: Varieties of PEDs: Positive Energy Districts as building blocks for strategic energy planning at the local level

Minh Thu Nguyen: Inclusive communication ecology for smart energy systems: Case studies from Positive Energy Districts across Europe

Peter Sorknæs: North and South, what is the difference: Energy communities across the Europe

Special session on Power-to-heat and thermal energy storage for faster and more affordable decarbonization

Hanne Kauko: Reducing grid impact of zero-emission passenger ports through power-to-heat and thermal energy storage

Lill Mari Engan: Impact of Seasonal Thermal Energy Storage on the Power System at Different Latitudes

Sebastian Zwickl-Bernhard: Defining Flexibility: A Key Performance Indicator Framework for District Energy Systems under Uncertainty

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Stian Backe: Quantitative Impact of Flexible Thermal Energy Resources in Future European Energy System Pathways

Sverre Stefanussen Foslie: Decarbonizing industrial process heat demands using hybrid solar thermal and photovoltaic systems in combination with thermal energy storages.

Till Holmes: The role of thermal energy storage in providing flexibility for the decarbonization of industrial process heat and district heating

Whitney Trainor-Guitton: Underground Thermal Energy Storage for Space Cooling: Reducing Electricity Grid Costs and Stress from National to District Scale

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Andrea Menapace: Unlocking Waste Heat Potential for District Heating Systems

Jacek Kalina: What can we do in Bucharest? The issues of decarbonising large district heating systems.

Łukasz Jendryasek: Modernization of a Cogeneration-Based DH Network: Low-Temperature Heat Recovery and Dual Heat Pump Integration in Opole Poland.

Marcel Barzantny: Cracking the code of PTES – the impact of atypical geological conditions on seasonal heat storage performance in Opole

Mariusz Tańczuk: Integration of distributed waste heat sources into second-generation district heating systems – technical and economic challenge.

Per Alex Sørensen: Know-how package and toolkit for transition of DHC systems using low temperature sources and heat pumps

Vilūnė Lapinskienė: Decarbonizing the Vilnius District Heating System: Modernization of the Heat Source in Naujoji Vilnia

Special session on Medium-duration thermal energy storage – Technologies, capacities and challenges - A Joint Workshop by IEA-ES Tasks 42, 44, 45

Adriano Sciacovelli: Carnot Batteries: Technological capabilities, challenges and emerging trends from IEA-ES task 44

Alice Tosatto: Optimizing large-scale Thermal Energy Storage Envelope Design for Enhanced Energy and Exergy Efficiency in District Heating Systems

Annelies Vandersickel: Beyond Grid Flexibility: Power-to-Heat and Carnot Batteries for Zero-Carbon Industrial Heat and Power Supply

Gerald Englmaier: Latent thermal energy storage for data center application

Jianhua Fan: Water pit thermal energy storage for district heating system

Ming Chen: Potentials of molten salt for medium duration thermal energy storage

Special session on Medium-duration thermal energy storage – System perspectives - A Joint Workshop by IEA-ES Tasks 42, 44, 45

Frederick Stender: Effects of different uses of molten salt storages in the national energy system – A case study on Denmark

Michael Bayer: Cascading of sTES for optimal operation of DHC networks – Case study on a cooling dominated grid

Morten Herget Christensen: Heat pump and e-boiler hybrid systems for charging of thermal energy storages – Techno-economic analysis of district heating and industry applications

Niels van der Veer: Cost-effective and low-carbon heat supply using medium duration molten salt energy storage in the industry

Silvia Trevisan: Heat integrated Carnot Batteries for Decarbonized Industries – System Opportunities Mapping

Wim van Helden: Accelerating the Role of Large Thermal Energy Storages as Elements for Medium and Long Duration Flexibility

4th Generation District Heating concepts, future district heating production and systems

Alireza Etemad is a PhD researcher in Mechanical Engineering at University College Dublin. His PhD focuses on modelling and techno-economic analysis of fourth-generation district heating systems. He also has industry experience in district heating planning.

A Multi-Scale Analytical Framework for Assessing Flexibility, Feasibility, and Performance of Decentralised 4th-Generation District Heating Systems

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Alessandro Maccarini, Department of the Built Environment, Aalborg University, Denmark;

Alireza Afshari, Department of the Built Environment, Aalborg University, Denmark;

Donal Finn, School of Mechanical and Materials Engineering, University College Dublin, Ireland;

Lisa Ryan, Department of Economics, University College Dublin, Ireland;

James O'Donnell, School of Mechanical and Materials Engineering and UCD Energy Institute, University College Dublin, Ireland

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As urban areas transition toward low-carbon heating, Thermal Source Networks (TSNs) have emerged as a promising concept for integrating decentralised heat supply with renewable electricity. TSNs are a subclass of fourth-generation district heating systems, using shared pipe networks as thermal sources for decentralised heat pumps. This research introduces a multi-scale analytical framework to support TSN planning and integration, addressing key challenges related to grid flexibility, building demand complexity, and substation operation. The framework covers three complementary scales: urban, building, and equipment. At the urban scale, an operational and market-based simulation framework assesses how TSNs with decentralised heat pumps and distributed thermal storage can support large-scale heat electrification and contribute to grid flexibility. The model simulates real-time interactions with electricity market signals and enables the evaluation of system responsiveness, peak shaving, and operational emissions. Results show thermal storage can enhance flexibility and unlock new value streams for TSNs. At the building scale, a techno-economic framework evaluates the feasibility of connecting low-efficiency buildings to TSNs. Heat demand is estimated from EPC data and building archetypes. The model examines how reducing heating system temperatures affects network performance and cost-effectiveness. Findings suggest shallow retrofits, supportive ownership models, and electricity pricing can improve feasibility in legacy districts. At the equipment scale, a dynamic thermo-hydraulic modelling framework evaluates how control strategies affect TSN substation performance. The model combines validated components and grey-box demand profiles to assess improvements in substation efficiency and supply temperature control. Together, these modelling approaches form a cohesive framework for planning and evaluating TSNs in integrated low-carbon energy systems.

Keywords: Fourth-Generation District Heating, Heat Electrification, Techno-Economic Analysis, Flexibility, Heating System Control, Heat Pumps, District Heating Substations

Andrea Franzoso holds a Master's degree in Energy Engineering and is currently pursuing a PhD. His research focuses on multi-energy systems, energy conversion and storage technologies, and advanced optimization methods for energy management.

Multi-Agent Deep Reinforcement Learning for Optimized Operation of Industrial Energy Systems

Andrea Franzoso, Politecnico di Torino; Gabriele Fambri, Politecnico di Torino; Marco Badami, Politecnico di Torino

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Industrial energy systems often supply diverse energy vectors: electricity, steam, hot and chilled water. To meet these demands, they integrate various technologies, including cogeneration units (e.g., internal combustion engines or microturbines), steam generators, chillers, and renewable sources like photovoltaic arrays. These components differ in efficiency, flexibility, and operational constraints, creating a tightly coupled and complex optimization problem. Traditional rule-based control strategies, common in practice, often fail to handle the variability of renewables and the complexity of multi-energy infrastructures. In this context, Deep Reinforcement Learning (DRL) has emerged as a compelling alternative. In DRL, an agent learns optimal policies through trial and error with an environment: it is a flexible framework for control and can be implemented using different structural paradigms, depending on how decision-making is distributed.

Typically, only a subset of technologies, those with greater flexibility and cost impact, are directly controlled, while others respond indirectly to upstream decisions. This modularity suits decentralized or hierarchical control, where decision-making is distributed across multiple DRL agents to improve scalability and responsiveness.

This work presents different DRL structures (centralized and decentralized) for the optimization of an industrial multi-energy system. All DRL models were benchmarked against a typical rule-based controller and a MILP-based optimization. Results show DRL outperforms the rule-based strategy, which cannot account for renewable variability. Among DRL configurations, performance varied, highlighting the importance of control architecture. Notably, the best-performing DRL setup used a hierarchical configuration, achieving results close to the MILP optimum and demonstrating the potential of hierarchical DRL agents for efficient, scalable energy management.

Keywords: Industrial multi-energy systems, Energy management optimization, Renewable energy integration, Deep Reinforcement Learning

Anna Dell'Isola is a PhD researcher in the European HeriTACE project, focusing on integrating sustainable energy supply in historic neighbourhoods. She explores the use of Model Predictive Control (MPC) as a system integrator to enhance system flexibility.

Upgrade of a Virtual 5th Generation District Heating and Cooling Network through Optimal Control

Anna Dell'Isola, KU Leuven, Lieve Helsen, KU Leuven

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District heating and cooling (DHC) networks, particularly Fifth Generation (5GDHC), effectively reduce building energy use and greenhouse gas emissions by integrating low-quality thermal energy sources at neutral temperature levels. However, the operation of these networks is not yet optimized. A key challenge is the integration and control of multiple distributed heat and cold sources, with pumping energy being crucial at neutral temperatures. Rule-Based Control (RBC) sequences are conventionally used to manage these networks, whereas more advanced strategies like Model Predictive Control (MPC) can act as a system integrator, facilitating the transition to an affordable decarbonized heating sector. This paper delves deeper into control strategies for a virtual 5GDHC network, comparing current-practice RBC with a white-box MPC approach through dynamic simulations. The MPC strategy aims to minimize primary energy use while ensuring thermal comfort in the connected buildings. Physics-based models of building envelopes, thermal systems, and hydraulic components are developed in Modelica. The study includes i) RBC development as a baseline, ii) optimal control with a one-year prediction horizon, iii) optimal control with a conventional three-day horizon, and iv) testing for two archetype districts with different insulation levels. A sensitivity analysis evaluates system sizing strategies and their impact on control and performance. Results show that optimal control significantly improves thermal comfort, particularly during transitional seasons, while reducing energy use by over 40%, and proving crucial for less insulated buildings. These benefits are achieved by lowering network temperatures, utilizing anticipatory control, and leveraging the buildings' thermal inertia and the different building loads. Additionally, MPC enables substantial component size reductions exploiting system flexibility during operation, and thus acting as an effective system integrator.

Keywords: 5th Generation District Heating and Cooling (5GDHC), Model Predictive Control (MPC), Rule Based Control (RBC), Building Insulation, Modelica

Dr.-Ing. Anna Cadenbach is Head of Department Thermal Energy Systems Technology at the Fraunhofer IEE in Kassel, Germany. Her focus is on the evaluation and optimisation of low temperature district heating concepts based on renewable energies and waste heat.

Influence of sector coupling on a district heating system in a German town: thermal simulation and comparison of different supply scenarios

Laura Vallese, University of Padova and Construction Technologies Institute of the National Research Council. Lina Wett, Fraunhofer Institute for Energy Economics and Energy System Technology. Michele De Carli, University of Padova. Anna Cadenbach, Fraunhofer Institute for Energy Economics and Energy System Technology.

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District heating networks (DHN) present a significant opportunity for decarbonising the heating sector, which accounts for 40% of total energy consumption in Europe. Despite being a well-established technology, the integration of renewable energy (RE) in DHNs remains underutilized. The increased use of heat pumps (HP), transformation measures, and the implementation of hybrid grid structures have significant potential to increase the share of RE, reduce primary energy demand and CO₂ emissions from district heating. To capitalise on this potential, this study presents a comprehensive simulation and evaluation of Hybrid Grid Solutions (HGS). It investigates different heat supply scenarios in a southern German town, comparing a reference scenario using a conventional DHN with two innovative HGS. The HGS scenarios incorporate rooftop photovoltaic (PV) systems for domestic energy appliances and decentralised thermal energy storage (TES) systems. In these scenarios, TES facilitates the integration of excess PV power into the heat supply through sector coupling technologies, including electrical resistances and air-to-water HPs. The first HGS scenario relies on waste heat, while the second consists of two distinct DHNs: one operates at a low temperature (45 °C) supplied by a large groundwater HP, and the other at 80 °C, using waste heat. Each scenario is modelled and simulated over a one-year period using MATLAB Simulink with the CARNOT Toolbox. The results show a significant reduction in greenhouse gas (GHG) emissions for the first HGS, primarily due to the utilization of excess PV power. However, an analysis of the second scenario reveals challenges related to GHG emissions from the large HP, as approximately half of its energy supply is derived from an electricity grid characterised by a high primary energy factor. This study provides valuable insights into the conceptualization of HGS, emphasizing the integration of RE while addressing associated challenges.

Keywords: District heating networks, Hybrid networks, Sector coupling, Power-to-heat, Heat pump, Waste heat, Sustainable heating solutions, Thermal simulations.

Asger Ulf Jensen is a PhD student at DTU Construct, specializing in the modelling of district heating and cooling systems. He holds an M.Sc. in Energy Engineering from DTU and has industry experience in district heating and geothermal heat pump systems.

Improved District Heating Network Hydraulics for Enhanced Energy Distribution and Excess Heat Recovery

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District heating and cooling (DHC) systems are expected to integrate decentralized energy sources, minimize heat losses, and adapt to variable demand profiles. Conventional branched-structured topology restricts bidirectional energy exchange and hinders the integration of distributed heat producers and prosumers. Additionally, the widespread use of bypass flows during low-load periods results in elevated return temperatures and substantial avoidable heat losses.

This work investigates an alternative double-loop topology with hydraulically separated warm and cold-water loops and cluster-level circulation. The double-loop is applied to a case study area in Copenhagen, Denmark, which was then simulated hydraulically.

The system's temperature levels were specifically designed to align with the targets for fourth-generation district heating and cooling (4GDH/4GDC), ensuring compatibility with low-temperature operations.

The double-loop topology opens up new opportunities for cooling delivery through the same infrastructure, decentral heat and cooling production, demand-side control, and seasonal energy storage.

The work outlines methodologies for configuring such a system from end to end covering pipe dimensioning, pressure and flow control strategies, and a substation design that enables return flow recirculation into the supply loop. These methods are broadly applicable for engineers and planners looking to deploy more flexible and energy-efficient DHC infrastructures.

Keywords: District heating and cooling, double-loop topology, decentralized energy integration, thermal networks, substation design, heat losses, DHC hydraulic modeling, cooling delivery, 4GDH, 4GDC

Since joining FairHeat as a Graduate Engineer in 2023, Avril has built expertise in Optimisation, Retrofit Design, and Quality Assurance of heat networks. She's contributed to diverse projects and is currently overseeing the install and commissioning of new build heat networks.

Achieving 4th-generation heat network performance by converting an existing UK communal heating system from a 4-pipe to a 2-pipe network

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Optimising communal heat networks for net-zero operation by improving energy efficiency and integrating renewable heat sources is critical to decarbonisation. Many 3rd-generation heat networks in the UK must be upgraded to attain 4th-generation performance while ensuring capital costs remain feasible.

This case study demonstrates a novel approach to optimising a 13-year-old, 69-dwelling communally heated residential building in London, UK. The existing system had high heat losses of c. 588 W/dwelling and poor year-round flow and return temperatures above 70 °C, contributing to corridor temperatures exceeding 30 °C in mid-winter.

The root issue was an oversized, poorly controlled and poorly insulated 4-pipe heating system. The solution was to convert the 4-pipe system to a weather compensated 2-pipe system, leveraging oversized space heating pipework and installing single plate heat interface units (HIUs) in all dwellings. This approach provided greater control of system flow rates and return temperatures, while also eliminating the need to replace failing HWS pipework.

Delivered in late 2023, the upgrades significantly enhanced network performance, with the retained system flow temperature weather compensated between 55 °C and 70 °C and achieving return temperatures below 35 °C. The lower system temperatures have aided in combatting overheating by reducing heat losses in corridors by c. 50%.

Available operational data after project completion shows a 65% reduction in heat loss to 163 W/dwelling, 35% lower CO2 emissions and corridor temperatures generally 5 °C lower than prior to works on a month-by-month basis. The system now operates within parameters compatible with air source heat pumps or a district heating network connection - laying the foundation for future decarbonisation.

This project demonstrates that converting existing 4-pipe systems to 2-pipe systems is a viable method for achieving 4th-generation heat network performance on a communal heating system.

Keywords: Heat Network, Retrofit, Optimisation, Decarbonisation, Heat Loss, 4th-Generation

Bart Homan received his PhD degree from the University of Twente in 2020 after defending his thesis "Batteries in Smart Microgrids". Currently he works as senior researcher at Saxion University of Applied Sciences. He focusses on the simulation, smart-control and integration of smart energy systems.

Exploring options for optimizing the energy consumption, production and storage of the Ecofactorij business park using HIL simulation

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The Ecofactorij is a business park in the eastern Netherlands, comprising 25 companies including offices, cold storage, transportation and car-parts manufacturing. This business park operates in a self-owned, local distribution grid with a connection at a transformer station to the main DSO grid. Due to grid congestion in the eastern Netherlands, the grid capacity has been limited to 12.5 MVA, which is problematic for expansion plans of the companies as exceeding this limit can have severe consequences, from fines up to disconnection.

To mitigate this limitation, park management has decided to add 1.6 MWp of PV panels and 3 MWh of batteries to the local grid, and implement measures to prevent exceeding the grid limit. Measures include e.g. switching off cooling compressors of the cold storage facility temporarily. Due to high thermal mass, this has only a small impact on the temperature of the facility.

Besides the grid capacity limitation, other motivations for introducing demand response and flexibility options include financial profit, reducing CO₂ emissions or the possibility to operate more autarkic. To this end, researchers of University of Twente and Saxion University of Applied Sciences, are researching and testing new control algorithms, that optimize all (flexible) energy consuming and producing assets at Ecofactorij towards these goals.

However, practical tests are difficult at the Ecofactorij, as these would potentially disrupt the operations of the companies. Therefore a real-time simulation of the Ecofactorij is created using an OPAL-RT Hardware In the Loop simulator, which enables the researchers to evaluate the effect of using the control algorithms and additional measures, without risking disruptions to the normal operations of the companies, before real validation tests can be conducted at Ecofactorij. In the presentation, we introduce the case, explain the control of flexibility options and show our research methods and first results.

Keywords: HIL-simulation, Control algorithm, Optimization, Energy Storage, Microgrids, Business Parks, PV-generation

A Regional Approach to Offshore Wind: The Key to a Cheaper & More Resilient European Power System

THEMA Consulting Group & Ørsted

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European countries predominantly operate with a national mindset, connecting offshore wind farms solely from their Exclusive Economic Zones (EEZs) directly to their own shores. As offshore wind capacity grows, this national focus creates inefficiencies. In densely developed areas, new wind farms can reduce the electricity output of existing ones due to the wake effect. This significantly increases the cost per unit of electricity generated. The national approach also means Europe fails to capture the substantial socio-economic benefits offered by a more interconnected power system.

By optimizing the deployment of offshore wind and grids in the Northern Seas for Europe as a whole, offshore wind and grid connections can be placed where it provides the most socio-economic value regardless of which country's EEZ it is in. Following this logic, countries can also do hybrid projects (offshore wind connected to two or more markets) which increase the utilization of cables lowering infrastructure cost for further-from-shore offshore wind projects and providing opportunity for cross-border electricity trade when wind speeds are low.

To quantify the value of collaboration, THEMA modelled future European power system costs under different levels of regional cooperation.

The results are compelling: compared to a status quo scenario, a high degree of regional cooperation in developing offshore wind and grids could save Europe nearly €4.5 billion annually by 2050 as seen to the figure on the right. These savings translate directly into lower energy prices for consumers and strengthen the cost-competitiveness of European industries, including energy-intensive sectors in Europe. The average power price in Germany falls by 5% compared to the status quo scenario. Limiting cooperation compared to the status quo will increase average German power prices with 11% compared to the status quo.

Keywords: Offshore Wind, Regional Cooperation, Transmission, Interconnectors, Hybrids

After a PhD in fluid mechanics, Charlie Prétot is a postresearcher at CEA LITEN since 2023. His research focuses on modelisation and optimisation of thermal source networks.

Innovative architectures of thermal source networks

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2) *Nicolas Lamaison, CEA - LITEN, Université Grenoble Alpes*

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The present work deals with Fifth Generation District Heating and Cooling (5GDHC) networks. In such networks, the water in pipes is at a near-ambient temperature and decentralised heat pumps and/or chillers are required to respectively raise /decrease the temperature for the consumers. Recently, the International Energy Agency has considered these 5GDHC networks as a subclass of fourth-generation networks, labelling them "Thermal Source Networks" (TSN). For consistency with this nomenclature, the term TSN is used here.

In the literature, 3 main architectures of TSN networks are described, namely "reservoir", "bidirectional" and "classical". Regarding the 2-tubes architectures, bidirectional networks use decentralized hydraulic pumps whereas classical networks are composed of one central hydraulic pump and only valves in substations. From a thermodynamic point of view, bidirectional networks are the most efficient. Reservoir networks are less efficient than the two-tubes networks, because it is based on a unique ring type pipe with mixing taking place. The main problem with bidirectional networks is the hydraulic complexity. Having decentralized hydraulic pump is a huge challenge and some authors argue that such networks are not controllable.

The objective of the present work is to present innovative architectures of TSN networks. These new architectures pretend to be easier to control, i.e. with only valves in substations, than bidirectional networks. However, the thermodynamic efficiency is increased, in comparison with existing architectures.

Performances of 3 new architectures are compared to the existing architectures for different heat and cold demand thanks to a detailed dynamic thermo-hydraulic simulator previously developed by the authors. A representative case study with 10 consumers is used. The best new architecture presents a 1.7% increase in overall efficiency with respect to "classical" TSN networks for representative operating periods of 2 weeks.

Keywords: Thermal source networks, 5GDHC, Heat pumps, District heating, District cooling

Charlie Davies is an engineer at FairHeat, a specialist energy consultancy focused on the design, delivery and quality of heat networks. Charlie joined FairHeat having graduated from the University of Oxford in 2023 with First-Class honours in Engineering Science (MEng).

Developing a heat loss key performance indicator for district heat networks

Charlie Davies, FairHeat

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As part of the UK Government's plan to achieve net zero emissions by 2050, heat networks are becoming a regulated utility and designated as the primary means of decarbonising heat in urban areas. As part of this regulation, minimum technical standards are being mandated for heat networks through regulations through a Heat Network Technical Assurance Scheme (HNTAS).

HNTAS is an outcome-orientated scheme, with performance assessed against key performance indicators (KPIs). Heat loss is one of the core performance parameters for distribution networks and high loss can increase costs for consumers. Accordingly, an appropriate minimum standard for the heat loss from district heat networks hence needs to be set as a KPI.

HNTAS assesses performance for both communal (building) networks and district heat networks.

While there are well established norms acceptable levels of heat loss from communal networks, the same is not true for district heat networks. As such, a KPI needed to be established. The KPI must:

- work for a range of network typologies (domestic / non-domestic);
- require high levels of insulation on networks with higher losses;
- be permissive enough to encourage the development of heat networks in the UK.

A district heat network's design is influenced by its peak demands; the heat loss KPI was hence set through a W loss per kW of peak demand on the network. This can be achieved by setting:

- a heat loss limit which a network shall meet; and
- a boundary which sets the insulation requirement.

The two heat loss values (in W/kW) were set by assessing the heat losses & peak demands from 35 district networks of varying typologies.

The heat loss limit / boundary should be fair when comparing direct domestic connections (such as houses) to dwellings in residential blocks - a 'notional building' was used to set values for direct domestic connections, which were expressed as a W/dwelling metric.

Keywords: District heating, heat networks, key performance indicator, HNTAS, heat network regulations

An expert in the field of district heating demand side. He is currently doing industrial PhD in TalTech and working in a district heating production and distribution company. He has worked in production companies, e.g. production of heating substation, heat exchanger and heat recovery systems.

A Data-Driven Framework for Assessing Building Readiness for Low-Temperature District Heating

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- 4) Martin Thalfeldt, Tallinn University of Technology, School of Engineering, Department of Civil Engineering and Architecture*
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Transitioning existing buildings to low-temperature district heating (LTDH) is a key strategy for reducing energy consumption and carbon emissions in urban areas. While previous studies and frameworks have introduced methods to assess LTDH readiness, there remains a need for scalable approaches that can screen larger building stocks based on available data. This study presents a data-driven framework that combines building registry spatial data (e.g., size, construction era, renovation history, location), historical knowledge of heating system types, and smart heat remote metering data to estimate the potential for reduced district heating supply temperatures.

A structured decision-tree logic is applied to group buildings into readiness categories, based on typical renovation scenarios and known heating system characteristics. Heat meter data is used to identify temperature-use patterns and flag buildings with potential for improved temperature control. While this approach does not eliminate the need for building-specific assessments, it offers a way to identify priority areas and clusters of buildings that warrant closer investigation for LTDH adaptation. The proposed method aims to bridge high-level theoretical assessments with real-world operational data to support more targeted and effective decarbonization planning.

Keywords: low-temperature district heating, building heating system assessment, LTDH readiness, data-driven assessment framework, supply temperature reduction, building stock screening

Dennis Lottis is a research associate at Fraunhofer IEE in Kassel and a PhD fellow at HCU Hamburg, specializing in thermo-hydraulic simulations within the field of district heating. Additionally, he is engaged in the planning and construction of a district heating test facility.

Simulation Study on Optimizing Substations: Challenges and Solutions in the Transition to Fourth Generation District Heating Systems

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The transformation of existing district heating systems into fourth generation systems is urgently needed to enhance efficiency and sustainability. A significant aspect of this transformation is the renewal of substations, as practical experience from Germany indicates that some currently used substations exhibit undesirable and inefficient behavior, including oscillatory behavior when controlling the secondary supply temperature. Such issues can lead to damage or even failure of the heat exchanger and may negatively impact the district heating network, with thermo-hydraulic conditions deviating from the design point identified as potential causes.

Since it is not feasible to renew all substations in a district heating system simultaneously, a transitional state will arise during the transformation process in which old and new substations are operated in parallel. This requires that the operating temperatures initially remain aligned with those of the old systems, which brings the challenge that the described oscillatory behavior could occur more frequently and with greater intensity.

This work pursues the hypothesis that these challenges can be addressed through targeted design of the components and control systems. First, models for control valves and heat exchangers are developed and validated. A detailed model of a substation is then created, and the temperature levels for the conventional and target systems are defined. The responses of various configurations at different temperature levels are analyzed as part of a comprehensive simulation study. The results aim to derive requirements for controls in transformable substations to avoid undesirable effects such as oscillations and to improve the efficiency of the systems.

Keywords: Fourth Generation District Heating Systems, Transformation Measure, Substation Control, Simulation Study

Dr Eoin Ó Broin has a background in Energy Systems Modelling and local politics. His formal education was at the University of Limerick and Chalmers University of Technology. He has worked at CIRED in Paris and at EnvEcon in Dublin and is a county councillor on South Dublin County Council.

Heat Recovery from Wastewater Treatment Plants to Supply Existing Buildings with Low-Carbon Heat via District Heating

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Wastewater treatment plants (WWTPs) have been used a source of low-carbon heating to supply buildings nearby via district heating since the 1980s. For example, in Sweden alone there were ~500 MW of heat pumps installed at WWTPs supplying local district heating networks in the mid-1980s. Today, Sweden has the highest share of renewable heat in Europe, while Ireland has the lowest, in part because Ireland has not used solutions like heat recovery at WWTPs. This research aims to highlight the potential of heat recovery at WWTPs around Ireland with a focus on the University of Limerick(UL) campus, which is located next to a WWTP facility. With the support of both Uisce Éireann (Irish Water) who own the WWTP plant, and the University of Limerick, this work quantifies how much heat can be recovered at the WWTP, how much is required in the nearby buildings on the UL campus, and subsequently designs a solution which could be put in place to connect the two. This solution consists of an Energy Centre, where the heat is recovered from the WWTP, a district heating network to connect the Energy Centre to the buildings in UL, and Building Connections which will outline how the heat network can be retrofitted into the existing heating systems in the buildings of UL. The district heating project presented will be based on the design principles of 4th Generation District Heating.

Keywords: District Heating, Wastewater treatment plants, Waste Water Heat Recovery, Green campus, Network optimisation, low-carbon heating, Energy Centre design.

Esther is a Postdoc at DTU Compute with prior research experience at UCL and ETH. She integrates building performance modelling and machine learning to develop control strategies that cut emissions, and contributes to IBPSA Project 2 on BOPTTEST and Annex 96 on Grid-Integrated Control of Buildings.

Enhancing Model Accuracy in Grid-Integrated Building Control: A Semi-Systematic Literature Review of Hybrid Modelling Approaches

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Seyed Shahabaldin Tohidi, Technical University of Denmark.

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The building sector accounts for 34% of global CO₂ emissions. One way to reduce these emissions is by optimising heating, cooling and air conditioning (HVAC) systems through model-based control strategies, which integrate buildings as active demand-side participants in the energy system. Their effectiveness not only depends on the digital maturity of the systems but also on the accuracy of the underlying models used for simulation, testing and implementation.

Traditionally, control strategies relied on either physics-based or data-driven models, each with limitations. As a result, hybrid models have emerged as a promising solution by combining the physical precision and interpretability of physics-based models with the adaptability and real-time capabilities of data-driven models. While grey-box models, often based on simplified resistance-capacitance networks, represent one form of hybrid models, this study focuses on more advanced hybrid models that integrate physics-based models with Machine Learning (ML) components.

Despite their potential, few reviews have examined the integration of physics-based and ML models for grid-integrated building control. Therefore, this study sets out to map the field, identify research gaps and explore opportunities through a semi-systematic literature review.

Preliminary findings highlight significant advancements in model accuracy, a key theme that emerged from the review. In the reviewed studies, hybrid models consistently outperformed baseline models – typically standalone physics-based or ML models – by 20% to 90% across various performance metrics. These improvements may be attributed to model decomposition, which enhances error correction and adaptability, among others.

These findings suggest that hybrid models may be more robust and effective in handling the complexity of grid-integrated building control compared to standalone physics-based or ML models alone, reinforcing their potential to optimise HVAC systems.

This work is supported by the Horizon Europe project BIPED (Grant Agreement No. 101139060).

Keywords: hybrid models, grey-box models, physics-based models, data-driven models, data-driven digital twin, machine learning, building control, grid-integrated control, model accuracy, literature review

Femke Janssen is a Scientist at TNO, with master degrees in the energy and control field. She has worked on multiple research projects related to district heating and other energy systems. The focus of her work is in the optimization of both the design and the operational strategies.

Roll-Out Strategy Optimization for District Heating Networks

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The Netherlands is facing a heating transition with the majority of the existing buildings being heated by natural gas. This has to be replaced with alternative solutions, of which it is expected that a large portion would include District Heating Networks (DHN) which are facing several challenges to be realized.

This work is based on the open-source code base MESIDO (Multi-Energy System Integrated Design and Operation) that allows for a techno-economic optimization of DHNs based on a Mixed Integer Linear Problem (MILP) approach. This code, still being expanded, integrally minimizes the costs by determining if assets (e.g. sources, storages, heat pumps, pipes) are required, their respective sizes and simultaneously the operational strategy for the end scenario. However, the planning is equally relevant to consider due to phased construction thereof. This indicates the need of a timing trade-off between consumer connections, investment decisions and operational constraints.

This paper proposes an integral optimization of the phased approach for DHNs. For this purpose an optimized end scenario design will be used in addition to yearly phasing constraints which can consist of maximum investments, pipe lengths or consumption.

Initially the “profit” will be maximized over the time horizon to confidently reach a viable network. Additional asset constraints, to limit financial risk, can be added e.g. a minimum utilization requirement and other non-financial factors like legislations or neighborhood plans can be accounted for by constraining the asset placement, before or after a specified year. Finally, some flexibility in the quantity and sizes of assets will be included to cater for scenarios where the optimal phased solution differs from the end scenario. This integral phased method will result in an optimal cost based design considering location specific phasing constraints. The end result being a design per phase that might differ from a conventional approach.

Keywords: Roll out strategy, Phasing problem, District Heating Network, Design and operational optimization, Mixed Integer Linear Problem

Hasib is a Marie-Curie fellow at VITO and a PhD researcher at KU Leuven. His work focuses on robust and optimal planning of district heating networks to support next-generation energy systems through modeling, simulation, and uncertainty analysis.

An automated framework to select the most profitable consumers for district heating network connections

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In the context of the energy transition, district heating networks will play a key role in decarbonizing the heating industry. To be deployed, district heating networks must demonstrate superior economic viability compared to individual heating solutions. When multiple consumers are available within proximity to a heat producer, strategic consumer selection becomes imperative to maximize network profitability. This work introduces an optimization framework to automatically select consumers based on economic merit. The optimization problem is formulated around a physically accurate (non-linear) heat and mass transfer model and minimizes a detailed net present value representation of the heating network cost. For the consumer connection optimization, techniques from the field of density-based topology optimization are used, where the cost of connections, i.e., the cost of substation and heat exchangers, along with the profit, are penalized. This approach encourages the optimizer to select a discrete configuration, effectively determining whether each consumer should be connected or disconnected. To validate the methodology, a detailed techno-economic assessment was conducted, followed by a sensitivity analysis on excluded neighboring consumers to ensure that their omission improved the overall profitability of the network. The framework was evaluated using an academic district-level case study, demonstrating its relevance for urban energy planning.

Keywords: District heating network, consumer connection optimization, topology optimization.

Ina Herrmann completed a B.Sc. in Environmental Engineering, followed by a M.Eng. in Renewable Energy Systems. Since 2017, she has worked as a research associate at the Competence Center for Renewable Energies and Energy Efficiency at HAW Hamburg, focusing on district heating systems and controller.

Analysis of peak load reduction with configuration of district heating controllers and a newly developed optimization box

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The reduction of peak loads is a key task in promoting sustainable heat generation in district heating systems (DHS). In German DHS, most control devices manage heat consumption with a simple heat curve that sets the flow temperature based on the current ambient temperature. In cases of short-term temperature drops, such as due to thunderstorms, the simultaneous opening of several affected control valves can cause a peak load in the system. Many controllers offer settings to prevent this by ensuring abrupt temperature changes don't directly impact the flow temperature. The set point is adjusted gradually to avoid a sudden valve opening, though these settings are often not activated. Thanks to a developed test rig, a research group from the Competence Centre for Renewable Energy and Energy Efficiency (CC4E) at the University of Applied Sciences Hamburg can assess the peak load reduction capabilities of controllers from different manufacturers. The test rig consists of four DH control units that can be tested in a hardware-in-the-loop environment. Detailed simulations of the DHS, along with high-quality temperature simulators, ensure realistic conditions for the controller. High-frequency measurements of the controller's output signals allow precise analysis of flow temperature control strategies. The simulation tool can also evaluate the impact of peak shaving on indoor temperature in buildings. An optimization box for peak load reduction has also been developed. Installed between the ambient temperature sensor and the controller, it optimizes the temperature measured by the controller during specific weather events which are detected by measuring ambient temperature and pressure. Studies show that controller-integrated peak shaving mechanisms reduce peak loads. Controllers with and without configured peak shaving settings were analysed, and it was found that using the optimization box can lower peak demand, even in controllers without peak shaving options.

Keywords: district heating controllers, peak load reduction, peak shaving, optimization, test rig

Director at the Danfoss Climate Segment Technology and Systems department. This includes internal and external consultant focusing on energy systems, feasibility studies and related system and component development.

REDUCING DISTRICT HEATING RETURN TEMPERATURES BY CASCADING CONCEPTS

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For reaching an optimal system efficiency and enabling the full potential of the 4th generation district heating (DH) concept, it is crucial to lower both the DH return and flow temperatures in parallel. This study assesses the potential of three cascaded substation concepts to reduce the annual flow-weighted DH return temperature. A lower return temperature can subsequently lead to reduced distribution losses, increased system capacity, improved heat generation efficiency, and in some cases, lower flow temperatures.

As part of the Horizon 2020 project ARV (<https://greendeal-arv.eu>), different DH substation concepts have been evaluated. The evaluated concepts include parallel, two-stage, aftercooling, and midcooling configurations, with the parallel concept serving as the baseline for comparison.

The analysis, based on annual simulations, covers generalized parameter combinations to demonstrate the potential for DH return temperature reduction across the different substation concepts in comparison to the baseline. The analysis is based on the climate profile of Copenhagen, anyhow the impact of various climate profiles is explored as well, represented by the cities of Copenhagen, Helsinki, Paris, and Rome.

The DH return temperature reduction potentials depend on the boundary parameter combinations and climate profile, and to address these, typical 3rd generation as well as 4th generation temperature profiles are applied.

For the cascaded concepts of aftercooling and midcooling, the analysis shows a reduction of the annual flow weighted DH return temperature in the range of 4-9°C for 4th generation DH temperature profiles compared to the standard parallel system. For 3rd generation temperature profiles, the improvement is 3-5°C.

This is a significant reduction, and a highly relevant path for both improving 3rd generation DH systems, as well as for realizing the design goals of the 4th generation DH system concept.

Keywords: District Heating, 4th Generation District Heating, Low Temperature District Heating, District Heating Return Temperature

Jerik Catal MSc. is a Research Engineer at AIT Austrian Institute of Technology in the field of Digitalisation and HVAC Technologies in Buildings. He is an expert in industrial refrigeration/heat pump technology, building energy simulation and innovative energy concepts.

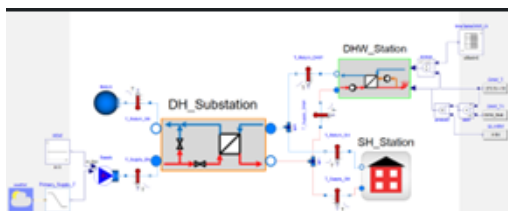
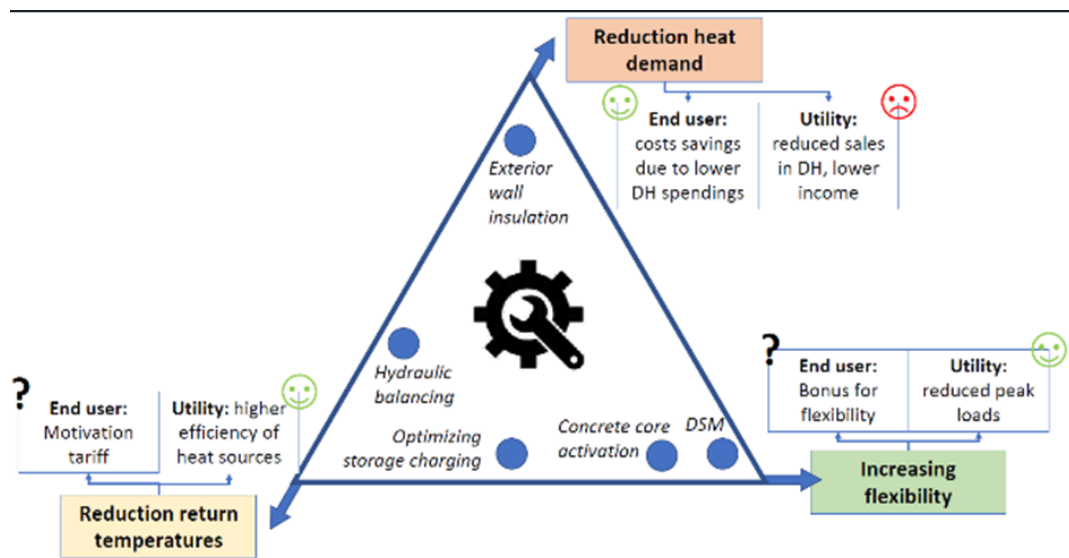
Optimized Buildings for Decarbonized District Heating: A Measures Catalogue for Reducing Temperatures, Enhancing Flexibility, and Cutting Costs

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The large urban district heating (DH) networks in Vienna, Linz, Graz, Klagenfurt and Salzburg are primarily based on combined heat and power (CHP) plants, using natural gas. With CHP expected to be very limited in the future and more customers likely to connect to DH networks, significant amounts of alternative heat sources like heat pumps, waste heat, solar, and geothermal energy will be necessary to decarbonize the DH supply. This presents challenges, especially related to optimizing return temperatures and flexibilities. The described concept aims to develop solutions on a technological level (e.g., optimized buildings, innovative secondary networks, DH network analysis). Key elements include reducing DH network temperatures and activating flexibilities. The measures are described in Figure 1. The concept uses an integrated simulation framework: IDA ICE models the thermal performance of buildings and evaluates the impact of refurbishments. Dymola analyzes the interaction between buildings and the DH network, focusing on supply/return temperatures and hydraulic balance. TRNSYS assesses domestic hot water preparation concepts and their potential to reduce return temperatures. Figure 2 illustrates how IDA ICE results and Dymola simulations are connected. Representative building archetypes (e.g., 6, 12, 24 flats from pre-1919 to post-2001) were modeled. Over 100 simulations were conducted and used in a co-simulation. In the final step, results are aggregated to the building stock level using Invert/EE-Lab to assess impacts on economic viability, efficiency, and temperature levels. A comprehensive measures catalogue was developed and structured into: DH substations, secondary systems, DHW preparation, and building envelopes. The results show how improved insulation, reduced infiltration, and optimized DHW systems can reduce demand and return temperatures. These findings support the transition to low-temperature DH systems and scalable decarbonization.

Keywords: building simulation, district heating, measures catalogue, temperature reduction, hydraulic simulation, demand reduction, flexibility enhancing,



Dr Chambers has more than 10 years experience in both academic and industrial research and development in energy in the built environment. Previously leading buildings energy research topic at University of Geneva, he co-founded Planeto in 2023.

5th Generation District Heating and Cooling with TESSA – pilot project in a UNESCO world heritage site

Jonathan Chambers, Planeto SA/UNIGE; Max Boegli, CSEM SA; Thomas Soderstrom, Strom SA

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District heating systems are increasingly recognized as a promising solution for decarbonizing space heating and domestic hot water, primarily using renewable energy sources and waste heat. A notable innovation in this field is the fifth-generation district heating and cooling (5GDHC). This system operates used a low-temperature, uninsulated pipe system that delivers both heating and cooling energy to buildings via heat pumps. This approach is advantageous for small villages, where space for large heat production units and pre-insulated pipes is limited. When coupled with long-term thermal storage solutions such as shallow geothermal boreholes, 5GDHC has significant potential to meet the growing demand for space cooling.

Despite its advantages, designing such systems requires extensive data and can be computationally expensive. To address this challenge, Planeto's innovative software TESSA, Thermal Energy System Simulation Assistant, provides design automation, engineering simulations, and integrated datasets for engineers.

A pilot project, in collaboration with the Swiss Federal Office of Energy (SFOE), was conducted in the UNESCO World Heritage village of Grandvaux to assess the feasibility of a 5GDHC system. The study evaluates the technical and economic feasibility of a 5GDHC system that integrates decentralized energy production via heat pumps and geothermal boreholes. This decentralized approach is made feasible by placing boreholes along the path connecting buildings, which minimizes thermal interference. Numerical simulations confirmed the technical and hydraulic feasibility of the network over 50 years. Compared to scenarios where each building is equipped with its own borehole, this approach reduces the required borehole length by 33%. Compared to traditional centralized district heating systems, the decentralized solution requires 25% fewer boreholes, 65% less pumping energy, and 30% less electrical energy to meet the same building heating needs.

Keywords: district, heating, thermal, network, 5G, shallow geothermal, borehole, low-temperature, cooling

Joe has previously contributed to the design of city-wide low carbon district heating initiatives in the UK. He now works within the Industry Standards team where he is aiding in the development of the Heat Network Technical Assurance Scheme for existing heat networks.

Equipment Condition and Resilience Requirements of UK Heat Networks

Joseph Shanley, Consulting Engineer at FairHeat

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Heat networks are a key part of the UK Government's strategy to achieve Net Zero emissions by 2050. However, poor operation & maintenance (O&M) practices within the UK frequently result in detrimental consumer outcomes, including interruptions to heat supply. The Government is supporting the growth of this sector with the introduction of a new regulatory regime. This includes the implementation of a Heat Networks Technical Assurance Scheme (HNTAS), to ensure UK heat networks meet minimum technical standards. In addition to setting a minimum technical standard for the development of new heat networks, this regime will set minimum standards for the operation and maintenance of new and existing heat networks.

As part of this, technical requirements have been developed to ensure:

- heat network equipment is maintained to an acceptable level of condition
 - heat networks demonstrate a minimum level of resilience against threats to supply
- Existing literature and industry engagement has informed the development of these standards, including the design of a framework which includes:
1. a condition grading methodology to assess heat network equipment
 2. a threshold for the grade of equipment condition to be required under HNTAS
 3. a schedule of activities to be conducted by an engineering surveyor to determine the condition of equipment
 4. a schedule of the information that should be collected and reported by an engineering surveyor
 5. a definition of the technical competency requirements of an engineering surveyor
 6. a risk-based framework that will highlight where improved resilience is required

This work sets the framework for ensuring that a minimum standard of O&M is maintained within the UK heat network market, as part of the incoming regulatory regime.

Keywords: Heat networks, district heating, assurance scheme, regulation, industry standards, Operation, Maintenance, Condition, Resilience

Julian Plautz is a research associate at the University Hildesheim/Holzminden/Göttingen. His re-search focus is on district heating systems, especially the integration of renewable energy sources into existing networks and the transformation towards 4th and 5th generation district heating.

Thermohydraulic Modeling and Simulation of a District Heating Network for the Optimization of Building Refurbishment Strategies

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The University of Göttingen aims to achieve climate neutrality by 2030. With natural gas consumption accounting for about 20-25% of the natural gas consumption of the city of Göttingen, the University, with its combined heat and power plant, is a major natural gas consumer. In the future, the goal is to replace natural gas with renewable energy sources or waste heat sources and to reduce heat demand. The combined heat and power plant supplies heat to the North Campus via a district heating system (DHS). The buildings on the North Campus, some of which are over 50 years old, have significant potential for heat savings through building refurbishment.

Strategies for building refurbishment or for the transformation and further development of DHS have already been analyzed in many studies. These studies highlight potential savings as well as opportunities to transform DHS into low-temperature networks of the 4th and 5th generation. However, the impact of building refurbishment on existing DHS in terms of pressure, temperature levels and other parameter has not yet been investigated.

This paper analyzes the effects of reducing heat demand from large consumers on the DHS of the University of Göttingen. Parameters such as pressure, temperature levels and heat losses are analyzed. In the first step, a simulation model of the district heating network is created. In the next step, the model is validated with measurement data. In three scenarios, the impact of the sequence of building refurbishment on the DHS is then examined:

- Refurbishment of the buildings furthest from the heat source
- Refurbishment of the buildings nearest to the heat source
- Refurbishment of the buildings with the highest heat demand

The results show that the sequence of building refurbishment can significantly impact the operation of a DHS and the distance of a building from the heat source should be considered when prioritizing building refurbishment.

Keywords: Building refurbishment, Climate neutrality, District heating, Heat supply, Scenario analysis, Transformation

Lucrezia Manservigi is an assistant professor at the Department of Engineering of the University of Ferrara, Italy. Her research interests are related to the diagnosis of energy conversion systems and district heating networks, climate change, and energy scenario forecasting.

Diagnosis of faults in district heating network components

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A District Heating Network (DHN) is a crucial infrastructure for the decarbonization of the heating sector, as it enables the recovery and utilization of waste and surplus heat to meet users' thermal energy demand. DHNs consist of multiple components that are susceptible to faults and, thus, diagnostic methodologies are required to detect faults that could make network efficiency decrease.

This study proposes a physics-based diagnostic methodology for fault detection and identification in the most crucial DHN components, such as pumps, pipes, valves, and heat exchangers. The possible failure of such components may cause different types of faults, such as anomalous pressure and heat losses and mass flow rate losses. Fault detection consists of localizing the faulty component, while fault identification allows recognizing the type of fault as well as estimating its magnitude. The proposed diagnostic methodology integrates a physics-based model with an optimization algorithm that targets the minimization of the difference between some measurable variables (mass flow rates, temperatures and pressures) and the same variables estimated by the diagnostic methodology. As a result, the health index of each DHN component can be identified.

The case study of this work is the DHN serving the Campus of the University of Parma, which includes two pumps, thirty-two pipes, nine valves and nine heat exchangers. The values of mass flow rate, temperature and pressure are provided by a digital twin of the network, under both healthy and faulty operating conditions.

The diagnostic methodology accurately determines the health state of the considered DHN components, proving to be suitable also for real-world applications. In such a manner, faults that may affect network efficiency can be promptly detected, thus reducing the costs for the management and maintenance of the network.

Keywords: district heating network, diagnostics, fault diagnosis, decarbonization

Mr. Morid Zadeh is a Ph.D. Fellow at the University of Southern Denmark (SDU) working on the development and demonstration of novel digitalization strategies for supermarket refrigeration systems.

Smart waste heat recovery in a Danish supermarket refrigeration system

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The refrigeration sector is of essential importance to modern society. Though, it is also accountable for 7.8 % of the global greenhouse gas (GHG) emissions, a figure predicted to rise due to the increasing overall refrigeration demand. In order to significantly reduce the carbon footprint of Danish supermarkets, transcritical CO₂ refrigeration systems have become standard. In fact, the use of CO₂ as the sole refrigerant offers a negligible direct contribution to global warming, besides leading to high energy efficiencies and thus to a limited indirect contribution too. In addition, transcritical CO₂ supermarket refrigeration systems feature significant waste heat, which can be recovered to satisfy its heating reclaim and/or to be sold to a district heating (DH) provider. However, an optimal high pressure maximizing the amount of heat to be recovered while the annual electricity bill is minimized needs to be found.

In this work an advanced simulation model of a cutting-edge transcritical CO₂ supermarket refrigeration system integrated with ejectors, false load and heat recovery unit (HRU), among others, was implemented and validated against field measurements of an actual Danish supermarket. Therefore, it was employed for developing a novel optimization algorithm providing the high pressure maximizing the recovered waste heat while minimizing the supermarket annual electricity bill. The new optimization methodology was developed with respect to the electricity price, heating purchase and sale price, supermarket heating and refrigeration loads, outdoor temperature, renewable energy source (RES) availability as well as energy storage charge/discharge status. Realistic requirements and constraints for the refrigeration system, HRU and energy storages were considered.

Keywords: District heating, Excess heat recovery, Optimization, Transcritical CO₂ supermarket refrigeration, Waste heat recovery

Morten works as a Data Scientist in the Analytics Team at Kamstrup, where he focuses on digitalization in the district energy sector. Kamstrup, headquartered in Stilling near Aarhus, Denmark, develops innovative products across hardware, software, and services.

End-user installation monitoring, diagnosing, and optimization at a very large scale.

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In order for the green transition to succeed within the measurable future, effective tools are needed to optimize the entire district energy value chain, from energy production and distribution, to the consumption level.

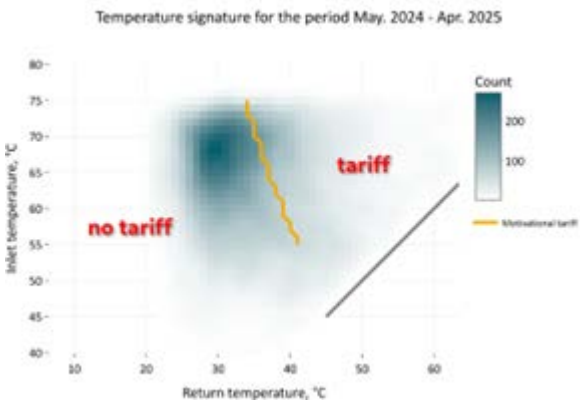
Several studies have shown large potential savings in the optimization of end-user installations, thereby reducing distribution network temperatures. The potential savings increase further when moving towards more renewables in the energy mix, and enabling optimization solutions such as Demand Side Management, where the building mass is used as thermal buffer capacity.

Working with end-user engagement is an overwhelming task for most utilities. It requires continuous attention to the performance of thousands of substations. Moreover, communication with owners of faulty installations also needs to be systematic, consistent and efficient. To facilitate this, Kamstrup recently developed and launched a commercially available service, RTO (Return Temperature Optimizer), which does exactly this on a very large scale.

Kamstrup RTO consists of an innovative software platform that analyzes end-user installations, and a notification system that automatically sends out customized letters to end-users with faulty installations. End-users are presented with their individual consumption data, estimated saving potential, and repair suggestions. The activity is closely supervised by dedicated energy consultants who also answer phone calls from the end-users on behalf of the utilities.

Kamstrup RTO already now monitors over 120,000 heating installations across many different utilities, and several case studies have already demonstrated the efficiency of Kamstrup RTO. The impact on e.g. distribution network temperatures has been proven to be highly significant. Moreover, by continuous monitoring and optimizing the end-user installations, many other positive effects are observed, e.g. a general decrease of energy losses and lowered overall energy consumption.

Keywords: District heating, return temperature optimization, heat loss reduction, demand side management, software as a service, analytics, end-user engagement.



Naomi Adam is an enthusiastic second-year PhD fellow in the Thermal Systems Simulation (The SySi) team. Her research focuses on the development and holistic assessment of integrated cost-effective collective thermal systems for urban clusters of buildings.

Environmental Trade-Offs in Collective Heating Systems: A Life Cycle Perspective on Cluster Size

Naomi Adam, KU Leuven. Jelger Jansen, KU Leuven. Lieve Helsen, KU Leuven - EnergyVille.

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Collective heating systems using renewable and residual energy sources are promising in reducing the environmental impact of the building stock in an energy-efficient and cost-effective way. However, the number of buildings connected to a collective system affects key system characteristics such as infrastructure needs, heat losses and control. To analyse the trade-offs associated with different cluster sizes, it is crucial to examine environmental impacts such as climate change, resource depletion, human toxicity, freshwater eutrophication and land use over the entire system's life cycle. This can be achieved through a Life Cycle Assessment (LCA).

Existing LCA tools usually consider individual buildings, rarely addressing collective systems. This research aims to extend KU Leuven's MMG tool from building to collective system level, enabling environmental assessment across different cluster sizes. Operational energy use is calculated through physics-based dynamic simulations in Modelica, with non-linear white-box model predictive control as system integrator. Environmental impacts of buildings and installations are assessed via the Ecoinvent database. The method is applied to district heating networks with clusters of buildings ranging from 3 units to larger-scale districts, each connected to a centralized heat pump (HP) and buffer tank, considering varying degrees of building renovation.

Preliminary results show that the environmental impact of collective systems depends on cluster size. Larger clusters benefit from installing one collective HP, requiring less capacity than multiple individual HPs, thereby reducing the impact of the technical installation. However, this is counterbalanced by increased heat distribution losses. Building renovation levels further influence this balance: in poorly-insulated, larger clusters distribution losses increase, while in highly-insulated clusters, infrastructure and domestic hot water inefficiencies become more significant.

Keywords: Collective heating systems, Life Cycle Assessment (LCA), Model Predictive Control (MPC), integrated dynamic simulations, cluster size

Nermina Abdurahmanovic is a research associate at Fraunhofer IEE and a PhD candidate at the Technical University of Munich, focusing on sector-coupled district heating systems through interdisciplinary research combining technical aspects and gamification.

Simulation-based validation of an AI-supported operation strategy for sector-coupled district heating system

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Heating represents a major share of energy consumption in Germany, making it a critical sector in the energy transition. District heating systems (DHS) play a significant role in decarbonizing heat supply, and the integration of renewable energy sources into fourth-generation DHS is essential for achieving this. Sector coupling offers significant potential to increase the share of renewables. However, the presence of renewable sources and sector-coupled components alone is not sufficient. To fully utilize the system's flexibility advanced operational and control strategies are required. In such complex systems, these challenges require the development of smart solutions, with AI offering a promising approach to address them.

This work explores the application of AI-driven operation in DHS, aimed at optimizing the advantages of sector coupling. Prior to real-world implementation, it is crucial to assess the performance of such operational strategies in a controlled environment. With this aim, a digital twin of an existing DHS has been developed using MATLAB/Simulink and the Simscape toolbox. The digital twin models the thermal and dynamic behaviour of the system, including heat generation units, thermal storages, and network components. The electricity supplied to the heat generation units is managed by an AI model trained to optimize system operation based on renewable electricity availability.

The simulation environment enables an evaluation of the proposed control method under realistic operating conditions. The validation of the AI model using simulation provides valuable insights into system behaviour and operational boundaries, forming a robust basis for a field test. Ultimately, this work contributes to safer and more effective integration of intelligent control strategies in modern DHS. Furthermore, results suggest that such an approach can lead to improved energy efficiency and reduced reliance on fossil-based backup systems, particularly gas boilers.

Keywords: District heating, AI-driven operation, sector coupling, digital twin, system optimization, decarbonization, energy efficiency

Nina Dungworth is a consulting engineer at FairHeat who is currently working with developers to review and provide quality assurance throughout the design, commissioning, installation and operation of both new build and retrofit heat networks.

Practical considerations and results of optimising residential heat networks, focusing on consumer connection retrofit works.

Nina Dungworth, FairHeat

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Heat networks are a key part of the UK Government's strategy to reach net zero emissions by 2050. A Heat Network Technical Assurance Scheme (HNTAS) will be introduced to ensure minimum standards are met. Many existing networks will require improvement to comply and an important route to improved performance is the retrofit of end user connection equipment.

This case study presents the optimisation of a 40-dwelling residential heat network in the South of England, where key issues included:

- Hot water cylinders in dwellings, increasing legionella risk and generating hot water up to 70°C posing a scalding risk
- Cold rooms due to poor heat distribution within the radiator circuits
- Network bypasses causing high return temperatures and flow rates, resulting in high gas and electricity consumption.
- Poor water quality, reducing network efficiency and lifespan

Full network and energy centre retrofits can be costly and disruptive. Resident comfort and network efficiency are largely controlled by the end-user connection. Optimising terminal units first can overcome many barriers to retrofit while still delivering strong outcomes.

The project involved replacing all 40 consumer connections with twin-plate Heat Interface Units for instantaneous hot water, retrofitting Pressure Independent Thermostatic Radiator Valves, improving water quality, insulation, and energy centre controls.

Technical delivery challenges are often underestimated, such as poor system water quality, differential pressure management, and existing equipment issues.

Results include:

- Volume-weighted flow/return temperatures reduced from 77/72°C to 67/37°C
- Flow rates reduced from as high as 600l/h to under 10l/h for each dwelling in standby, significantly reducing energy centre pumping energy consumption.

- Legionella risk reduced through removal of storage cylinders

Ongoing monitoring via remote BMS and heat meter data is essential to validate and sustain performance improvements.

Keywords: Retrofit design, optimisation, decarbonisation, low carbon heat, district heat network, low temperature hot water

Nirav is a research associate and PhD candidate at the Energy Economics Group (EEG). His research focus is on Low-temperature district heating and cooling planning within positive energy districts (PEDs).

A techno-economic feasibility study of 5th generation district heating and cooling in Vienna

Nirav Patel, Lukas Kranzl, Aadit Malla, TU Wien – EEG; Marcus Hummel, Mostafa Fallahnejad, e-think energy research

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Decarbonizing urban heating and cooling remains a central challenge for climate-neutral cities. Under certain conditions, decentralized low-temperature thermal source networks, such as 5th Generation District Heating and Cooling (5GDHC) systems might play a role (as shown in other, earlier studies). This study explores the viability of 5GDHC as an alternative for such contexts, using Vienna as a case study. Based on a technical analysis in another study, we identify typical areas where 5GDHC could be feasible. For those areas, we then economically assess two decentralized 5GDHC configurations based on low-temperature renewable sources: (1) borehole heat exchangers and (2) groundwater systems.

This study addresses the central research questions: “What configurations of supply systems and building-side technologies (e.g., heat pumps, thermal storage, electric boilers) lead to economically viable 5GDHC solutions, and under what conditions are these systems more cost-effective than renewable individual heating alternatives?”

A techno-economic model is developed to simulate each configuration, accounting for heat pump operation, distribution losses, investment and operational costs, and subsurface thermal characteristics. The Levelized Cost of Heat (LCOH) is calculated for each configuration, along with sensitivity analyses on electricity prices, building connection rates, and thermal source temperature. The resulting LCOH is compared to the case of a reference, renewable, individual heat supply.

Findings show that under specific conditions, such as favourable subsurface conditions, clustered demand, and sufficient building connection rates, 5GDHC can provide a competitive LCOH compared to traditional systems. The results provide guidance on the conditions under which 5GDHC becomes a viable alternative and offer a framework for planners to match building typologies and local resources with suitable DHC technologies.

Keywords: Low temperature district heating, thermal networks, 4th generation district heating, 5th generation district heating, economic assessment

Nyasha Grecu is a Junior Research Engineer at AIT, with an MSc in Energy Science from Utrecht University. Her work focuses on optimization models for robust decarbonization of heating and cooling, considering future uncertainties such as energy prices and weather scenarios

The role of geothermal energy in decarbonizing district heating under future uncertainty: a techno economic analysis for an Austrian case study

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Decarbonizing the heating sector requires long-term planning amid future uncertainties. District heating can contribute substantially to this goal by enabling the implementation of sustainable heating solutions on a large scale and the use of heat sources that are difficult to integrate on a small scale. This includes geothermal energy, which can act as a reliable, weather independent baseload source.

However, district heating systems are subject to economic risks arising from uncertainty in the future development of key factors. This includes changes in heat demand due to building retrofitting and climate change, and the development of electricity and biofuel prices. Similarly, geothermal energy development is subject to significant uncertainties prior to drilling, for example regarding the subsurface temperature and output flow rate.

This contribution conducts a techno economic analysis to explore the role of geothermal energy in district heating decarbonization under future uncertainty, applied to an Austrian case study. To do so:

- Techno-economic performance is measured by optimizing investment and operation decisions and calculating the levelized cost of heat, and
- Future uncertainty is modeled through Monte-Carlo simulation (MCS) and sensitivity analyses, enabling the planning of robust solutions.

Three scenarios are analyzed which consider various renewable heat supply technologies (e.g. air heat pumps, biomass boilers, thermal storages):

1. Reference scenario (excluding geothermal)
2. Reference scenario + medium-temperature geothermal
3. Reference scenario + high temperature geothermal

First, an investment optimization is conducted to define the optimal system configuration and sizing. Then, an operation optimization is run. Finally, MCS and sensitivity analyses are applied to the operation optimization to assess system performance across a wide range of future scenarios and quantify associated economic risks.

Keywords: District heating, Decarbonization strategies, Geothermal energy, Economic risk assessment, Uncertainties, Monte-Carlo-Simulation, Optimization

Philipp Gradl is a scientific researcher within the technology development division of AEE INTEC. His expertise is centered on optimizing energy systems and enhancing smart building control. In his work, he is actively engaged in developing and implementing simulation and optimization models.

Return-flow and bi-generation upgrades: Real-world results from an Austrian district heating network

Philipp Gradl, AEE INTEC

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District heating is increasingly recognized as a cornerstone of future lowcarbon energy systems and improving its efficiency can therefore deliver substantial environmental gains. This study presents two novel scalable systems that aim to enhance the performance of district heating networks. Both are in operation and currently tested by one of the largest energy providers in Austria.

The demonstration site is located in Vienna, Austria and has 201 apartments, covering a total floor area of 13,000 m². The residential buildings are fitted with underfloor heating systems that deliver 375 kW of heating capacity at 40°C, and 150 kW of cooling capacity at 21°C. An additional 180 kW is allocated to the production of domestic hot water at 63°C.

The first implemented system is the supply-return-return-flow configuration. This system allows buildings to utilize the relatively high temperatures of the return flow within the district heating network to cover the heating demand. The conventional supply flow is only activated when the return flow cannot fully satisfy the heating requirements. This approach effectively lowers the return flow temperature, contributing to greater energy efficiency across the network.

The second system implemented is a heat pump that provides radiative surface cooling during summer at a temperature of 21°C. Simultaneously, the heat pumps waste heat is utilized to produce domestic hot water or fed back into the district heating network. Operating in this "bi-generation" mode enables the system to utilize both temperature levels provided by the heat pump. This significantly enhances the efficiency of the system by maximizing the thermal usage per unit of electrical energy input.

The studies results show that by implementing these systems, cities can achieve substantial energy savings and get possibilities for sector coupling without affecting consumer comfort.

Keywords: District heating network, heat pumps, buildings, return flow temperature reduction, energy efficiency, bi-generation, supply-return-return-flow configuration

Rahul Mohandasan Karuvingal has been working as a research associate and a PhD candidate at the RWTH Aachen University. His research interests are dynamic thermo hydraulic network simulations, advanced controls for LTDH substations, and operation optimization of LTDH systems.

Advanced Modeling of District Heating Networks and Analysis using uesgraphs v2.0.0 Tool: A Case Study from a German Living Lab Project

1) Rahul Mohandasan Karuvingal, Institute for Energy Efficient Buildings and Indoor Climate - RWTH Aachen University. 2) Leon Kopka, Institute for Energy Efficient Buildings and Indoor Climate - RWTH Aachen University. 3) Kai Droste, Institute for Energy Efficient Buildings and Indoor Climate - RWTH Aachen University. 4) Jonas Klingebiel, Institute for Energy Efficient Buildings and Indoor Climate - RWTH Aachen University. 5) Dirk Müller, Institute for Energy Efficient Buildings and Indoor Climate - RWTH Aachen University.

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Advanced simulation and analysis tools are essential for designing efficient and sustainable low-temperature district heating (LTDH) networks. In this work, we introduce uesgraphs v2.0.0, a robust tool that significantly expands the capabilities for modelling, simulation, and performance evaluation of district heating systems. This new release features a streamlined installation process through the elimination of redundant Python dependencies, integrated logging functions for improved traceability, and enhanced compatibility with new version of Modelica and AixLib simulation package. Additionally, an updated model generation template automates the creation of multiple simulation models, while advanced visualization modules and a dedicated analyze.py script enable dynamic post-processing of results, facilitating detailed inspection of network behavior and hydraulic performance.

We demonstrate the applicability of uesgraphs v2.0.0 by means of a comprehensive case study from the Transurban.NRW living lab project. The investigation focuses on assessing the hydraulic feasibility of Supply Station 1 under increased demand, where the district heating network operates with a supply temperature of 43 °C and a planned return temperature of 29 °C. Detailed evaluations quantify network losses, pumping power requirements, temperature gradients, and flow velocities. The resulting analysis reveals critical operational bottlenecks and hydraulic instabilities that affect overall system efficiency, providing a sound basis for optimizing component sizing and refining operational strategies in LTDH networks.

Our findings underscore the pivotal role of advanced simulation tools in identifying performance issues and informing targeted design improvements. Using uesgraphs v2.0.0, this study yields insights and recommendations for planning, dimensioning, and operating future LTDH infrastructures. By integrating simulations, it advances resilient, energy-efficient urban thermal systems.

Keywords: Low-Temperature District Heating (LTDH), Urban Energy Systems, Hydraulic Performance, Simulation Modeling, System Optimization, Dynamic thermo-hydraulic model

Sajedah Roustaei is a Building Engineering graduate from Politecnico di Milano and an incoming PhD student. Her research focuses on optimizing district heating systems using data analysis for improved energy efficiency.

Data-driven approach for diagnosing inefficiencies and optimizing district heating networks

Sajedah Roustaei, Alice Denarie, Giulia Spirito

Sajedah Roustaei (presenter)

District heating networks provide a sustainable and efficient solution for large-scale heat distribution, and one of the most important factors affecting their performance is return temperature. Lower return temperatures enhance overall DH efficiency. However, identifying the causes of high return temperatures and implementing effective interventions remains a challenge, particularly in large-scale networks. This study develops a scalable, data-driven framework to optimize return temperatures and enhance demand-side management in DH systems. First, time-series clustering is applied to categorize substations considering their temperature behaviors. A representative temperature metric is then calculated for each substation to accurately reflect its operational patterns. To assess the impact of each substation on overall network efficiency, a structured ranking method is introduced based on this metric. Furthermore, by analyzing user-side data, the study tries to identify the underlying causes of high return temperatures in problematic substations and proposes targeted corrective measures. The results indicate that out of 49 substations, 10 exhibited inefficiencies related to heat exchangers, while 23 had issues within the user-side system. Finally, the effectiveness of these interventions is evaluated through scenario-based simulations, showing that optimizing problematic substations can reduce network return temperature from 62°C to approximately 56°C.

On parallel, this study also examines heat consumption patterns to support more effective network planning. Users are categorized into 9 distinct load profiles using time-series clustering, providing a clearer understanding of demand variations. To address cases where monitoring data is incomplete, a scaling-based estimation approach is introduced, leveraging real user data and cluster representatives to reconstruct missing consumption profiles.

Keywords: District heating, return temperature optimization, time-series clustering, impact-based ranking, heat load analysis, data-driven approach

Her research area is energy transition and its economic and environmental impact. She has published over 40 research papers in academic journals such as Nature Climate Change, Applied Energy, and Energy.

Decarbonization of district heating in China

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District heating decarbonization is a big challenge towards carbon neutrality in China. Heat pumps are considered as one solution, but there are still problems like the seasonal imbalance of power system, indoor thermal comfort, etc. District heating using combined heat and power generation (CHP) and industrial waste heat is another option. In this study, we try to conduct a research to analyze the potential of district heating in northern urban China able to answer two questions: 1) how much heat supply potential of CHP and industrial waste heat in the future, and 2) what the role of using CHP and industrial waste heat for district heating towards carbon neutrality in China? .

A regional energy system model, the China Regional Energy System Model, was used here to project the potential heat portfolio from 2020 to 2060 under the scenario designed toward carbon neutrality. Results show that, 1) in 2020, the technical potential of CHP and industrial waste heat for residential building heating was 46.6 billion GJ, which is 7.8 times the winter heating demand for northern urban China; 2) the technical potential of CHP and industrial waste heat will reach the peak of 47-52.6 billion GJ by 2030 in line with the slight demand increase for electricity and some industrial products. By 2060, the technical potential will decline significantly to 27.1-40.4 billion GJ due to the retirement of energy intensive facilities towards carbon neutrality, with a decrease of 42%-13% compared to 2020; 3) In the future, with the continuous expansion of building area and the improvement of building energy efficiency, the heating demand of residential buildings in northern urban China will increase slightly to 6.4 billion GJ by 2060. About 16%-27% of the heat demand is met by CHP and industrial waste heat, and the rest is mainly met by air-source heat pumps and ground-source heat pumps. Excess heat from energy-intensive facilities is a viable heating supply option towards carbon neutrality.

Keywords: Decarbonization, District heating

Simon Müller, based at the University of Applied Sciences Ingolstadt, concentrates on enhancing thermal source networks at industrial sites through technical optimization, economic analysis, and the implementation of AI technologies for improved efficiency and reliability.

Optimizing the Operation of a Thermal Source Network Based on a Digital Twin Using Matlab/Simscape

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Simon Müller (presenter)

The transition to sustainable and flexible energy systems requires robust modelling tools for the design and optimisation of thermal source networks (TSNs). However, TSN models for industrial-scale systems with significant cooling demand remain scarce, with most existing work focusing on heating-dominated applications using Modelica-based tools. This study addresses this gap by presenting a digital twin of the incampus TSN in Ingolstadt, developed using MATLAB/Simscape. The system has a strong focus on cooling, integrating industrial-scale thermal sources such as data centre waste heat and groundwater wells.

The digital twin includes reduced-order building models, a pipe model, heat pumps, and an energy hub. Calibration of buildings and TSN pipes focused on measured heat output and temperature profiles, while heat pumps were represented using a simplified Carnot efficiency model. Validation was based on two years of operational data. The validated model supports a detailed analysis of the TSN operation, especially in its current ramp-up phase, where system flexibility allows the exploration of different rule-based control strategies.

Two exemplary operating strategies are analysed:

1. TSN supply temperature optimisation, comparing maximum waste heat utilisation to lower electricity consumption of decentralised heat pumps versus minimising thermal distribution losses.
2. Pump operation strategy, investigating the trade-off between centralised and decentralised pump operation during low load periods. While decentralised pumps in the substations can temporarily maintain heat supply without circulating the entire TSN, extended operation reduces heat pump efficiency, requiring strategic transitions.

The results provide new insights into TSN operation, particularly for cooling-focused, industrial-scale networks, and demonstrate the potential of MATLAB-based modelling. The digital twin also lays the foundation for transparent system representation and advanced control.

Keywords: Thermal Source Network (TSN), District Heating and Cooling (DHC), Digital Twin, MATLAB/Simulink, Thermo-Hydraulic Modelling, Energy System Optimization

Simran Chaggar is a Senior Engineer at FairHeat. Her work currently focuses on preparing existing building to connect to large-scale city-wide district heat networks within the UK.

A data driven approach within retrofit design to reduce emitter upgrades for commercial buildings connecting to low-temperature heat networks.

Simran Chaggar, FairHeat

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Connecting existing commercial buildings to low-temperature heat networks is particularly challenging as UK buildings have generally been designed with operating temperatures of c.82°C and small temperature differentials (dT) in the region of 10°C.

To optimise the heat generation efficiency within the centralised energy centre, heat network operators will require lower flow and return temperatures with larger dTs.

The output of the existing heat emitters would reduce at the new operating temperatures which may reduce in underheating. However, emitter replacement is costly and disruptive which could dissuade offtakers from pursuing a connection.

Using an industry led approach to model the building heat losses typically leads to oversizing of heat losses prompting significant emitter replacements, due to a reliance on assumptions.

Conducting a temperature lowering test over the heating season replicates a similar average emitter temperature compared to that experienced when connected to the network. This provides measured data of expected operation post-connection.

This data driven approach is preferable as it gathers building-specific data on the ambient temperatures compared to comfort set-points as well as factoring in the occupant experience.

This approach has been followed within multiple commercial buildings in north of the UK. On average, the number of radiator replacements have reduced by 20-38 per building, resulting in a cost reduction of roughly £13,000-£25,000.

Furthermore, this approach allows funds to be targeted to areas to achieve the required overall blended return temperature. For example, where heat is predominantly served by AHUs, it may be prudent to allocate funds to heating coil replacements rather than radiators as this will have a bigger impact on overall performance.

The cost saving coupled with a significant reduction in disruption during works can promote heat network connection and drive decarbonisation within the heating sector.

Keywords: Temperature lowering, decarbonisation, building upgrades, low carbon heat, district heat network, low temperature hot water

Stanislav graduated from Omsk State Transport University with a major in Energy Engineering in 2015 and successfully finished the PgD course in 2021, combining it with 6-year of experience as an engineer at a company providing district heating. He joined Vrije Universiteit Brussel in September 2022.

Design and Integration of 5th Generation District Heating and Cooling Systems: Economic Viability, Technical Methodologies, and Urban Applicability

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The transition to low-carbon energy systems has accelerated the development of 5th Generation District Heating and Cooling (5GDHC) networks, which offer a decentralized, low-temperature, and bidirectional approach to thermal energy distribution. This presentation explores three central research questions: (1) the economic viability of 5GDHC systems compared to previous generations and standalone heating solutions, assessed through benchmarks involving natural gas systems and heat pumps; (2) a methodological framework for designing a 5GDHC network from the ground up, incorporating scouting processes, GIS-based analysis, and criteria for prosumer selection; and (3) the feasibility of integrating 5GDHC systems or their components into existing and future urban or peri-urban contexts, supported by case studies and planning tools, electric vehicle (EV) infrastructure, and hydrogen integration. Through the application of robust modeling tools—such as genetic algorithms and Python-based simulations—alongside spatial analysis and case studies like the Ingolstadt project, this study demonstrates how 5GDHC can not only outperform earlier district heating generations in specific scenarios but also align with evolving urban energy demands. The

results underline the importance of coordinated spatial planning, flexible system architectures, and hybrid energy storage (e.g., BTES, ATES) in achieving scalable, sustainable, and economically viable energy networks.

Keywords: 5GDHC, district heating and cooling, energy systems, GIS, thermal energy storage, prosumer networks, economic viability, system design, urban integration, renewable energy, heat pumps

He is professor emeritus in energy technology since his retirement in 2018, but he is still very curious on district heating. One subject of interest is to develop efficient warm distribution networks with an annual return temperature of 25°C by dividing the flow into delivery and circulation flows.

Thermal lengths in district heating systems

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District heating systems for providing heat for meeting the customer's heat demands in buildings contain basically five different heat exchange processes. In this presentation, the various strategies for these five processes will be assessed by using the standard heat exchanger vocabulary consisting of the two basic variables: the thermal length (NTU) and the ratio (R) between the lowest and highest heat capacity rates, where the thermal length is the ratio between the ability to transfer heat and the lowest heat capacity rate in each heat exchange. These two variables provide the input for obtaining the necessary effectiveness for each heat exchange process together with the heat exchange configuration, where the counter-flow configuration is the most efficient one.

The five heat exchange processes are (1) keeping the pipe network warm, (2) heat transfer for preparation of domestic hot water, (3) heat transfer to the space heating system, (4) heat transfer from the space heating system by radiators to the rooms, and (5) heat transfer from the space heating systems to the incoming air. Past, current, and future examples of combinations of NTU and R will be presented for the five heat exchange processes in district heating systems. In order to develop efficient low-temperature district heating (LTDH) systems, these examples can provide insights how the thermal lengths and the corresponding heat capacity rate ratios should be chosen.

The main conclusion is that everyone that intend to perform research in LTDH must learn, understand, and utilise the standard heat exchanger vocabulary for providing contributions to efficient LTDH systems. Every LTDH pilot project should be assessed by the proposed methodology in order to identify the specific benefits and drawbacks in each project.

Keywords: district heating, low-temperature, thermal lengths, ratios of heat capacity rates

Sylvester Ofili is a Postdoctoral Researcher in the department of Energy Technology at Tallinn University of Technology, Estonia. His research focus is on system optimization and integration of geothermal energy/energy geostructures and other renewable energy in DHC systems

Feasibility Analysis of Geothermal Energy Integration in Ultra-Low Temperature District Heating Networks

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Conventional district heating (DH) systems often operate at high supply temperatures, which result in a heavy dependence on fuel-based heat generation and substantial distribution heat losses. In this context, ultra-low temperature (< 35°C) district heating is emerging as a sustainable alternative, enabling the integration of low enthalpy renewable energy sources such as geothermal energy. Despite its potential, ultra-low temperature (ULT) geothermal DH systems present both technical and economic challenges, including the cost and technical requirements of heat pumps needed to raise temperatures to meet indoor heating demands. This necessitates comprehensive system optimization to maximize both energy efficiency and cost-effectiveness. Existing research is relatively limited and primarily focuses on optimizing individual system components. This study aims to perform a holistic system optimization of ultra-low temperature shallow geothermal district heating systems, considering the production, distribution and consumption sides. Firstly, modelling and simulation of the district configurations will be performed using a flexible modelling framework, potentially incorporating existing digital twins suitable for ultra-low and low-temperature DH operation. The models are validated using data from open-source geothermal borehole projects and typical heat demand data from small-scale district heating networks. The proposed methodology considers different scenarios with variable pipe layout and insulation, heat distribution (via tunnels or underground), heat pumps (centralized or/and decentralized), and thermal energy storage. Various configurations of geothermal district heating are modelled and compared to low temperature (< 60°C) and high temperature (< 90°C) DH networks. These configurations are evaluated based on key performance indicators. The resulting optimal system configurations provide valuable insights into the design and operation of ULT-geothermal DH systems.

Keywords: Ultra-low temperature district heating, shallow geothermal energy, system optimization, heat pump

Theда Zoschke is researching the advanced control of multi-producer district heating networks

Demonstration of model predictive control for optimal power dispatch in a district heating network with decentralized producers

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District heating networks are crucial for achieving emission-free heat supply by optimizing renewable heat sources and industrial waste heat. As these networks expand with more decentralized producers, controlling them becomes challenging. Model Predictive Control (MPC) is a promising approach for cost-optimized heat distribution. This paper evaluates a linear MPC approach in a real network.

In the German-funded project WOpS, MPC will be implemented in existing district heating networks to optimize heat production units and ensure stable operation. A Mixed Integer Linear Programming (MILP) problem was integrated into the MPC routine, linked to the Weil am Rhein network with nine producers serving about 120 consumers, including biomass boilers, CHP, oil, and gas boilers, plus a storage tank.

MPC aims to meet demand while considering constraints like heat output limits and storage capacity. Interfaces between existing control technology and the new server enable real-time operational data for the MPC.

The MPC calculates optimal heat distribution over a 24-hour forecast horizon. An AI-based algorithm, trained with historical data, predicts heat load. The resulting power dispatch is integrated into existing control routines to maintain operation despite forecasting errors.

Analysis indicated that the MPC strategy could reduce peak load coverage by fossil boilers, especially in the mornings. Functional tests confirmed this trend under real conditions. Instances were noted where subordinate control loops override MPC values to prevent errors, and efforts are being made to reduce these occurrences.

We outline how MPC was integrated with network control, presenting advantages and limitations. Initial tests confirmed that MPC leads to fewer switching cycles and reduced fossil boiler operation, but adjustments are needed for more reliable operation. Suggestions are made how to overcome these shortcomings.

Keywords: Model Predictive Control (MPC), District Heating Networks, Decentralized Producers, Demonstration, Mixed Integer Linear Programming (MILP)

Tom is the department head for the Industry Standards team at FairHeat, who is the technical author for the Heat Network Technical Assurance Scheme (HNTAS). Throughout his time at FairHeat, Tom has published various literature, including the Heat Network Optimisation Guide.

An Overview of proposed Technical Assurance Requirements for Existing Heat Networks in the UK

Tom Burton, Principal Engineer at FairHeat

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Heat networks are a key part of the UK Government's strategy to achieve Net Zero emissions by 2050. The Government is supporting the growth of this sector with the introduction of a new regulatory regime. This includes the implementation of a Heat Networks Technical Assurance Scheme (HNTAS), to ensure UK heat networks meet minimum technical standards. This regime is to be applicable to both new networks in development, as well as existing networks in operation.

While the requirements for Existing network will not be as exacting as for new networks, there will be a minimum standard of performance required across all heat networks to ensure that consumers receive a reasonable standard of service, irrespective of the network that they are supplied by.

As part of the implementation of this regime, it is expected that many existing networks will need to undertake improvement works in order to comply with HNTAS, with these works phased over time.

In developing HNTAS, a framework has been designed for existing networks to achieve compliance with the new technical requirements:

- In a relatively short period, existing networks will be expected to:
 - o install metering infrastructure to provide visibility of performance
 - o meet a minimum threshold of reliability, to so as to ensure that detrimental consumer outcomes are avoided
 - o provide an improvement plan which outlines the required steps to be taken in order to meet long-term performance requirements
- In the longer term, existing networks will be required to meet performance thresholds, comparable to those of new heat networks

This work will ensure that all heat networks within the UK are brought up to an acceptable level of performance, in a structured and deliverable way for the market.

Keywords: Heat networks, district heating, assurance scheme, regulation, industry standards, Existing Systems

CCUS and PtX technologies and the production and use of electrofuels in future energy systems

Alexander Meisinger is a PhD student at OTH Regensburg, Germany. His work focuses on sector-coupled energy system modelling to analyze global energy partnerships and import instruments for a sustainable, competitive energy transition in Germany and the EU.

Financing energy partnerships beyond Europe through H2Global: A case study on the way to a German-African energy transition

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Germany and the European Union (EU) have traditionally maintained a strong economy and a high-value chain in energy-intensive industries. However, the current situation is challenging, with energy-intensive industries facing structural barriers, such as the intermittent availability of green energy, to compete with climate targets and international competitors. African countries can play a key role in addressing these challenges, but are dependent on financial support and remain under-represented in energy research. Therefore, this research investigates potential energy partnerships between Germany and African countries, with a particular focus on the H2Global auction mechanism as a financing instrument for green hydrogen exchange and its impact on the local energy transition.

The open-source tools PyPSA-Eur and PyPSA-Earth are used and further developed to analyze the transformation of sector-coupled energy systems in line with climate targets. This allows to match the German and EU hydrogen demand with green exports from African countries. The H2Global auction mechanism is analyzed by comparing merit order curves for hydrogen demand and supply while achieving a cost-effective local energy transition. The financial gap between both merit order curves shows the relevance of the H2Global mechanism for each country and identifies potential green energy partnerships.

The results highlight the role of H2Global in structuring transparent and effective auction mechanisms, enabling long-term contracts and reducing investment and supply risks for both European off-takers (energy-intensive industries) and African producers. The findings show that a well-designed H2Global mechanism can reduce the cost of hydrogen while increasing the availability of green energy for industry. However, this research also highlights the importance of complementing such mechanisms with sustainability criteria and policy coherence to ensure local developments and global climate benefits.

Keywords: Energy system modelling, Decarbonization, Energy transition, Energy partnership, H2Global, Power-to-X

Fabio is a part-time PhD researcher at the University of Galway where he studies the effect of energy policies in the deployment of hydrogen and derivatives in the energy system. He works in the Innovation department at ESB where he develops efuels and carbon-negative technologies projects.

Deployment of hydrogen in energy systems: finding the right policies to foster a nascent industry.

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Hydrogen (H₂) and its derivatives will play an important role in a decarbonised energy system. In some hard-to-abate sectors like seasonal energy storage, aviation, and heavy-duty industries, H₂/derivatives are the only green alternatives to fossil fuels. However, the deployment of these technologies presents a challenge due to the high costs. As with renewable energy, creating the right incentives and market conditions to allow the production costs of H₂ to decrease is key for the future of the energy system. In this study, we modelled the Irish energy system of the year 2035 where we considered the production of H₂/derivatives in 5 different hubs across the island and we modelled different policy scenarios to investigate the effect of such policies in the deployment of H₂/derivatives. The base scenario was the current set of policies which include the Emissions Trading Scheme (ETS) and the RFNBO delegated act from the EU (additionality). The opposite scenario included strong incentives for H₂ production (comparable to HAR1 in the UK), very high fossil CO₂ penalties and no additionality for the production of H₂.

The main results show that with the current policy scenario, no H₂ or derivative is produced for seasonal energy storage, and only is produced to fulfil industrial demand. Besides, the system still produces electricity from natural gas as a backup. The strong incentives scenario shows an overproduction of hydrogen to fulfil the demand, but also to produce products to export and as a backup power generation fuel. This last scenario presented zero fossil CO₂ generation. The analysis shows that the current set of policies does not create the right market conditions for the production of H₂ to be profitable. Finally, the total costs of both scenarios are not significantly different, but one does present the right market conditions for H₂ deployment based on subsidies and penalties.

Keywords: Hydrogen, Power-to-Liquid, PtL, Seasonal Storage, Optimisation, Ireland, Renewables, SPINE, Energy system

Falk Birett is a researcher at FENES, OTH Regensburg. His work focuses on hydrogen systems, energy data analysis, and infrastructure planning. He contributes to the Wasserstoffatlas (Hydrogen Map) Germany project, supporting evidence-based policy and energy system modelling.

Mapping the Gap: Analyzing the Status and Future Prospects of Power-to-X Deployment in Germany

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The ongoing expansion of Germany's hydrogen economy requires robust insights into the actual status of Power-to-X (PtX) deployment. This research presents a comprehensive analysis of the PtX landscape in Germany, with a specific focus on the gap between announced, realized, and required electrolyzer capacities. Using a combination of proprietary and public datasets, the study maps regional distribution, project timelines, and cumulative capacities of PtX initiatives.

To ensure consistent and transparent dataset integration, a Python-based open-source toolkit—electrolyzermatching—is developed. This tool enables filtering, synchronization, and geospatial alignment of PtX data from multiple sources, supporting standardized inputs for energy system modeling and policy analysis. Inspired by open-source power plant mapping approaches, the toolkit improves reproducibility and facilitates integration into broader modeling frameworks such as PyPSA.

First findings reveal a significant lack of implementation that challenges current infrastructure planning and policy targets. If this lack is not addressed in scenario design and regional energy strategies, it may lead to misallocated investments, regulatory mismatches, and delays in grid and storage infrastructure development. The analysis contributes to a better understanding of hydrogen and PtX rollout feasibility, offering guidance for aligning investment, policy, and energy system models. By improving PtX data quality and compatibility, the project enhances the foundation for sector-coupled modeling and smart energy systems planning.

Keywords: Power-to-X, Hydrogen Strategy, Energy System Planning, Electrolyzer Matching, PtX Gap Analysis, Open-Source Tools

Hans Gelten is project manager in the research group Sustainable Energy Systems and responsible for hydrogen related projects. He has a MSc. in chemical engineering with a special focus on hydrogen. Currently, he is in a PhD-project on the value-chain of hydrogen especially for industrial use.

Power-to-Methanol: Techno-Economic Analysis of a regional, decentral case-study

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The global energy transition aims to reduce greenhouse gas emissions and limit global temperature rise, with goals set by the Paris Agreement, including a 40% emissions reduction by 2030 and net-zero emissions by 2050. Carbon Capture, Utilization, and Storage (CCUS) plays a key role in decarbonizing industries, with methanol (MeOH) production being a promising application. Traditionally, methanol is produced from fossil fuels like natural gas and coal, but sustainable alternatives such as Power-to-Methanol (PtM) are emerging. PtM uses renewable energy to produce green hydrogen (H₂), which is then combined with captured CO₂ to create methanol. This method is part of the broader "Power-to-X" (PtX) framework, which converts sustainable electricity into chemical energy carriers.

However, PtM is currently more expensive than traditional methods due to the high costs of renewable hydrogen and CO₂ capture. Techno-economic assessments (TEA) are essential for evaluating the feasibility of decentralized green methanol production, particularly in regions like Twente, The Netherlands. These assessments account for capital expenditure (CAPEX), operational costs (OPEX), and overall economic viability. While green methanol is more costly than conventional methanol (ranging from 530 to 2,706 €/ton), it may become more competitive as renewable energy prices decrease.

A process simulation for renewable methanol production compared three methods: grey hydrogen-based, green hydrogen-based, and combined electrolysis-methanol. The green hydrogen-based process was the most expensive due to high electrolysis costs, with a Levelized Cost of Methanol (LCoMeOH) of €4,510/ton compared to €2,244/ton for grey hydrogen-based methanol. Future trends, such as rising fossil fuel prices and decreasing renewable electricity costs, could make green methanol more competitive by 2050, though subsidies and cost reductions are needed for short-term viability.

Keywords: Power-to-Methanol, Hydrogen, Techno-Economic Analysis, ASPEN Plus[®], CAPEX, OPEX, Levelised Cost of Methanol

Dr. Haoshui Yu works in chemical process systems engineering, applying PSE and AI methods to optimize energy systems. His research includes multi-generation systems, CCUS, Power-to-X, waste heat recovery, heat/work integration, and LNG cold energy utilization.

Exploring optimal Power-to-Methanol configuration with SOEC-based technologies

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Methanol produced via Power-to-Methanol (PtM) processes—using hydrogen from renewable electricity and captured CO₂—is emerging as a promising large-scale energy storage solution. Efficient hydrogen production is critical to the overall energy performance of methanol synthesis, with solid oxide electrolysis (SOEC) currently considered the most promising technology. Using H₂O and CO₂ as feedstocks, SOEC-based PtM offers multiple pathways to generate CO₂/CO/H₂ mixtures suitable for methanol synthesis, including steam SOEC, co-SOEC, CO₂ SOEC, and combinations thereof with reverse water-gas shift (RWGS) and water-gas shift (WGS) reactions. Due to the variation in CO₂/CO/H₂ ratios resulting from these routes, identifying the optimal configuration for SOEC-based PtM systems is essential.

This study addresses that need through a superstructure-based optimization approach. Various production routes are simulated to obtain mass and energy balances, which are then approximated using surrogate models. A mixed-integer linear programming (MILP) problem is formulated and solved using deterministic algorithms to identify the configuration that minimizes methanol production cost while maximizing efficiency. Finally, a techno-economic analysis is conducted to assess the feasibility of methanol production using SOEC-based technologies.

Keywords: Power-to-Methanol, renewable energy, CO₂, MILP, SOEC

He works as an Assistant Professor at the Department of Green Technology, University of Southern Denmark. His research focuses on modeling and techno-economic assessment of green hydrogen and power-to-X pathways, with experience from DTU, AAU, and NTNU.

Grid Capacity-Aware Investment Roadmap for Sector-Coupled Industrial Clusters

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Industrial clusters are critical enablers of the green transition, offering opportunities for integrated energy solutions and sector coupling. However, their development is influenced by local bottlenecks, such as limited electricity grid capacity, and investment uncertainty in emerging energy technologies, including hydrogen and e-fuel production. We introduce a framework to address these challenges by creating a grid capacity-aware investment roadmap for industrial clusters. The study combines detailed multi-energy mapping, energy system design, techno-economic assessment, and business model innovation to support strategic decision-making. The methodology includes potential expansion plans for biogas production, positioned as a central unit in the cluster, as well as modeling of hour-by-hour electricity prices. It evaluates the integration of flexible technologies under three scenarios: (a) leveraging existing grid capacity with flexible demands, (b) incorporating new supply and storage options, and (c) expanding grid capacity. These scenarios are analyzed through techno-economic assessments that consider market dynamics and seasonal variability. A case study at GreenLab Skive serves as a real-world testbed to validate the developed roadmap. The results highlight optimal investment in biogas facility, grid infrastructure and power-to-x technologies and reveal pathways to unlock co-benefits through coordinated grid and technology development. The findings are directly relevant to industrial clusters, grid operators, power-to-x investors, and policymakers seeking to advance smart, sector-coupled industrial clusters through integrated, grid-aware planning. This project is funded by Villum Fonden grant 65732 in collaboration with GreenLab.

Keywords: Industrial cluster, Green hydrogen, Power-to-X, Sector coupling, E-fuel, Techno-economic

With a Ph.D. in chemical process control, Julian Straus aims at incorporating process details within energy system optimization models to improve the results. Most of his research focuses on systems containing hydrogen.

Modelling details matter – Representation of electrolysis in energy system models

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Electrolysis is estimated to play a crucial role in a future decarbonized energy system. However, the potential of electrolysis in a decarbonized energy system may be overestimated in capacity expansion studies due to neglecting both stack degradation and the requirement for stack replacement at the end of the life.

This study now incorporates both stack lifetime and degradation within the energy system optimization framework EnergyModelsX (EMX) to investigate the impact of neglecting stack lifetime (with appropriate stack replacement) and degradation. Two new mathematical descriptions are introduced within the existing framework of EMX, the first only including stack lifetime and replacement while the second incorporates both stack lifetime, replacement, and degradation. Both descriptions are compared with a standard, linear description of electrolysis over the timeframe from 2030-2055. The comparison is conducted with fixed but increasing capacities for electrolysis.

Including both stack lifetime and replacement, we can see a change in the operational usage of electrolysis by 4.6 % of the installed capacities of 2030 while not affecting any capacities introduced in later years. Implementing stack replacement also decreases the net present value by 8.3 %. Introducing stack degradation in addition changes the picture dramatically. The net present value is reduced by 15.8 % while electrolysis usage is moved from earlier to latter stages to exploit periods of lower electricity prices at higher efficiencies.

Given the results, it can be concluded that stack lifetime and stack degradation can have a significant impact on the decisions of capacity expansion models. Stack lifetime, should be included in capacity expansion models through increased CAPEX or fixed OPEX given an expected production profile, if it cannot be implemented directly. Stack degradation is more difficult to implement, but important to consider when discussing results from capacity expansion models.

Keywords: Electrolysis, Energy system optimization, PtX

Karl Vilén is an energy systems expert with proven experience in energy systems modelling. He performed his PhD at Chalmers University of Technology where he investigated the development of heating systems. At IVL he has performed research in various projects relating to energy systems.

Impacts of Capacity Pricing Mechanisms and Motivation Tariffs in District Heating

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The increase in renewable intermittent electricity production allows for an electrification of district heating (DH) by power to heat using electric boilers and heat pumps. The implementation of flexibility measures to handle intermittent electricity production sources allows DH to remain economically competitive and be compatible with other parts of a smart energy system.

In this study, a TIMES model has been developed which analyze an existing DH system in Visby on Gotland which evolves over time. The cost-optimal development for the DH is analyzed until year 2050 under different pricing mechanisms and tariffs of DH. The analysis was performed under two different future electricity price cases, stemming from the different availability of offshore wind power.

The investigated policies for the DH in this study are the following:

- 1: A policy to encourage peak shaving by adding a seasonally varying capacity pricing in proportion to the maximum heating power used during each season.
- 2: Implementation of a motivation tariff for DH users for decreasing the supply and return temperatures in the DH network.

The results indicate that a capacity pricing on DH decreases the economic viability of DH significantly for both electricity price cases. This stems from an increased use of individual heating solutions. The motivation policy has only a marginal increase in the DH use in the case with offshore wind power, but a larger increase in the case without offshore wind power. With both policies implemented, the result for the offshore wind power case is similar to the case with only the capacity pricing is implemented. In the case without offshore wind power and both policies implemented, the results show a slight decrease in the DH use compared to the case with only the motivation tariff is implemented. Heat storage is utilized in both offshore wind cases, but the amount of charged and discharged heat energy is higher in the case where no offshore wind power is available.

Keywords: District heating, Flexibility, Smart Energy Systems, TIMES

Leon Schumm is a PhD candidate at TU Berlin, leads the Energy System Modeling & PtX group at OTH Regensburg, and serves on the PyPSA-Earth Steering Committee. Active in renewables since 2014, he's an open-source modeling enthusiast and project lead of H2Global meets Africa.

Green Steel: Integrated Modeling of Global Value and Supply Chain Configurations and Trade

Leon Schumm, OTH Regensburg University of Applied Sciences & TU Berlin; Falko Ueckerdt, Potsdam Institute for Climate Impact Research; Michael Sterner, OTH Regensburg University of Applied Sciences

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Decarbonizing heavy industry is expected to reshape global value chains, especially in the iron and steel sector, where hydrogen- and electricity-based production routes create new trade patterns. A promising strategy is co-locating iron ore extraction and direct reduced iron (DRI) production at renewable-rich mining sites (e.g. Australia, Brazil), enabling export of hot-briquetted iron (HBI) as a green intermediate. However, we show that the most cost-efficient configurations may differ when broader factors are considered.

Mining regions are often remote, with limited infrastructure, skilled labor, and access to finance. These constraints drive up EPC (Engineering, Procurement, Construction) costs and can undermine the viability of on-site DRI production. Preliminary results show an alternative three-step value chain: iron ore is extracted in traditional mining regions and shipped to sites that combine abundant renewables with industrial infrastructure and favorable financing (e.g. parts of the Middle East, US). There, ore is processed into green iron and exported as HBI to established steelmaking hubs like Central Europe for final processing.

We develop a spatially resolved linear techno-economic model using the PyPSA framework to jointly optimize the locations of iron ore mining and direct reduction of iron with green hydrogen, along with associated trade flows. The model includes region-specific renewable electricity and green hydrogen production, transport, capital, EPC, and steel production costs, minimizing total system costs while meeting steel demand.

This research highlights the importance of spatial decoupling in green steel supply chains, provides an open-source model for assessing alternative configurations of the global hydrogen and steel trade, and contributes to a deeper understanding of how industrial value chains might evolve under climate policies. The modeling can be expanded to also consider geopolitical fragmentation and supply chain security.

Keywords: green steel, hydrogen trade, direct reduced iron, global value chains, spatial decoupling, PyPSA

He earned his Ph.D. in Electrical Engineering from IUST in 2012. Before joining DTU in 2022 as a Professor and Section Head, he held academic roles at Aalborg and Southern Denmark Universities. His research focuses on renewables, microgrids, power quality, and protection.

Unlocking Frequency Ancillary Services Potential in Eco-Industrial Clusters

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Eco-industrial clusters are increasingly recognized for facilitating sector coupling and integrating energy systems by leveraging the inherent flexibility of renewable energy sources, industrial demand, and energy storage solutions. This systemic integration promotes both economic efficiency and a sustainable energy transition. GreenLab Skive (GLS), a pioneering eco-industrial cluster in Denmark, exemplifies Power-to-X (PtX) technologies within an industrial symbiosis network. As part of GLS's investment roadmap, it is essential to incorporate emerging technologies to enhance flexibility and profitability. One promising approach is to enable current and prospective cluster participants to contribute to providing frequency ancillary services for the electrical grid. To capitalize on this opportunity, it is necessary to identify and unlock the ancillary service capabilities of individual cluster components. This paper investigates the potential ancillary services that can be provided by components within GLS, specifically wind and solar farms, battery storage, heat pump systems, and power-to-X processes. The flexibility characteristics of these units are analyzed and compared through simulation studies focusing on start-up times, load variation capabilities, ramp rate limits, and operating ranges relevant to ancillary service provision. These insights are intended to inform future investment strategies and can serve as selection criteria within a smart energy system framework to identify which participants are best suited to contribute to ancillary service provision in GLS. This project is funded by Villum Fonden grant 65732 in collaboration with GreenLab.

Keywords: Eco-industrial clusters, Frequency ancillary services, Power-to-X, wind and solar farms, battery storage, heat pump systems, GreenLab Skive

Meng Yuan is an Assistant Professor at Aalborg University. She works with energy system modelling and analysis at different geographic scales. Her current research interests include 100% renewable energy systems, energy infrastructure, PtX and CCUS and energy planning in general.

European Energy Independence: Trade-offs in Domestic Production vs. Renewable Fuel Import

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Achieving a fully decarbonised Europe requires the integration of renewable liquid and gaseous fuels for sectors that are difficult to electrify. However, the source of these fuels remains a topic of debate. On one hand, local production within Europe could, in principle, improve energy security of the overall energy system by reducing dependence on external sources, which is especially important given the current geopolitical uncertainty. On the other hand, importing these fuels from other regions could potentially offer a more cost-effective solution, as suggested by some recent studies. This study explores the trade-offs associated with achieving a secure and affordable energy system, focusing on the varying degrees of dependence on domestic production of renewable methanol versus imports. The analysis is grounded in the Smart Energy Europe scenario that models a sector-coupled 100% renewable-based European energy system in 2050. The EnergyPLAN tool is adopted to provide a range of alternative scenarios for renewable methanol imports—from complete self-sufficiency to full reliance on imported fuels. A curve of the marginal production cost of renewable methanol is identified, which represents energy security across the alternative scenarios. Additionally, the associated key techno-economic metrics are also examined such as primary energy consumption and electricity curtailment.

Keywords: Energy security, Renewable methanol, Power-to-X, Energy import, Europe, EnergyPLAN

Ramin Ghiami Sardroud earned his Master's degree with a specialization in energy systems engineering. He is currently pursuing a PhD at Montanuniversität Leoben in Austria, focusing on investigating different pathways to convert captured CO₂ into methanol from energy and techno-economic aspects.

Detailed energy and techno-economic comparison of three CO₂-to-methanol integration pathways: Novel direct CO₂ capture and electrolysis

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The implementation of various CO₂ capture and utilization methods (CCU) is essential for the transition to a decarbonized economy and for mitigating climate change. Employing renewable energy sources can enhance the reliability of these methods. Moreover, these systems are beneficial for different CO₂-emitting industries. CO₂ also serves as a key feedstock in many processes, underlining the importance of CCU systems. This study aims to compare a novel pathway using direct CO₂ capture and electrolysis (DCCE) with the conventional and SOEC co-electrolysis pathways. This analysis is based on converting CO₂ emissions of flue gas from cement plant into methanol, considering energy and techno-economic perspectives. In this novel DCCE system, the bicarbonate electrolysis produces CO and H₂ from a CO₂-rich solvent-stream. The system's subsystems, including CO₂ capture, electrolysis units, and methanol production, are modelled in Aspen Plus. Each unit is individually validated using data from operational systems available in the literature. Heating and cooling process streams are modelled in Aspen by independent heat exchangers. These heat streams are afterwards analyzed and numerically connected in order to simulate system-internal heat recovery. The current study includes the effects of internal recovery of waste heat. Parametric studies are performed to study the effects of the stoichiometric hydrogen-to-carbon ratio in the reactor feed on the energy efficiency, levelized cost of CO₂ capture to methanol (LCCCM), and CO₂ conversion efficiency. Additionally, the impact of the levelized cost of electricity from seven different renewable energy sources on the LCCCM and levelized OPEX is studied in detail. Preliminary results indicate that DCCE technology could be a promising alternative to fossil-based methanol production, offering notably reduced CO₂ emissions in terms of energy and techno-economic analyses.

Keywords: Direct CO₂ capture and electrolysis, CO₂ capture and utilization, bicarbonate electrolysis, Waste heat recovery, Techno-economic analysis, Methanol

Components and systems for district heating, energy efficiency, electrification and electrofuels

Dr. Abdulrahman Dahash works as a scientist at the AIT Austrian Institute of Technology GmbH, Center for Energy. He is engaged in several national as well as international research projects focusing on large-scale thermal energy storage and heat pumps for DHC

Techno-economic advantages of coupling large-scale seasonal thermal energy storage with heat pumps in district heating systems

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Large-scale seasonal thermal energy storage (sTES) coupled with heat pumps (HPs) plays a pivotal role in the decarbonization of district heating (DH) systems by facilitating a higher share of renewable energy, enhancing operational flexibility, and enabling sector coupling. However, the optimal planning and integration of HPs with sTES remain a key challenge due to complex interactions between system components and varying operational conditions.

This study presents a simulation-based investigation focusing on the coupling of HPs with sTES using validated numerical models implemented in the simulation environment Modelica/Dymola. A systematic parametric analysis is conducted, exploring a wide range of design and operational parameters that influence the overall performance of the sTES-HP system. These parameters include sTES type, storage volume, insulation, charging and discharging port configurations, number of sTES units, operating temperature ranges, and other critical factors.

To thoroughly assess the system's performance, multiple key performance indicators (KPIs) are employed, covering both technical and environmental aspects. The evaluation considers energy, ground temperature variations, and CO₂ emissions, providing a holistic assessment of the sustainability and efficiency of different integration strategies.

The findings of this study offer valuable insights into the planning, design and operation of sTES-HP systems, supporting the development of more efficient and sustainable DH networks.

Keywords: Seasonal thermal energy storage, heat pumps, district heating, sector coupling, planning and integration.

Davide Rizzi is an Application Engineer at Turboden, responsible for Large Heat Pump applications in industrial processes and large district heatings.

High-Temperature, Large-Scale Heat Pumps: The Key to Decarbonizing Energy Systems

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Turboden, a Mitsubishi Heavy Industries (MHI) company, is an Italian leader in sustainable energy solutions, with a global presence in over 50 countries and more than 400 installed plants. The company has developed innovative technologies to support the decarbonization of heat generation through the electrification of thermal systems. As part of MHI Group's Energy Transition Strategy, Turboden is spearheading the development of high-performance Large Heat Pumps for hot water and steam production, capable of reaching temperatures up to 200°C, with capacities ranging from 5 to 50 MW output per unit. Leveraging its extensive expertise in heat transfer, high-temperature applications, turbomachinery design, and natural refrigerant working fluids, Turboden provides customized, efficient solutions for both district heating networks and industrial processes, including chemical, petrochemical, refinery, pulp & paper, food & beverage, and power-to-X facilities. By integrating High-Temperature Large Heat Pumps into energy systems, Turboden plays a pivotal role in advancing electrification and energy efficiency, offering a sustainable pathway to reduce carbon emissions and accelerate the transition to cleaner thermal energy solutions.

This presentation will showcase Turboden's cutting-edge solutions in this domain: Large Heat Pumps and Mechanical Vapor Recompressors (MVRs). The session will also highlight real-world applications, including a 6 MW heat pump installed in a district heating network in Italy, as well as a 12 MW large heat pump combined with an MVR system implemented in a paper mill.

Keywords: High Temperature Heat Pump, Heat electrification, District Heating, Sustainable Heating Solutions, Mechanical Vapor Recompression, Carbon Emissions Reduction, Smart Energy Systems

Diego is a researcher at the Energy Innovation Center (EIZ) of Brandenburg University of Technology Cottbus-Senftenberg. As a PhD student in energy economics, he investigates factors affecting the efficiency and performance of photovoltaic systems within the broader context of the energy transition.

From Shine to Decline: Analysis of Power Loss Rate of Photovoltaic Systems in Germany

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Christin Hoffmann, Brandenburg University of Technology Cottbus-Senftenberg, Chair of Energy Economics.

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Introduction

Solar energy is vital for decarbonisation, hence PV capacity additions have surpassed all other energy sources since 2021 (Haegel and Kurtz, 2023). To measure the decline of PV systems requires distinguishing between irreversible losses (degradation) and Power Loss Rates (PLR), which include reversible effects (Mannino et al., 2023).

As maintenance records are not available, we estimate PV system PLR from ageing, climate, and pollution using 16 years (2007–2022) of data from over 1 million German systems.

Methodology

We use panel regressions to map PV system performance over 2–16 years after commissioning. Our dependent variable is the normalised performance ratio (PRN). System age, hot days, frost days, precipitation, and concentration of particular matter (PM₁₀ $\mu\text{g}/\text{m}^3$) are the predictors. We use a high-dimensional fixed effects model clustering standard errors at system level. The coefficients represent the annual PLR attributable to each factor.

Results

We found that system age significantly reduces PRN by -0.44% to -0.52% annually. Each additional hot day decreases PRN by -0.058% to -0.068%, and each frost day by -0.04% to -0.044%. Precipitation effects are ambiguous. Air pollution lowers PRN by -0.011% to -0.06% per additional $\mu\text{g}/\text{m}^3$. We found non-linear effects: ageing accelerates losses, hot days affect older systems more, while frost day effects fade. precipitation benefits older systems, and pollution impacts decrease with age. Systems with capacity over 30 kW lose more (-0.57% to -0.717% per year) compared to smaller ones (-0.427% to -0.522%).

Conclusions

Our study extends the knowledge of PV system power loss by addressing key gaps. We analyse over 1 million installations across 16 years, unlike earlier studies with limited scope. We challenge the assumption of linear loss and include diverse system sizes for performance comparisons. While we identify size-related power loss patterns, further research is needed on larger systems' drivers.

Keywords: Power Loss Rate, Photovoltaic systems, performance

Francesco Neirotti holds a PhD in Energy and Nuclear Engineering at Politecnico di Torino. He worked in electrical engineering and R&D. He co-founded the startup Aquaseek and joined Armstrong International Italiana in 2023 as a Thermal Engineer.

From waste to value: Circular Thermal systems and heat pumps driving industrial energy efficiency and decarbonization

1) *Francesco Neirotti, Armstrong International Italiana*

2) *Alice D'Alessandro, Politecnico di Torino*

3) *Gabriele Fambri, Politecnico di Torino*

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In more than 100 years, Armstrong international delivered intelligent system solutions that improve utility performance, lower energy consumption and reduce environmental emissions while providing an enjoyable experience. In particular, the Circular Thermal approach is based on capturing and recirculating waste heat within industrial plants towards the production of useful energy, improving the thermal efficiency and reducing the need for primary energy and the emission of CO₂ and other pollutants. This can greatly contribute to the thermal decarbonization roadmap of industrial sites.

This work aims to present key lessons learned from real-world applications of industrial energy efficiency solutions, with a particular focus on high-temperature heat pumps. These technologies have proven capable of delivering up to 50% reduction in both energy consumption and CO₂ emissions in selected thermal and production processes. By recovering and upgrading low-grade waste heat, heat pumps enable a significant shift toward circular thermal systems, reducing the need for primary or purchased renewable energy. Moreover, the analysis will also explore combined strategies that integrate heat pumps with other technologies to increase the overall system efficiency. These approaches support both large industrial players and SMEs in accelerating their thermal decarbonization roadmap.

Finally, the presentation will include key engineering and regulatory barriers that currently limit the wider adoption of these solutions in real-world case studies, offering insights and recommendations for policy evolution and future innovations in the sector.

Keywords: High-temperature heat pumps, industry, emissions, performance

Jakob has more than 15 years of experience with energy planning, strategy and regulation. He has been heading energy planning at COWI consulting engineers and chief consultant at the Danish Energy Agency. Now he is heading HOFOR's Electrification Program ensuring the implementation of the strategy.

Transition to an Electrified and Low Temperature Heat Supply in Copenhagen

Jakob Nymann Rud, HOFOR – Greater Copenhagen Utility

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During the last couple of decades, HOFOR has developed the district heating (DH) system from steam to water and from coal to biomass. In the coming years, a significant step will be taken towards a new chapter in Copenhagen introducing electrified and low temperature (LT) DH. The Electrification Strategy aims to reduce the use of biomass and fossil fuels in the DH production by implementing heat pumps (HP), electric boilers, and heat storage systems, with a total expected investment of approx. €400-700 million.

Initially, up to 300 MW of HP's - mainly utilizing energy in seawater and wastewater – will be implemented through a series of HP systems. The HP's will displace some of the biomass currently used in the combined heat and power plants (CHP). In the long term, the HP's, together with the CHP's, will form the backbone of a diversified DH system with high flexibility and high price robustness.

Low temperatures are crucial to pave the way for the implementation of high effective and low-cost HP plants. Therefore, while working with the implementation of the HP's, HOFOR has also initiated a targeted effort among DH consumers to reduce the supply and return temperature within the next decade.

Furthermore, multiple large-scale electric boiler systems will be installed, along with heat storage systems. The electric boilers will partially replace fossil fuels during peak load periods and aid in regulating the power system.

The shift from the current system mainly consisting of a few large-scale power plants to establishing many medium-sized decentralized plants in the city leads to new multifaceted challenges and risks – such as handling the freezing of seawater or fouling of the HP's - taking the complete portfolio into consideration. To support the implementation of this complex electrification strategy, HOFOR has established an electrification program – addressing issues such as identifying locations, ensuring sufficient electricity supply, and portfolio risks.

Keywords: Electrification, electric boilers, heat storage, heat pumps, district heating, renewable energy integration, development, sector coupling

Meisam Sadi is a researcher at DTU, specializing in the design, modeling, and optimization of sustainable energy systems with expertise in district energy systems, heat pumps, thermal storage, renewables integration, and system analysis, with strong skills in thermal energy optimization.

Carbon dioxide-based district energy systems in heating and cooling applications

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The energy consumption in buildings accounts for more than one-third of energy-related greenhouse gas emissions in the EU. Therefore, ensuring an efficient and environmentally sound energy supply to residential and commercial buildings is important. In urban areas, district energy systems are a well-known and efficient method. Simultaneous supply of heating and cooling using one common system is suitable when consumers are located in a limited geographical area, as the demand can be balanced between the buildings. The system only requires one set of pipelines, which is beneficial when planning new energy networks in well-established urban areas, as the space within the ground can be limited due to existing infrastructure. Conventional district energy systems utilize water as the energy carrier. In 2010, using CO₂ as an energy carrier was proposed by Weber and Favrat [1]. Since then, the concept has been investigated to a limited extent in the literature. The CO₂ system utilizes the latent heat of vaporization and condensation for energy exchange as opposed to sensible heat in conventional water-based systems. This allows for smaller flow rates of the energy carrier and thereby reduces the pipe sizes, which occupy less space within the ground, resulting in reduced construction time and costs.

In this project, it is investigated whether the CO₂ system is suitable for a small cluster of heating and cooling consumers. Understanding the differences in operation mode is important for implementing a system with dynamic loads and multiple services. It was found that the system can provide economic benefits compared to conventional water systems when the system is dimensioned for the cooling load. Due to higher efficiency, the heat-only mode was found to consume less power than the cool-only mode. It remains to optimize the system and investigate the performance under simultaneous supply of heating and cooling, which is the focus of future work in the project.

Keywords: District energy system, carbon dioxide, energy carrier, system concept, performance evaluation, heating and cooling applications

Pauli Hiltunen is working as a postdoc-researcher in VTT. In his research, he is focusing in decarbonised district heating as a part of surrounding energy systems.

District heating providing flexibility for the North European electricity system

Pauli Hiltunen, VTT - Technical Research Centre of Finland; Miika Rämä, VTT - Technical Research Centre of Finland

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The increasing share of wind and solar in the power sector has led to increasingly volatile electricity prices in the Northern European power markets. Finland's pathway towards the 2035 carbon neutrality target has led to decommissioning of several fossil fuel-fired power plants. At the same time, fuel prices have risen, which has led to extremely high hourly electricity price peaks. On the other hand, high capacity of renewable power can lead to low and even negative prices. Electrified heat production and heat storages can provide flexibility to the power system by consuming electricity when it is cheap. For these reasons, the district heating systems in Finland will see a rapid expansion of the use of heat pumps and electric boilers during this decade.

In this study, the power system of 14 European countries was modelled using an open-source model (Backbone) to analyse the potential of heat storages, electrified heat supply and district heating customers' demand response on providing flexibility in volatile power markets. The study was conducted by developing scenarios with differing capacities of heat storages and demand response in the Finnish district heating systems, but a scenario, where the district heating sector of Sweden and Baltic countries, will see a similar expansion of electrified production, was considered as well.

The results show that electrified heat production coupled with heat storages can provide flexibility in the power system and reduce the curtailment of renewable power. District heating customers' demand response has similar but lower impact than the heat storages. Electrified heat production capacity in the neighbouring countries has an increasing impact on the electricity price in Finland, which increases the production costs of the Finnish district heating systems. Because of the cross-border power transmission, the electrification of district heating has an impact on entire modelled system.

Keywords: Power system, Power-to-heat, Heat storage, District heating, Renewable energy, Demand response

Rasmus Frost Lund has a background with an MSc in Sustainable energy planning and management from Aalborg University (2013), followed by a PhD within 4th generation DH (2017). Since then, he has been working as project manager on developing DH projects from an engineering consultancy.

200 MW air source heat pumps for district heating: Challenges in large-scale application

Rasmus Frost Lund, COWI

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In this study, the challenges of upscaling air source heat pumps (HP), for the supply of district heating (DH), are investigated. The aim is to establish 200 MW capacity and +85°C supply temperature. At present the largest known operating facility is 22 MW and 70°C, located in Silkeborg in Denmark.

Several theoretical challenges, related to technical, economic and environmental issues, may occur in the upscaling of this type of facility. These include spread and short circuit of cold air, HP reaction to temperature changes in the DH system and operation at +85°C supply temperature.

Also supply chain issues can occur, as all the contractors who built the existing operating systems as well as the component manufacturers may not have the capacity to deliver on this scale and technical complexity of projects. High supply temperature to DH poses a challenge with the traditional refrigerant for HPs because of high pressure. Other refrigerants that can supply +85°C are not developed for high capacities.

Some experience is already gained in the development and operation of smaller facilities. This experience can give important insights into the potential upscale, to assess the risks and develop mitigation strategies.

To collect this experience, all known facilities >6 MW air source heat pumps for DH supply are listed and owner, capacity, manufacturer, refrigerant and supply temperature are registered. An initial survey with the around five contractors, followed by an interview is conducted and their inputs, suggestions and experience is recorded. Similarly, interviews with the about 20 facility owners/operators are conducted to collect their inputs, which is also recorded.

The recorded experience is summarized and discussed in comparison with theoretical challenges and put in perspective of the upscale and the possible increase of existing

challenges. Finally, some key recommendations are drawn up based on the results and discussion.

Keywords: District heating, Heat pump, Electrification, Risk management,

Electrification of transport, heating and industry

Andra Blumberga's primary research interest is the socio-technical energy transition. She uses system dynamics modeling to study how the system's underlying structure generates dynamic behavior.

Unintended long-term consequences of short-term climate and energy policy decisions: the case of diffusion of electric vehicles

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Policymakers need analysis tools to address socio-technical energy transition. They allow quantitatively rigorous capture of the dynamics of co-evolution and the mutual interaction of different linked sectors based on knowledge from various disciplines. Such tools would provide the insights needed for robust policy decisions to remove bottlenecks that hamper a transition to sustainable energy systems. Various driving forces that work against climate policies, e.g. distrust in government, nationalism, ideological opposition to redistribution, social tension, income inequality, and energy affordability, exist. On the other hand, many drivers are favorable, e.g., expansion of new renewables, the shift from resource-intensive to dematerialized sectors, the urbanization.

In this study, we propose an approach to study the dynamics and feedback mechanisms of the energy transition to understand unintended long-term consequences of short-term climate policy decisions and their impact on the energy system, economy, environment, and society. The system dynamics model is developed to assess the impact of support policies for the diffusion of electric vehicles (EV) on the energy production, transport infrastructure, and social inequality. The case study is based on a previous study on EV diffusion in Norway. The simulation model includes modules of vehicles, energy production, transportation infrastructure, and public institutions and politics. They are interlinked in causal structure. Subsidies for EV purchase and exemption for tolling are applied as policies to enhance EV diffusion. In addition, the model provides insights into reduction of the total number of vehicles. Results show how these short-term policies feed on longer-term dynamics and impact energy production, power dynamics in politics, social inequality, and transportation infrastructure. The trade-offs between these factors and GHG emission reduction are challenging for policymakers from various ideologies.

Keywords: socio-technical transition, electric vehicles, social inequality

Antonia Golab is a PhD Candidate at TU Wien, Austria. Her research has been focusing on modeling at different spatial granularity levels and targeting spatially dependent interactions between the electricity system and the transport system.

Density and speed of public charging infrastructure rollout: Accelerating the electrification of the passenger car stock at the federal state level

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A focal point in the "Smart Mobility Strategy" published by the European Commission is the expansion of public charging infrastructure as a key driver for the electrification of the passenger vehicle stock. Quantified targets have been set for the coming years. In the scientific literature, the geographic allocation of charging stations and the short- and long-term expansion of public charging networks have been frequently studied. These studies typically emphasize high geographic resolution of street networks and traffic flows, while assuming an exogenously determined electrification pathway for passenger cars. Another strand of literature focuses on modeling the adoption of battery-electric vehicles (BEVs), based on detailed representations of consumer decision-making, as well as developments in costs and technical performance. The objective of this work is to bridge these two perspectives by modeling the interaction between charging infrastructure expansion strategies and vehicle adoption. This is done from the viewpoint of a policy-maker operating at the federal-state level, aiming for system-cost-optimal decision-making. We focus on two crucial aspects of public charging infrastructure expansion: network density and expansion speed. Additionally, we analyze income-dependent adoption behavior and cross-regional effects between subregions of a federal state. The case study is the Basque Autonomous Community. Preliminary results indicate that early increases in charging site density have a significant positive impact on BEV adoption, particularly among the middle-income population.

Keywords: public charging infrastructure, vehicle stock turnover, charging infrastructure expansion strategies, EU targets

Arven Sylva is a PhD fellow at the University of Geneva in the Energy Efficiency Group. His research focuses on assessing the impact of electrification through electric vehicles (EVs) and heat pumps (HPs) on future energy systems, with a particular focus on the role of flexibility options.

What is the interplay between smart charging, V2G and distributed charging infrastructure as flexibility options in the Swiss energy system?

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Sector-coupling between transport and power through electric vehicles (EVs) is a key strategy to decarbonise the transport sector. Without coordinated planning, the integration of EVs into electricity systems will burden the grids (e.g., congestion). However, EVs can provide flexibility for the energy system in various ways, in particular by smart charging (i.e., charging during periods of renewable production), bidirectional charging (vehicle-to-grid, V2G), and distributed charging (i.e., spatial-temporal flexibility by charging at various locations based on activities such as workplaces, commercial areas, and other sites). So far, comprehensive assessments of these flexibility options in energy system models are underrepresented. This study analyses the interplay among the abovementioned EV flexibility options from a social planner perspective. The focus is on capacity expansion, specifically for photovoltaics (PV) and (stationary) battery storage. To this end, we extend the open-source energy optimization model (GRIMSEL), which is characterised by high temporal resolution and a detailed representation of Switzerland's energy system.

According to our findings, each flexibility option provides different types of flexibility to the system. Smart charging leads to more PV capacity (+6%) and less battery storage (-19%). A distributed charging infrastructure leads to significantly lower overall capacity expansion (e.g., 66% less battery storage), while V2G acts as a peak-shaving measure while reducing the need for additional storage capacity. Moreover, flexibility options allow to reduce total electricity costs from 133 to 105 €/MWh. Self-consumption and self-sufficiency at the national level are also studied. These insights may be relevant for policymakers and energy utilities to design solutions adapted to their specific policy objectives.

Keywords: Energy system modelling, electrification, flexibility, electric vehicles, smart charging, spatial analysis, V2G, battery storage, PV

Delight is a PhD candidate at the Heat and Power Division of KTH Royal Institute of Technology's Energy technology department. He conducts research on the electrification of process heat for the decarbonization of hard-to-abate industrial sectors.

Techno-economic assessment of flexible electrification systems for heat decarbonization in hard-to-abate industries

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Process heating is responsible for approximately 50% of the energy used in the industrial sector [1], and due to its reliance on fossil fuel combustion, it contributes to about 18% of the world's annual CO₂ emissions [2]. To decarbonize this sector and meet up with EU goals of attaining climate neutrality by 2050, transitioning to clean, efficient, and flexible industrial heating technologies is essential. Technologies like induction and microwave heating have been recognized as potential solutions for electrifying industrial heat [3], and Thermal Energy Storage (TES) devices have also been identified as a promising means to improve energy efficiency and operational flexibility [4]. However, making a compelling case for adopting these technologies necessitates a comprehensive evaluation of the most effective methods for their integration, alongside a detailed assessment of their feasibility and impact on overall system performance. This study, therefore, aims to perform a techno-economic assessment of the incorporation of electrification technologies in high temperature hard-to-abate industries like the ceramics industry. The analysis will encompass an evaluation of the system's performance and viability when replaced with electrification technologies and would also include a study on enhancing flexibility and energy efficiency via the incorporation of regenerative gas-solid TES. Generally, this work seeks to benchmark the performance and viability of heat electrification technologies in industrial systems while exploring improved efficiency and flexibility options via the use of TES devices.

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Keywords: Electrification technologies, Energy Efficiency, Enhanced flexibility, Techno-economic assessment

Endeshaw Bekele is a PhD fellow in Sustainable Development and Climate Change at Sapienza University of Rome and IUSS Pavia, Italy. His research focuses on the modelling and optimisation of integrated renewable energy sources and the hydrogen supply chain within Hydrogen Valley concepts.

Optimal Strategies for a Zero-Emission Transport Sector in 100% Renewable Energy Cities

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The transportation sector is at the forefront of driving the adoption of clean fuels for a sustainable future. Achieving fully decarbonized transport systems within 100% renewable energy systems envisages a synergistic approach in planning the clean energy technologies and transport segments. The integration of renewable energy into transport sectors, particularly in terms of balancing supply and optimising energy storage systems, remains a critical challenge. The aim of this work is to analyse the optimal pathways for fully decarbonizing multimodal transport sectors by leveraging direct electrification and alternative fuels within zero-carbon energy systems. Four scenarios have been proposed considering distinct fuel deployment strategies in different transport segments such as light-duty, heavy-duty, trains, and ships. The port city of Taranto, Italy, has been selected as a case study to achieve complete decarbonisation within each transport segment by 2050. The hourly operation of the energy system per scenario has been simulated using EnergyPLAN software. Thereafter, per each scenario, the optimal configuration of energy conversion technologies and storage systems have been identified using a multi-objective optimisation framework implemented by means of the MATLAB Toolbox for EnergyPLAN. Moreover, a comprehensive techno-economic assessment has been carried out to evaluate the cost-effectiveness of each proposed strategy. This study also examines different e-fuel production pathways and identifies the potential role of biomass in supporting scalable electrofuel production and enhancing system flexibility. Furthermore, the different refueling and charging infrastructures required for each solution have been assessed. This study underscores the implication of sector coupling between renewable energy systems and the transport sector to facilitate the optimal deployment of clean fuels, thereby enabling deep decarbonization.

Keywords: Smart Energy Cities, Sustainable mobility, Energy Planning, Energy System Optimization, Sector coupling, Zero-carbon energy systems

Marko Stračević is a PhD student at the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb. His research focuses on long-term energy planning, primarily in the field of road transport electrification, alongside activities related to energy communities.

The Role of Electric Vehicles as Flexible Consumers in Energy Communities

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The integration of electric vehicles (EVs) into energy communities offers a significant opportunity to enhance self-consumption, increase renewable energy utilization, and strengthen local energy autonomy. By leveraging the flexibility of EV charging, energy communities can align energy demand with periods of excess renewable generation, reducing curtailment and improving local energy balance. This flexibility allows energy communities to reduce reliance on external energy sources and better utilize local renewable production. Energy communities could serve as a platform for incentivizing optimal EV charging behavior, encouraging users to shift charging to periods of renewable energy surplus. Mechanisms such as dynamic pricing and community-based incentives promote more efficient energy use, positioning EVs as active participants rather than passive consumers. In addition to flexible consumption, EVs can support community energy needs through vehicle-to-community (V2C) interactions, where stored energy from EV batteries is used to meet community energy needs during periods of low renewable production. This flexibility enhances the community's ability to maintain self-sufficiency and balance local energy supply and demand. The optimization of EV integration into energy communities will be performed using the H2RES modeling tool. By aligning EV consumption with local production and enabling support for community energy needs through V2C interactions, energy communities can achieve higher levels of self-sufficiency and promote the transition to a decentralized, community-driven energy future. This paper outlines strategies to optimize EV integration and highlights key measures to maximize the role of EVs as flexible consumers and storage assets within energy communities.

Keywords: Electric vehicles, energy communities, vehicle-to-community (V2C), self-consumption, local energy balancing

Dr.-Ing. Michael Krüger is a mechanical engineer and has been part of the DLR since 2008. His focus is on developing high-temperature heat storage systems, including CAES and Carnot batteries. He leads projects on thermal design and system simulation of innovative heat storage technologies.

Systematic Evaluation of Brayton Battery Concepts for Multi-Purpose Energy Applications

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Brayton batteries offer substantial potential for enhancing energy storage efficiency. However, there remains a significant gap between theoretical and practically achievable performance. These differences are mainly due to turbomachinery limitations: current compressor discharge temperatures are restricted to 400–500 °C, and isentropic efficiencies for large-scale units range between 80–90 %, leading to considerable heat losses. As this waste heat cannot be fully utilized for electricity generation alone, optimizing system efficiency requires not only appropriate topology and parameter selection but also broadening functionality beyond pure electricity production.

This study systematically analyzed over 200,000 Brayton battery configurations using Epsilon Professional®. The investigation covered four operational modes: electricity-only; combined electricity and heat; combined electricity and cooling; and combined electricity, heat, and cooling - each considered both with and without waste heat utilization.

Electric-only efficiencies ranged from 20 % to 50 %, with better performance at 625 °C compared to 450 °C. Adding heat or cooling recovery improved overall efficiency but reduced electric output. Simultaneous generation of electricity, heat, and cooling was not feasible within the studied framework.

The most promising configurations were predominantly air-based systems with or without charging line recuperators and various heat exchanger placements. These topologies will be further explored through dynamic simulations focused on thermal energy storage. A key finding is that effective heat exchanger integration is critical. Only specific combinations of parameters and layouts proved viable.

This work stands out due to its scale and systematic methodology, enabling better identification of optimal Brayton battery solutions and highlighting their potential for flexible, efficient energy systems.

Keywords: Brayton battery; Carnot Battery; CHP; CCHP

Energy savings in the electricity sector, buildings, transport and industry

Arttu Häkkinen is a Data Scientist at Danfoss Leanheat and a PhD Fellow at LUT University. His industrial and academic research efforts focus on improving the energy efficiency of Nordic central heating systems via Model Predictive Control and Bayesian methods.

Bayesian LSTM for indoor temperature modeling

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Improving energy efficiency of building heating systems is essential for reducing global energy consumption and greenhouse gas emissions. Traditional control methods in buildings rely on static heating curves based solely on outdoor temperature measurements, neglecting system state and free heat sources like solar gain. Model predictive control (MPC) not only addresses these limitations but further optimizes heating control by incorporating weather forecasts and system state predictions. However, current industrial MPC solutions often use simplified physics-inspired models, which compromise accuracy for interpretability. While purely data-driven models offer better predictive performance, they face challenges like overfitting and lack of transparency.

To bridge this gap, we propose a Bayesian Long Short-Term Memory (LSTM) architecture for indoor temperature modeling. Our experiments across 100 real-world buildings demonstrate that the Bayesian LSTM outperforms an industrial physics-based model in predictive accuracy, enabling potential for improved energy efficiency and thermal comfort if deployed in heating MPC solutions. Over deterministic black-box approaches, the Bayesian framework provides additional advantages by improving generalization ability and allowing interpretation of predictions via uncertainty quantification. This work advances data-driven heating control by balancing predictive performance with the transparency and reliability required for real-world heating MPC applications.

Keywords: Model predictive control, Central heating systems, Variational inference, State-space models, Bayesian neural networks, Long short-term memory, Uncertainty quantification, Time series modeling

Astrid Leitner is currently a senior researcher in the area of Automation and Control at BEST - Bioenergy and Sustainable Technologies GmbH. Her research focus lies on optimization-based energy management systems in single-family homes.

Real-World Implementation of Residential Energy Management Systems: Balancing Thermal and Electrical Energy

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Since there are still many private households that do not have batteries, sector-coupling solutions for heat and electricity have come into focus that utilize already existing or easy-to-install components, for example heating rods feeding into a thermal buffer storage. Although supervisory control systems for both the heat and the electricity sector exist, the coupling between these sectors within one system in a real-world application is still challenging. The main objective of this work is to extend an existing thermal energy-based optimization framework to be able to use surplus power from photovoltaics within the multi-energy system.

The optimization framework computes on-line an optimal schedule for the controllable components within the multi-energy system. While, e.g., a biomass boiler has large time constants, which led to a sampling time of 15 minutes for the supervisory control, surplus power usage demands a much faster reaction. This challenge has been tackled in a first step by using a faster low-level controller for surplus power usage, which is considered by an estimation. In a second step, the low-level surplus power usage is directly influenced by the supervisory control, which allows for a reasonable combination of thermal and electrical energy.

An implementation of this framework is used in a software product that by now successfully runs in more than 200 single-family homes, 40 of which already use the first step of surplus power usage. Results show that this already improves the energy efficiency within the building, while new challenges arise with the tests of the second step.

We will present the framework, its extensions towards the electricity sector and the challenges and experiences from the practical validation.

Acknowledgment: The research leading to these results has received funding from the Austrian funding instruments COMET Programme under Grant No. 892426 and the Basisprogramm under Grant Nos. FO999901468 and FO999913247.

Keywords: renewable energy systems, sector coupling, power-to-heat, supervisory control, energy management systems, buildings, smart energy systems, electricity, heat

Blanca Luz Foliaco Romero, PhD in Mechanical Engineering, is a researcher at the University of Southern Denmark. She specializes in dynamic modeling and HVAC systems, with industry experience in refrigeration and the design, installation, and commissioning of HVAC systems.

Comparative Analysis of Transcritical CO₂ and R410 Heat Pumps for Electrical Ferries: Simulation and Control Optimization

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The objective of this study is to evaluate the feasibility of replacing R410A heat pumps with transcritical CO₂ (R744) heat pumps for electrical ferries. A reversible heat pump system operating in both heating and cooling modes was simulated using Dymola software and the TIL suite. Initial simulations were conducted under nominal conditions with R410, followed by simulations with CO₂ while maintaining similar operational parameters. A comprehensive sensitivity analysis was performed to optimize control strategies for the CO₂ heat pump, aiming to achieve comparable or superior Coefficient of Performance (COP). The results indicate that the CO₂ heat pump can potentially offer enhanced energy efficiency and environmental benefits. This study provides valuable insights into the dynamic performance and control optimization of CO₂ heat pumps, supporting their application in sustainable maritime transportation.

Keywords: Transcritical CO₂

Heat Pump

Electrical Ferries

Energy Efficiency

The presenter is a research associate and PhD student in the field of energy system analysis with focus on renewable heating networks, network simulation and economical assessment of heating supply systems. His special interest is the investigation of anergy/5GDHC networks.

5GDHC networks in urban settlements - Barriers and technological prerequisites for applications in existing buildings

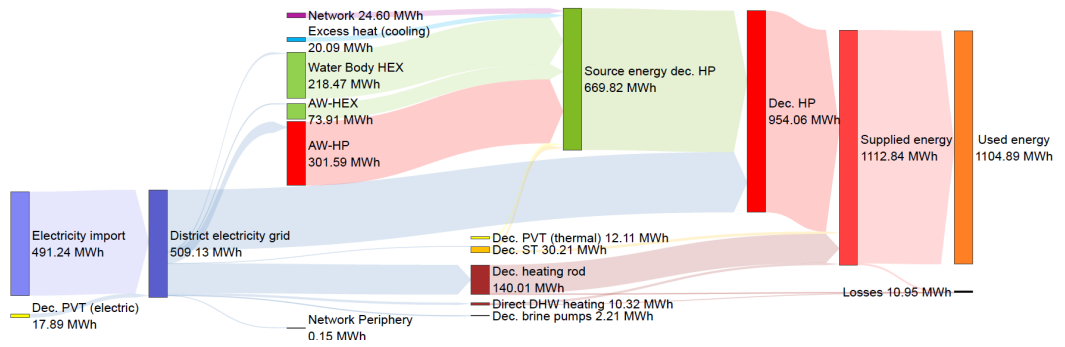
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District heating networks are seen and promoted as one of the main pillars for decarbonisation of the heating sector. 5th generation district heating and cooling (5GDHC) networks are mainly used in new development areas and in conjunction with geothermal energy as primary heat source. The first part of this work presents barriers and necessary adjustments for the transfer of known concepts in 5GDHC networks to existing urban settlements. Identified barriers preventing such direct transfer of technologies stem from legal restrictions and from technical difficulties for the supply structure. To minimise the use of water-polluting substances in extensive network structures, pure water can be used as heat carrier fluid, but a frost-free operation has to be guaranteed at all load points. High heat demand densities and space requirements for renewable heat sources in densely populated districts add to conflicts with existing infrastructure. In the second part of the work, the concept of 5GDHC networks is exemplified for an existing urban district in a town in Mittelhessen, Germany. The district is modelled in the open-source environment OpenModelica. Borehole heat exchanger fields and surface water resources are juxtaposed as the two main suppliers of environmental heat to the network. Both system variations are complemented with decentralised sources of excess heat, ambient air heat exchangers and roof-mounted solarthermal and PVT-systems on selected buildings. It is shown that the incorporation of peak-load heat suppliers such as centralised heat pumps is essential to ensure a frost-free operation for a common distribution of heating demands in existing urban areas. Achievable operation time of water-water and air-water heat exchangers as base load suppliers are limited, resulting in respective contributions of 33% and 11% of the total source heat supplied to the network. Thermal gains from the network account for 4% of the source heat in the presented setup.

Keywords: 5GDHC, district heating and cooling, OpenModelica, urban energy system

Energy distribution of heat supply system (district level)



Ece Özer is a PhD student at TU Wien and a researcher at the Energy Economics Group. Her work focuses on energy modeling and building stock analysis, using bi-level optimization to design subsidy schemes for staged retrofits that balance affordability and decarbonization.

Bi-Level Optimization for Designing Subsidy Schemes for Staged Energy Retrofits in Residential Buildings

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Ece Özer (presenter)

Decarbonizing residential buildings is essential to achieving climate neutrality, yet high upfront costs and unequal access to subsidies hinder the adoption of energy-efficient renovations. Staged retrofits—stepwise upgrades over time—offer a more financially feasible path for households, especially those with limited resources. However, existing approaches often fail to reconcile emission reduction goals with affordability and fairness across different income groups.

This study presents a bi-level optimization framework to design subsidy schemes that reflect the dual objectives of policymakers and homeowners. The upper-level model represents policymaker goals of minimizing cumulative CO₂ emissions while ensuring equitable subsidy distribution, in line with the dynamic performance targets set out in the recast Energy Performance of Buildings Directive (2024/1275). The lower-level model captures household decisions to minimize total renovation costs over time, accounting for individual budget constraints and available financial support.

The framework differentiates between single- and multi-family buildings and stratifies households by income, enabling a more nuanced analysis of investment behavior. Staged renovation options are evaluated over a long-term horizon (until 2070), using mixed-integer linear programming to ensure scalability and computational feasibility.

Results will provide insights on emissions savings, cost-effectiveness of staged support schemes, and distributional outcomes. The findings will support the development of inclusive, efficient policies that promote equitable retrofit adoption and sustained decarbonization in the residential sector.

Keywords: building sector, building sector modeling, EPBD, optimization, bi-level optimization

Francesco Ghionda is a researcher at the Fondazione Bruno Kessler in Italy and has a master's degree in Mechanical Engineering. He is mainly involved in Horizon Europe projects, with a focus on modeling, simulation, and optimization of energy systems to support energy efficiency and decarbonization.

From Waste to Worth: Integrating a Double-Effect Heat Pump in a Pharmaceutical Industry for Process Cooling & District Heating

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Improving the efficient coupling of energy demands is vital for industrial decarbonization, flexibility, and cost savings. This work is part of the Horizon Europe FLEXIndustries project, founded on a holistic strategy to deploy energy efficiency and flexibility solutions across six industrial sectors. The Italian demonstrator is SUANFARMA Italia, a pharmaceutical company based in Rovereto (TN, Italy). The industrial facility is characterized by energy-intensive production processes and diverse demands for energy services and utilities. Its multi-vector energy system and proximity to Rovereto's district heating network (operated by Novareti), make it an ideal site to showcase the potential of collaboration between companies pursuing decarbonization. Specifically, on one side, the pharmaceutical site's need for process cooling (10 °C) and on the other side the district heating's need for hot water (90°C) aligns seamlessly with the deployment of a double effect (MW-scale) high-temperature heat pump for combined heating and cooling production. Developed by HiRef, within the Italian cluster coordinated by Fondazione Bruno Kessler, the heat pump delivers 0.99 MWth of cooling at 10 °C and 1.25 MWth of useful heat at 90 °C. The manufacturer selected R515B, thanks to its suitability in industrial applications with strict fire safety requirements. Compliant with F-gas regulations, R515B has a low GWP of 239 and is classified as A1 (non-flammable). The heat pump will supply 3.8 GWh/year to the DHN and 3 GWh/year of useful cooling to the industrial site. This work presents a roadmap for deploying a double-effect heat pump in an industrial environment. By sharing insights from design, dynamic modelling, integration, commissioning, and real-world monitoring, it highlights key technical, regulatory, and operational challenges and the solutions adopted. It offers lessons to support similar industrial applications, promoting energy efficiency and sector coupling for decarbonization.

Keywords: pharmaceutical industry, heat pump, waste heat recovery, district heating, sector coupling, energy efficiency, energy system integration, flexibility

She is a second-year PhD student working on "Flexible Energy Management for Buildings and District". Her research interests include modeling and operation of integrated energy systems, model predictive control, hierarchical control, and their applications.

Optimizing the operation of an integrated energy system for a small district using a two-level control strategy

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Integrated energy systems (IES) that combine renewable energy sources, energy storage, and flexible loads offer significant potential for improving energy efficiency and reducing operational costs in urban districts. However, effectively managing these systems under uncertain conditions such as fluctuating electricity prices and variable renewable generation remains a key challenge. This study examines a small residential district with rooftop photovoltaic (PV) panels and batteries in each building and a centralized heat pump (HP) with thermal energy storage (TES) for space heating. To unlock the flexibility of this integrated energy system, leverage dynamic electricity prices and demand response (DR), a bi-level operation strategy is developed, combining supervisory Model Predictive Control (MPC) with local PI controllers. The upper-level MPC performs day-ahead scheduling based on forecasts of weather, PV generation, and heat demand, optimizing HP, TES, and battery operations to minimize costs while meeting system constraints. The lower-level PI controllers ensure real-time alignment with this schedule by coordinating heating load dispatch in individual buildings. This approach enables both power-to-heat and power-to-power flexibility, allowing the system to shift energy usage and enhance PV self-consumption. The results of a two-week simulation in winter for a small district of 19 residential buildings in Denmark demonstrate that the proposed strategy can reduce total energy costs by up to 27% compared to a rule-based control baseline while maintaining indoor thermal comfort. Scenario analyses evaluate different combinations of control strategies and system setups to determine the most effective and robust operational scheme. Overall, the proposed framework provides a practical and scalable energy management framework that enhances the resilience, efficiency, and sustainability of urban energy systems, supporting the transition to low-carbon energy communities.

Keywords: Heat pump, Photovoltaic-battery (PVB) system, Thermal energy storage, Operation strategies, Model predictive control (MPC), Energy flexibility, Community integrated energy system (CIES)

The author's field of work includes the energy system analysis of buildings and neighborhoods. This involves developing bottom-up solutions to simulate components, buildings, and neighborhoods in as much detail as possible, yet with minimal computational effort.

Renovation paths of single-family-houses and their impact on the heat transition in German districts

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Energy-efficient renovation is key for Germany's energy transition, especially to reduce greenhouse gas emissions from buildings. Heat generators are often oversized, as they are designed for peak loads, which raises energy use and emissions. This study analyzes renovation pathways for single-family houses using a 1958–1968 neighborhood as an example.

A three-stage concept is examined: (1) full renovation of the building envelope, (2) adding photovoltaic (PV) systems with battery storage, and (3) replacing gas boilers with air/water heat pumps and buffer storage. Renovating the envelope significantly lowers heating demand. Installing heat pumps before envelope upgrades risks oversizing and inefficient operation. Anticipating future renovations helps optimize system sizing, though heat pumps designed for future loads may underperform in cold periods.

Hybrid systems — combining heat pumps and existing gas boilers — offer a flexible interim solution. PV integration improves self-consumption, reduces grid dependency, and enables load shifting with dynamic electricity tariffs.

Renovation also changes the building's external appearance, influencing the neighborhood. District-level analysis can reveal preferences for renovation strategies that remain hidden at single-building level. The benefits of one building's renovation can vary for its surroundings.

The study emphasizes that considering the interaction of renovation measures helps avoid oversizing, high costs, and inefficient energy use on both building and district scales. Hybrid systems could support the shift to fully electric heating while improving cost-effectiveness. Coordinated renovation sequences are especially important in neighborhoods with infrastructure limits. Future research should examine the cost-benefit ratio of major measures like window or facade upgrades in more detail, especially regarding community-wide impact.

Keywords: District, Retrofitting, Simulation, Single-Family-Houses, Heat Transition, Energy-efficiency renovation, energy system analysis

Jaap Neven is a Ph.D. researcher in the Thermal Systems Simulation research group at KU Leuven and in the Algorithms, Models, and Optimization group at Energyville/VITO. His work focuses on MPC in buildings, specifically modeling and state observation requirements for effective MPC performance.

Evaluating Model Predictive Control Performance with Various Combinations of Building RC-Models and State Observers

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Model Predictive Control (MPC) can reduce energy use while enhancing building users' thermal comfort by solving an optimization problem, which minimizes a specific objective using a building controller model and weather forecasts (feedforward action). However, its effectiveness depends on model accuracy. Thanks to the MPC feedback action, controller model states are updated by measurements. However, only a few states can be directly measured, making a state observer essential. A state observer estimates the unmeasured states by correlating them with discrepancies between real measurements and controller model states. Consequently, control action optimality depends on both model accuracy and the choice of state observer.

Resistance-capacitance (RC) models can represent building dynamics, where different levels of detail lead to a range of model orders. However, it is not known which combinations of controller RC-models and state observers lead to good MPC performance. This work performs a simulation-based comparison using the BOPTTEST test case BESTEST Hydronic Heat Pump.

Four RC-models are developed, ranging from first to fourth order, each fitted using two system identification methods: conventional least-squares, or enhanced least-squares by tracking the first derivative of the indoor temperature profile. These 8 controller models are combined with a time-varying Kalman filter or a Moving Horizon Estimator to formulate an MPC, and compared to an MPC without a state observer. All MPC formulations are benchmarked against a rule-based controller acting on the same emulator in BOPTTEST and using the same performance indicators: thermal discomfort and energy use).

System identification results show that tracking derivatives improves and facilitates the challenging parameter estimation process. Moreover, MPC benchmarking elucidates the necessity of both a good derivative-tracking controller model and a dedicated state observer to guarantee good MPC performance.

Keywords: Model Predictive Control, State observer, Building energy management, Optimal control, energy efficiency

Karl Walther's research focuses on control of building energy systems and districts, performance simulation for model-based building and HVAC design, and digital twins. He holds a PhD from the University of Wuppertal (DE) and is currently a postdoctoral researcher in The Sysi team at KU Leuven (BE).

The advantages of integrated versus non-integrated optimal control for district energy systems and buildings: Insights from four case studies

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District heating networks and heat pumps are the key technologies for a decarbonized and electrified heating supply for the built environment. While district heating networks unlock energy flexibility by coupling intermittent renewable energy sources with thermal storage, network capacity, and the thermal building mass, heat pumps offer further flexibility options by coupling thermal networks to the electricity grid. Efficient use of flexibility requires an advanced control strategy, such as optimal control, however, optimal control strategies today are either focusing on the network level (using simplified building load curves) or on the building level (using predefined network supply temperatures).

This work investigates the benefits of increased efficiency and flexibility of an integrated optimal control strategy for district energy systems and building-side systems (storage tanks, floor heating etc.) over a decentralized control strategy. To demonstrate the differences both approaches are simulated and analyzed for four small-scale district energy systems: (1) a micro energy community of 3 buildings focuses on the interaction of buildings with thermal and electric networks through heat pumps and batteries, (2 and 3) two 4th generation district heating systems of 12-15 buildings with different supply concepts show the interaction of heating networks with the building mass and thermal storage, and (4) a 5th generation district heating and cooling system connects different building types (3 residential and 3 office buildings) with different renovation levels.

The optimizations use detailed physics-based Modelica models and the non-linear optimal control tool TACO. Preliminary results show that the integrated controller significantly increases the overall system performance by more efficiently utilizing the available flexibility in the district energy system, resulting in lower energy use for equivalent thermal comfort, and lower controller tuning effort.

Keywords: Integrated optimal control, hybrid district energy system, 4GDH, 5GDHC, micro energy community

Lars Hellemo has long experience with modelling and analyses of energy systems and value chains. He has a special interest in combining different modelling techniques and has worked on optimization tools to combine short-term and long-term uncertainty/variations (e.g. production, prices or demand).

Striving for realism in analyses of building retrofit potential for the green energy system transition with agent-based modelling

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Analyses of the role of implementing energy efficiency measures for building mass upgrades in Norway suggest that there is a large extent of cost-efficient measures that can and should be implemented and would contribute to lowering the overall energy demand. Despite the available potential, upgrades are observed to be performed at considerably lower rates than cost-effective rates in practice. When including energy efficiency measures as investment decisions, results from energy systems models may thus be overly optimistic in suggesting that all cost-efficient measures will be implemented.

We attempt to improve the realism of estimates of the realizable potential of building upgrades for Norwegian households based on existing behavioral research, where humans are not purely rational decision-makers, but rather act according to their values, motivations, barriers and mental shortcomings. The behavioral decision-making is modeled with an agent-based model (ABM) that incorporates both psychological factors of individual households as well as setting limits on how much agents can spend on upgrading the energy standard of their residence by different measures (insulation, changing windows/doors etc).

In simulations, the households perform retrofits more gradually than cost-driven forecasts, consistent with survey results. The results from simulating different hypothetical policies to stimulate household retrofits suggest that households are sensitive to economic subsidies, and this can indeed increase the realized potential for energy efficiency in households. We combine the results from the ABM with IFE-TIMES-Norway to provide more realistic estimates of the savings achievable on a national scale through economic policies targeting Norwegian households.

Keywords: agent-based modelling, energy efficiency, TIMES, energy behaviour

Leif Holm Tambjerg is the product manager of energyPRO developed by EMD International. energyPRO is a software for modelling, analyzing, and optimizing complex energy systems. Through his work with energyPRO both in developing and using the tool in various national and international projects, he has detailed knowledge energy systems modelling.

Renewable and Affordable Industrial Process Heat supplied from District Heating

Anders N. Andersen, Linn Laurberg Jensen, Leif Holm Tambjerg, EMD International A/S

Leif Holm Tambjerg (presenter)

The Danish Energy Technology Development and Demonstration Programme (EUDP) has financed an ongoing development project about Renewable and Affordable Industrial Process Heat supplied from District Heating. The project is managed by the consultancy company Artelia, EMD International A/S, Danish Board of District Heating and Energy Cluster Denmark. The Production Industry (PI) sector and District Heating (DH) sector both play an important role in reducing Danish CO₂ emissions, and a rapid transition is crucial to meet the goals of the Danish climate law of reducing CO₂ emissions with 70 % by 2030 and reaching climate neutrality by 2045. A shift to providing process heating from DH will lessen the need for the alternative industrial decarbonisation measure – as e.g. electrification, which will reduce the increasing loading of the electricity grid caused by a general electrification of heating, transportation, PtX and more.

The process heat sector requests new and CO₂-neutral energy sources, and CO₂-neutral heat supplied through the DH infrastructure is an attractive - but largely unexploited and unknown – resource. Combinations of DH with local high-temperature heat pumps and electrical boilers will enable process energy solutions utilising DH-based CO₂ free energy sources such as:

- Deep geothermal heat
- Excess heat from other industries
- Excess heat from PtX facilities
- Excess heat from datacentres

A key in this project is the analyses of a variety of cases including both different types of industrial processes and different types of DH systems is analysed, in total 11 cases from Denmark and Germany, amongst others Orkla, Kohberg Bakery Group and nearby DH.

In the project is shown that increasing the heat load of DH companies creates opportunities for these to optimise production both due to scale effects and temporal load characteristics, as well as new opportunities for connecting new consumers to DH.

Keywords: Industrial Process Heat supplied from District Heating,

Professor Lieve Helsen leads the Thermal Systems Simulation research group (www.sysi.be) at KU Leuven. She is member of the Royal Flemish Academy of Belgium for Science and the Arts, the Board of Directors of the Flemish Organization Sustainable Energy, AcademiaNet and co-founder of Builtwins.

A system of systems approach to decarbonize heating and cooling in the built environment

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Creating a comfortable and healthy indoor climate in a carbon-neutral society is part of the decarbonization challenge we face. Cost-effective decarbonization requires a balanced approach, where heat and cold demand reduction is combined with decarbonization measures at the supply side. A sustainable energy transition is all-inclusive, so we need to find the optimal balance in interaction with other sectors.

For the built environment, electrification is seen as the way to go (given the electricity is fossil-free), either as local individual or centralized collective heat pumps, complemented by the efficient use of residual and geothermal heat, thereby increasing the share of R2ES (residual and renewable energy sources). When heat pumps are installed on a large scale, electricity demand will grow, while the share of variable R2ES in the electricity generation system will also be steadily increasing. Both require additional grid expansion and demand flexibility.

On the demand side, flexibility can be offered by building thermal mass, district heating networks, heat pumps and active storage. To exploit this flexibility, an effective system integrator is needed that co-optimizes the needs of building occupants and the energy system. This smart system integrator needs to know the system's behaviour (and its disturbances) to be able to anticipate demand and supply based on forecasts and to automatically optimize an objective. This is exactly what model predictive control (MPC) does. This presentation shows multiple use cases where white-box MPC is used as the smart system integrator, unlocking the full system flexibility. The strength of system integration is shown for (1) a real-life fully renewable small-scale 4th generation thermal network in a heritage context, (2) a small-scale mixed-use neutral-temperature thermal network and (3) a multi-energy vector tiny cluster. The benefits in both operation and sizing are illustrated.

Keywords: system integration, model predictive control, collective heating and cooling, sector coupling, decarbonization, flexibility

Lukas Kranzl works as a senior scientist in the Energy Economics Group at TU Wien and leads a research team on heating and cooling in integrated energy systems. He has more than 25 years of experience in analysing future perspectives for sustainable energy systems.

Implementing the EPBD: the impact of policy settings on energy savings and heating system mix

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The EPBD (2024/1275) foresees new policy instruments such as Minimum Energy Performance Standards (MEPS) for non-residential buildings and trajectories for progressive building renovation in residential buildings. Both will affect the roadmaps for building renovation to be outlined in the national building renovation plans. Although the targets are defined, Member States (MS) have some degree of freedom in the implementation.

Following research question guides the analyses in this paper: How do different policy choices to implement MEPS in non-residential buildings and the trajectories for progressive building renovation in residential buildings affect the overall achievement of targets in the national building renovation plan?

We adapt the building stock model Invert by updating the building stock data, cost database and policy settings according to Art 9 EPBD provisions. A focus is put on the definition of MEPS-thresholds for non-residential buildings and the identification of worst performance buildings (WPB) for the residential sector. Then, we perform a scenario analysis for selected MS by modifying different policy settings and testing to which extent the assumed policies achieve targets, in particular: (1) primary energy savings according to Art 9, (2) consistency with Zero-Emission-Building standards, (3) renewable energy share target according to the RED. As result indicators we show final and primary energy demand by energy carrier, energy savings in the whole building stock as well as in WPBs and economic indicators.

Our results show that the targets for the trajectories of progressive building renovation are difficult to achieve without regulatory measures. The reduction of primary energy factors for electricity and district heating delivers a certain contribution to the target achievement, but do not replace stringent and ambitious policies of improving buildings' energy performance.

Keywords: Buildings, energy savings, policies, Energy performance of buildings directive, modelling

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Improving system efficiency using low temperature and latent waste heat

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The targets of environmental protection, efficiency improvement and decarbonisation can be achieved simultaneously and are supported by current legal regulations in the EU. Recovering energy in the downstream stages of production is one of the key methods to achieving it. However, with the current configuration of the generating units across all industry sectors, the amount of heat released to the environment during the final phase of the production stages is significant. This research assesses the potential for energy recovery in low-temperature waste and latent heat applications in the range of 30-140C in various industries such as agriculture, papermaking, forestry ceramics and industrial boilers in general. The research conducts a comprehensive review of the waste heat recovery technologies and highlights their limitations including investment costs, integration complexities and corrosion issues. As a result an innovative countercurrent gas-to-gas plate heat exchangers thermally designed with the use of HTRI software was proposed. The potential benefits of using low temperature waste heat, such as CO₂ emission reduction and financial savings, were calculated. The study further explores the application of plate heat exchangers, emphasizing their advantages in compactness, scalability, and anticorrosion treatments compared to traditional tube heat exchangers, particularly in handling condensation from cooled exhaust gases. Results show significant improvements in energy efficiency, economic and environmental benefits, contributing to effective decarbonisation strategies. The proposed heat exchanger solution was evaluated using industrial data from a 6 MW natural gas boiler.

Keywords: Low Temperature Waste Heat Recovery, Decarbonisation, Energy Efficiency, Energy Transition, Condensation, Latent Heat

Rachel Parziale is a scientist at the Institut für Solarenergieforschung Hameln (ISFH). They earned their bachelor's in the USA before continuing their physics education in Germany. Their work includes simulating energy systems, ranging from the entire Germany energy system down to individual homes.

Monitoring the heat and electricity requirements in 4 northern German heat pump districts

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The heating sector plays a key role in energy systems with large potential for decarbonization and coupling with the electricity sector. In particular, heat pumps are a key technology in this area. Although there is literature on the potential of heat pumps and their usage is increasing, there are still issues that can emerge with their real performance and more analyses that can be performed. These assessments can be done when heat pump monitoring is carried out, allowing their actual performance to be analyzed. This work looks at residential use heat pumps. Using an open metering system, characteristics like temperature losses, energy requirements, and performance can be monitored. The results presented focus on heat pump usage in four residential districts with new built and existing single-/two-family homes as well as multifamily homes. Currently, monitoring systems are installed and running in 28 houses with more planned. Monitoring data is continual and can be viewed and analyzed in real time on a newly developed dashboard. First results of this monitoring and analysis are already available. In particular, for countries in the temperate zone such as Germany it is of interest to look at the correlation of heat pump electrical load per day and daily outdoor temperature. Temperature-dependent heating requirements are a major challenge for the future energy system, which will be supplied almost exclusively with renewable electricity.. Especially in Germany, where there are currently hardly any electricity-powered heating systems on the market, this link is lacking in the literature. Our study will provide real world practical data on this issue.

Keywords: Measurement data, heat pumps, energy consumption, heat requirements

Project leader at the Institute for Solar Energy Research Hameln (ISFH). He has been researching energy monitoring in residential buildings for five years, focusing on optimized operation of low-energy timber-frame houses.

Optimizing residential energy systems in low-energy houses in timber-frame construction using Smart EMS for dynamic electricity pricing

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The transition to renewable and efficient energy systems in residential buildings requires innovative management strategies. In this study, we examine newly built, low-energy single-family houses in timber frame construction equipped with photovoltaics (PV), battery storage, an electric vehicle charging point, and either infrared panel heaters or a heat pump for heating. Comprehensive energy monitoring captures electricity consumption at all key components, alongside room temperature and occupancy data.

We couple validated simulation models using TRNSYS and Python with an intelligent energy management system (EMS), enabling optimization of three interconnected optimization targets: minimum operational cost, local CO₂-equivalent emissions, and total energy consumption. The study specifically explores the impact of optimizing for each of these targets individually and the trade-offs involved. Additionally, we analyze variations due to heating technology choice and investigate how battery and buffer storage capacities influence system performance with and without the EMS.

A particular emphasis lies on the integration and effectiveness of considering dynamic electricity pricing and dynamic grid fees that are available in many countries over Europe but represent a new option in the German electricity market. Results demonstrate significant cost-saving potentials when employing smart EMS strategies in combination with dynamic tariffs. Optimization outcomes vary depending on the selected target, highlighting possible trade-offs despite inherent interdependencies. Dynamic electricity pricing proves highly advantageous for cost optimization but requires careful management to ensure minimal trade-offs regarding emissions and total energy consumption.

Our findings underscore the value of smart EMS in presence of dynamic pricing mechanisms in driving residential buildings toward increased flexibility, efficiency, and lower cost within integrated smart energy systems.

Keywords: Smart energy systems, energy management, photovoltaics, battery storage, electric vehicles, TRNSYS simulation, dynamic pricing, CO₂ emissions, heat pump, infrared heating, optimization trade-offs, EMS

Valentin Kaisermayer is currently a Senior Researcher in the area of Automation and Control at BEST - Bioenergy and Sustainable Technologies GmbH. His research focus lies on optimization-based energy management systems.

Smart System Integration of Waste Heat Recovery, Heat Pumps and PV to Unlock the Energy Potential of Thermal Baths

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Thermal baths typically exhibit high energy demands, yet they also offer substantial potential for waste heat recovery. This study presents an innovative approach to harnessing this untapped energy by integrating compression heat pumps, thermal energy storage systems, and photovoltaic (PV) into a smart system. The goal is to maximize the use of waste heat while minimizing reliance on external energy supplies and fossil fuels. Managing such a complex energy system requires advanced control strategies. To address this, we propose a comprehensive optimization-based Energy Management System (EMS). The EMS dynamically coordinates energy flows to balance renewable energy generation with real-time thermal demand. To ensure computational efficiency, our modelling approach discretizes variable-temperature mass flows into streams at constant temperatures, enabling the application of Mixed-Integer Linear Programming (MILP) and avoiding the challenges of nonlinear optimization. For instance, allowing for more general heat pump models with detailed, temperature dependent COP maps.

The EMS leverages predictive algorithms and operational data to minimize energy costs and greenhouse gas emissions, all while maintaining thermal comfort and operational reliability. We will present simulation results from a case study of a thermal bath in Austria, which demonstrate significant reductions in both energy costs and emissions. These results form the basis for planned infrastructure investments and the real-world implementation of the EMS. This project illustrates how advanced energy system design and control can enhance sustainability in energy-intensive sectors, offering a replicable model for broader application.

Acknowledgment: The research leading to these results has received funding from the Climate and Energy Fund under Grant No. 894630 and COMET Programmes under Grant No. 869341.

Keywords: energy management system, smart control, electrification of industry

Xin is a PhD researcher focused on energy efficiency in industrial processes. Their work explores waste heat recovery and renewable integration using mathematical programming, aiming to reduce emissions and support sustainable energy transitions.

Cost-Effective Retrofit of Heat Exchanger Networks in Dairy Industry: Integrating CIP Scheduling and Multiple Utility Sources

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Retrofit analysis of heat exchange networks (HEN) is commonly carried out to improve energy efficiency and reduce operating costs. This work presents a structured retrofit approach that not only optimizes HEN configuration but also incorporates cleaning-in-place (CIP) scheduling and the use of multiple utility sources available from different sections of a dairy process plant.

The main objective is to minimize the total annualized cost (TAC) by enhancing energy recovery and operational planning. The proposed procedure is divided into two stages: a diagnosis stage and an optimization stage. In the diagnosis stage, candidate topology modifications are identified using a combination of pinching points matches by mathematical programming techniques. The resulting HEN topology is then passed to the optimization stage, where a mixed-integer nonlinear programming model is used to simultaneously optimize the network configuration, utility selection, and CIP scheduling. A case study from a dairy process line is carried out to demonstrate the effectiveness of the proposed method in achieving economic and operational improvements through integrated retrofit design.

Keywords: heat exchanger networks, retrofit, CIP scheduling, multiple utilities, total annualized cost, dairy industry, network pinch, optimization, mixed-integer nonlinear programming model

GIS for energy systems, heat planning and district heating

Researcher with interest and experience in integration of renewable energy technologies in urban energy systems through GIS modeling.

GIS-based data-driven simulation of load profiles in industrial and urban areas

Alejandro Zabala Figueroa, Jürgen Knies, Wided Medjroubi

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Despite the increasing use of renewable energy generation in Europe, accounting for 41%, progress in the decarbonization of the heating sector has been comparatively limited, with only 25% of the total energy from renewables. To address this disparity, the European Union's RED III policy framework has been implemented, with the objective of accelerating the adoption of renewable energy generation, including in the heating sector. The present study proposes a Geographic Information System (GIS)-based data-driven model, leveraging which utilizes spatially resolved data to map energy demand in industrial and adjacent urban areas. The primary objective is to identify energy demand of specific areas of interests in cities, as well as potential sources of waste heat, which could be used for renewable energy generation. The model employs Nomenclature of Economic Activities (NACE) classification codes to provide time series data on heating, cooling and electricity consumption, facilitating the identification of potential district heating opportunities. The model applies the Kalundborg's 'symbiosis' principle, whereby a waste product from one company becomes a resource for another, benefiting both the environment and the economy, while also meeting the RED III objective of identifying renewable energy sites, thereby helping local stakeholders to efficiently identify zero-carbon solutions for the region's energy transition. In order to verify the application of the model, it is applied to the industrial area around the steel company in Bremen.

Keywords: Heating and cooling, renewables, GIS, district heating, waste heat, Kalundborg's 'symbiosis' principle, RED III.

She is a researcher in the field of potential analysis for renewable energies and possibilities for a closed carbon cycle in the chemical industry.

Spatially-Explicit Technical Potential of Onshore Wind Energy in Germany: A Regulatory and Geographical Assessment

Alina Kerschbaum, Technical University of Munich, Sebastian Fendt, Technical University of Munich, Hartmut Spliethoff, Technical University of Munich

Alina Kerschbaum (presenter)

Wind energy serves as a cornerstone in the transition toward greenhouse gas-neutral energy systems and is essential for achieving national and supranational climate targets. The quantification of renewable energy supply within future sustainable energy systems is called potential analysis and plays a crucial role in energy planning. In this study, the spatially-explicit technical potential of onshore wind energy in Germany is assessed using governmental geographical information system (GIS) data.

Since wind energy potentials are influenced by regulatory, geographical, and technical constraints, a scenario-based approach is applied. In order to identify key barriers to renewable energy expansion, a regulatory potential is determined, illustrating the impact of policy changes on wind energy deployment. The findings indicate that regulatory restrictions reduce the overall potential significantly more than physical-geographical constraints. Additionally, the scenario and its associated regulatory as well as technical parameters strongly influence the projected energy supply.

The spatial analysis reveals substantial regional variations in land availability for wind turbine deployment, with certain federal states facing greater challenges in meeting national expansion targets. This highlights the need for more progressive land designation policies in specific regions. Minimum setback distances from residential areas and restrictions related to military interest zones are identified as key regulatory levers affecting wind energy potentials. Overall, the spatial availability of wind energy potential in Germany is shown to be highly dependent on both the territorial characteristics of each federal state and the regulatory framework in place. By identifying critical constraints, this study contributes to a more informed discourse on the expansion of onshore wind energy, supporting evidence-based policy decisions for enhancing renewable energy deployment.

Keywords: Energy Systems, Potential Analysis, Wind Energy, Resource Assessment

Anton Achhammer is a researcher at Regensburg University of Applied Sciences (OTH Regensburg). He co-develops the open-source model PyPSA-Earth and works on energy system decarbonization through sector coupling and green hydrogen production via integrated modelling.

The impact of hydrogen underground storage on fair partnerships: A GIS-based integration of salt caverns into PyPSA-Earth

Anton Achhammer, OTH Regensburg

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The increasing demand for hydrogen in Europe and the development of cross-border infrastructure, such as the SouthH2 Corridor connecting Tunisia, Italy, Austria, and Germany, underscore the importance for hydrogen storage solutions to ensure supply security and competitive pricing. In the absence of storage, producers face increased market dependency, as electrolyzers require continuous operation to remain economically viable. At the same time, storage capacity presents an opportunity to enhance local value chains by securing hydrogen availability for domestic industries.

This research extends the open-source energy system model PyPSA-Earth by integrating GIS-based hydrogen underground storage in salt caverns and applies the model to Tunisia as a key hydrogen exporter along the SouthH2 Corridor. Salt caverns are considered the most economical option for large-scale hydrogen storage, offering operational flexibility for both export and domestic use. By simulating various storage scenarios, we assess their impact on hydrogen export dynamics, price stability, and local industrial development.

Preliminary results indicate that underground hydrogen storage significantly enhances the economic feasibility of hydrogen production by mitigating price volatility and enabling continuous electrolyzer operation. Furthermore, stored hydrogen can serve as a reliable supply for domestic sectors such as manufacturing and transport, fostering economic growth. This study contributes to the discourse on socially and climate-just hydrogen partnerships by demonstrating how strategic storage integration can balance Tunisia's role as a hydrogen exporter with domestic development benefits.

Keywords: Energy transition, Hydrogen export, Climate-neutral, Hydrogen underground storage, Hydrogen prices, Power-to-X, Salt caverns, Local value chains, PyPSA-Earth

Giulia works on district heating and cooling (DH&C) systems with renewable energy sources, focusing on low-temperature networks and excess heat recovery. She manages geo-referenced data through GIS software and Python to model and optimize distribution networks at both local and national scale.

HeatNODE, a cost-optimized model for the creation of the Italian Atlas of potential district heating networks to recover industrial waste heat.

Giulia Spirito, Politecnico di Milano; Alice Dénarié, Politecnico di Milano; Giuseppe Muliere, Politecnico di Milano; Mario Motta, Politecnico di Milano; Ada Del Corno, RSE SpA; Andrea Rossetti, RSE SpA

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This work presents the Italian Atlas of waste heat sources for district heating, an online tool developed by RSE and Politecnico di Milano using the model HeatNODE (Heat Network Optimization Designer). HeatNODE is an open-source optimization model designed to dispatch renewable and industrial waste heat across real urban areas through DH systems, in competition with individual heating solutions. It has been applied to over 800 Italian industries with the aim to highlight the significant untapped potential of industrial waste heat recovery for DH systems. The main results consist in the total amount of waste heat recovered from each source, with the optimized DH network topology required to optimally allocate that heat to the nearby existing and potential heat demands while minimizing total costs. Results also include economic parameters, notably the Levelized Cost of Energy that is the composition of capital and operational costs required to perform heat recovery from waste heat sources. It represents the annualized cost of supplied heat, and it is used to assess DH economic feasibility by comparing it to the cost of any individual heat source.

The results obtained at national level suggest that 15.7 TWh/year of industrial recovered waste heat could be cost-effectively supplied through DH systems, covering 15.6% of the estimated connectable heat demand. Distribution losses of 12% are experienced and the LCoE is equal to 75 €/MWh for the modelled industrial waste heat recovery projects, on average.

The Atlas features interactive, user-friendly visualizations of the industrial waste heat recovery potential and supports customized calculations and sensitivity analysis aimed at different scenarios investigations. In line with recent EU directives, the main objective is to push industrial operators, DH utilities and local administrations to promote a faster implementation of industrial waste heat initiatives towards a progressive energy system's decarbonization.

Keywords: District heating; Waste heat recovery; Industry; Minimum-cost optimization; Linear programming; Heat dispatch strategy; Energy planning; DH network design

Marina Georgati, PhD in Geoinformatics, specialises in high-resolution mapping and ML. Her work focuses on energy systems modelling, district heating, and carbon capture planning. Passionate about spatial dynamics and data-driven solutions for sustainable urban development.

A spatial assessment of the district heating potential in Europe

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District heating (DH) systems use local energy resources to meet consumers' heating needs and play a key role in decarbonising Europe's heating sector. By integrating renewable energy and heat recovery, DH can reduce dependency on fossil fuels, improve energy security, and deliver both environmental and economic benefits. However, efficient DH planning requires detailed spatial analysis: firstly, to accurately map the geographical distribution and level of heat demand; secondly, to identify cost-effective DH areas suitable for development; and finally, to assess the integration of renewable and surplus heat sources.

This study updates the Pan-European Thermal Atlas to improve the representation of heat demand compared to previous versions. The updated data is used as input to an improved DH model that maps areas based on heat density contingency and estimates the associated grid costs for 3rd and 4th generation district heating systems, incorporating heat losses. Additionally, a scenario-based analysis maps potential heat sources, including industrial surplus heat at different temperature levels, geothermal and solar energy, across Europe and associates them to the modelled DH areas, providing country-level insights into the range of potentials at different European market share levels.

Keywords: Energy planning, Spatial modelling, Heat mapping, Excess heat, GIS

Steffen Nielsen has a research background with a specialization in strategic heating planning. His focus is on utilizing GIS for energy planning. He links these spatial analyses to energy system models, to understand the dynamics crucial for transitioning towards 100% renewable energy systems.

High Resolution Spatial Mapping of Biogas Potentials and Site Selection – A Danish case study

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In fully decarbonized energy systems, biogas will play a crucial role in balancing the electricity system and enabling the use of electrofuels in industry and heavy transport. Various technologies can produce biogas, but in heavy agricultural countries, utilizing agricultural waste in anaerobic digestion plants holds significant potential. In recent years, the number and capacity of biogas plants have increased, evolving from small-scale farms to large-scale industrial facilities.

This analysis uses Denmark as a national case study to quantify biogas potential and map the locations of biogas facilities in the context of fully decarbonized societies. It quantifies the biogas resources from manure, bedding, and straw in a spatially explicit model. Furthermore, the existing biogas facilities and the resources they use are mapped. Finally, the primary focus of the analysis is to investigate various scenarios for locating new biogas facilities, with a particular emphasis on their impact on biogas production costs.

The results indicate that there are sufficient biomass resources to produce what is needed in the future Danish decarbonized energy system, which can be achieved in all scenarios. In decentralized scenarios, the transport distance is reduced, allowing for more local utilization of resources. Conversely, centralized scenarios generally have lower overall costs, despite higher transportation costs. From an economic assessment, the most centralized scenario is the optimal solution; however, considering the negative environmental and local community impacts, a more decentralized solution might be the overall preferable option.

Keywords: GIS; Biogas; Location-Allocation; Renewable Energy; Bioenergy

Ulrike Jordan is associated professor at the University of Kassel. She is co-leader of a researchers' team in the department of solar and systems engineering, working on municipal heat planning, district heating, industrial process heat and liquid desiccant systems.

Potential of wastewater, rivers and residual material as heat sources for district heating in the German federal state of Hesse

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Ulrike Jordan and Joachim Sieglar (presenter)

Identifying heat sources is a major challenge in municipal heat planning. An interdisciplinary consortium is currently systematically analyzing the heat supply potential available for larger municipalities in the German federal state of Hesse (6.3 mio inh.).

Wastewater treatment plants

Based on measurements of wastewater temperatures and flow rates after purification at seven wastewater treatment plants, generalized profiles for temperature and dry weather flow are developed. These profiles are used to calculate the heat supply potential via heat pumps for nearly 450 wastewater treatment plants > 1,000 population equivalents. The seasonalities of wastewater flow and temperature partially compensate each other, so that the heat potential has only minor seasonal fluctuations.

Rivers

Following recent guidelines, all river sections in Hesse with at least 0.5 m³/s mean low discharge are considered. An integrated database is built from public geodata, river temperature and discharge measurements to determine the heat extraction potential for each municipality. Furthermore, a one-dimensional thermal node model is developed to analyze the regeneration of water temperatures after heat extraction by heat pumps.

Biogenic residues and waste incineration

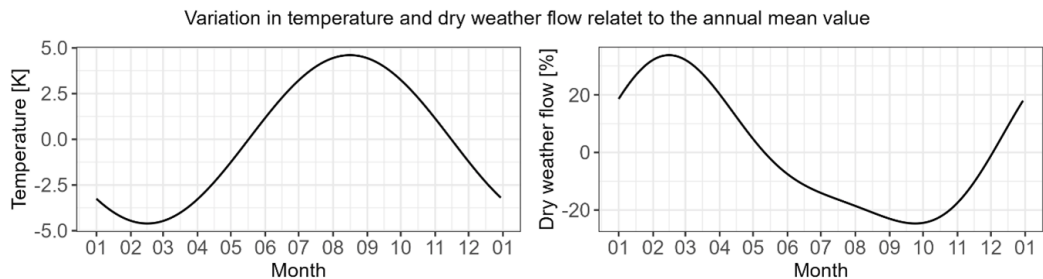
First results of the study reveal an only rather low potential for the utilization of selected biogenic residues (e.g. leaves and roadside greenery) as fuels for peak load coverage of heating networks of a maximum of about 300 GWh/a.

In addition, the study identifies additional, currently unused heat supply potentials of existing public waste incineration plants in Hesse, due to heat optimized operation, flue gas condensation and turbine exhaust steam utilization.

Renewable heat supply scenarios

The aim of the study is to match heat supply and demand, to identify areas that are suitable for being fully supplied with the aforementioned heat sources and thus to determine the heat supply potential for district heating.

Keywords: Heat Sources, Wastewater, River, Waste Incineration, Biogenic Residues, Renewable Heat Supply, Municipal Heat Planning



Institutional and organisational change for smart energy systems and radical technological change

Alessandro Mati is a postdoc at the Department of Sustainability and Planning of Aalborg University. His research focuses on the design of integrated renewable energy systems and he is currently involved in projects on eSAF pathways in the EU and the development climate-resilient energy futures.

Fueling sustainable aviation: prospects for electrofuels and policy frameworks

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Progress towards the achievement of a net-zero economy by mid-century demands transformative decarbonisation efforts across the policy, infrastructure and technological landscape of the European Union. Accounting for 2.5% of global CO₂ emissions, the aviation sector stands out as one of the most challenging to decarbonise, owing to the lack of viable technological alternatives in the short-term. Amidst these pressures, momentum is building around the adoption of clean fuels, particularly electrofuels (e-SAF), as the primary measure to decrease aviation emissions, from both technological and regulatory standpoints. The ReFuelEU Aviation initiative introduces blending mandates for e-SAFs of up to 35% in all EU airports by 2050, thereby committing to a systemic shift away from fossil fuels dependency. Taking the Danish energy system as a point of departure, this study aims to assess the viability of e-kerosene in the aviation sector under varying technological development trajectories and policy framework scenarios. Grounded in projections of both domestic and international aviation fuel demand of Danish airports, the analysis incorporates key elements of the supply chain, including green hydrogen and point-source carbon commodity prices. By exploring a range of scenarios, the study aims to identify the main drivers influencing the competitiveness of e-SAFs towards 2050.

Policy instruments such as the EU Emissions Trading System (ETS) and national subsidies schemes are examined as key regulatory mechanisms to narrow the cost gap between with fossil-based jet fuels. Within this framework, the study further explores the potential impact of e-SAF deployment on airfares, providing an estimate of expected changes in ticket pricing. These findings highlight that net-zero aviation will depend on timely and strategic interventions that bridge the cost gap, ensure investor confidence, and enable the scale-up of synthetic fuels in line with Europe's decarbonisation ambitions.

Keywords: Sustainable European Aviation, Electrofuels, e-SAF, Energy policy, Airfare.

The author is a professor in Energy Planning at Aalborg University, and has a Doctor Degree within this area. His educational background is international Economics and Social anthropology. He has written several books and articles on social science and energy planning.

Fundamental policy changes in a transition from around 50% to around 100% Renewable Energy.

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We are in a transition phase where renewable energy systems are in a metamorphosis of changing from being a supplement to fossil fuel energy systems to a situation where smart energy systems based on mainly renewable energy sources such as solar and wind energy in combination with some biomass and geothermal energy is the main energy system

This transition from being a supplement to fossil fuel based energy system, to being THE ENERGY SYSTEM meets huge challenges as shown by the present implementation problems, which are:

- (a) Ongoing cannibalism at the Nord Pool electricity market,
- (b) not getting sufficient bids on new large offshore wind power plans,
- (c) an almost 100% stop in building wind- and solar power on land,
- (e) problems of developing sufficient consumption flexibility and Power- to- X capacity.

A 100% Renewable Energy System is fundamentally different from a 50% Renewable Energy system with regard to cost structure of new capacity, need for consumption flexibility, and the need for a network of technologies to handle the fluctuations of Renewable Energy.

This paper deals with the discussion- and development of the institutions that are needed for this fundamental transition from around 50% Renewable Energy to energy systems based 100% on Renewable Energy.

Keywords: (fundamental policy changes), (Renewable energy cost structure), (Renewable Energy fluctuations),(Renewable energy and high sunk costs), (Renewable Energy and low price cannibalism)

George is a Graduate Engineer at FairHeat, and has experience in quality assurance and optimisation of new build and existing heat networks. His main focus now over the past year has been on the development of industry standards and leading several pilot projects for the Heat Network Technical Assurance Scheme (HNTAS) on behalf of the UK Government, with the goal of shaping the scheme ahead of its 2026 launch

Structuring a technical assessment to support regulation of minimum heat network standards

Mark Reynolds and George Pickens, FairHeat

George Pickens (presenter)

The UK Government estimate that heat networks will be required to supply almost 20% of the UK's heat in order to achieve Net Zero in 2050, a significant increase from 2-3% in 2023. Heat networks in the UK range from older networks nearing end of life, to new build networks, both of which experience reliability and performance issues, due to the absence of enforced best practices and heat network standards.

Therefore, to support the anticipated growth and assure against poor quality design, construction and operation and maintenance practises, the UK Government is launching The Heat Network Technical Assurance Scheme (HNTAS) to mandate minimum technical and performance standards.

To facilitate assessment and certification of heat networks through the Scheme, a technical assessment structure was developed to enable a straightforward binary decision for the regulator. This assessment structure encompasses the following:

- Assignment of duty holders with associated responsibilities during assessment.
- Sequential stages which must be passed throughout the assessment regime.
- The introduction of specific technical requirements to be met, Key Failures to be avoided and KPIs to be achieved at each stage.
- Data-based evidence requirements to be submitted at each stage for assessment.
- A binary pass/fail decision at each stage made by impartial assessors.
- 3rd party certification as a condition of receiving a license to supply heat to customers from the regulator.

In summary, this work provides an overview of how a technical assessment structure has been developed and piloted for the UK market but which tackles issues that may be prevalent in other markets.

Keywords: Regulations, Heat Networks, Net Zero

His research fields are statistics database, scenario study, policy framework and business model of renewable energy in Japan. He took a degree as doctor of Engineering for Energy Conversion from Tokyo Institute of Technology in 1990.

Progress of Regional Decarbonization in Japan and Challenges to Realization

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In Japan, as various measures are implemented to achieve carbon neutrality by 2050, 81 regions have been selected by the national government (Ministry of the Environment) as model areas to achieve decarbonization by 2030, and the implementation of smart energy systems through the introduction of renewable energy sources such as solar power has begun. The implementation of smart energy systems based on the introduction of solar and other renewable energy sources has begun. The progress of regional decarbonization in Japan is assessed in terms of the regional energy self-sufficiency of local governments and the progress of leading decarbonization areas. In addition, we will evaluate the implementation status in Ogata Village, Akita Prefecture and Sosa City, Chiba Prefecture as specific regional examples of the challenges to implementation. Plans are underway for a district heating system using rice husk biomass as fuel in Ogata Village, an on-site PPA using solar power generation and battery storage by a regional power company in Sosa City, Chiba Prefecture, and an off-site PPA using agrivoltaics system.

Keywords: Smart energy system, Decarbonization, PPA, District Heating, Agrivoltaics, community power

Kristina is working as Professor at Lund University and as a consultant in her own company, Kristina Lygnerud AB. She is specialized in business model innovation and design, and has worked extensively with district heating applications (for over 20 years).

The impact of social sustainability on district heating competitiveness

Kristina Lygnerud, Lund University, Kerstin Sernhed, Lund University, Hanne Kortegaard-Stoechel, Danish Board of District Heating, Johanna Ayrault, University of Vienne

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District heating companies are facing ample change. Fuel supply must shift; climate urgency to shift away from gas, high cost of biomass and waste heat was put at par with renewables in the most recent update of the EED (2023) increasing its use. Customer demands are shifting; higher demand of energy as a service, inclusion-empowerment- fairness are required and it is possible to profit from balancing services on the electricity market. New kinds of investments are needed; digitalization, seasonal energy storages and carbon capture storage / carbon capture usage are examples. Energy companies are increasingly responsible for resilience. In sum, the boundary conditions of the district heating business are shifting. Additional values are being provided, new kinds of investments and partnerships are undertaken.

Sustainability reflects economic, environmental and social aspects. In the conventional district heating context, the first of the two sustainability aspects are well reflected whereas the social dimension is not. An organization's action can generate social values directly for targeted stakeholders but also indirectly for other, non-targeted stakeholders. To be aware of what social impacts the actions of a district heating company have, and to harvest those, is important for the future competitiveness of district heating companies. In our study, we have explored the case of a new district heating installation in a new district heating market (Canada). Based on literature review, interviews and value chain analyses of district heating activities in both mature (Sweden, Denmark) and expanding (Belgium and Canada) district heating markets 26 social key performance indicators have been identified and their importance to district heating business model competitiveness have been quantified. Main conclusions are that some social values can be linked to a direct, monetary value whereas others cannot. Even so, their impact on competitiveness is significant.

Keywords: Social Key Performance Indicators, District Energy, Competitiveness

Pascal Fröhlich holds a degree in electrical engineering with a focus on energy technology from BTU Cottbus-Senftenberg. He is currently pursuing a PhD in energy system modelling at the university's Chair of Energy Economics, where his research focuses on the market development of renewables.

Historical Cost-Optimised Expansion of Renewable Energy Sources

Pascal Fröhlich, Maximilian Bernecker, Felix Müsgens, Brandenburg University of Technology

Pascal Fröhlich (presenter)

Electricity generation from renewable energy sources is essential for decarbonising the energy sector. Investment and generation costs of renewable and conventional power plants drive the relative competitiveness. Historically, it is undisputed that a ramp-up of renewables required subsidies. However, two elements have changed in recent years. First, investment costs for renewables have decreased significantly, while investment and fuel costs for conventional generation have risen. Second, negative externalities from CO₂ emissions have been priced, e.g., in the EU Emission Trading System, increasing conventional generation costs. Both trends favour renewables.

The current cost competitiveness of renewable electricity generation is still controversially discussed. Some studies argue renewables can compete with conventional sources. Others point out that due to their intermittent nature, back-up capacities or storage are required, making renewables uncompetitive for years to come. As a consequence, it is still unclear how much renewable energy sources would already be part of a cost-optimal electricity system.

Our paper computes the optimal share of renewables in the German electricity system, purely based on system cost, without subsidies. We present a linear cost minimisation model optimising investment and dispatch. It is set up greenfield, optimising one year in hourly resolution with annuitised investment costs.

We parameterise the model for Germany from 2015 to 2024. Technology-specific historical investment, fuel, and carbon costs are included. Weather, load, and trade flows are based on hourly real-world data. The model determines the historical mix purely on a cost-optimal basis. We show that despite their intermittency, renewables would have entered the market even without subsidies. Their growing economic efficiency makes them a core part of the energy system. Our contribution supports policymakers and investors in assessing future subsidies and costs.

Keywords: Renewable Energy Expansion, Cost Optimisation, Historical Analysis, Energy Transition, Energy Systems Modelling

Ruta Vanaga is a researcher in building energy efficiency, innovative construction materials, and social innovation. Her research focuses on integrating technological advancements with societal engagement to promote sustainable and resilient built environments.

Integrated Approach for Sustainable Urban Energy Transition: Citizen Engagement, System Dynamics Modeling, and Immersive VR Decision-Making Tools

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The long-term goal in EU is to implement the energy transition. However, on communal and individual level, the most effective actions are often missed. According to C. Snell “Climate change is boring”, yet due to its pressing matter, “it requires that we finally all work together if any of us are to continue working at all”. Municipalities often lack the tools and communal know-how of how to speed up the energy transition, even though measures, policies and technical solutions exist. Municipalities face challenges in engaging citizens meaningfully in urban planning processes to accelerate the adoption of energy efficiency and renewable energy systems. Study carried out under the ENVISION CHANGE project addresses this gap by developing and testing key enabling methodologies that integrate creative, participatory, and technological approaches to foster community-driven urban energy transitions. By combining system dynamics modeling and immersive virtual reality, the study explores how imaginative engagement can enhance decision-making, behavior change, and social innovation at the neighborhood scale. Building on participatory design, human-computer interaction, and experimental urban living labs, the study tests tools for citizen empowerment and co-creation of resilient, carbon-neutral communities. Comprehensive citizen needs analysis carried out in three case studies Riga, Amstergam and Borlange, serves as a cornerstone for the project, identifying community-specific motivations and barriers. Based on these insights, ENVISION CHANGE develops immersive virtual reality and system dynamics models tailored to local contexts, supporting collaborative visioning and decision-making.

Through case studies, ENVISION CHANGE tests how interdisciplinary methods can support technological uptake and social transformation, contributing new knowledge to the field of smart energy systems by bridging analytic modeling with visionary, experiential learning techniques.

Keywords: Energy transitions, citizen engagement, virtual reality system dynamic modeling, building energy efficiency, quality of life, urban design

Aadit Malla is a Research Associate at the Energy Economics Group at the Technical University of Vienna (EEG-TUW). His research focus is on strategic heating and cooling planning aimed at energy efficiency and sectoral decarbonization.

Assessing the Potential for Biomass Reduction Through Targeted Retrofitting of District Heating Systems in Austria

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Austria's extensive biomass-based district heating (DH) infrastructure — with over 2,400 heating plants and 150 biomass CHP plants — supplies nearly half of the country's district heat. While central to Austria's decarbonization strategy, the sector faces growing pressure to improve efficiency, reduce biomass consumption, and align with climate neutrality goals.

This study assesses the techno-economic potential of retrofitting existing biomass DH systems using technologies such as CO-lambda control, active flue gas condensation, and electric heat pumps. The goal is to evaluate how retrofitting can enhance system performance while reducing reliance on biomass.

The central research question guiding this work is:

How can the roll-out of suitable retrofit solutions in Austria's biomass-based district heating sector reduce biomass consumption while improving economic performance and system-level efficiency?

To address this, a criteria-based classification is applied to existing DH systems, using technical parameters such as plant size, age, temperature regime, and local energy sources. A clustering approach groups systems with similar characteristics, and a multi-criteria assessment evaluates the technical and economic feasibility of matching retrofit technologies to each group.

Key performance indicators (KPIs) are used to assess impacts on biomass use, cost savings, and system efficiency. Roll-out scenarios are developed based on the clustering results and technology applicability at national and international levels. These scenarios help estimate the potential for biomass savings and broader impacts on the energy system.

By combining system classification with scenario-based analysis, the study offers insights into viable retrofit pathways and their contribution to a more resource-efficient and economically sustainable heating sector in Austria.

Keywords: Biomass district heating, Retrofit technologies, Energy efficiency, Biomass reduction

Integrated energy systems and smart grids

Dr Isabelle Best received her PhD in low temperature district heating from the University of Kassel, Germany, in 2022, after which she led projects focused on municipal heat planning. Since 2024, she is Solutions Lead at Gradyent BV, implementing digital twins to optimise district energy systems.

Dynamic supply temperature optimization of a complex nested district heating network

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In this study, the supply temperature of a 500 GWh/year complex district heating network consisting of one primary transmission line and 20 secondary networks, hydraulically separated by heat exchangers, is optimised. The Gradyent Digital Twin has been used to optimize the operational behaviour of the entire network, including the 20 heat exchangers, coupling the secondary networks with the transmission line. Significant potential for reducing supply temperatures was identified, particularly within the primary network, while ensuring security of supply and adherence to consumers technical connection requirements.

Key findings from Gradyent's Digital Twin dynamic optimisation approach include the potential to reduce supply temperatures by approximately 13°C during peak load conditions and an average reduction of 17°C at ambient temperatures below 15°C, e.g. during periods of space heating demand. This reduction is expected to decrease heat losses in the primary network by about 9.5 %. The implementation of dynamic supply temperature control is of crucial importance and forms the basis for the integration of large heat pumps in the transmission line. Given the current technical connection requirements of consumers, the supply temperature can be below 95°C for more than 80% of the year, whereas previously the primary network was never operated at temperatures below 110°C. Higher supply temperatures are necessary during peak load periods to avoid hydraulic bottlenecks. Secondary networks exhibited limited potential for further supply temperature reduction due to the existing consumers technical connection requirements ,and already low operating supply temperatures.

This case study highlights the importance of dynamic supply temperature control with a real-time Digital Twin to improve efficiency, enable the transition of district heating systems to renewable temperature-sensitive heat sources and ensure that user requirements are always met.

Keywords: district heating; dynamic operational optimization; digital twin; supply temperature; case study; cost savings; reduction of thermal losses

Dr. Jacobus van Rooyen is currently a Scientist with a doctorate specialization in Computational Fluid Dynamics Based Optimization. He has applied his skills in a wide range of industries, with his main focus currently in modelling and optimization applied research for the energy transition.

Operational strategy optimization under dynamic electricity prices; utilizing tank storages and high temperature seasonal storages

Femke Janssen, Jacobus van Rooyen

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The Netherlands is facing a heating transition with the majority of the buildings utilizing natural gas, with District Heating Networks being an alternative. Even though lower temperature networks are becoming increasingly relevant due to the additional need of cooling, higher temperature networks are still needed, specifically for buildings with a specific or high heating demand requirement. In addition to these challenges, the congestion in electricity (e-) networks are increasing, which highlights the need for a multi-commodity design approach.

To meet sustainability goals, the approach in high temperature heating network designs is to phase CHP usage towards renewable sources, while negatively impacting the limited e-capacity. Simultaneously PV parks are installed, which introduces new opportunities for optimal usage of any local e-production by considering the dynamic pricing and seasonal energy demands.

For this purpose, a new workflow for operational optimization has been added to the open-source code base MESIDO (Multi-Energy System Integrated Design and Operation). The first step in this workflow being seasonal optimization where a water-source heat pump is used. The latter is used to upgrade the low temperature heat during summer for storage in the high temperature seasonal subsurface thermal storage (HT-ATES), and during winter upgrading it once again to cover temperature losses in the HT-ATES. The impact of a varying HT-ATES temperature, during discharging, on the heat pump COP and the e-consumption is also incorporated. The net result being a charging/discharging profile of the HT-ATES. With the goal to utilize the abundant low e-prices in summer for heat to be used in the winter. Finally a more refined allocation of assets are determined, with smaller timesteps, by using the hourly e-price and e-production profiles to ensure optimal use of buffer tanks during peak hours and reduce e-usage in these periods.

Keywords: District Heating Network, Operational optimization, Dynamic electricity prices, Electricity network congestion, High temperature seasonal storage, Intraday buffer storage, Mixed Integer Linear Problem

Jihong Hang received the M.S. degree in Sustainable and Green Finance from the National University of Singapore in 2023. He is currently with PetroChina Co Ltd., mainly engaged in research on energy security and low-carbon transition strategies.

Developing strategies for the electrification of Oil and Gas Industry in China

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Jihong Hang (presenter)

In the context of low-carbon transformation, China's oil and gas industry must optimize the structure of energy consumption in the production stage through electrification, focusing on overcoming two major challenges – the consumption of high-carbon electricity in the production stage and the reliance on natural gas for heating. This study systematically clarified the energy-intensive production processes in the oil and gas industry. It assessed the techno-economic feasibility of electrification substitution and the corresponding substitution potential for each production process. Furthermore, this study enhance analysis on realistic scenarios. Unique features of the oil and gas blocks at different development stages are characterized, while the availability of external grid facilities are considered. We proposed a phased and economically viable electrification strategy for large oil and gas fields with multi-scenarios aimed promoting decarbonization targets while ensuring reliable power supply for production. Its feasibility was analyzed and validated through an empirical case study of a large oil and gas filed in China. Results showed that implementing the proposed electrification strategy reduced the carbon emission intensity of the oil and gas field by 60%, while enhancing the commercialization rate of natural gas and cutting fuel costs. This study proposed electrification transformation paths that align with realistic conditions for oil and gas fields at different stages of development, providing a scientific decision-making support for policymakers and relevant companies.

Keywords: Oil and gas industry, electrification transformation path, heating, China

Jinze Li received the B.S. and Ph.D. degrees from the Department of Energy and Power Engineering, Tsinghua University, Beijing, China, in 2017 and 2022, respectively. She is currently with PetroChina Co Ltd., mainly engaged in research on low-carbon transition strategies.

Hybrid Renewable Energy Integration for Oil and Gas Power Supply: Optimization and Feasibility in China

Jinze Li(corresponding author), Research Institute of Petroleum Exploration and Development (RIPED); Jihong Hang, RIPED; Pei Liu, Tsinghua University; Guosheng Zhang, RIPED; He Liu, RIPED.*

Jinze Li (presenter)

To meet carbon reduction targets and counter rising energy costs, renewable energy integration offers a sustainable and economical solution for energy supply in the oil and gas industry. However, the intermittent output of renewable energy conflicts with the continuous production demand of the sector. High renewable energy integration also affects the grid, limiting baseline interaction capacity. In this study, we designed an optimized grid-integrated hybrid renewable energy system (HRES) for oil and gas production, which integrated solar energy, wind turbines, natural gas power generation, and energy storage. Its feasibility was analyzed through a case study in China. This study aimed to enhance the characterization of a realistic scenario. An economically optimal system configuration was proposed to ensure a reliable energy supply. Furthermore, sensitivity analysis revealed the impact of load variations and grid security margin limitations on the optimization plan. When compared with the completely grid-dependent mode, the proposed grid-integrated HRES reliably supplied energy and reduced the system cost of energy by 40%, while achieving a 70% renewable energy penetration rate and CO₂ reduction of 4,070 tons. The proposed grid-integrated HRES offers a flexible and scalable solution for sustainable power supply in the oil and gas industry, while enhancing decarbonization strategies.

Keywords: Hybrid renewable energy system, optimal planning, grid-integrated, oil and gas industry

Kristina is a researcher specializing in energy system modelling and analysis, focusing on the Norwegian and European energy transition. Her research covers competition and interaction between energy carriers and technologies, with solid experience in offshore wind, hydrogen and energy flexibility.

Hydrogen at sea: Evaluating offshore production for Europe's future demand

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Hydrogen demand in Europe is projected to grow rapidly as the continent decarbonizes its industry and transport sectors. The EU's REPowerEU plan targets 10 Mt of renewable hydrogen production by 2030, but recent assessments suggest these goals will be difficult to achieve. Key challenges include limited hydrogen transport and storage infrastructure, constrained electricity supply, and grid congestion. Offshore wind-based hydrogen production can help overcome these barriers by providing large volumes of clean electricity, bypassing grid bottlenecks, and enabling cost-effective transport via pipelines. The North Sea is a strategic location, offering abundant wind resources and the potential to repurpose gas infrastructure. However, offshore hydrogen production remains expensive due to high capital costs and low capacity utilization.

We investigate the potential for offshore hydrogen production around Sørlige Nordsjø II and subsequent hydrogen transport via pipeline to Germany, evaluating how key parameters and uncertainties affect competitiveness relative to onshore production via electrolysis and production via ATR with CCS, considering production in Norway and locally (Germany). The study aims to identify the most effective strategy to support Europe's hydrogen demand—whether by transferring electricity or hydrogen, producing onshore or offshore, green or blue, and the role of storage in ensuring a stable, reliable supply.

To better understand the operational dynamics and feasibility of hydrogen production, we develop and compare two energy system models with varying technological and temporal resolutions. The results indicate the required CAPEX levels of offshore electrolysis and hydrogen to be viable investments and the sensitivity of these investments to onshore electricity and natural gas prices. The results indicate a business case for offshore hydrogen; however its viability depends on constrained domestic production capacities and adequate storage.

Keywords: Offshore hydrogen production, Offshore wind, Electrolysis, ATR, CCS, Salt caverns, Hydrogen pipelines, North Sea, Energy system modelling

Marius Güths is an Engineer at Stadtwerke Bielefeld GmbH in Germany and PhD student at the Institute of Power Systems Engineering University of Wuppertal developing cross-sectoral operating and planning principles for quarter energy systems in research project “NeuPlan”

Optimization of energy flows with differing optimization goals on quarter level

Marius Güths, Stadtwerke Bielefeld GmbH

Marius Güths (presenter)

In light of decarbonization goals and current geopolitical uncertainties, reducing import dependencies and primary energy consumption—particularly through electrification—is increasingly critical. Local energy generation and storage are gaining importance, necessitating evaluation criteria beyond economic costs, such as primary energy use and CO₂ emissions, for practical energy system optimization.

Electricity pricing is shaped by diverse parameters including taxes, network fees, and dynamic labor prices. This study simulates energy demand and supply in newly developed urban quarters using time series data for heating, cooling, power consumption, and electromobility, based on building structures and socio-economic profiles. Various supply concepts—such as all-electric systems, combinations with district heating or gas, and self-generation options—are optimized using a bottom-up approach from individual buildings to the neighborhood level.

Centralized and decentralized solutions are compared under objectives like cost-efficiency and reduced primary energy usage. The approach supports planning of sustainable, resilient energy infrastructures adaptable to different urban settings.

Findings show that sharing solar power across buildings enhances economic and ecological performance by increasing local consumption and lowering CO₂ emissions. District heating is advantageous in dense urban areas but depends on cost-effective heat sources. Conversely, gas-based heating, particularly for single-family homes, proves economically unviable, even without regulatory constraints. These insights underscore the need for a transition toward decentralized, renewable, and economically sustainable energy systems.

Keywords: Integrated energy systems, optimization, integrated planning, automation

He holds a Master's degree in Mechanical Engineering from ETH Zurich. Since 2023, he has been a research associate at Empa, focusing on data-driven modeling and model predictive control for energy systems, with hands-on experience in experimental validation.

Model Predictive Control in Small-Scale Hydraulically Coupled District Heating Systems

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The city of Basel has set an ambitious goal of achieving CO₂ neutrality by 2037. However, many neighborhoods still lack access to centralized district heating and continue to rely heavily on gas boilers. The Nanoverbund project addresses this challenge by introducing two key innovations that offer a novel approach to local thermal energy supply.

Firstly, at the system level, the project presents a small-scale thermal network that can be easily retrofitted into existing buildings. This network enables energy sharing between neighbors through hydraulic coupling [1]. Experimental results demonstrate that a heat pump-equipped building can cover up to 90% of the combined space heating and domestic hot water demand of all three buildings using simple rule-based control strategies.

Secondly, at the control level, it implements a model-based optimal power control strategy composed of two layers: a high-level finite-horizon optimization controller that determines the optimal thermal power exchange between buildings, and a lower-level power tracking controller that ensures accurate execution. This hierarchical control structure allows the system to respond dynamically to external signals such as energy prices or CO₂ emissions, thereby supporting demand-side management and enhancing operational flexibility.

Experimental results confirm that the system achieves precise power setpoint tracking and effectively shifts thermal loads in response to cost signals, all while maintaining occupant comfort within defined limits.

[1] Février, S., & Born, D. (2024, June). Dezentraler Wärmeverbund (Patent No. CH720288). Swiss Federal Institute of Intellectual Property.

Keywords: local small-scale district heating, model predictive control, power control, demand-side management

Oddgeir holds a PhD in Engineering from the University of Iceland and has worked globally with district energy at Danfoss since 2012. He was Director of Projects (2016–2023) and is now Director of District Energy Solutions, focusing on knowledge sharing, developing and modernizing systems.

Revealing the Hidden Potential of Energy Efficiency in DH Networks

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As district heating (DH) systems transition toward a decarbonized heat supply, improving energy efficiency in specific components of the heat supply chain can yield significant upstream benefits. However, there is a risk that these benefits may be overlooked if decision-making processes are based on the conventional, carbon-intensive DH model. In fossil-fuel-based systems, such benefits are typically marginal and therefore often neglected in system analyses and investment decisions. With the new paradigm introduced by the decarbonization of energy systems, it is crucial for the DH sector to recognize and incorporate these upstream benefits when evaluating the impact and value of energy efficiency improvements.

By implementing a holistic, end-to-end methodology, from building technical installations to primary energy generation, decision-making processes can more accurately capture cascading effects. This approach supports improved investment appraisals, enhanced energy efficiency, cost savings, and greater environmental sustainability across the entire energy system.

This presentation explores the impact of system boundary selection on performance evaluation, highlighting the importance of adopting a broad systemic perspective, that extends beyond the immediate point of intervention. Using case studies of energy efficiency measures in both conventional and decarbonized DH networks, we demonstrate how a more comprehensive assessment framework can uncover hidden efficiency gains and support improved system-wide optimization.

Keywords: District Heating, Decarbonization, Cost efficiency, Energy efficiency

Savvas Panagi received his Diploma in Electrical and Computer Engineering. He is currently pursuing an industrial Ph.D. under the Dependable Smart Energy Systems project. His research focuses on the optimization of electric vehicle and heat pump operation within active distribution networks.

Grey-Box Modeling Methodologies for Integrating Building Thermal Dynamics into Power System Studies and Planning Tools

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The consequences of climate change are urging most countries to accelerate the deployment of clean energy technologies. Consequently, the transition from conventional fossil-fuel-based heating to electricity-driven systems is becoming increasingly inevitable. According to Eurostat data, about 50% of all energy consumed in the EU is used for heating and cooling, and more than 70% still comes from fossil fuels.

The electrification of heating and cooling systems is reshaping how buildings interact with energy networks, as thermal demands are increasingly met by electricity. This shift creates both challenges and opportunities for power system planning. Accurate modeling of building thermal dynamics is essential to capture these effects and support network studies.

This work proposes a comprehensive grey-box modeling framework combining physical insights with data-driven parameter identification. The thermal behavior is described through a compact ordinary differential equation, discretized into a state-space form to facilitate optimization and simulation. Four main inputs are considered: solar irradiation, heating input, and outdoor/indoor air temperature.

Model training is structured around a two-stage optimization: a meta-heuristic phase generates good initial parameters, followed by fine-tuning through nonlinear programming (such as IPOPT). The iterative identification framework minimizes the risks of infeasible solutions and local minima. Performance is assessed via RMSE metrics across both training and validation datasets.

In addition to developing the grey-box models, the work investigates key open questions: the influence of training data quantity, parameter plausibility, sensitivity to initialization, and the

selection of appropriate model structures. Extensive sensitivity analyses are performed to assess these aspects.

The presented methodology aims to enable tunable models that can be integrated into smart energy systems, and network planning.

Keywords: Grey-box models, Building thermal dynamics, System identification, Power system planning, Smart energy systems, Model tuning methodologies, Energy flexibility.

The presenter is a postdoctoral researcher at the Applied Mathematics and Computer Science Department of Technical University of Denmark. His background is in control engineering. His current field of research is grid-aware control of energy systems, and demand-side management.

Analysis of flexibility characterization using flexibility function in residential buildings

Anton Mjöbäck Haudrum, Technical University of Denmark, Oskar Bak Jannings, Technical University of Denmark, Seyed Shahabaldin Tohidi, Technical University of Denmark

Seyed Shahabaldin Tohidi (presenter)

Demand-side management (DSM) plays a crucial role in maintaining energy balance, particularly as the penetration of renewable energy sources increases. Flexibility characterization of residential demand is essential to enable responsive load adjustments, facilitating grid stability and efficient energy use. As renewable resources introduce greater variability into the grid, understanding and utilizing residential flexibility becomes a key component of energy systems planning and operation.

This paper analyses the characteristics and dynamics of flexibility in residential buildings by considering societal behaviours and the thermal properties of buildings. Specifically, the study investigates how different resident preferences, such as high/low temperature choice and electricity price, affect demand flexibility. Additionally, the impact of building thermal characteristics, including thermal capacitance and resistance, on flexibility performance is examined. For example, buildings with higher thermal capacitance demonstrated a smoother and more delayed demand response, enhancing their flexibility potential. By establishing the links between behavioural responses and building properties, the analysis provides deeper insight into demand responsiveness under various conditions.

The flexibility function, representing the dynamic relationship between price and demand, is employed to predict residential demand and characterize flexibility. Flexibility function parameters are identified using synthetic datasets generated by a detailed residential energy simulator. The estimated flexibility functions are then utilized to explore how different societal behaviours and building thermal properties influence overall flexibility, offering valuable insights for the control design and demand-side management strategies in modern energy systems.

Keywords: Price-demand relationship, Flexibility function, flexibility characterization, demand prediction

Passionate business developer and digitalisation expert in the district energy and industrial heating space. Business Development Director at Gradyent and before that 20+ years experience in smart metering. Member of EU Commission Smart Energy Expert Group

Potential of real-time end to end optimization of the full district heating system from heat source to distribution and demand

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In this study, a real-time Digital Twin Platform from Gradyent is optimizing a 3TWh+ system in Europe, real-time co-optimizing the network with the sources placed on different geographical locations. The Digital Twin provides live 24/7 production plan and decision support to the operators to optimize the dispatch of 2GW of Combined Heat and Power (CHP) units and immediately achieved a 3,5% CO2 reduction, equal to 17000 tons, in just 90 days - and at the same time both saving costs and improving profits.

During the day, operators can adjust the networks configurations in the Digital Twin. Combined with live valve signals, user data, pressure sensors, the Digital Twin runs a pipe-by-pipe thermohydraulic calculation engine every minute to understand how the heat flows distribute throughout the network. As a result, the operators know exactly how much heat flow they should distribute from the different asset locations and can efficiently divide the 37 network zones and the heat demand of 10,000 substations across these plants.

On top, the Digital Twin Platform consists of Digital Twins of each boiler (10+ pieces, operating either on coal, biomass or gas), the quality of the steam they produce, and how much heat or electricity can be produced with this steam. In real-time, these values are updated such that the operators know which boiler to use for maximum economic result and minimal emissions.

The uniqueness of this application is that both the real-time thermohydraulic calculations as well as the real-time boiler and turbine efficiency optimizations are combined in one Digital Twin optimization to ensure that production schedules are always hydraulically validated and operators can run their assets closer to the limits to avoid emissions and costs, and guarantee reliability of heat supply.

Keywords: district heating, real-time optimization, digital twin, end-to-end, decision support, CO2 reductions, cost savings, increased profits

Solar Economy team is a research group at LUT University, Finland, focusing on full-sector energy transition. Their work explores the role of renewable energy in achieving sustainable, carbon-neutral energy systems.

Impact of solar photovoltaics on the energy-industry transition in the Nordics

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The Nordics are committed to establish sustainable energy-industry systems in near future. The energy systems of Denmark, Norway, Sweden, Finland and Iceland are going through an accelerated energy transition (ET) reducing the use of fossil fuels and upscaling renewable energy (RE) capacities. Currently, hydropower, bioenergy, and wind power play a key role in the ET of the Nordics but declining costs of solar photovoltaics (PV) position it as a viable additional option. To examine the role of solar PV, five scenarios were studied with LUT-ESTM in country resolution and exchange with entire Europe: Best Policy Scenario (BPS) for a cost-optimised ET towards self-sufficient carbon neutrality by 2050; lower and higher shares of PV (BPS_lowPV, BPS_lowWind); e-fuels imports from outside Europe (BPS_Imports); accelerated ET for defossilisation by 2040 (BPS_2040).

In all scenarios renewable electricity becomes the main supply for primary energy demand (PED) (Fig. 1). In the BPS, PED reaches 2600 TWh by 2050, though in the BPS_lowWind the overall PED is substantially lower as Nordics lose its role as energy exporter to the EU and even less in the BPS_Imports as e-fuels are imported from outside EU. In the BPS, PV represents 53% of capacities (443 GW utility-scale and 72 GW rooftop) and 27% of supply (629 TWh) (Fig. 2). The BPS_lowWind represents the highest PV share in capacities (70%) and supply (41%) with lower absolute values, as electricity costs increase by 13% (Fig. 3) and Nordics' e-fuels lose its competitiveness in EU and exports reduce. Results show that the optimal share of PV in the Nordics supply mix can reach 27% with 62-63% from wind power. Optimal operation of PV and wind power, supported by flexible bioenergy and hydropower will provide the Nordics with low-cost energy and enable exports to neighbours. Reduction or increase of PV shares leads to smaller changes in electricity cost, but may threaten Nordics' potential to maintain itself as energy exporter.

Keywords: solar photovoltaics, energy transition, Nordics, LUT-ESTM, renewable energy, e-fuels, wind power, LCOE

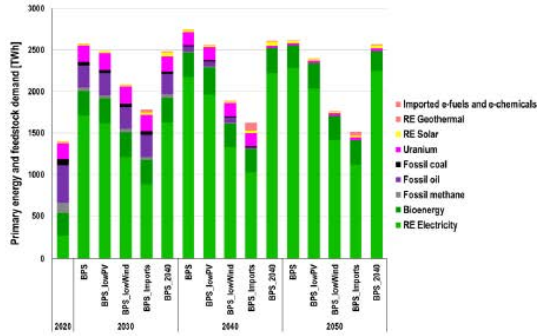


Figure 1. Primary energy and feedstock demand in the Nordics.

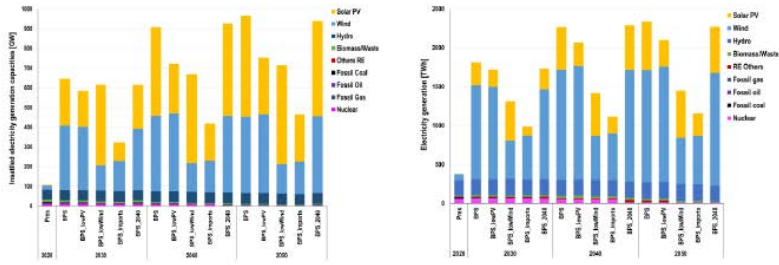


Figure 2. Installed electricity generation capacity (left) and electricity generation (right) in the Nordics.

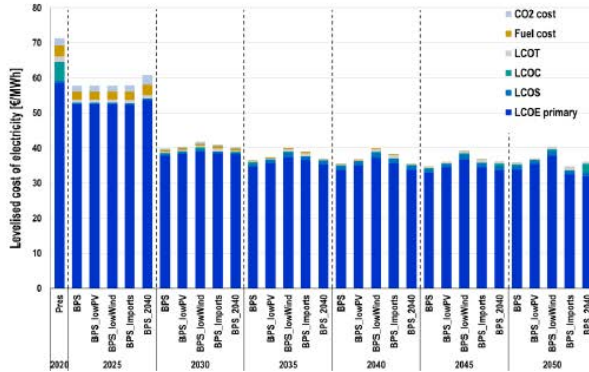


Figure 3. Levelised cost of electricity in the Nordics through the transition among different scenarios.

Planning and organisational challenges for smart energy systems and district heating

Abdulraheem Salaymeh, Research Associate, specializes in heat supply concepts, renewable energy, and waste heat recovery. Proficient in heating network modeling, various software, and programming languages for geospatial analysis.

Techno-Spatial Evaluation of the Practical Usability of Industrial Waste Heat in Urban Heating Systems

1,2) *Abdulraheem Salaymeh*

1) *Stefan Holler*

2) *Irene Peters*

1) *HAWK University of Applied Sciences and Arts*

2) *HCU HafenCity University Hamburg;*

Abdulraheem Salaymeh (presenter)

The transition to a climate-neutral energy system demands a significant increase in renewable energy and waste heat sources within smart and multi-energy systems. Industrial excess heat is advantageous due to its higher temperatures and lower integration costs, making it an attractive option for reducing carbon emissions in heating supply systems.

This study evaluates industrial waste heat potential in Germany, comparing literature-based methodologies with newly available operational data. The primary research question is: How do real-world operational data compare with theoretical estimates, and what are the practical implications for integrating industrial waste heat into urban heating systems?

Initially, technical potentials are calculated using literature-based values for facilities regulated under the EU Emissions Trading System (EU ETS) and electricity-intensive companies under the Special Equalisation Scheme (BesAR). These sites are georeferenced using the Google Maps API and spatially intersected with surrounding buildings to estimate the technically usable heat potential. The study incorporates actual operational data from the German Federal Office for Economic Affairs and Export Control (BAFA), covering waste heat reports from over 3,000 companies, totalling 171 TWh annually. A techno-spatial analysis is conducted using GIS tools to assess the practical usability of industrial waste heat, considering proximity to buildings, heat demand, building typology, and renovation status.

The results show that the practical usable potential is about half of the initially calculated technical potential, primarily due to significant distances between heat producers and consumers. Approximately one million buildings could be supplied with industrial waste heat,

depending on their renovation status. Around 45% of these buildings were constructed between 1949 and 1978, indicating the required supply temperatures for these buildings.

Keywords: Building Typology, Energy Efficiency, EU Emissions Trading System (EU ETS), Heat Demand, Real-World Data, Special Equalisation Scheme (BesAR)

Andreas Müller is lead researcher and co-managing director of e-think energy research. His research focuses on efficient and renewable energy systems, energy economics, modelling and policy for space heating and for district heating.

The potential of local heat networks in the city of Vienna

Marcus Hummel, Mostafa Fallahnejad, Andreas Müller, e-think energy research; Lukas Kranzl, Nirav Patel, Aadit Malla, TU Wien – EEG; Eva Wiechers, Jakob Worm, PlanEnergi

Andreas Müller (presenter)

Heating and cooling (H&C) planning has become a recognised approach to advance the decarbonization of H&C in cities. In 2024, the city of Vienna published the Vienna Heating Plan, a plan for decarbonising its H&C systems until 2040. In this plan, the city territory was divided into three different types of regions: 1) regions where the main district heating network (DHN) already exists or will be expanded, 2) regions where individual supply will most likely be the best solution, and 3) regions where local network solutions could be a meaningful option. Nonetheless, the question persisted, which types of local networks could potentially be used in the latter areas, and which areas are more suited for certain types of networks than others.

This work presents an analysis of the potential for local H&C networks in the city of Vienna. It starts with a definition of local H&C network concepts and a compilation of existing examples. This step is followed by a GIS-based analysis of the suitability of these concepts in the territory of Vienna, in which the main DHN will not be expanded. In a first step, the technical analysis considers the demand for H&C in the buildings and related peak loads, as well as potentials for local renewable resources like boreholes, groundwater, PV, PVT, solar thermal systems and air source heat pumps, as well as the heat from return pipes of the main DHN. The suitability of different concepts is further specified taking into account potentials for renovation as well as economic indicators like costs for pipes and supply systems as well as necessary adaptations in the buildings itself.

The results of the work show in which areas of the city, which of the defined concepts of local H&C networks might be suitable under different framework conditions. It also shows selected building blocks with conditions that more often occur in the city, and which potential local network solutions might be followed more frequently in the territory of Vienna.

Keywords: Local heating and cooling planning, low temperature district heating, thermal networks, cold heat networks, technical potential, economic characteristics, network concepts

Anna Lackner works at AIT Austrian Institute of Technology in the Center for Energy since 2020. She is part of the Integrated Energy Systems Unit, focusing on energy scenarios and system planning. Anna is completing her Master's in Energy Engineering at Montanuniversität Leoben.

Decarbonization Pathway Optimization and Risk Assessment for District Heating applied to a Polish Case Study

Anna Lackner, Austrian Institute of Technology; Nyasha Greco, Austrian Institute of Technology; Ralf-Roman Schmidt, Austrian Institute of Technology; Daniel Schwabeneder, Austrian Institute of Technology; Gerhard Totschnig, Austrian Institute of Technology

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To meet the EU's climate neutrality targets by 2050, district heating systems must transform toward climate-neutral solutions. Achieving this transition requires the identification of optimal, long-term investment pathways that consider both economic efficiency and potential uncertainties.

This study presents a deterministic investment optimization for a district heating case study in Poland using IESopt, AIT's in-house energy system modeling and optimization tool. IESopt enables the optimization of complex, multi-carrier energy systems across different sectors. The model assumes perfect foresight and risks are considered via a Monte Carlo Simulation.

In the first step, the supply side of the district heating network is modeled, incorporating both existing and potential future heat sources such as large-scale heat pumps, industrial waste heat, and biomass boilers. Several scenarios are defined to evaluate the impact of different strategic approaches: a base case, a biomass-reduction case, a temperature-reduction case, and a seasonal-storage case. For each scenario, an investment pathway is optimized through 2050, in alignment with the EU Energy Efficiency Directive.

To address uncertainty, such as fuel price volatility or biomass availability, key parameters are analyzed and assigned probability distributions. A quantitative risk assessment using a Monte Carlo Simulation is then conducted to assess the robustness of the optimized pathways. Finally, each investment strategy is evaluated based on its economic performance and associated risk profile.

Keywords: District heating, Investment optimization, Risk, Perfect foresight, Pathway Model, Monte Carlo Simulation

PhD cum Laude, is Associate Professor in Smart Energy Systems for the Built Environment at Tor Vergata University of Rome, Italy, dealing with innovative energy systems across several scales. He has been awarded as the Best Young Researcher in Hydrogen Technologies 2023 and in Building Science 2022.

Renewable District Cooling by leveraging renewable energy sources via advanced energy storage systems

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Renewable District Cooling (RDC) systems have currently limited applications and full deployment due to the almost absence of cold sink from whom deliver low cost or free cold energy to final users and the concept of cooling services as individual service.

As a matter of fact, energy planning is facing challenges in the general Renewable Heating Cooling applications but where waste heat is already available to be integrated in the local energy systems. The growing concern for the climate change and worsening of heatwaves and urban heat island effect is pushing for dedicated cooling service planning.

The article explores how to leverage renewable energy sources to meet the growing global demand for air conditioning via master-planning including advanced energy storage technologies from electric to thermal systems to ensure continuous, efficient and low cost operation.

Scalability and ability to connect diverse end users as different kind of buildings (residential, commercial and industrial) will enable the optimal time and amount of use to keep fully renewable the cooling supply of the district.

A case study is presented to present numerical values of RDC performance.

Keywords: District energy systems, Sustainable Cooling, Cold energy storage, Energy planning.

Bent Ole Gram Mortensen is a professor of Law at the University of Southern Denmark. He has more than 30 years of postgraduate experience with a background in law firms, the oil industry, the Danish Ministry of Justice and the university sector.

Price caps as part of the green transition

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As part of the green transition, successive Danish governments have implemented a number of measures to reduce the use of fossil fuels. This is, for example, the case in building heating, which traditionally represents a significant part of energy consumption in the Danish latitudes. Among other things, incentives have been given to replace gas with district heating.

District heating in Denmark is considered a natural monopoly area, and legislation has for decades contained price regulation provisions that are intended to protect district heating customers against monopoly exploitation.

In order to further protect (potential) district heating consumers against high district heating prices, two different price caps have been introduced in the district heating sector in recent years. One had only a very short lifespan, and the other is possibly more of a price cap in name than in benefit.

This paper will analyze the use of price caps in Danish heat supply legislation.

Keywords: Price cap, consumer protection, green transition

Clara Büttner is working as a researcher in the field of power grid modeling based on open source tools and open data since 2020. In her PhD project, she focuses on the optimal use of flexibility options from the sectors electricity, heat, mobility and gas at different grid levels.

Open source tools and data for cross-sectoral grid planning on all voltage levels

*Clara Büttner, Flensburg University of Applied Sciences and
Katharina Esterl, Europa-Universität Flensburg and
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The electricity grid infrastructure currently represents a significant constraint in the ongoing energy transition in Germany. It is imperative that the grid demonstrates adaptability to address novel demand patterns emerging from coupling other sectors such as heat and mobility, as well as the variable output of renewable energy plants. Concurrently, the roles of distribution and transmission grids are undergoing a period of transition. The primary function of distribution grids, which was originally to deliver electricity from transmission grids to consumers, is evolving to adapt to the integration of distributed generation.

However, as the sectors become increasingly interconnected, a variety of flexibility options become available that can reduce the need to expand the grid infrastructure.

Presently, the coordination of generation dispatch is executed in a top-down manner. The coordination of decentralized flexibility options remains to be resolved. The prevailing discourse on these matters frequently utilizes price-based mechanisms, thereby perpetuating a top-down approach that fails to account for grid bottlenecks.

To enable the analysis of the impact of these approaches, the open source tool eGo and a comprehensive open data model have been developed. The tool incorporates methodologies to quantify the expansion requirements of the grid at all voltage levels, taking into account flexibility options from the sectors of electricity, heat, gas, and mobility.

The spatially and temporally high-resolution data model offers a representation of the energy system in Germany by the year 2035.

Case studies have demonstrated that, while top-down dispatch optimization is effective for transmission grids, it can result in higher investment needs in the infrastructure of distribution grids. Future research will explore possible solutions for the effective use of flexibility options that support all grid levels.

Keywords: Energy system planning, Sector coupling, Open Source Tools, Open Data

She holds a Ph.D. in Chemical Engineering, an Executive MBA, and a diploma in Leading Sustainable Management. She works at Euroheat & Power, with expertise in EU projects, sustainable development, and fostering impactful collaborations in the district heating and cooling sector.

Empowering the DHC Sector: Focus on Education and Skills

1) Connie Ocando, EHP 2) Aksana Krasatsenka, EHP 3) Sara Comparetto, EHP 4) Martin Stroleny 5) Gabriele Pesce, EHP

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Decarbonising the district heating and cooling (DHC) sector is essential to achieve Europe's climate and energy goals. Yet this transition is not only technological but also human. A skilled, adaptable workforce is crucial for planning, building, and operating sustainable DHC systems. Two EU-funded projects from the Euroheat & Power / DHC+ platform, Skills4DHC and DHC Academy, tackle complementary aspects of this challenge.

Skills4DHC, a consortium of training organisations and industry, strengthens the DHC workforce by developing 13 targeted training programmes for diverse profiles, from staff in DHC enterprises to white-collar civil servants. The programmes cover topics such as decarbonisation of existing systems, renewable integration, waste heat use, and systems efficiency. Piloted in six European countries, the project also delivers a transnational framework for broader EU uptake.

DHC Academy, a consortium of labour market actors and education and training providers, builds a collaborative alliance, as well as an innovative and sustainable digital platform connecting higher education (HE) and vocational education and training (VET). It develops modular curricula aligned with labour market needs and EU policies such as the Green Deal and the European Skills Agenda. The project reflects the cross-sectoral distinctiveness of DHC, integrating green, digital, and resilience skills into an innovative educational framework that captures cutting-edge knowledge and research on district energy.

In this presentation, we will explore the purpose, approach, and expected outcomes of both projects, as well as their role in enabling smart energy systems and technologies such as 4th-generation DHC. Together, these initiatives drive institutional and organisational change, encouraging utilities, municipalities, and educators to adopt continuous learning, agile practices, and digital innovation.

Keywords: education, training, skills, workforce, digitalisation, innovation, decarbonisation

Daniel's research focuses on economic, planning and financial aspects of heating. After his PhD in flexible district heating from Technical University of Denmark and postdoc focusing on energy economics, he now leads a project on district heating finance at Lund University and Energy Modelling Lab.

Financing district heating investments

Daniel Møller Sneum, Lund University/Energy Modelling Lab; Luis Sánchez García, Halmstad University; Urban Persson, Halmstad University; Kristina Lygnerud, Lund University; Tobias Popovic, Steinbeis Transfer GmbH; Kenneth Karlsson, Energy Modelling Lab; Marion Lois Tan, Energy Modelling Lab; Till Benbrahim, Energy Modelling Lab

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Since its commercial inception in the late 1800s, district heating (DH) has made slow and steady strides. Currently, it meets 9% of global heating demands in buildings and industry, with Europe leading at 13% adoption. By mid-century, Europe could see DH covering up to 48% of its heating needs. Historically, DH expansion has grown by approximately 1%-point per decade, but achieving the 2050 potential requires, theoretically, increasing this to 1%-point annually. The estimated investment needs for European DH deployment towards 2050 varies. Mathiesen et al. (2023) estimates 685 billion EUR at 48% market share, illustrating the challenge and opportunity for the DH and investment communities. Our research bridges these two communities by interpreting financial structures for DH and deriving recommendations.

Through a comprehensive literature review and interviews with 31 experts, we identify key financial frameworks and data points, such as capital costs. These frameworks are analysed, using a high-resolution city model within the TIMES framework, focusing on investor and policy-relevant outcomes, including CO₂ emissions, fuels, costs, and financial metrics.

Initial findings suggest that existing DH infrastructure aligns well with the infrastructure asset class, offering stable and low returns. However, new DH systems are seen as riskier, potentially facing higher initial capital costs, which could hinder the projected 48% market share expansion.

Risk mitigation in the design and operational phases helps attract investment and reduces capital cost. During the design phase, economic derisking can be achieved through public risk-sharing (e.g. guarantees), such as blended finance, or access to low-cost capital. Regulatory derisking can involve zoning or phasing out competing heat sources. The operational phase, akin to lower-risk brownfield systems, can focus on managing operational expenses and revenues through long-term contracts, diversification, and stable regulation.

Keywords: district heating, funding, financing, investment, economics

Daniel Zinsmeister works at Stadtwerke München GmbH on a detailed geoinformation system, which was used for Munich's local heat transition planning. Prior, he did his PhD on innovative district heating networks and their integration into a smart energy system at the Technical University of Munich.

Transforming the Heating Sector: A Techno-economic Analysis of Munich's Local Heat Transition Planning

Daniel Zinsmeister, Stadtwerke München GmbH;

Maik Günther, Stadtwerke München GmbH;

Andreas Müller, e-think energy research

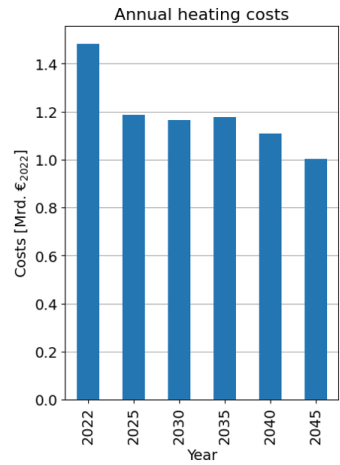
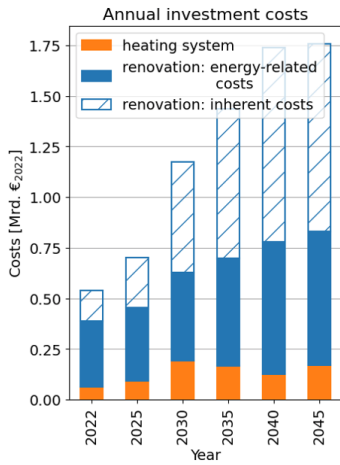
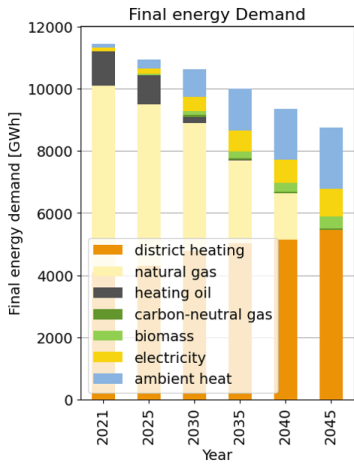
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The transformation of the heating sector is a central pillar for successfully converting the energy system and achieving national climate goals. The German government emphasizes the urgency of this transition with a target to exclusively use renewable energy sources and unavoidable waste heat in the heating sector by 2045. To facilitate this transformation, a law has been introduced mandating local heat transition planning, providing residents with a clear framework for making informed decisions regarding heating solutions. These local heat plans consider local conditions and residents' needs to ensure efficient, environmentally friendly, and socially equitable heat supply.

Munich's local heat planning utilizes the Geographical Information Systems (GIS) based data model "Modell München", developed by Stadtwerke München. This model integrates comprehensive information on building structures, energy consumption, energy carriers, and existing district heating infrastructure. Additionally, it includes planned extensions of the heat network and building-specific deployment potentials for various heat pump technologies. To simulate the development of the heating sector, the agent-based simulation model "Invert/EE-Lab" is employed. This model utilizes the "Modell München" data alongside embedded price assumptions and policy measures to simulate the future heat supply system. Each building is represented by an agent making investment decisions based on available technologies, heat generation costs, and specific preferences.

The analysis for Munich indicates a significant investment requirement for transforming the existing building stock. By 2045, cumulative investments of €17.8 billion (in 2022 values) are necessary, with €3.6 billion designated for the conversion of heating systems and €14.2 billion for the energy-related costs of building renovation. These costs are offset by long-term savings in heat generation and a CO₂-neutral heat supply for Munich by 2045.

Keywords: local heat transition planning, techno-economic analysis, Geographical Information Systems (GIS) based data model, agent-based simulation



Dietrich Schmidt is affiliated with the Fraunhofer Institute for Energy Economics and Energy System Technology (IEE) in Kassel/Germany. He works as Manager of innovation Field Decentralized Flexibility – Digitalization Heat Infrastructures in the Department Energy Informatics and Information Systems

PERSPECTIVES ON THE DIGITALIZATION OF THE DISTRICT HEATING SYSTEMS

Dietrich Schmidt, Fraunhofer IEE & Michele Tunzi, DTU

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Decarbonizing our heating infrastructure has become critical for the green transition, aiming to address climate change while ensuring fair energy costs for consumers. District heating (DH) systems offer a opportunity to support this transformation, thanks to their ability to harness and distribute energy from diverse sources. Unlocking the full potential of these systems requires more than technical adjustments. As DH networks grow more complex and flexible, digital technologies are becoming the backbone of smarter, more responsive energy systems. From optimizing system performance to integrating low-carbon heat sources more effectively, digital tools are key enablers of an efficient, resilient, and climate-friendly thermal energy future. Digitalization supports improved system management, enhances operational efficiency, and facilitates the integration of low-carbon energy sources. However, despite its high potential, the development and deployment of digital solutions in DH networks remain at a relatively early stage. In most cases, their application is still limited to pilot projects or specific system components rather than being fully embedded across the entire network. Recognizing that digitalization will play a central role in optimizing system operation and enhancing energy efficiency across production, distribution, and end-use levels, a new initiative has been launched that provides a concrete response to many of the named challenges, offering a structured framework to advance digitalization in DH systems. While digital technologies have already shown promising results in isolated applications, broader deployment remains limited. The mission the initiative is to promote more cooperative efforts in the digitalization of district heating while providing a forum for global knowledge sharing.

The presentation gives insieds to IEA DHC Annex TS9 “Digitalisation of District Heating and Cooling - Improving Efficiency and Performance Through Data Integration”.

Keywords: digitalization of district heating, operation and maintenance, business processes and models

Eike Schuler recently obtained his master's degree at the Technical University of Darmstadt. In his thesis at the Energy Information Networks and Systems Lab he focused on two-stage robust optimization of the urban heat sector.

Do common multi-stage energy planning models underestimate regrets in the face of long-term uncertainties?

Eike Schuler, Technical University of Darmstadt. Carolin Ayasse, Technical University of Darmstadt. Florian Steinke, Technical University of Darmstadt.

Eike Schuler (presenter)

A key challenge in the decarbonization of the urban heat sector is the robustness of decisions to long-term uncertainties such as energy prices. Decisions have to be close to the optimal outcome across a range of possible future scenarios, thereby minimizing regret, which refers to the additional costs arising from unexpected future developments.

In this study, we use a linear optimization framework with multiple investment periods to evaluate the regret of short-term decisions under long-term uncertainties, including CO₂ constraints, energy prices, and generation potentials in the urban heat sector. We implement a two-stage robust approach, where robust short-term decisions are made in the first stage and long-term decisions are determined in the second stage based on different scenarios. An evaluation model is introduced to compare the regrets of different short-term decisions under a range of possible future scenarios.

First, in a minimal case study, both robust and naïve decisions under perfect foresight in the first stage result in immediate, extensive investments after the realization of uncertainty in the second stage, as well as low regret. Due to constraints, such as the limited availability of skilled workers for heating system replacement, this level of flexibility to react to new developments is unrealistic. By limiting the system's flexibility by introducing investment constraints, the regret increases to a level that reflects the intensity of the current political debate. Second, in a real-world case, restricting investments also leads to an increase in regret, but to a lesser extent. This raises the question of whether we often overestimate the adaptability of energy systems to unforeseen events and therefore underestimate regrets. Consequently, careful consideration of factors that may limit system flexibility is essential when working with multi-stage energy planning frameworks.

Keywords: urban heat sector, uncertainty, regret, robust optimization, multi-period investment

Enric Gonzalez is a research assistant in the SEP group at Aalborg University. He holds a MSc in Sustainable Cities and a BSc in Energy Engineering from Universitat Politècnica de Catalunya. He conducts research on Smart Energy Systems contexts and modelling.

Key findings on organizational and planning challenges across different actors on PEDs

Enric Gonzalez Gonzalo, Jens Iuel-Stissing, Kristian Borch, Aalborg University

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Positive Energy Districts (PEDs) have been promoted as a key component in the decarbonization of cities by the European Commission. PEDs are envisioned as new paradigms in urban energy governance that signifies a shift from a centralized to a decentralized energy systems giving citizens the possibility to generate, self-consume, store, and sell renewable energy at the scale of the urban district. The ultimate ambition of PED strategies is to develop low carbon urban districts that produce more energy than they consume combining sectors like electricity, heating, and mobility - and at the same time contribute to balance production and consumption within the district.

The practical implementation of PEDs thus seeks to promote new 'district level' engagements among established urban energy system actors – including utilities, urban authorities and housing owners. Engagements defined by a commitment to the 'the district' is, however, likely to be incompatible with a range of the engagement that these established actors are already part of. Actors engaging in PED strategies are thus likely to experience contractions among their conventional energy system engagements and new engagement concerned with producing, sharing and balancing energy as district scale

In this study we investigate how such tensions are practically articulated by actors involved in PED conversation in Copenhagen. We conclude that actors tend to remain more committed to their established energy system engagements than to potentially new 'district' level ones promoted by the PED concept. This indicated that effective implementation of PED strategies requires a very high coordination between energy system actor's established engagements and concerns and PED strategies.

Keywords: Positive Energy Districts, stakeholders, urban governance, smart energy systems, renewable energy, network,

Eric Schulze Berge is a PhD student at the Institute of Power Systems Engineering of the University of Wuppertal developing cross-sectoral operating and planning principles for quarter energy systems in the research project "NeuPlan"

Peripheral integration of medium voltage network structures within the framework of automated greenfield power network planning

Eric Schulze Berge, University of Wuppertal, Wiebke Gerth, University of Wuppertal, Marius Güths, Stadtwerke Bielefeld, Markus Zdrallek, University of Wuppertal

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Due to the complexity and potentials in planning an integrated energy infrastructure, especially when developing new quarters, a structured and integrated approach is necessary. This becomes even more crucial with the increasing integration of new loads and generators in these quarters, as their reliable and efficient incorporation into the peripheral structures must be ensured. Therefore, a method is presented, which determines the optimal integration of new secondary substations into the existing medium voltage (MV) network taking into account all potential n-1 failures. Further, the method is developed as part of an overarching, novel methodology for automatically determining an integrated energy network for a new quarter.

According to this methodology, first the new quarter is clustered into low voltage (LV) network supply areas, for which optimal trench structures with minimal overall length are determined, along with suitable locations for secondary substations. Using these positions and considering their simultaneous supply task, a network topology is selected based on the thermal current limit of standard cable types to be utilized and the resulting maximum load in case of a n-1 failure. Therefore, the method distinguishes for the MV network topologies between a single ring or two rings, which are switched open in normal operation, as well as a three-legged structure against an opposing station with two open switches in normal operation. Each of these structures guarantees to maintain the supply of each secondary substation in case of failure of any line.

Furthermore, the voltages can be utilized for planning the following individual low voltage networks. Thus, the methodology considers a cross-voltage level perspective in planning integrated and optimized network structures for a new quarter. Due its seamless integration into the overall automated planning process, the method enables an efficient and reliable peripheral integration of new quarters.

Keywords: Greenfield Planning, Distribution Networks, Energy Infrastructure

Assoc. Prof. Dr.-Ing. Fabian Ochs studied Energy Engineering at TU Berlin. After completing his doctorate at Uni Stuttgart, he went to Uni Innsbruck in 2009. He researches and teaches in the areas of energy-efficient buildings, HVAC technology, RE and energy storage. He is also contract Prof at FUB.

Design Workflow for Optimized Heat Pump Systems for Positive Energy Districts

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A Positive Energy District (PED) is a vision aiming at supporting the energy transition in cities based on improved technologies and planning processes. With highly efficient buildings, with efficient heat pump (HP) systems and on-site RE a net positive energy balance is possible for new buildings even in cold climates. However, in existing or in high-density districts, reaching PED on the footprint can be very challenging. In addition, the degree of freedom of design is significantly higher and the planning of HP systems is far more complex.

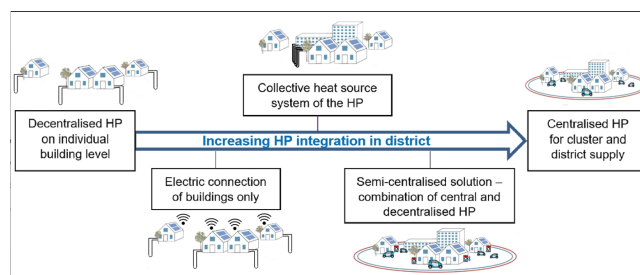
Depending on climate and type of buildings (residential, non-residential) the HP system has to cover different energy needs on different temperature levels such as space heating (SH), domestic hot water (DHW) and space cooling (SC). Depending on the load and the HP source availability on site (or nearby) different HP system design and integration options are available:

- Central, one per district
- Semi-central, central low temperature HP + decentral booster HP on building or flat level
- Decentral, building-wise HP
- Mixed, e.g. central for SH, decentral for DHW

This contribution focuses on the HP system design for PEDs with different design options and boundary conditions (source availability and temperature) considering local constraints such as space limits or sound emissions. The design workflow follows the cost-optimality approach as suggested by the EPBD. While decentral HPs feature generally the best system performance (lowest thermal losses, best HP performance), they compete with central systems with presumably lower invest costs. Decentral booster HPs allow for lower distribution temperature and could be interesting in PEDs with an inhomogeneous building structure.

A workflow is proposed to support decision-making in terms of cost-optimal design. It can serve as a basis for a future integral planning approach. Case studies from Germany (Quarree100), Austria (Campagne) and Switzerland (Papieri) serve as examples.

Keywords: Positive Energy Districts, Heat Pump Systems, Pre-Design, Workflow, Optimization



Postdoctoral fellow in the Department of Mechanical Engineering at the University of Ferrara. The main research topics are:

- Design and optimization of multi-generation energy systems.
- Hydraulic energy storage and recovery for power generation purposes.

Energy and economic analysis of technologies suitable for energy transition in the hospital sector

1) Giulia Anna Maria Castorino, Università degli Studi di Ferrara; 2) Lucrezia Manservigi, Università degli Studi di Ferrara; 3) Pier Ruggero Spina, Università degli Studi di Ferrara; 4) Mauro Venturini, Università degli Studi di Ferrara.

Giulia Anna Maria Castorino (presenter)

Energy transition and decarbonization are the guiding principles of European policies of the last years. The energy sector, which accounts for both production and consumption, focuses its efforts to reach decarbonization targets.

This work explores the electrification and the decarbonization challenges in the hospital sector, by upgrading the existing energy systems that meet the energy demand of hospitals. The energy analysis considers replacing current fossil-fuel-powered systems with renewable energy technologies. Photovoltaic systems and green hydrogen are also included to increase electrification and meet the electrical, thermal, and cooling energy demand. The economic analysis evaluates the investment feasibility by evaluating different plant configurations that are compared by means of economic metrics (e.g., net present value). The energy and economic investigation targets the sizing and the operation optimization of the upgraded multi-generation energy system (MES) plant by means of the implementation of a combination of two algorithms. The best sizing is identified by using surrogate modeling optimization algorithms (SMO), while the smart management strategy of MES operation is identified by using MILP algorithm. A case study of a hospital located in Italy is used to validate the proposed approach. Although decarbonization is a central aim of energy transition, it is crucial to emphasize that ensuring continuous energy supply also requires storage and/or backup systems powered by fossil fuels to quickly respond to any disruptions caused by the inherent intermittency of renewable energy sources.

Keywords: Renewable energy, Energy storage, Decarbonization, Sizing and operation optimization.

She is a research engineer with a doctoral degree in energy economics from the Technische Universität Wien. Her research focus is the European decarbonisation of space heating performing techno-socio-economic analysis through data analysis and energy optimisation modelling.

Applying Monte Carlo to assess district heating decarbonisation strategy risks: first insights of the Vienna case study

Iná Maia Novak (AIT), Nyasha Greco(AIT), Daniel Schwabeneder(AIT), Stefan Strömer(AIT) and Ralf Roman-Schmidt(AIT)

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Vienna's district heating energy operator supplies about 460,000 households and generates annually about 6,000 MWh of thermal energy. In 2021, about 50% of the thermal energy was generated by a gas combined heat and power generation plant. The local energy supplier company (Wien Energie) has set goals to decarbonize the thermal energy generation by 2040 through a mix of measures: expansion of geothermal and high-capacity heat pumps, introduction of carbon capture technologies, installation of green gas power station, use of energy storage and low temperature district heating network. The present work aims to investigate the decarbonization strategy uncertainties by performing Monte Carlo Simulation combined with the optimization model IESopt for generic energy systems analysis (Integrated Energy System Optimisation)(Strömer & Maggauer, 2024). The deterministic Monte Carlo approach is a mature and well-established method to assess system's uncertainties (Janssen, 2013). However, it has the disadvantage of requesting high computational effort to achieve a desired accuracy level. Then, the main challenge of the present work is the trade-off between feasible computational performance and meaningful results. Expected outcomes are the identification of the higher risks in terms of electricity energy price volatility, CO2 tax introduction and energy demand decrease through retrofitting and/or climate change. Furthermore, we aim to prove and discuss the application of the Monte Carlo Simulation to assess risks related to European energy supplier's district heating decarbonization strategy. The present work is part of the EU funded project ENABLE DHC that aims at fostering the transformation of district heating and cooling networks according to the Energy Efficiency Directive by developing investment plans.

Keywords: District heating decarbonization, uncertainties analysis, optimisation model

Jacob Estevam Schmiedt is a physicist and leads a team in the field of buildings and districts at the German Aerospace Center. He specializes in data-driven approaches and innovative measurement methods to assess the energy performance of existing buildings for design and operation purposes.

Data for Optimizing Heat Supply Systems in Existing Districts

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The planning and modernization of heat supply systems in existing districts rely heavily on high-quality data about the building stock. Heat demand densities are a minimum requirement for designing heat networks. Moreover, knowledge of the efficiency status of individual buildings is crucial for determining required supply temperatures, potential reductions in heat demand through future retrofits, and the likely connection rate of buildings to a heat network. To address this, we combine data from various sources to obtain this information with high accuracy and minimal investment of time and resources.

Our harmonization process integrates 3D data from public surveying offices, OpenStreetMap, the federal census, regional cadastres, and earth observation data – all of which are freely available in many European countries. Machine learning models are employed to fill data gaps and disaggregate information that is only available in aggregated form. This chain of data cleaning, harmonization, and building classification generates the input for heat demand calculations without the need for on-site inspections.

In this contribution, we treat this purely remote analysis as a baseline and explore how it can be extended by data from thermographic drive-through assessments. A car-mounted multi-sensor system equipped with a thermography camera captures a series of images, location and time stamps, and potentially additional data. An automated processing pipeline evaluates the recorded data and estimates the insulation quality of all building facades visible from the streets. This approach enables the estimation of the efficiency and retrofit status of each building for entire districts or towns using real on-site data with minimal human labor. By combining these datasets, we can provide the high-quality information required for district energy concepts and heat network planning, ultimately supporting the development of more efficient and sustainable heat supply systems.

Keywords: heat network design, heat demand, open data, thermographic survey, machine learning, retrofit status, efficiency, automation

Jakub Skórczynski is a PhD student at the University of Southern Denmark Esbjerg at the Department of Law. The topic of Jakubs thesis encompasses regulation of personal data and non-personal data in the context of the European energy sector with a particular focus on the European Energy Data Space.

Cyber Resilience Act and NIS2: Two legislative initiatives on cybersecurity that might change the way we work with smart energy systems

1) Jakub Skórczynski 2) University of Southern Denmark, Department of Law

Jakub Skórczynski (presenter)

The purpose of this abstract and presentation is to propagate knowledge about EU's two legislative initiatives in the form of Cyber Resilience Act (The 'CRA') and NIS2 directive (The 'NIS2'). The legal acts were adopted by the European Union in 2023 and 2024 and are currently in the process of being applied into national legislation.

The significance of this paper follows the fact that the CRA and NIS2 shall be regarded as key elements in EU's legal approach to cybersecurity in the future. The reason behind this is that both legal acts can be considered as derivatives of the significant advancements in the field and represent a need for a high level of cybersecurity across critical sectors. The requirements set out by CRA and NIS2, will be relevant for majority of actors that develop, distribute or use smart energy systems.

To ensure a broader understanding of the legal acts, the presentation will encompass the main legal requirements set out by CRA and NIS2 by presenting them in a context of different types of smart energy systems.

This includes a presentation of the CRA, which imposes the stringent cybersecurity requirements set out for all products with digital elements and software. The regulation inter alia imposes the implementation of security measures in the whole lifecycle products, mitigation of vulnerabilities and the use of cyber security standards for products and software. The NIS2 Directive broadens the scope of security requirements on companies in critical sectors. This directive sets out requirements for the security of network and information systems in companies, by addressing relevant technical and organisational measures.

In conclusion, the understanding of CRA and NIS2 might be crucial for ensuring robust cybersecurity in smart energy systems. This follows the fact that the legal requirements imposed by the two legal acts can affect many actors but also, be a driver for innovation in the digital transformation of the energy sector.

Keywords: Cybersecurity, Legislation, NIS2, Cyber Resilience Act, Energy systems, IoT, EU Law,

Jan Markowski is a PhD candidate at the AGH UST Doctoral School, Discipline of Environmental Engineering, Mining and Energy. His scientific activities include compressed air energy storage, energy efficiency of air expanders and their development.

Intelligent energy management in compressed air energy systems on the base of inverse problem solving

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The initiative of the “European Green Deal” and energy policy framework enforce the transformation and operational improvement of the industry sector towards climate neutrality. Compressed air covering up to 10% of electricity consumption in the industrial sectors is widely used as energy source in industrial applications. However, despite its benefits, compressed air remains the most expensive among standard industrial energy utilities because of its low efficiency from 10-15% .

An energy audit aimed at improving efficiency, can be conducted by performing measurements of parameters in local scale of pneumatic components to monitor industrial energy consumption and identify inefficiencies. Assessing variables such as pressure, temperature, and mass flow rate provides valuable insights into system performance and potential areas for optimization. This data-driven approach allows for targeted improvements, ensuring that the system operates at optimal performance levels while minimizing energy waste. However, in many cases, the measurements required for the analysis cannot be performed. This limitation arises due to the lack of access for installing sensors directly inside the chambers of pneumatic components with variable volume, where the work is performed.

This paper presents a thermal model of gas expansion dynamics along with experimental studies. The methodology for temperature measurements and the approach for determining the temperature inside pneumatic components using the inverse problem method are introduced. An analysis was conducted on the relationship between the temperature of the air exiting the chamber and the internal temperature of the pneumatic component. A semi-empirical method was applied to decipher the temperature inside a constant-volume chamber by examining its dependence on the gas temperature at the outlet of the exhaust port. This model can be used to predict the temperature inside a chamber where direct measurement is not feasible.

Keywords: Compressed air , Energy audit, Inverse problem, Efficiency

Jelena Ziemele is a senior expert at the "Riga Energy Agency" with broad experience in thermal engineering. Her professional interests relate to energy systems and their transformation into smart energy systems.

Achieving Carbon Neutrality in District Heating: Lessons Learned from the Climate City Contract of the City of Riga

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The ambition to reach climate-neutrality by 2030 drives the urban decarbonization strategies, particularly within the energy sector, including district heating (DH) systems. As part of the EU Mission for 100 Climate-Neutral and Smart Cities—and to obtain the EU Mission Label—Riga has developed a Climate City Contract outlining its commitment, targets and actions, and earmarking investments.

Riga's climate goals include reducing CO₂ emissions from its DH system by 48% by 2030 compared to 2019 levels, which equals an 87% reduction compared to 1990. To meet these ambitious targets, Riga's DH system is set to undergo a significant transformation through the adoption of several technological solutions: sector coupling and electrification of the DH system, such as deploying high-capacity heat pumps and hydrogen; integration of biomethane into the gas supply; development of CO₂ capture technologies; and other net-zero emission technologies.

The aim of this study is to address the decarbonization challenge through a quantitative analysis, establishing economic, environmental, energy, diversity, and social indicators using a bottom-up approach. Simultaneously, the study adopts a top-down approach to analyze national policies and assess their impact on the city's ambition to develop a CO₂-neutral DH system.

The transformation of the DH system involves all stages—heat generation, transmission and distribution infrastructure, and end-use consumption. The measures outlined in Riga's Climate City Contract demonstrate that each stage plays a crucial role, specifically: transformation and efficiency improvements of heat sources contribute to a 65% CO₂ reduction, distribution system upgrades account for 1%, enhanced energy efficiency at the consumer level contributes 24%, and improved public engagement add another 7%.

The research also provides recommendations for scientists, urban planners, and policymakers involved in guiding the transition of DH systems toward climate neutrality.

Keywords: District heating, decarbonization, energy transition, climate neutrality, techno-economic analysis, energy policy, climate city contract

Johan Granberg is a foresight and scenario analyst with RISE, focused on the future of energy and other critical systems. Trained as an industrial engineer at Chalmers University of Technology and as a military intelligence officer, he is also a PhD candidate at the Swedish Defence University.

ELECTRICITY GRIDS IN ENERGY ISLANDS – A FUTURE SCENARIO ANALYSIS WITH CYBER SECURITY IMPLICATIONS

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The integration of intermittent renewable energy sources, extreme weather impact, and evolving geopolitical tensions are challenging the stability of transmission grids. In response, there is a trend toward developing island-capable microgrids, particularly in Sweden, where the concepts of societal resilience have gained renewed importance. Microgrids, capable of operating independently from the main grid, are seen as vital for providing resilience in the face of growing threats. Technologically, island-capable grids can range from basic reserve power systems to configurations that allow seamless de- and resynchronization.

Research funded by the Swedish Energy Agency explored the future of energy islands and associated cyber security risks. The study employed classic scenario analysis augmented by “the Futures Triangle”, drawing on expert workshops to identify and analyse critical variables of future grids: intermittent renewable energy sources and smart demand-side control systems. A second workshop assessed cyber security implications of the different scenarios.

The analysis revealed that both variables are likely to increase mid to long-term, due to cost, convenience, and technological advancements. However, these trends bring cyber security risks, as previous research on smart grids have indicated. As interaction between devices increases, the potential for remote access is a significant risk. Municipal grid operators do not have internal expertise to assess or remedy these risks.

While costs have historically slowed the development of rudimentary island-capable grids into smart grids, it is now feasible to do so. However, the associated costs are dependent on the security measures that are implemented and maintained, thus giving perceived room for savings if these risks are not understood. Addressing cyber vulnerabilities is crucial for the sustainable and secure advancement of energy islands, particularly as they become a cornerstone of modern energy systems.

Keywords: Microgrids, Smart grids, Energy islands, Cyber security, Scenario analysis, Foresight

Jonathan Hachez works on multi-energy systems optimization, with a focus on uncertain energy demand modelling. With a strong background in data management and optimization, he studies the uncertainty of the demand on an optimal system sizing.

Methodology to develop an investment plan for heating and cooling systems under climate uncertainty

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Today, over 5 billion people face at least 100 more annual cooling degree days than they did 40 years ago. In parts of Europe, the increase exceeds 55%, largely because these regions were previously less exposed. Despite this rapid change, most European households and many tertiary sector buildings are still unprepared for rising cooling demand. A key reason is deep uncertainty: projections for the next 30 to 50 years vary widely across shared socioeconomic pathways. As a result, decision makers face unclear signals, delaying the adoption of effective adaptation measures.

To address this limitation, we developed a method for long-term investment planning under climate uncertainty. We start by generating a thermal demand model using climate projections from the Copernicus Institute and integrating it into an energy system optimization model. Using multi-stage optimization, we identify early investment decisions that can adapt over time through recourse actions.

Our case study focuses on a university campus (Vrije Universiteit Brussel) in Brussels, Belgium, which currently lacks adequate cooling infrastructure. The results provide a stepwise investment strategy that stays cost-effective across a wide range of climate futures.

Keywords: climate change, heating systems, cooling systems, uncertainty, multi-stage optimization

Kai Droste focuses on sustainable heating and cooling supply for the neighborhoods of tomorrow. He emphasizes integrating sustainable energy sources into cold district heating networks, focusing on geothermal sources.

Determining the potential of very shallow geothermal collectors in Germany

Kai Droste, Rahul Karuvingal, Jonas Klingeiel - RWTH Aachen Institute for Energy Efficient Buildings and Indoor Climate

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Given the climate goals, the demand for renewable heat sources and the decarbonization of district heating (DH) networks in Germany are becoming increasingly important in light of climate targets. Very shallow geothermal (VSG) energy can contribute to the transformation of the heating sector and the reduction of greenhouse gas emissions. However, a comprehensive analysis of the underlying potential is currently lacking. The aim of this study is to fill this data gap by estimating the technical potential of VSG energy for integration into existing district heating networks for the supply of residential buildings. VSG energy via ground heat collectors is a space intensive technology. Therefore, a spatial comparison between heating networks and nearby available open spaces is crucial to assess the potential for integration.

Based on the recently published building and housing census of 2022, a methodology using clustering algorithms was developed to identify district heating networks in Germany. The heat demand of the networks is estimated using heat density maps and calibrated with a special evaluation by the statistical office in Germany. To determine the heating potential for VSG collectors supplying existing DH networks, the Corine land cover database was used to identify available open spaces surrounding the network through a proximity search. Heat pumps were then used to elevate the temperature level from the soil to a usable level for the DH network.

The results demonstrate that the developed methodology is robust and can be applied nationwide across Germany. However, key characteristics of the heating networks, particularly network temperatures and hydraulics, could not be incorporated due to a lack of data. Overall, about 22% of the domestic heating demand for DH networks in Germany can be met by the use of VSG collectors in combination with a heat pump.

Keywords: District heating networks, Very shallow geothermal energy, retrofitting of existing networks, geothermal potential analysis, horizontal ground heat exchanger

Since 2022, Katharina Esterl has been working as a researcher in the field of open power grid modeling. In her PhD project, she focuses on the complexity management for cross-grid level optimisation of open sector-coupled energy system models.

Importance of integrating models within a broader systematic perspective when planning local energy systems

Katharina Esterl, Europa-Universität Flensburg. Carlos Andrés Epia Realpe, Flensburg University of Applied Sciences. Clara Büttner, Flensburg University of Applied Sciences.

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In the analysis of local energy systems, the overall systematic perspective is frequently overlooked. In both scientific and practical contexts, the planning of medium and low voltage grids is often conducted without considering upper grid levels. This oversight is particularly critical given new requirements arising from fluctuating renewable generation across all grid levels and increasing sector coupling, which introduce new demands and flexibilities, particularly at lower grid levels.

This work aims to demonstrate the importance of integrating local energy systems within the broader systemic perspective and proposes a methodology for considering the supra-regional system following open science strategies.

A local sector-coupled energy system in the village of Dörpum in northern Germany is analysed. A biogas plant functions as the central electricity and heat supplier. The community endeavours for self-sufficiency, integrating renewables along with exploiting various flexibility options, such as heat pumps.

In order to facilitate the integration of the local system within the supra-regional grid, a 'zooming' approach is employed. This aggregates the upper grid in Germany based on the distance of the grid nodes from the local system. Consequently, the local system is optimised taking into account the upper grid levels and therefore applying a macroeconomic perspective. A comparison is made between the results obtained and those achieved through optimisation from a local techno-economic perspective without considering the supra-regional system.

The results show that the prevailing market conditions render it more viable to utilise the biogas plant for the base load coverage of the self-sufficient system. In contrast, from a macroeconomic standpoint, the flexibility of biogas plants in electricity generation holds significant value for the energy system, as it contributes to the integration of fluctuating renewable generation and to a reduction in overall costs.

Keywords: Energy system planning, Local energy systems, Macroeconomic perspective, Complexity reduction, Open source and open data

Lars Goray is a mechanical and energy engineer and has been working at Münster UAS since 2023. He works in the field of “Integrated Energy Systems”, particularly on the development of “F|Heat”, a software ecosystem for municipal heat planning.

F|Heat – An Open Software Ecosystem for Municipal Heat Planning

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Municipal heat planning is a critical tool in the transition toward greenhouse gas-neutral energy systems, yet small and medium-sized municipalities often lack the technical and financial capacity to implement comprehensive solutions. Germany is beginning to establish regulatory and methodological standards through the Heat Planning Act (WPG).

In terms of heat planning, F|Heat adopts a holistic approach that accelerates the overall process by bridging knowledge gaps and enabling faster access to professional software solutions. The technical design can then be carried out through seamless interoperability with established engineering tools.

F|Heat provides a free and open-source extension to the GIS platform QGIS, enabling municipalities and planning authorities to develop local heat plans. It facilitates the integration, aggregation, and visualization of essential geospatial data in alignment with the WPG §§ 14–15 and § 18.

F|Heat is composed of three functional modules F|Heat.map, F|Heat.net, and F|Heat.tec, integrated within a unified QGIS interface:

F|Heat.map automates the import and enrichment of spatial data such as building footprints, parcels, and roads, alongside census-based heating fuel types. It leverages open data sources (particularly from North Rhine-Westphalia) and applies national heat planning guidelines to compute metrics such as district heating suitability.

F|Heat.net uses dedicated algorithms to model district heating networks, identifying optimal routing paths between heat sources and demand nodes based on pipe length.

F|Heat.tec supports technical analysis by aggregating annual heating demand, generating load profiles, and producing duration curves. These outputs are designed to calculate the sizing of heat generators in future software versions.

Overall, F|Heat (v0.1.0) lowers the entry barrier for municipal heat planning by combining transparency, automation, and accessibility.

Keywords: Geographic Information Systems (GIS); Heat Planning; Open Source; QGIS; Spatial Data; District Heating Networks

Laura Kuper is pursuing her PhD with Siemens AG in cooperation with TU Darmstadt, researching the design of district heating network topologies in consideration of economic feasibility and sector coupling effects. She earned her master's degree in energy engineering at RWTH Aachen University.

Economic Risk Assessment of District Heating Network Topologies: A Scenario-Based Analysis of Consumer Connection Rate Uncertainties

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In the design of district heating networks, uncertainties regarding consumers connection willingness pose a major risk to economic viability of the networks. The relevance of resulting uncertain consumer connection rates is aggravated by further uncertain parameters, like building costs, as these can be divided by the supplier among the consumers and therefore influence consumer willingness.

Specifically, the network's optimal topology depends on this consumer willingness. Yet, the effect of uncertain connection rates on topology design has been scarcely studied. We therefore present a scenario analysis that studies optimal topologies for different connection rates. We thereby investigate both spatially homogeneous and heterogeneous distribution patterns of connection willingness across a district planned for heating network implementation. The scenarios model consumer willingness in two forms: either as discrete binary decisions or as probabilistic connection likelihoods.

For the analysis, we utilize a computationally efficient graph-algorithm based method to generate near-optimal topologies. We compare the topologies of different scenarios regarding characteristics like costs, revenue, size, and selected connections. We also evaluate the topologies' performances across different scenarios and discuss how to handle uncertain connection rates in topology design. The results show that variances in the expected connection rate especially affect the area covered by optimal topologies. We further point out that efficient topology optimization supports identification of a minimal viable network for a minimal necessary connection rate. Moreover, efficient topology optimization supports the assessment of case-specific risks using scenario analyses and helps derive appropriate design decisions that consider connection rates above the minimum and thereby decrease opportunity costs and enhance utilization of district heating potentials.

Keywords: district heating, network topology design, uncertainty, connection rate, scenario analysis, economic risk, graph algorithms

Lennart Trentmann is a PhD student at the Chair of Energy Systems at the Technical University of Munich researching in the field of urban energy systems with the focus on the heat sector.

Combining High Temporal and Spatial Resolution of District Heating Network Design – A Iterative Approach of DHN and Supply Structure Design

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District heating networks are a promising technology for the supply of heat to densely populated areas, as they offer considerable potential for efficient integration of renewable energy sources. The investment costs of the heat distribution network represent the largest cost factor of a district heating system, which is why precise planning is essential [1]. Optimization methods offer a promising approach for the efficient planning of district heating networks [2]. However, these methods lead to high computation costs for large-scale grids, so that either the temporal or the spatial dimension must be aggregated to reduce run times [2]. The central question that this study seeks to address is how large grids can be designed with both high temporal and high spatial resolution in reasonable computing times [2]. This is of particular importance for district heating networks with seasonal storage. The added value of the seasonal shift of heat can only be displayed in a model with a high temporal resolution. To combine these two resolution criteria, an algorithm that incorporates the advantages of single-node district energy system optimization models (DESOM) with those of graph-based district heating network design formulations is proposed. The fully spatially resolved graph-based DHN design models calculate exact investment costs and optimal economic network expansion while the fully temporally resolved single-node DESOM computes the energy supply costs. Thus, this approach is able to integrate seasonal storage and the associated enhanced utilization of heat sources in the network design.

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Keywords: district heating, mixed-integer linear programming, district energy system, district heating networks, renewable energy

Lisa Hjerrild is an associate professor of energy law and public administrative law at the University of Southern Denmark. Research areas include energy transition, citizens, administrative challenges for the energy sector.

Regulative challenges of energy communities

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The purpose of this contribution is to give a brief overview of the regulatory legal challenges faced by energy communities and citizen-driven energy communities within the European Union (EU). These communities are pivotal in advancing the EU's energy transition goals by promoting local renewable energy production and fostering community engagement. However, their expansion is hindered by various legal and regulatory obstacles that need to be addressed to fully realize their potential. Energy communities are governed by EU regulations, notably the Clean Energy for All Europeans package, which includes directives such as the Renewable Energy Directive (RED II) and the Electricity Market Directive, which both aim to empower citizens and local entities to participate in the energy market, ensuring fair access to energy resources and promoting sustainable energy practices. Despite the supportive regulatory framework, energy communities face several significant challenges that impede their growth and sustainability: Inconsistent implementation of EU directives across member states creates a fragmented regulatory environment, making it difficult for energy communities to navigate and comply with varying national regulations. Furthermore, securing access to the energy grid is a major hurdle for energy communities. Regulatory barriers related to grid connection, such as high connection costs, lengthy approval processes, and technical requirements, can impede the integration of locally produced renewable energy into the wider energy system. Third, Energy communities frequently encounter financial and administrative obstacles that limit their expansion. This abstract underscores the need for harmonized regulatory frameworks, a coordinated effort to harmonize regulatory frameworks, streamline administrative processes, and enhanced support mechanisms to empower energy communities.

Keywords: Energy communities, citizens, planning and organizational challenges

Marja Heikkinen is a doctoral researcher at Tampere University, and she is focusing on her work on energy communities, energy solutions, and sector coupling. She is working on her research in collaboration with an industry partner and the university, as a goal to produce industry focused solutions.

Energy system modelling of urban infrastructures and energy storage – quantifying the impacts of policy (in)coherence

Marja Heikkinen, Tampere University, Tuomas Vanhanen, Tampere University, Hussain Ahmed, Tampere University

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The expansion of energy infrastructures and the electrification of end-use sectors, i.e. sector coupling, are needed to support the growth of variable renewable electricity production. Energy communities development is one way to further advance energy transition as they support sector coupling applications.

However, the regulatory frameworks of electricity, gas, heat, and fuel infrastructures have traditionally been developed in isolation, leading to suboptimization as part of the sector-coupled energy system. The regulation of energy communities can be seen as an advancement towards a more coherent regulatory framework.

Policymakers often seek advice from Energy System Models (ESMs) and advanced analytical tools to assess energy communities under varying operating conditions and to quantify their potential in addressing energy system distribution challenges. However, these models and tools typically lack a comprehensive representation of both policies and infrastructures: the expansion needs of pipes and wires all the way down to people's homes and workplaces and the concept of energy communities.

Therefore, the aim of this study is to demonstrate a techno-economic analysis that considers urban energy distribution infrastructures, energy storage, energy communities, and a selection of related regulatory and policy measures. We utilize an ESM tool to analyze the system cost, emissions, and other indicators of an urban energy system under different policy target scenarios, such as carbon neutrality or self-sufficiency, and compare coherent and incoherent regulatory framework scenarios.

The results of this study contribute to the policy coherence literature by quantifying the potential benefits of aligning the targets of regulatory frameworks across infrastructures. Our results also quantify the range of urban infrastructure expansion costs (although very context-dependent) that can be further analyzed in future ESM studies and to make mature operational decisions.

Keywords: Energy system integration, regulation, energy policy, energy community, infrastructure

CEO of Optit, Italian digital company that develops Decision Support Solutions & Services for the District Energy Industry in the EU and beyond, Matteo Pozzi is serving as Chair of DHC+, innovation and research hub of Euroheat & Power, where he coordinates the Digital DHC Working Group

Bridging the skills and competence gap in District Heating & Cooling: the DHC Academy Alliance

Matteo Pozzi, Optit srl and DHC+ Chair and Marta Cavaleiro

Marta Cavaleiro (presenter)

The District Heating & Cooling industry requires a vast labor force with a wide range of capabilities and skills to ensure operators across the whole value chain can upskill existing staff and recruit new resources to overcome their challenges.

As Education & Training is one of the key pillars of DHC+, the innovation and research hub of Euroheat & Power (EHP), EHP is coordinating the Erasmus+ project “DHC Academy”, which tackles this issue with a systemic approach. The project lasts 3 years starting from February 2025 and will produce both Higher Education and Vocational Training modules to ensure that not only Technical, but also Green, Digital, Resiliency and General skills requirements are available to the DHC Industry.

In this presentation, we will focus on the “DHC Academy Alliance”, a long-term partnership between enterprises, research institutes and universities, with the mission of scaling the DHC Academy project beyond the capability of the consortium partners, to support the development of a modern and sustainable District Heating & Cooling industry in the EU and beyond, based on 2 enablers:

- A Digital Platform, to be developed and perfected throughout the project, to create a virtual arena with a range of functionalities: allow operators find the best training and education solutions to meet their needs; guide young talents access the best universities to become the workforce of tomorrow’s DHC industry; bridge the gap between competence and practice facilitating access to skilled resources to meet the sector’s workforce requirements.
- A DHC Academy Alliance governance model, to set the rules of engagement for high quality academic and professional access to the Platform, in order to provide Education and Training services across the entire EU, with the awareness that local needs have to be met while guaranteeing high quality levels across a wide range of technical, regulatory and operational challenges.

Let us ensure DHC has the skills to grow!

Keywords: Skills, Competences, Green, Digital, Resiliency, Jobs

Oskay Ozen works as a research associate at the Institute for Production Management, Technology and Machine Tools at the Technical University of Darmstadt. His research is focused on site-specific transformation scenarios for producing companies using data-driven simulations.

A Qualitative Investigation of German Manufacturing Companies' Efforts to Incorporate Sustainability Into Production Site Transformations

Oskay Ozen, TU Darmstadt. Michael Frank, TU Darmstadt. Borys Ioshchikhes, TU Darmstadt. Matthias Weigold, TU Darmstadt.

Oskay Ozen (presenter)

As part of the European Green Deal, Germany is committed to greenhouse gas neutrality by 2045. With depreciation tables indicating that new energy systems should have a service life of at least 15 years, and companies aiming for 20-25 years, investments into energy systems in the upcoming years already need to consider climate goals. In the case of systems that are still in use, companies are beginning to future-proof them by planning and executing site transformations aimed at enabling sustainable production. Such efforts are being investigated in the DELTA Energy Laboratory, a city-wide project in Darmstadt that aims for holistic, cross-sectoral energy systems. At the center of site transformations lies an inherent competition for usable space; each successive transformation changes the overall site composition. Despite economic viability having the highest priority for companies, land is nonetheless being allocated to social and environmental measures, such as next generational energy supply systems.

To gauge current industrial efforts for sustainable transformation, a qualitative study with over 12* expert interviews was conducted. The representatives were professionals involved in the fields of site planning, facility management, and sustainability management. The study primarily focused on plans for energy systems and how they interact with available space, supplemented by how land is used for further sustainability measures. Transcriptions of the interviews were coded and analyzed using Kuckartz' qualitative content analysis. The results show proactive engagement by companies to meet climate goals ahead of regional policies. Within this scope, the goal of ensuring economic competitiveness is pursued through a variety of different means, such as security of the energy supply, self-sufficiency, adaptability to new technologies and regulations, and staff retention. Specific measures detailed in the study are generalized for use by other companies.

*17 planned

Keywords: energy efficiency, self-sufficiency, renewable energy, sustainability, adaptability

Ryoga Ono is a Ph.D. student at Tohoku University. His research focuses on energy systems, particularly the integration of sustainable woody biomass into regional energy supply using models like EnergyPLAN to support decarbonization.

Strategic planning for installation of district heating systems in Japan: Opportunities and Challenges

*Ryoga Ono*1, Poul Alberg Østergaard*2, Remi Delage*1, Toshihiko Nakata*1*

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In Japan, district heating systems have scarcely been introduced, except in a few selected areas, mainly due to the frequent occurrence of natural disasters such as earthquakes, which make it difficult to design pipeline-based systems, as well as the lack of existing district heating infrastructure. However, Japan's urban areas have extremely high population densities, indicating a strong potential for district heat demand. Additionally, previous studies suggest that utilizing industrial waste heat for district heating could contribute to a reduction in electricity demand. Furthermore, Japan is expected to face increasing electricity demand in the future due to the expansion of data centers and semiconductor manufacturing, making the role of district heating even more essential in alleviating electricity consumption. This study estimates both the supply potential of renewable electricity and heat sources and the feasible potential for district heating systems, applying EnergyPLAN model to conduct an integrated energy system analysis. Both types of potential are assessed based on geospatial information, and in particular, the feasible district heating potential is derived using 1-km mesh heat demand maps for the residential and commercial sectors. Based on these findings, this study presents a more concrete discussion on the role of district heating in Japan, identifying the scale of potential opportunities and the key challenges that must be addressed for practical implementation.

Keywords: District heating, EnergyPLAN, Renewable energy, Geospatial information, Japan

Saltanat Kuntuarova is a project coordinator and doctoral candidate at the Technical University of Munich (TUM). The primary research focus pertains to the energy market and innovative solutions in the coupling of thermal and electrical grids.

Game-theoretic modeling of energy-sharing communities within integrated district heating and electricity systems

Saltanat Kuntuarova, Technical University of Munich; Peiyao Guo, Technical University of Munich; Prof. Vedran Peric, University of Bayreuth; Prof. Thomas Hamacher, Technical University of Munich

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While the electricity sector is increasingly integrating renewable energy, the heating sector still heavily relies on fossil fuels. District heating (DH) systems are important for climate-neutral energy transitions, enabling close coupling between thermal and electrical systems. Integrating DH and electricity networks supports renewable energy use, alternative heat generation, and system flexibility. This paper introduces a modeling framework for a decentralized energy-sharing community with prosumers in a local market, focusing on integrated electricity and DH systems to enhance sustainability and efficiency.

Our methodology employs a non-cooperative game-theoretic approach for the energy-sharing community within an integrated electricity and heating system, comprising profit-maximizing prosumers and a community manager who seeks to maximize overall social welfare. Each prosumer optimizes electricity and heating consumption to minimize energy exchange and generation costs, while the manager coordinates energy flows and market-clearing prices. This game-theoretic model incorporates quadratic cost functions, ensuring convexity, and proves existence and uniqueness of the Nash equilibrium. The equilibrium solution can be obtained by its equivalent optimization problem.

Additionally, the DH system is modeled using hydraulic and thermal equations to accurately capture heat flow, incorporating quadratic relaxation for pressure dynamics, linearization methods and McCormick relaxations for bilinear terms to ensure computational feasibility. The DCOPF model is used for the electricity system.

The model is tested on an integrated six-bus electricity and three-node DH network. The results show that the framework achieves a unique equilibrium with optimized electricity and heat use, reduced costs, and improved efficiency for the community. The proposed game-theoretic model serves as a benchmark for future energy-sharing mechanisms in integrated DH and electricity systems.

Keywords: Energy-sharing community, game-theoretic model, district heating, integrated energy systems, prosumers

Théodore Fontenaille is a second-year PhD fellow working on heating networks in rural areas, combining technical studies of network dimensioning and analysis of their management processes. He holds a master's degree in energy and has experience at the French Ministry of Ecological Transition.

Rural Heating Networks: A Processual Approach for Overcoming Challenges and Identify Levers

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Théodore Fontenaille (presenter)

Heating networks in rural areas have recently emerged across Europe, but their development remains limited. Yet, they can significantly contribute to reducing reliance on fossil fuels in areas where oil is commonly used for heating. In this context, this study aims to analyse the main obstacles facing rural heating network projects and to identify key levers.

The methodology is based on qualitative research, involving 20 interviews with French private and public stakeholders, from national to local. To enhance robustness, the interview data were cross-checked with secondary data sources. Then, the results obtained were analysed from a processual perspective. Recent literature has already used some timelines. They focused on either the diffusion of innovations or the management of the system, neglecting the project initialisation or the network operation.

Based on it, the analysis suggests a four-step timeline. Each step is characterised by milestones and challenges. This more holistic timeline allows to include future risks in operation phase in the decision-making process. For instance, user disconnections are more detrimental to the economic balance of rural projects, rarely able to reach out to new customers.

Moreover, it highlights the need of funding criteria adapted to rural specificities. The linear heat density criteria is useful and easy to evaluate during the pre-project phase. However, funding threshold can be disputed, particularly in rural areas where installation costs are lower, or if the new generation networks using heat pumps are installed.

Finally, the timeline helps to provide levers for the development of rural networks. The study argues for implementing new appropriate tools, bringing together players together and adopting a broad scale of action. The study suggests general guidance for policymakers and practitioners to facilitate the design and operation of heating network development in rural areas.

Keywords: Timeline, Energy transition, Process, Micro-heating networks, Low densities

Thuvaraahen is an Energy Advisor at the Center of Global Cooperation of the Danish Energy Agency. He has spent most of his career working with the Danish heating sector. He has experience at both the municipal and utility levels.

Strategic Heat Planning for Decarbonisation: Insights from Denmark and Implications for China's Clean Heating Development

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This article investigates how strategic heating planning can support China's carbon neutrality goals, drawing lessons from Denmark. Particularly the long-standing experience with coordinated heat planning. While China has introduced significant policies to decarbonize its heating sector, efforts remain largely focused on technological upgrades and clean energy integration, with less emphasis on spatial planning and policy mechanisms. In contrast, Denmark has prioritised heat planning for over several decades, emphasising sector coupling, heat mapping, and pricing strategies to reduce emissions and enhance efficiency. By analysing the case of a Chinese city, Ulanqab, in Inner Mongolia, this article highlights the need for China to adopt more heat planning frameworks, improve data-driven decision-making, and implement targeted policy instruments. These insights aim to support China's transition to a sustainable heating system and contribute to its broader climate ambitions for 2030 and 2060

Keywords: District Heating, China, Denmark, Multiple heat source design, Heat planning

Tim Mandel is a senior researcher at Fraunhofer ISI in Germany. His research focuses on energy systems modelling and cost-benefit analysis, particularly in the area of decarbonising the building sector through energy efficiency and related electricity and heat infrastructures.

Who pays, who benefits? Multi-stakeholder cost-benefit analysis for strategic heat planning in three German neighbourhoods

Tim Mandel, Fraunhofer Institute for Systems and Innovation Research

Markus Fritz, Fraunhofer Institute for Systems and Innovation Research

Lukas Liesenklas, Fraunhofer Institute for Systems and Innovation Research

Marko Rojnica, Fraunhofer Institute for Systems and Innovation Research

Tim Mandel (presenter)

This contribution presents ongoing research in the Wärme4Alle (Heat4All) project, which identifies optimal renovation strategies for residential buildings in three German cities (Leipzig, Karlsruhe, Bochum). While strategic heat planning is central to building-sector decarbonization, it is often approached from a private or a strictly societal viewpoint. The combination of these perspectives remains underexplored in the literature – partly also within smart energy systems research, where understanding multi-stakeholder considerations (who bears which costs and benefits) and incentive structures are crucial to moving local planning into practice.

Using the building simulation tool SIM-VICUS, we model each building's hourly heat demand and conduct thermo-hydraulic network simulations for potential local district heating. The results inform the newly developed EconHEAT model, which evaluates different neighbourhood renovation options – from building envelope retrofits to heat pumps, biomass, or gas boilers – across multiple perspectives: (i) society (including negative externalities), (ii) tenants (including rent changes), (iii) housing associations, and (iv) owner-occupiers. These perspectives are grounded in cost-benefit analysis literature and stakeholder consultations within Wärme4Alle.

Our results highlight a significant mismatch between the societal optimum (i) and private interests (ii to iv). This suggests that current policy instruments and pricing mechanisms in Germany insufficiently reward low-carbon, energy-efficient solutions such as centralized heat pumps. We also find strong evidence of a landlord–tenant dilemma: while housing associations (iii) can pass some costs on to tenants (ii), misaligned incentives hamper deeper retrofits. We conclude that policy reforms, targeted subsidies, and innovative financing are essential to align stakeholder interests and fully leverage smart energy systems in residential neighborhoods.

Keywords: strategic heat planning, cost-benefit analysis, renovation, district heating, heat pumps, external costs

Verena Alton is a researcher at the Austrian Institute of Technology with a background in mathematics and computational science. She focuses on sector coupling, energy system modelling and forecasting algorithms to accelerate renewable integration and industrial decarbonisation in the EU.

Early-stage techno-economic assessment of DHC networks and individual systems - The FAST-DHC web-tool and its application to an Austrian case study

Verena Alton, Austrian Institute of Technology GmbH; Oddgeir Gudmundsson, Danfoss A/S ; Henrique Lagoeiro, London South Bank University; Graeme Maidment, London South Bank University; Catarina Marques, London South Bank University; Alessandro Maccarini, Aalborg University; Nicolas Marx, Austrian Institute of Technology GmbH; Ralf-Roman Schmidt, Austrian Institute of Technology GmbH;

Verena Alton (presenter)

The FAST DHC (Feasibility Assessment Tool for District Heating and Cooling) project, funded through the IEA DHC Annex XIV, has developed a publicly available web-based tool for early-stage techno-economic assessment of heating and cooling systems. This presentation will present the final version of the FAST DHC tool and demonstrate its use through a live case study.

The tool allows a quick comparison between 4th generation district heating (4GDH), thermal source networks (TSNs) and individual solutions for heating, cooling and domestic hot water (DHW). Designed for planners, municipalities and consultants, it supports early decision making through simplified input. To make the tool usable where little system-specific data is available, it includes a range of default values for technologies, demand assumptions and costs, which users can refine as more information becomes available.

To reflect the seasonal mismatch between supply and demand, the tool uses four representative time steps, one for each season. Unlike many existing planning tools, cooling is an essential component. With rising temperatures and the increasing use of low-temperature solutions, this has become a key consideration for long-term planning.

The system model is structured in layers that include supply, transformation, distribution, storage and demand. Results are presented in terms of comparative indicators such as levelized energy cost and total annual cost. Users can test different scenarios by adjusting boundary conditions, tariffs and technology options.

A live demonstration of an Austrian case study shows how the FAST DHC tool can help identify cost-effective configurations in real-world conditions. By making early-stage comparisons easier and more transparent, the tool aims to support the wider adoption of

sustainable heating and cooling solutions in both emerging and established markets.

Keywords: District heating and cooling, techno-economic assessment, planning tools, 4th generation (4GDH), thermal source networks, low temperature networks, individual H&C Systems

Viktoria Illyés is a research engineer in the Competence Unit Integrated Energy Systems at the AIT Center for Energy. She works on projects in the field of district heating and integrated energy systems with a focus on low-temperature systems.

Adopting low-temperature heating and cooling networks in the core of sector-coupling energy communities: a multidisciplinary task

Viktoria Illyés, Ivan Mariuzzo, Nyasha Greco, Bernhard Mayr, Edith Haslinger, Ralf-Roman Schmidt, Branislav Iglar; Austrian Institute of Technology (AIT)

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The building sector has yet to be revolutionized to achieve climate neutrality by 2040. Low-temperature networks seem attractive from a technical standpoint – they utilize low-grade heat, offer cooling, enable the integration of (thermal) storages and flexibility to the grid through sector-coupling.

However, perhaps precisely because of the many available options, potential energy communities face multidisciplinary challenges when implementing sector-coupling.

So far, efforts have been limited to individualized solutions, often centered around a specific technical component, typically the balancing components on the heating side – namely heat pumps or thermal storage options. Standardization could be organized in a cellular system (Lehmann et al. (2019)), in which grids and platforms connect energy community participants physically and virtually.

Another challenge is the regulatory framework. Energy communities, as per the European Commission, are either citizen energy communities (CEC), where participants share electricity with no geographical limitations, and renewable energy communities (REC), who also share heat from renewable sources. In the latter, two worlds meet: 1) the highly regulated and financially-centered electricity-based CEC and 2) unregulated heating cooperatives, with financial gain being not the primary focus, according to the Austrian legislator, while looking back on a rich history in the district heating sector.

Current research projects lean towards a more integrated approach covering techno-economics, standardization of concepts or business models (Reis et al. (2021)), legal, financial, and organizational guidelines.

This contribution presents a structured overview of the barriers potential sector-coupling energy communities face and solutions to address them. Selected case studies will be used to illustrate solution options.

Lehmann et al. <https://doi.org/10.1109/EEM.2019.8916358>

Reis et al. <http://dx.doi.org/10.1016/j.rser.2021.111013>

Keywords: Decentralized district heating, energy communities, sector-coupling

Wiebke Gerth is a PhD student at the Institute of Power Systems Engineering of the University of Wuppertal developing cross-sectoral operating and planning principles for quarter energy systems in research project "NeuPlan"

Automated planning of multiple-supply heating networks within the framework of greenfield planning

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The complexity and opportunities involved in planning integrated energy infrastructure, especially when developing new quarters, make an integrated approach essential. This is necessary for planning electricity, heating and gas networks and it is important to consider requirements for a climate-neutral heat supply, such as those outlined in the Buildings Energy Act of Germany.

In this contribution, a method for calculating multiple-supply heating networks is presented. The first step involves dividing the new quarter into different heating network areas based on an automated clustering process. This process considers the potential of each heat source to meet supply requirements of connection areas (e.g., buildings or parking lots). Spatial relationships from a development plan or municipal heat planning serve as input parameters for clustering. The identified heat clusters form the basis for detailed planning of heating networks.

For each cluster, the optimal routing of the heating networks is calculated, with the goal of minimizing the total trench length. Additionally, ideal locations for the respective heat sources in local heating networks are determined. As part of the method for analyzing multiple-supply heating networks, a heating network is initialized which distributes the total mass flow based on the heat supply potential of the considered heat sources. The method evaluates whether the implementation of a multiple-supply heating network offers advantages over a single-supply heating network. The use of multiple-supply heating networks can reduce trench lengths and prevent the parallel routing of multiple heating systems along the street. This contributes to a more efficient and cost-effective network infrastructure.

The presented method can be used to expand existing automated planning of heating networks. This allows a systematic analysis and evaluation of additional solutions, from both an economic and a technical perspective using a bottom-up approach.

Keywords: Greenfield Planning, Heating Networks, Energy Infrastructure

Renewable energy sources and waste heat sources including PtX for district heating

Alisson is a Mechanical Engineer with a PhD in Energy Conversion Systems from Universidade Federal de Itajubá, Brazil. His research interests primarily focus on Carbon Capture, Utilization, and Storage (CCUS) and Hydrogen Energy, aiming to decarbonize energy and industrial systems.

From Carbon Neutrality to Negative Emissions: Evaluating the Impact of CCUS on Energy Systems and Power-to-X supply

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Carbon capture systems are crucial for achieving carbon management goals in Denmark. This study is based on the simulation of a post-combustion CO₂ capture process using chemical absorption with a 30% MEA solution in Aspen Hysys® v.11, evaluating the thermal and electrical demands across the capture, compression, and transport stages. Different capture rates are analysed to reflect scenarios of carbon neutrality and negative emissions, assessing the energy demands of integrating CCUS into industrial sites and its impacts on regional and municipal district heating networks and electricity grids. Furthermore, the study examines how varying capture rates affect CO₂ availability for Power-to-X applications. The results provide insights into the trade-offs between energy consumption, costs, and system-wide benefits, highlighting their influence on the integration of CO₂ capture technologies into existing infrastructure. This work contributes to the discussion on the feasibility and economic viability of large-scale carbon capture deployment in energy-intensive sectors, besides underscoring the role of CCUS in mitigating industrial emissions while enhancing energy system flexibility and ensuring a stable CO₂ supply for PtX.

Keywords: CCUS, Power-to-X, Cement industry, Carbon Neutrality, Negative Emissions

Christian Schützenhofer works at the Austrian Institute of Technology within the Center for Energy on aggregate Industry decarbonization models and net zero energy systems.

Excess heat availability from a net zero emissions industry: sector-specific potentials considering widespread electrification and carbon capture

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We present industry-subsector specific excess heat potentials for utilization in district heating networks under the assumption of a net zero emissions industry. We formulate these as percentage values based on current low, medium and high temperature heat demand. From a bottom-up, technology based analysis of current and probable future production and auxiliary technologies we derive excess heat in theoretic, technical and economic potentials. Main game changers from a current perspective are additional heat demands from carbon capture and synthetization of hydrocarbons, diminished sources from heat recovery via heat pumps and new, mostly low temperature sources from electrolysis and CO₂ condensation. Naturally, we find still high excess heat use potentials in the energy intense industry ranging from [“work in the finishing phase, specified until June”] % to [“-“]%, but very limited ones in the non-energy intense industries due to efficiency gains from direct and indirect electrification. We estimate a total excess heat economic potential of the European industry of [“-“] TWh per year. This potential is [“-“]% of the values given in the literature for currently employed technologies. This significant reduction we attribute to the gap between technical and economic potential opening up wider because of excess heat largely offered on lower temperature levels which cannot be compensated by lower district heating network temperature levels.

Works originate from the Heatmine DH project. We build on Manz et al. 2021 for current technology specific excess heat potentials who find a halving of the potential assuming full energy efficiency rollout in the industry. We projected future technologies based on previous work of Böhm et. al for estimating potentials. We do not replicate geographical matching as Manz et. al found a 98% overlap of potential sources with potential DH areas exceeding demand of 500 GJ/hm² within 10km.

Keywords: waste heat, excess heat, industry, sector-specific, net zero industry

Dagnija Blumberga is the director of institute of Energy Systems and Environment. She has experience in developing renewable energy resources and energy efficiency research.

Gaseous Bioresources Towards Climate Neutrality

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Gaseous bioresources play the most important role in replacing fossil natural gas towards climate neutrality. This is especially important in technological processes with special requirements for gaseous fuel use.

In European countries with a developed natural gas long pipeline network, it is important to transform the energy systems following sustainability principles. To carry out such a task, it is necessary to consider the entire broad spectrum of gaseous bioresources: biogas, biomethane, bioethanol, biohydrogen, and biogenic CO₂. Each has a different composition, physical and chemical properties, heat value, price, application, and environmental and climate impact.

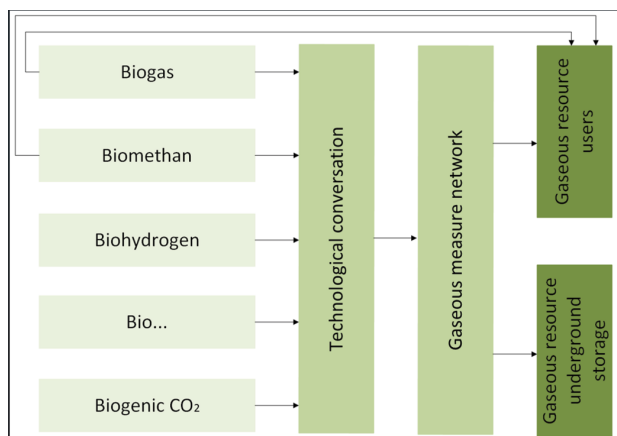
The use of gaseous bioresources depends on factors such as adapting consumers' technologies, the necessary capital investments and operating costs, the combustion process emissions, the greenhouse gas reduction potential, and the social aspect (employment and reduction of imports).

The study is based on the example of Latvia, which is characterised by a developed network of natural gas pipelines and underground storage.

A multi-criteria decision-making analysis (MCDA) is finalised. Its results show that adding biomethane into existing natural gas pipelines is the closest to the ideal solution.

Analysis of reduction of GHG emissions for four scenarios presents a comparison of potential solutions.

Keywords: Gaseous bioresources, biohydrogen, biomethane, biogenic CO₂, multicriteria analysis



Experienced energy consultant and PhD researcher specializing in energy system modelling with an emphasis on district heating and renewable energy integration. Proficient in project management and development of international project consortiums.

Participation of district heating systems in balancing power markets via power-to-heat technologies

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The growing share of variable renewable energy sources in power systems calls for increased system flexibility to ensure stability and reliability. District heating systems have been identified as a crucial solution for facilitating the integration of demand response technologies, enabling participation in power balancing markets and the provision of essential flexibility services. Beyond conventional cogeneration plants, power-to-heat technologies—such as heat pumps and electrical heaters—can be coupled with thermal energy storage systems to further enhance flexibility. These technologies can be utilized in both power spot and balancing market operations, providing district heating operators with new revenue streams that can support the decarbonization and modernization of heating networks.

This study aims to conduct a comprehensive techno-economic analysis of various district heating technologies that provide flexibility services. The analysis will be conducted at a case study level, taking into account multiple factors, including the technical configurations of the proposed solutions and the regulatory frameworks in place. Screening of national legislation and transmission system operators' (TSOs) boundary conditions, such as market participation rules and financial incentives, will also be performed to determine the feasibility and potential profitability of district heating participation in balancing markets.

The use of modeling tools such as energyPRO will enable the simulation of various technology scenarios, offering insights into operational strategies and potential economic benefits. The study's results will inform recommendations for optimal implementation scenarios, identifying the conditions under which district heating systems can effectively participate in the balancing market.

Keywords: district heating, power markets, optimisation, energy systems modelling, power-to-heat technologies, heat pumps, thermal storage

Rikke is a mechanical engineer with a specialization in sustainable energy. She is a PhD fellow in the Section of Thermal Energy at DTU working with the thermal energy processes within CCUS transport infrastructures by evaluating these from energetic and economic perspectives.

A techno-economic analysis of infrastructure for CCS: Can biogas facilities benefit from a shared CO₂ conditioning system?

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Negative CO₂ emissions are necessary to reach the Danish climate goal. Several methods for achieving negative emissions exist, of which bio-energy carbon capture and storage (BECCS) is one promising solution. The Danish biogas facilities hold an estimated potential of 1.3 Mt CO₂ per year in 2040 and can contribute to achieving negative emissions. CO₂ separation is already implemented in 80 % of the biogas facilities. The remaining challenge is to determine how the CO₂ is conditioned and transported to a storage site in the most cost-effective way as the CO₂ potential is distributed on more than 50 minor remotely located sources. Co-utilization of infrastructure is expected to yield economic benefits and be more efficient than single-source to single-sink transportation, especially for small emitters such as biogas facilities.

Through a techno-economic analysis, this study evaluates the costs associated with liquefaction and purification of CO₂ from one biogas facility in a shared conditioning system at a nearby plant. The costs are compared to a fully decentralized system. The required subprocesses were modeled in thermodynamic modeling software, and fit-for-purpose cost functions were used for each of the subprocesses based on detailed evaluation regression, literature, supplier information, etc.

The analysis showed that it is economically beneficial to utilize a shared system for distances between the two plants of up to 10 km when the nearby plant has a sufficiently large capacity. For the smallest plants with emissions of 4000 t CO₂/year, the centralized system can be more economically beneficial for distances up to 20 km. Additionally, the analysis was extended to consider several biogas facilities in a limited geographical area in Denmark. It was evaluated where the centralized system should be located considering the location and sizes of the biogas plants. Furthermore, the possibility of sector coupling to local district heating systems was considered.

Keywords: CO2 conditioning, CO2 liquefaction & purification, shared infrastructure, techno-economic analysis, biogas, BECCS

Sander Dijk, M.sc. started his Professional Doctorate (<https://www.vereniginghogescholen.nl/professional-doctorate-faq#watispd>) in 2024 in enlarging biomethane production with a focus on the gas infrastructure, by making interventions in complex business practices.

Balancing the energy system: a system-integrated approach to enlarge biomethane feed-in capacity into the gas infrastructure and reduce fossil fuels

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Transmission System operators (TSOs) and Distribution System Operators (DSOs) are facing large growth of biomethane injection in their gas infrastructure in the coming years, as the EU set the production target to 35 bcm in 2030 (4 bcm in 2024). This injected biomethane has the same quality as natural gas and can serve as a direct sustainable alternative for it. This has advantages because the existing gas infrastructure can be used and no equipment adjustments are required at the end user. As part of the EU target for biomethane, The Netherlands has set the target to 2 bcm in 2030 (0.29 bcm in 2024). There are some challenges to achieve that goal, such as the disbalance of supply and demand. The most commonly used production method is the fermentation of biomass through a constant process, while the demand for it largely depends on the demand from heating purposes. This could lead to a surplus of biomethane at times of low demand, such as during the summer period, especially when production meets the 2030 target. As with the electricity grid, it is important to maintain the balance in the gas grid and measures will have to be taken to prevent a surplus of biomethane from arising.

Using a simulation method based on hourly data from two regional DSOs from the Netherlands, we investigated a possible solution to tackle the surplus of biomethane by converting it into electricity at times when the electricity grid is fed with electricity from fossil fuels. Results show significant growth of 50 to 100% in annual biomethane injection capacity, reducing dependence on fossil fuels in both gas and electricity infrastructure. These results are in line with the aim of the Multi-Commodity Energy System concept, in which synergies are achieved by integrating multiple energy carriers. Based on this research, a pilot project will be started to evaluate this in practice.

Keywords: Biomethane, gas infrastructure, decentral production, distribution system operator, flexibility, multi-commodity energy system, balancing, multi-energy system, feed-in capacity

Smart energy system analyses, tools and methodologies

Abdul Azzam, M.Sc., researches decentralized intelligent systems at the University of Stuttgart. His focus areas include simulation, modeling, optimization, and control engineering, with a research emphasis on Model Predictive Control.

A Model Predictive Control Framework for Integrated Thermal and Electric Systems in Multi-Energy Grids

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The heating sector remains a major obstacle to decarbonization, with renewable integration still lagging behind the power sector. Cross-sector synergies between thermal and electrical grids hold significant promise, yet realizing their full potential is hampered by renewable intermittency, demand uncertainty, and the complexity of coordinating assets such as combined heat and power plants, heat pumps, and storage.

This work addresses these challenges by presenting a unified Economic Model Predictive Control (EMPC) framework for the coordinated, market-driven operation of multi-energy systems. Existing approaches often neglect the interdependence of heat and electricity networks, leading to missed flexibility and under-utilized resources. The proposed EMPC integrates linearized models of thermal storage and district heating networks with reduced-order representations of electrical grids in a single real-time control architecture.

Key innovations include:

- (i) Co-optimization of power plants, heat pumps, and both battery and thermal storage to leverage complementary flexibility;
- (ii) Cross-domain balancing strategies that address renewable variability and market signals;
- (iii) Convex cost formulations supporting low-carbon, economically efficient operation.

Additionally, a distributed optimization approach based on the Alternating Direction Method of Multipliers (ADMM) is employed, making the framework suitable for large-scale decentralized multi-energy systems.

Simulation results show that joint optimization of electric and thermal grids significantly enhances the exploitation of flexibility, improves renewable integration and demand response, and reduces reliance on fossil fuels. The approach is computationally tractable and supports real-time use in campus-scale energy systems. This scalable framework presents a critical step toward integrated, sustainable thermal and electrical infrastructure in support of decarbonization targets.

Keywords: Economic Model Predictive Control, Multi-Energy Microgrid, Energy Management, Renewable Energy Integration, Market-Driven Optimization

Alejo Silvarrey holds a Ph.D. in Sustainable Development from Deakin University, Australia. Currently a researcher at DeustoTech, he specializes in environmental monitoring through remote sensing techniques and the development of decision-support applications for urban planning.

Ilsim: an source to source compiler of industrial process simulation models

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Alejo Silvarrey Barrufa (presenter)

Modeling the industrial sector in Energy System Models (ESM) presents significant challenges due to its inherent complexity and heterogeneity. Top-Down models have been the usual way to represent the industrial sector. In these models, the energy consumption of the industry is derived as a function of overall economic activity, energy prices, incomes, and the costs of other production factors. Computable General Equilibrium (CGE) models, which use input-output tables representing inter-sectoral economic flows are then used to find a market equilibrium, often by maximizing overall economic welfare (or consumer utility) or minimizing the total cost of meeting demands across the economy.

The major drawback of CGE models is their lack of technological detail and the need to use low spatial and temporal resolution. Specific industrial processes were generally not explicitly represented and this made it difficult to accurately model the effects of technology-specific interventions. Furthermore, purely economics modeling usually leads to the violation of fundamental physical laws. Moreover, when considering higher spatial and temporal resolutions, CGE models will collapse into a modeling of a single or a very few industrial sites which no longer fulfill their general hypothesis.

In order to overcome these problems we present here a bottom-up approach based on a data model plus a source to source compiler. Each industry is splitter into a list of industrial sub processes that could be represented in a text file by a list of recurrence equations that relates the input materials and energy requirements to their industrial outputs and wastes. The compiler translates this set of equations into computer code allowing consistency checks and other optimizations. Following this approach, the system acquires highly modular options allowing it to simulate different industrial technologies available in both soft and hard link optimization scenarios.

Keywords: Industrial modeling, data model, source to source compiler.

She specializes in the field of waste heat recovery, its utilization, and thermal energy storage. Their work focuses on developing and implementing innovative solutions for capturing excess heat from industrial and energy processes.

Experimental Investigation of a PCM Storage Unit with Process Visualization

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Industrial waste heat recovery starts to play a significant role in reducing CO₂ emissions and the consumption of primary fuels. The current work is focused on a low-temperature waste heat accumulation in PCM storage and its possible management.

This article presents thermal profiles for the charging and discharging phases inside a PCM storage unit supplied with low temperature heat (max. 70°C). The profiles were measured using a dedicated testing and demonstration facility, which was built using copper pipes and it was equipped with a multiple-camera setup enabling a visualization of the storage tank's operating modes. The storage tank is composed of one module which is formed by concentric transparent tube filled with a phase change material and inner copper pipe with water flowing inside the tube. The selected materials have a phase change temperature range of approx. 50-60°C. A water heater tank with the volume of 35 L was applied as the heat source for the PCM system. The working medium supplying/receiving heat was water, which circulated in a closed circuit where the water flow was forced by a pump.

Moreover, a comparable analysis of heat storage technologies based on water and PCM was performed, and the areas of industrial applicability of PCM were discussed.

The presented work is part of a PhD project realized within the industrial doctorate programme concerning waste heat recovery and its further accumulation.

Keywords: PCM, waste heat, heat storage, visualization

Allan Iraqi is a Ph.D. candidate in Energy and Processes at Mines Paris – PSL in collaboration with Kipsum. His work focuses on the modeling and optimization of district heating networks, combining physical modeling and energy efficiency.

A generic substation heating power forecasting approach using machine learning

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To improve the energy performance and decarbonize the district heating (DH) systems, optimal control of systems is essential. A better energetic control of DH networks requires the forecast of the heating demand in substations. Among Machine Learning (ML) methods, regression techniques have found especially useful in short-term heat demand forecasting for DHNs, identifying patterns that assist in optimizing energy distribution.

This study aims to provide a robust and generic approach to build statistical predictive models applicable to diverse building types. First, the selection of features is analyzed, and then various machine learning models are explored such as Artificial Neural Networks (ANNs), Linear Regression (LR), Ridge Regression (RR), Support Vector Regression (SVR), and Extremely Randomized Trees Regression (ETR).

The approach is based on the analysis of 9 substations (SSTs) in 3 different DHNs. Initially 20 features are used to forecast the heating power. The different models are compared using Mean Absolute Percentage Error (MAPE) and R2 values. In addition, this study investigated the influence of threshold values on model accuracy, finding minimal impact, and examined how reducing data availability affected predictions.

The performance metrics underscore the ANN and ETR's abilities to capture complex, non-linear heating power demand patterns, particularly in standard building categories like residential and tertiary buildings with predictable heating demands. The irregular patterns of certain SSTs highlighted the need for further features and additional data to enhance predictive accuracy. Feature selection and data availability played critical roles in model performance specifically in these SSTs. While tertiary substations demonstrated resilience to reduced datasets, the swimming pool substation's performance notably deteriorated, emphasizing the importance of comprehensive datasets and robust feature engineering.

Keywords: Machine learning regressions, District heating networks, Forecast heat demand

Anders N. Andersen is one of the leading experts in Denmark for economic optimization of energy systems. He is regularly involved in flagship projects from industry and research. Through this involvement he follows closely the technical and economic knowledge of the latest Power-to-X technologies.

The role of Non-Asset Traders in the European Day-ahead and Intraday electricity markets

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The electricity markets in Europe are split into two financial markets and five physical markets. These seven markets allow amongst others to integrate the fluctuating productions from wind power and photo voltaics. The two financial markets are the Day-ahead (Marginal price settled) and the Intraday continuous trading (PayAsBid settled) while the five physical markets are FCR (Frequency Containment Reserves), aFRR CM (automatic Frequency Restoration Reserves Capacity Market), aFRR EAM (automatic Frequency Restoration Reserves Energy Activation Market), mFRR CM (manual Frequency Restoration Reserves Capacity Market) and mFRR EAM (manual Frequency Restoration Reserves Energy Activation Market). These five physical markets are all Marginal price settled.

In the five physical markets only Asset traders are allowed to make bids. Asset traders are traders that owns or has contracted with physical consumers (e.g. an electrolyser, a heat pump or a charger of a battery) or physical producers (e.g. a Combined Heat and Power unit or a discharger of a battery).

However, in the two financial markets, it has been allowed in Europe, that Non-asset traders are also allowed to make bids. That is, even if Non-asset traders have not contracted with physical consumers or producers, they are allowed to offer say in Day-ahead 200 MW in a certain quarter of an hour (50 MWh). If this bid is won, as a simple starting point this will create an imbalance, because there is no production unit behind. To avoid eventually to have a punishment for imbalance, the Non-asset trader may try to buy the same amount in the Intra-day market.

To study the interdependency of the prices in the seven markets, we have created a simplified model for West Denmark. The simulations show that Non-asset traders make Day-ahead and mFRR EAM prices converge, and that Non-asset traders influence how the Euphemia-algorithm in Day-ahead finds the prices in each of the European price areas.

Keywords: Non-Asset Traders, Day-ahead, Intraday

Anna Billerbeck holds a PhD in energy economics. She works at Fraunhofer ISI in Germany on national and international research and consulting projects in the field of renewable energy. Her research focuses on transformation pathways and policy measures for climate-neutral district heating.

Modelling climate-neutral district heating in energy system models – insights from an expert survey

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District heating (DH) networks can play a key role in achieving a climate-neutral energy system, as they can efficiently supply renewable and excess heat. In addition, DH can provide valuable flexibility to an electricity system that needs to cope with fluctuating renewables. Model-based assessments are used to analyse the future role of DH in terms of demand, supply, costs and the impact on the energy system. Different approaches are used, ranging from simulations and optimisations of individual DH networks to large-scale energy system models (ESM) that consider interactions between heat and electricity across the EU.

While there are reviews of various aspects of ESM and of specific DH models, there is still a gap in understanding how DH is modelled in country or EU-wide multi-sector ESM that capture aspects of sector coupling. Our research addresses this gap by investigating the modelling of DH in large-scale ESM through a literature review and an expert survey. The survey, open from January to March 2025, included 28 questions and provided high-quality data for 12 ESM: Balmorel, EnergyPLAN, EnergyScope (Pathway and TD), Enertile, GENeSYS-MOD, JMM, PyPSA-Eur, REMIND, REMod, SCOPE and TIMES PanEU.

The results of our analysis show that ESM generally differ in terms of geographical and sectoral coverage, as well as in temporal and spatial resolution. While some ESM model DH with a single node per country, others use up to four nodes per model region. In addition, the level of techno-economic detail varies: Some cover more than 15 DH generation technologies (e.g. GENeSYS-MOD and Balmorel), including different heat pumps, excess heat sources and types of thermal storage. Others cover fewer technologies but model DH demand endogenously (e.g. REMIND and REMod). In summary, all models have distinct advantages but also some shortcomings, indicating that there is room for improved modelling techniques to better capture the complexity of DH networks in ESM.

Keywords: district heating, integrated energy system modelling, expert survey

Antti Solonen leads the Leanheat Building data science team in Danfoss Digital Services, that focuses on intelligent control algorithms for district heated buildings. He holds a PhD in applied mathematics and acts as a Docent in LUT University.

Demand Side Response in large scale: the Virtual Heat Storage concept

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Flexibility is crucial in modern district heating systems for various reasons, such as integrating renewable energy sources efficiently, avoiding expensive peak boiler usage, enhancing reliability and interacting better with the electricity markets. Demand side response (DSR) solutions can add an extra dimension to the flexibility by connecting producers and consumers. In this talk, we present our DSR approach, where we essentially present the flexibility in the connected buildings as a Virtual Heat Storage (VHS) that seamlessly integrates to various production planning solutions and allows utilities to directly utilize the flexibility in buildings within the agreed limits. We discuss the basics of the VHS concept and our experiences in large-scale implementations of the approach.

Keywords: Demand Side Response, Virtual Heat Storage, Flexibility, District Heating

Ari Laitala M.Sc. (Tech.) works as a specialist in Sykli Environmental College and leads research related projects in the field of real estate, energy efficiency and carbon neutrality. As latest, Laitala has served as a project manager in ongoing project www.smartcitywind.net

Investment case of city scale wind power

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During the 2020s there has been an explosion on the supply side of small and affordable wind turbines. Dozens of different kinds of turbines for different kind of conditions have entered the market at the same when prices have gone down. However, the investment case differs from solar energy exploitation. Sun radiation is evenly available in city scale when shadings don't prevent radiation. But situation with the wind is somewhat totally different. Shapes of roofs and direction of streets and existence of parks can affect to wind speed essentially even in different situations in the one and same roof top.

A starting point of an investment analysis is the use of electricity consumption curve of a building. In Helsinki, this data is freely available from all Helsinki owned service buildings. Target value of sizing the production capacity is that the produced electricity can be used in all given time periods throughout the year. This time period, where produced and used electricity is calculated is one hour. If and when the produced electricity is sold back to energy company (to grid) the received price is much cheaper than the price of bought electricity.

Case building of the investment case is Katajanokka elementary school in Helsinki. This case building is chosen especially for three reasons. First, the building and the consumption of electricity are somewhat small. Usually, larger scale investments are profitable, but we want to test if smaller scale investments be profitable as well. Second, solar panel investments (photovoltaics) are not found very interesting, since their production is concentrated on summertime. But since the case building is a school, the summertime use of electricity is minimal. And third, the wind conditions are somewhat well known in the area. There is no metered data of the case building, but open weather data seems to offer a solution.

In the investment scenario payback time, internal rate of return and net present value is calculated.

Keywords: wind, wind turbine, wind energy, electricity, open data, payback time, internal rate of return, net present value, sun radiation, photovoltaics

Phd-student with ten+ years experience from working in the energy business.

Exploring the Possibilities of Using Day-Ahead Environmental Impact Forecasts for Electricity Generation

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This study explores the potential of electricity consumption flexibility (ECF) aimed at environmental impact optimization (EIO) in various domestic appliances, and examines how EIO influences financial outcomes. The integration of renewable energy sources has altered the energy supply landscape, often causing mismatches between supply and demand.

We utilized a forecast of the environmental impact of Swedish electricity generation to optimize the electricity usage of an electric car charger, a dishwasher, and a heat pump. These appliances represent common household items that can shift electricity consumption over time, each with specific operational constraints. The electric car charger operates only when the car is stationary, the dishwasher runs during daytime hours and must complete its cycle before the afternoon, and the heat pump turns off for four hours each day.

The optimization was conducted using three approaches: EIO, financial optimization (FO), and combination optimization (CO), which balances environmental impact and cost. This study investigates the feasibility of achieving both financial and environmental savings and assesses the accuracy of the environmental impact forecast.

Keywords: Electricity consumption flexibility, Environmental impact optimization, renewable energy integration

Benjamin Kwaku Nimako is a PhD Fellow in Sustainable Development and Climate Change at IUSS Pavia and Free University of Bozen-Bolzano. His work focuses on energy system modeling, machine learning, and climate-smart solutions for sustainable futures.

Novel Multi-Criteria Decision Analysis Based on Performance Indicators for Urban Energy System Planning

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Urban energy systems planning presents significant challenges, requiring the integration of multiple objectives such as economic feasibility, technical reliability, and environmental sustainability. While previous studies have focused on optimizing renewable energy systems, many lack comprehensive decision frameworks that address the complex trade-offs between these objectives in urban settings. Addressing these challenges, this study introduces a novel Multi-Criteria Decision Analysis (MCDA) framework tailored to the evaluation and prioritization of energy scenarios in urban contexts, with a specific application to the city of Bozen-Bolzano. The proposed framework integrates various performance indicators to provide a comprehensive assessment tool, enabling urban planners to make informed decisions that balance different strategic priorities. At the core of this framework is the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), which is employed to systematically rank energy scenarios based on their proximity to an ideal solution. This approach accommodates the shifting priorities of urban planners, whether they emphasize economic, environmental, or technical outcomes. The study's findings underscore the importance of a holistic approach to energy planning, where trade-offs are inevitable but can be managed effectively through a structured decision-making process. Finally, the study addresses key gaps in the literature by providing a flexible and adaptable tool that can be replicated in different urban contexts to support the transition toward 100% renewable energy systems.

Keywords: Renewable energy, urban energy systems, multi-criteria decision analysis, EnergyPLAN, performance indicator

Bernd Riederer is currently a senior researcher in the area of Automation and Control at BEST - Bioenergy and Sustainable Technologies GmbH. His research focus lies on optimization-based energy management systems, with a specialization on industrial applications and hydrogen related topics.

Smart control of hydrogen-based multi-energy systems

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Decarbonization of energy systems relies increasingly on the integration of volatile energy carriers as part of a broader sector coupling strategy. Especially in the industrial and the transport sector hydrogen has become increasingly important, since it enables flexibility across several domains. As energy systems grow more interconnected, also the need for smart, supervisory-level control of such systems increases. However, integration of hydrogen components introduces unique operational challenges due to its nonlinear dynamics. This work contributes to the development of such supervisory control strategies, supporting the transition to climate-neutral, smart multi-energy systems.

Therefore, we extend an existing model predictive control framework for multi-energy systems to hydrogen subsystems by inclusion of key hydrogen components. This expanded framework enables coordinated control of hydrogen flows alongside other energy carriers, with a focus on operational optimization and strategic component use. Various modelling strategies for the pressure–mass flow relationships were implemented, ranging from linear to linearized and nonlinear formulations. These were benchmarked in simulation scenarios for typical load profiles and system constraints.

We show that while nonlinear models provide higher fidelity, they introduce significant computational overhead without delivering proportionate benefits in control quality and linear models severely underestimate pressure levels, leading to severe damaging of components, if not considered correctly. Linearized models, by contrast, offer a strong compromise between speed, accuracy and safety-related issues, making them a practical choice for real-time supervisory control applications. Thus, they should be considered as the favourable modelling approach for smart energy management systems.

Acknowledgment: The research leading to these results has received funding from the COMET Programmes under Grant Nos. 869341 and 892427.

Keywords: integrated energy systems, sector coupling, hydrogen utilization, smart control, optimization, energy management systems

Bram has a PhD in optimal design and control of district heating and cooling, including thermal energy storage (KU Leuven, 2019). He is experienced in energy market regulation and policy development. He recently joined VITO as a researcher in the field of thermal energy system control.

Energy flexibility from smart district heating and cooling control in smart energy systems: An updated review

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District heating and cooling (DHC) systems play a crucial role in unlocking synergies between various energy carriers in a Smart Energy System, namely increasing waste heat and renewable energy shares, and mitigating network congestion issues through energy flexibility between energy carriers. This paper focuses on how the flexibility potential of DHC can be maximized through smart control algorithms. The main aim of this paper is to provide an updated review of smart control algorithms that unlock flexibility in DHC systems, compared to a previous review from 2018 [1]. Additionally, the term flexibility appears to be often used without truly delimiting the scope of the concept. The authors deem it beneficial to determine a more rigorous framework of what flexibility means and how it is established in the context of DHC. Stinner et al. [2] provide a starting point for delineating the concept of flexibility.

Preliminarily, we can say that the flexibility potential in DHC in essence stems from the presence of dedicated storage systems, and systems with activatable thermal inertia in such networks. Smart control strategies may utilize the storage and inertia to either delay or advance production, transfer or consumption of energy. The main contributors to storage and thermal inertia connected to DHC are: 1) dedicated thermal energy storage (TES) systems, 2) storage potential in the piping network, and 3) thermal inertia of the loads connected to the DHC network.

The paper has the following objectives: 1) to delimit a meaningful definition of the concept flexibility, 2) to identify recent trends and patterns in research and technology related to flexibility in DHC and present this in a structured way, and lastly 3) to identify research gaps and suggest focal points for further research.

[1] <https://doi.org/10.1016/j.energy.2018.03.034>.

[2] <https://doi.org/10.1016/j.apenergy.2016.08.055>.

Keywords: Flexibility, Thermal Energy Storage, District Heating and Cooling, Smart Control Algorithms, Review

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Challenges and prospects of electricity access in Angola

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Electricity production and consumption play a crucial role in the development trajectory of countries, especially in Africa, where challenges related to affordability and sustainability persist. Despite the abundance of renewable and non-renewable energy sources, achieving universal access to electricity remains a significant challenge. A reliable and affordable energy system is still far from being realized in many African countries, hampering economic and social progress. This paper analyses the specific challenges faced by sub-Saharan Africa, particularly Angola, in achieving clean energy goals and universal electricity access. In the case of Angola, energy plays an indispensable and fundamental role in the reconstruction and development of the country. Through a comprehensive analysis of current conditions in the electricity sector, the study identifies the main obstacles and discusses potential solutions. The paper specifically addresses the education (basic schools and universities) and health (distributed health posts and general hospitals) sectors as major socio-economic drivers. A methodology was proposed to estimate the current electricity consumption in each of these subsectors and to determine the minimum required levels needed to significantly improve population access to these services, aiming to achieve coverage at least comparable to that of other African countries. The results highlight that the current situation remains far from the minimum acceptable standards, reflecting not only the difficulties in accessing energy in existing health and education units but also the urgent need to implement new units to expand access to education and healthcare services for the population.

This study was supported by FCT – “Fundação para a Ciência e a Tecnologia” within the R&D Units Project Scope: UID/00319/Centro ALGORITMI (ALGORITMI/UM).

Keywords: Africa, health sector, education sector, energy planning, energy demand

Carlos Santos Silva is an Associate Professor at the Mechanical Engineering Department of Instituto Superior Técnico in Lisbon, Portugal where he teaches and researches in the area of modeling, design and management of energy systems.

Using ENERGYPLAN to model energy systems with high spatial resolution: the case study of mainland Portugal electrical system

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Increasing the spatial resolution of energy planning tools to capture the dynamics of renewable energy resources is fundamental for designing resilient energy systems heavily based on renewable resources. For electrical systems, this is particularly important for understanding the limitations arising from the transmission network, especially in cases where demand centers are far away from generation plants and these plants use different energy resources.

ENERGYPLAN is an energy planning tool that has been used to design strategies for the decarbonization of energy systems, typically considering the overall demand and supply of a country or region. This tool includes the capability to consider interconnections with other systems or countries. In this work, we explore the use of this feature to model different sub-regions within the same country, considering the specific resources and demand within each sub-region, using as case study the electrical system of mainland Portugal. We compare the model accuracy using different disaggregation levels to the whole country modeling approach and conclude with the additional insights that can be drawn from this higher spatial resolution modeling approach.

Keywords: ENERGYPLAN, spatial resolution, Portugal electrical system

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Evaluating Peak Shaving Potential with Open-Source Software

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This paper presents PeakShaving-Analyzer, an open-source Python-based software tool developed to support academics and engineers in the analysis and optimization of energy storage systems for peak shaving. With declining battery storage costs and rising grid capacity costs, peak shaving has become increasingly relevant as a means to reduce grid load and capacity costs. By analyzing user-defined consumption profiles, the software identifies opportunities for peak demand reduction, determines optimal battery and inverter sizing, and provides a detailed economic assessment—including investment requirements, annualized costs, and total savings, particularly in reduced capacity costs. Users can flexibly define a wide range of input parameters, such as component costs, energy tariffs (fixed or time-series), interest rates, and component lifetimes. Integration of photovoltaic systems is optionally supported for combined system optimization. PeakShaving-Analyzer is written entirely in Python, published on the Python Package Index, and released as open-source software, offering a transparent, accessible, and easy-to-use solution for evaluating and planning peak shaving strategies.

Keywords: peak shaving, energy storage, battery systems, open source

Dr.-Ing. Anna Cadenbach is Head of Department Thermal Energy Systems Technology at the Fraunhofer IEE in Kassel, Germany. Her focus is on the evaluation and optimisation of low temperature heating concepts based on renewable energies and waste heat.

Optimal domestic hot water and space heating system architecture for flexible heat pump operation in residential buildings

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Christopher Graf (presenter)

Transitioning to renewable heating systems requires integrating low-temperature units like heat pumps. Improved building insulation reduces space heating (SH) demand, enabling low temperature heating systems and creating opportunities for renewable energy integration. However, domestic hot water (DHW) temperature requirements remain constant due to hygiene regulations, presenting barriers for energy-efficient systems. Research indicates that system efficiency is substantially affected by optimal design and hydraulic integration of storage, SH, and DHW system components. Further, the intermittent nature of renewable energy necessitates demand-side management and flexible consumption strategies to synchronize usage with supply. Advanced control algorithms adjusted to regional climate conditions and decentralized DHW configurations that reduce circulation and storage losses significantly enhance system flexibility.

This study addresses the research gap in optimizing heat pump flexibility by simultaneously considering different SH and DHW system architectures across heterogeneous German building typologies. Heat demand is calculated through thermal simulations in TRNSYS based on system architecture and buildings characteristics, and optional system operation is determined by solving a mixed-integer linear programming (MILP) optimization problem. This approach enables the assessment of flexibility options for various combined SH and DHW architectures, evaluating the impact of flexible heat pump operation and variable price signals on minimizing energy costs and maximizing renewable energy usage.

The paper highlights both strengths and weaknesses of different system architectures and operation modes and provides specific recommendations and practices for flexible heat pump management. These recommendations are illustrated by simulation results, contributing to the development of design and control guidelines.

Keywords: heat pumps, building heating systems, domestic hot water, renewable energy, flexibility, mixed-integer linear programming, optimization, demand response

Costanza Saletti is a researcher at the Department of Engineering for Industrial Systems and Technologies of University of Parma, Italy. Her research interests are related to simulation, optimization and control of integrated energy systems, district heating and renewable fuel production systems.

RECoS – An open-source tool for multi-energy system analysis

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Energy communities are revealed as a key solution in the transition towards sustainable and decentralized energy systems, since they promote the integration of renewable energy sources and virtual energy sharing. Whereas communities are currently seen as electricity sharing systems, the thermal domain remains critical. Thus, it is expected that their complexity will increase with the integration of several energy vectors (i.e. multi-energy systems) and the interaction with networks and micro-grids. To estimate potential benefits or determine feasible system configurations, it is essential to evaluate the operation and performance of the community as a whole. Hence, reliable tools for analysis of energy systems are key drivers for the development of such distributed energy systems.

This work presents an open-source tool developed by the authors, named RECoS (Renewable Energy Community Simulator), devoted to the simulation of distributed multi-energy systems. The tool comprises a library of models that represent energy conversion technologies, storages, buildings, networks, and an energy management algorithm based on priority rules. The models have a coherent structure and causality, and can be used in a modular way to represent complex energy systems with different layouts.

Once configured with the system features and management logic, RECoS determines the operation of the plants, buildings and networks for the desired time horizon and resolution, maintaining the energy balances of all energy vectors. It can be used for several tasks, e.g. simulating future scenarios of electrification, calculating shared electricity, and representing management changes in presence of components faults. In addition, RECoS enables the investigation of thermal demand side management options, differently from calculation methods entirely focused on the electricity balance. The potential of the tool is shown in two different case studies at district and small-city level.

Keywords: renewable energy community; integrated energy systems; multi-energy systems; simulation; energy management; electrification

Dana Orsolits is a physicist working in the field of integrated energy systems at the Austrian Institute of Technology (AIT). Her research focuses on hydrogen technologies and dynamic gas network simulations to support the transition towards a decarbonised energy system.

Coupling Power System and Gas Grids Through Dynamic Hydrogen Injection: Enhancing Flexibility in Smart Energy Systems

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Excess renewable electricity can be converted into hydrogen via electrolysis. This process supports renewable hydrogen production and helps to stabilize the power grid by balancing the mismatch between intermittent renewable energy generation and demand. In areas with local oversupply of electricity due to limited grid capacities, electrolysis applications could enable the system integration of otherwise curtailed renewable energy production, delaying the need for grid expansion. However, transporting substantial amounts of hydrogen remains an obstacle, due to absence of large-scale hydrogen infrastructure. As an interim solution, hydrogen can be blended into the existing natural gas grid, allowing renewable energy to be integrated into the energy system. Nevertheless, the gas grid's ability to absorb hydrogen is limited by hourly variations in gas flow and regulatory limits on hydrogen concentration.

To evaluate the potential of hydrogen blending we developed a dynamic simulation model. The model is based on adaptable components which allows to simulate arbitrary grid topologies. Further it captures temporal and spatial variations in gas flow, pressure, and hydrogen concentration. Our current research focuses on the coupling of this model with the electrical grid using electrolyzers, which are simulated by detailed physical models. This integrated modeling approach enables a comprehensive analysis of all system components. Goal of our research is to map the realistic hydrogen integration potential in gas grids, considering technical characteristics of electrolyzers, availability of renewable electricity and gas flow. Results from these investigations are the basis for profitability analyses, supporting the efficient integration of fluctuating renewable energy and thereby contributing to the development of hydrogen production and infrastructure.

Keywords: hydrogen blending, electrolysis, sector coupling, energy system modeling, integrated energy systems, renewable energy integration, gas grid modeling

Diamantis Almpantis is a PhD candidate at the Department of Energy Sciences at Lund University, specializing in the development of comprehensive energy system models and sector coupling, aimed at optimizing the coupling efficiency between photovoltaic systems and electrolyzers.

Smart Control Strategies for direct coupled PV-PEM Hydrogen Systems: Real-Time Optimization with Machine Learning Support

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The optimization of photovoltaic (PV) and proton exchange membrane (PEM) electrolyzer systems is crucial for efficient and scalable hydrogen production. Traditionally, static coupling methods use a fixed electrical interconnection between PV modules and PEM cells throughout the entire operation period, regardless of fluctuating solar conditions. While effective for location-specific design, such approaches struggle to accommodate the dynamic variability of solar irradiance. To address this, we propose an adaptive reconfiguration control strategy algorithm that dynamically adjusts the electrical configuration between fixed PV arrays and PEM stacks on an hourly basis. This enables the system to emulate maximum power point tracking (MPPT) and power management functions without the need for additional power electronics or rigid static setups. Building upon this foundation, a hybrid approach combining machine learning with real-time optimization is introduced to further improve system adaptability. Specifically, a Random Forest regression model is trained to predict hourly the electrical connected optimal number of PV modules and electrolyzer cells based on environmental inputs such as solar irradiance and ambient temperature. This adaptive method progressively reduces reliance on computationally intensive optimization, offering a practical and intelligent solution for real-time energy system management. The results show that the integration of machine learning significantly reduces computation time in the half while maintaining system performance compared to full optimization alone, while hydrogen production and solar-to-hydrogen efficiency kept the same. This demonstrates the potential of the proposed approach to deliver fast, reliable, and efficient real-time control for direct PV-PEM systems in every location, supporting scalable renewable hydrogen production with reduced computational demand.

Keywords: Smart energy control, Direct coupling PV-PEM, Solar-to-Hydrogen efficiency, Machine Learning

Dmitry Romanov is a research associate whose field of interest includes integration of waste heat and renewable energies into district heating systems (DHS), reduction of temperatures in existing DHS, modelling of thermohydraulic processes, and geothermal heating and cooling systems.

Applicability of pygfunction for modelling deep coaxial borehole heat exchangers

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Deep borehole heat exchangers (BHE) draw the attention of researchers and specialists due to their higher heat extraction rates and lower surface area requirements compared to shallow geothermal systems. Numerical, analytical, and semi-analytical models for simulating deep borehole heat exchangers exist. However, they are not always versatile or computationally efficient. The Python package “pygfunction” allows for evaluation of thermal response factors (g-functions) of shallow geothermal borehole fields. The package is used in some software tools and requires little computational effort, but it has not been tested for simulating deep BHEs. Thus, this work addresses the research question of whether pygfunction is applicable for modeling deep co-axial BHEs and what margin of error can be expected.

In pygfunction, the undisturbed ground temperature and thermophysical properties of the ground were averaged along the borehole depth to simulate deep BHEs. This model was then compared with the results of numerical and semi-analytical simulations, as well as experimental data from the literature. Scenarios with different depths (from 700 to 3000 m), different target parameters, and configurations accounting for multiple underground layers with distinct thermophysical properties were considered. The results show that the current version of pygfunction (2.2.3) cannot accurately simulate the fluid temperature profile of a deep borehole heat exchanger along its length, due to assumptions valid for shallow boreholes only. Nevertheless, pygfunction predicts fluid inlet and outlet temperatures, as well as heat extraction rates of deep BHE, reasonably well, with a mean error (underestimation) of about 10%. Therefore, modeling deep BHEs using pygfunction can provide sufficiently precise and computationally efficient results for further modeling of ground-source heat pumps, which may be of interest to researchers and engineers in the field of deep and medium-deep geothermal energy.

Keywords: Benchmarking, borehole thermal energy storage, g-function, ground-source heat pump, medium-deep geothermal energy, numerical models, pygfunction

After completing a B.Sc. and M.Sc. in Computer Science, Dominik Stecher started working on research projects using machine learning in industrial applications. He is currently working on fault detection and classification in district heating networks as part of his PhD.

Fault Detection and Classification in District Heating Substations using Supervised Machine Learning – Case Study and User Experience

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With the ongoing digitalization of heat meters and the transition to 4th generation district heating, using the data stream from individual district heating substations for anomaly or fault detection has become increasingly popular. Increased customer satisfaction, higher efficiency, lower operating costs, and better maintenance and repair schedules are among the advantages motivating this trend.

At the same time, there is an ongoing effort to make the most of this data by using machine learning algorithms – both to manage the large quantity of data and to optimize performance in a setting complicated by weather patterns and consumer behaviour.

We present a case study showing the deployment of a machine-learning based fault detection and classification tool targeting individual district heating substations. Using labelled data from a local German district heating network supplying a city of 65k inhabitants to train our models, we evaluate model performance for both detection and classification tasks using two different strategies. For this, we use typical classification metrics such as precision, recall, and F1 score as well as task-specific metrics such as detection delay and remaining time to customer complaint.

In addition, we discuss expert and end-user feedback regarding user experience and benefits such as repair scheduling, improved reaction times, fault diagnosis, and spare part management.

Keywords: Fault Detection, Fault Classification, District Heating, District Heating Substation, Machine Learning, Supervised Learning,

He is working since 2022 at the Workgroup for Economic and Infrastructure Policy (WIP) at Technische Universität Berlin on electricity market modeling.

Enhancing Flow-Based Market Coupling with Uncertainty and Forecast Integration for Renewable Energies

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As the energy sector transitions toward a carbon-neutral future, the integration of large shares of variable and hard to predict renewable energy sources (RES) presents unprecedented challenges for electricity markets. This can lead to system imbalances and curtailment of renewable generation when there is excess production or a shortage when generation falls short. This research explores the enhancement of flow-based market coupling (FBMC) through the integration of uncertainty and forecast data, aiming to improve market efficiency and grid security under high RES penetration.

FBMC enables a more accurate representation of physical grid constraints compared to traditional zonal models, yet its current implementations often lack systematic treatment of forecast errors and intraday variability. This means that market prices may not reflect real-time network constraints or the true economic costs associated with generation and transmission, especially in systems with high variable renewable energy generation (e.g., wind and solar). We propose a novel framework that embeds probabilistic forecasts and uncertainty quantification into the FBMC algorithm, enabling more adaptive and resilient market outcomes. The role of intraday markets is also revisited, emphasizing their potential to complement day-ahead decisions and provide dynamic re-balancing in the face of short-term RES variability.

Through simulations on realistic power system topologies, we demonstrate how enhanced FBMC can reduce redispatch costs, improve RES integration, and support system reliability. This research contributes to the design of smarter, more responsive electricity markets that align with the operational realities of renewable-heavy grids making the market coupling process not only more responsive to real-time conditions but also more attractive for future investment and market integration.

Keywords: Variable renewable energy sources, flow-based market coupling (FBMC), Zonal models, Intraday markets, Uncertainty quantification

Erik Ahlgren is professor in Energy Systems at Chalmers Univ Tech, Sweden. He is studying integrated energy system transitions mainly at the local scale in North European and in Global South contexts currently focussing on urban energy systems and solar mini-grids for rural electrification.

Modeling long-term sectoral integration in urban energy transitions

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As large contributors to greenhouse gas emissions, but also drivers of change, cities are playing an increasingly important role for the climate transition, which in particular in cities require system integration across the electricity, heating/cooling and transport sectors in order to utilise synergies and constrained resources in smart ways. It also requires collaboration of city departments and stakeholders with different mandates and interests. Such integration and collaboration are thus essential to drive emission reductions, capturing of synergies and solving of potential goal conflicts, but research shows that planning is often done in silos. Transitions should also be just, both to be implementable and to leave no-one behind. This complexity of urban transitions leads to demand for tools enabling assessments and providing action support across temporal and spatial scales and across a multitude of stakeholders. To deal with these complexities and provide policy and decision support to city planning and transitioning processes, we have developed urban scale technology-rich cost-optimization models based on the TIMES modelling framework covering spatial dimensions. The developed models have been applied to various local energy systems in Denmark and Sweden and used in close stakeholder interaction. The modelling have aimed to drive city climate transitions by addressing, and providing solutions to, different types of integration (and potential conflicts): between city and urban planners, between supply and demand sides of the energy system, between large-scale and decentralised technologies, between the city and its rural surroundings, between short- and long-term targets, between different city areas, and through alignment between city and national climate strategies and policy. The presentation builds upon six recently completed and published studies within the research group and will cover a combination of case specific results and methodological advances.

Keywords: Modeling long-term sectoral integration in urban energy transitions

Ethan is an engineer at FairHeat, with almost 2 years of experience in heat network design, quality assurance and optimisation. He has been involved in the development of the UK's Heat Network Technical Assurance Scheme, specialising in technical standards for heat network metering systems.

Heat Network Metering and Monitoring Standard: Regulating metering systems within UK heat networks

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In 2025, a new regulatory framework for heat networks will come into effect in the UK, with key changes starting April 1st and further developments in 2026 and 2027. Ofgem (the Office of Gas and Electricity Markets) has expanded its remit to include heat networks and will begin regulating the sector in January 2026, with full implementation by January 2027.

As part of this regulatory framework, the Heat Network Technical Assurance Scheme (HNTAS) is being established to ensure that heat networks in the UK meet minimum technical standards. This is primarily an outcomes-based regime, with operational heat networks required to report against a set of key performance indicator (KPI) targets on an ongoing basis, with exception-based reporting and escalation.

To meet the reporting requirements of the scheme, it is a requirement for minimum levels of metering and monitoring infrastructure to be installed on new networks and, over time, existing networks. These requirements are being set out in a new Heat Network Metering and Monitoring Standard (MMS), which has been developed in draft form and is being circulated to market as part of the government consultation process for HNTAS.

MMS sets out requirements for thermal energy meters and other utility meters, together with requirements for automatic and remote monitoring systems, home display units and other advanced metering infrastructure.

MMS also introduces requirements for the replacement or recalibration of thermal energy meters, which is not well addressed within current UK regulation. In developing these requirements, the procedures followed in several European countries have been taken into consideration, with the approach being adopted most heavily influenced by the Danish standards.

In summary, this work explores the upcoming regulation for metering systems within the UK heat network sector, and the development of the Heat Network Metering and Monitoring Standard.

Keywords: Heat networks, district heating, metering systems, heat metering, assurance scheme, regulation, industry standards, key performance indicators, UK

The abstract is presented by Finn Weiland from the Institute of Solar Energy Research in Hameln ISFH.

Energy supply concepts based on shallow geothermal energy for existing urban districts

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Finn Weiland (presenter)

In order to achieve climate targets in the building sector in Germany, a significantly greater market penetration of heat pumps in existing buildings is necessary. In this respect, the conversion of existing heat supply structures to geothermal-based heat pump systems plays a central role due to their high efficiency, especially for small and larger districts. Using model-based potential studies, the feasibility of central and decentral heat pump systems has been investigated for five existing districts spread out over Germany. Starting with the evaluation of the existing buildings and the energetic quality of their building envelopes and supply systems, a demand-consumption adaptation has been done using provided energy consumption reports. Geothermal properties, regulatory conditions as well as the area availability within the districts are describing the potentials of the geothermal energy sources and represent the basis for designing the energy supply concepts. Hereby, centralized concepts with cold and low temperature grids, both with and without active regeneration using solar thermal collectors, are compared to decentral geothermal concepts and air-to-water heat pump systems. In a first step, the assessment of the concepts is focusing on energetic, ecologic and economic aspects. Especially regarding economic aspects, different operating models of energy suppliers have been evaluated considering flexible energy pricing and investment sharing between the different stakeholders as well as the impact of the different heating supply concepts on the maximum grid load. In a second step, a multi-criteria analysis has been established considering further aspects like preferences of building owners or future retrofit plans. Based on this, design criteria considering different district properties have been developed and integrated into a design guide for geothermal systems for the heat supply of existing districts.

Keywords: Shallow geothermal energy, existing districts, planning tools, regulation

Gabriele Fambri holds a PhD in Energy Engineering (2023) and is currently an Assistant Professor. His research focuses on multi-energy systems, energy conversion and storage technologies, bioenergy processes, and advanced optimization methods for energy management

Deep reinforcement learning to explore multi-energy systems: a methodological approach

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This work investigates the application of Deep Reinforcement Learning (DRL) to optimize energy flows in a multi-energy system (MES). The system integrates electricity, heat and gas grids and includes various energy storage and conversion technologies that enable energy exchange across sectors. While this integration increases flexibility and improves the use of non-dispatchable renewables, it also introduces significant complexity, making it difficult to define optimal control strategies a priori.

Several optimization approaches have been proposed in the literature, ranging from metaheuristic methods to traditional deterministic models. DRL is emerging as a promising alternative due to its ability to handle nonlinear, high-dimensional problems without requiring structural simplifications. However, DRL generates black-box solutions where the internal logic of the learned policy is not directly interpretable. To understand the actual synergies within the MES and to extract meaningful control logic, it is necessary to analyze the policies learned by the DRL agent and uncover the underlying principles that govern its decisions.

In this study, DRL is used as an exploratory tool to optimize the operation of an MES. The same scenario is first solved with a rule-based control algorithm based on efficiency prioritization. The DRL policy is then analyzed with interpretable surrogate models that allow us to extract the key rules and operational logic behind the agent's decisions.

This process transforms the DRL outcome from a black box solution into a deterministic control strategy where the interactions between technologies are explicitly known. This makes it possible to identify the most effective sectoral synergies and define an operational optimum for the given scenario. This combined approach thus offers both the performance advantages of DRL and the transparency of rule-based control.

Keywords: Deep reinforcement learning, multi-energy systems, energy management, cross-sector synergies

Gerrid Brockmann is a research associate at the HRI, TU Berlin since 2015 and is leading the research field for district heating since 2023. With first steps in thermal storage and gas turbine R&D, he collects over fourteen years' experience in numerical methods and experimental validation processes.

Analysis of District Heating Network Configurations for a Suburban Region: a Sensitivity Study about the Heat Demand Density and Supply Temperature

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Reducing CO₂ emissions is one of the main goals to minimize global warming. The use of heat networks offers a sustainable way to meet consumers' heating needs while reducing greenhouse gas emissions.

The SubWW2 project investigated how a sustainable, climate-friendly heat supply can be realized in suburban areas. Leeste, near Bremen, Germany, served as a model region, characterized by different building types such as residential buildings, schools, offices, supermarkets and sports halls. As the study area includes existing buildings as well as new and planned buildings, the required flow temperatures for heat supply vary considerably.

The article compares different technical concepts for heating networks from an economic and environmental point of view. Particular attention is paid to the shift in the parameters heat line density (e.g. due to different household connection willingness) and the proportion of buildings with a high supply temperature of 75°C to those with a low supply temperature of 50°C (. Analyzed are the following network concepts:

- A single-temperature network in which all consumers with high supply temperatures are supplied from a central generation unit,
- A cascade network that uses the return flow from high-temperature consumers for buildings with low heat demand,
- A multi-pipe system with two different temperature levels from the central heating plant,
- And a low-temperature network in which the central supply is limited to low temperatures and high-temperature demand is covered decentral.

Keywords: heat grid, rural area, network concept, network scenario, multi-pipe system

Dr. Ingeborg Røe has a background in materials science from the Norwegian University of Science and Technology, where she also completed her PhD in battery technologies. The past four years, she has been working with renewable energy solutions and integration in industry at SINTEF Energy.

Smart integration of renewable energy technologies in heat- and power-intensive industries in Europe

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Renewable energy has the potential to play a significant role in the decarbonization of energy-intensive industry. Recent years have seen an exponential growth in the deployment of photovoltaic systems due to the decreased costs and relative ease of installation and maintenance [1]. However, heat is the largest single demand in industry, and solar thermal collectors may offer a more energy efficient path to decarbonization.

This study investigates the potential for increased renewable energy uptake and reduced green-house gas emissions in heat- and power-intensive industries through integration of solar thermal compared to photovoltaic technologies. The open-source energy systems modelling tool EnergyModelsX [2], together with a geographical information system for the calculation of location dependent solar yields, is used to map the integration potentials considering different annual energy demands and power profiles in a range of industries, also accounting for the different geographical locations across Europe. Furthermore, conversion technologies, such as heat pumps and electric heaters, are combined with the solar technologies to investigate the overall integration potential, and how the supporting technologies can enable additional uptake of renewable energy.

Preliminary results from the study show that the solar thermal technologies benefit from the milder climate of south-Europe, whereas photovoltaic panels can contribute to significant decarbonization of the heat- and power-intensive industries also in the northern parts. Both technologies are, however, impeded by space constraints in the industrial sites, particularly for grey-field projects, limiting the on-site integration of these technologies in industry.

[1] CETO (2024) Photovoltaics in the European Union–2024 Status Report on Technology Development. DOI: 10.2760/1812909

[2] Hellemo, L. et al. (2024) EnergyModelsX: Flexible Energy Systems Modelling with Multiple Dispatch. DOI: 10.21105/joss.06619

Keywords: Industrial decarbonization, solar thermal, photovoltaics, process heat

Ivan Sukhanov (M.Sc., HVAC, Kyiv National University) is a Ph.D. student in Computer Systems, specializing in data-driven solutions for engineering systems, at Tallinn University of Technology and an Engineer at R8 Technologies, focusing on AI-driven HVAC optimization and control.

Adaptive demand-based logic for the Heat pump using supervised machine learning algorithms

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Europe's goal of installing 45 million residential heat pumps by 2030 highlights the need for advanced control strategies to achieve net-zero emissions and enhance energy security. Traditional heat pump control methods, which primarily rely on ambient temperature curves, often fail to address real-time system and building demands. This paper introduces a machine learning, demand-based control approach that utilizes live data, including network temperature differences, consumer unit valve positions, energy prices, weather forecasts, and room temperature sensor readings, to dynamically adjust the heat pump's supply water temperature. The application of machine learning models, such as Random Forest, facilitates more accurate predictions while incorporating integrated fail-safes to prevent system malfunctions and maintain indoor comfort. Moreover, forecasting the supply water temperature based on building demand not only provides insights into district heating and heat pump usage patterns but also supports the optimization of heat source switching in hybrid systems in response to energy price fluctuations.

The proposed method was evaluated in two real-world settings: a Portuguese office building with fixed control settings and an Estonian building employing a dynamic, ambient temperature-based system. In both scenarios, the AI models demonstrated improved performance over standard control strategies, reducing compressor fluctuations and achieving energy savings, increasing overall system efficiency. The solution can be seamlessly integrated into existing building management systems without the need for additional hardware, making it both adaptive, scalable, and cost-effective.

These findings suggest that integrating real-time, supervised machine learning based feedback into heat pump controls can significantly improve energy efficiency and system reliability, supporting a more sustainable and responsive energy infrastructure for the future.

Keywords: heat pump, Machine learning, adaptive demand-based control, data-driven optimization, Random Forest forecasting

Energy executive with over 25 years of experience driving change in organisations and developing new market opportunities. Managing director within flexibility markets and demand side response. Prior roles within trading, operations, and consulting. Widely recognized energy expert in media.

Harnessing AI and IoT to Unlock Household Electricity Flexibility for a Smarter Energy Future

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The increasing integration of renewable energy sources into the power grid presents both opportunities and challenges for energy management. With the Flex Platform we are leveraging the flexibility of end-user electricity consumption through advanced technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT). This session keynote explores how AI and IoT can be utilized to optimize residential energy use, enhance grid stability, and support the transition to a more sustainable energy system.

The electrification of energy consumption via heat pumps and electric vehicles is emphasized by the increased investments in solar panels and batteries. Such devices, that are natively IoT-enabled, can collect real-time data on energy usage and environmental conditions. When combined with AI algorithms, this data can be analyzed to predict consumption patterns, identify opportunities for load shifting, and automate energy-intensive tasks during off-peak hours or when renewable energy is abundant. This not only reduces electricity costs for consumers but also alleviates pressure on the grid during peak demand periods.

Furthermore, AI-driven demand response systems can coordinate energy use across multiple households, creating a virtual power plant that responds dynamically to grid signals. This decentralized approach enhances energy resilience and enables more efficient integration of solar and wind power.

In conclusion, the synergy between AI and IoT offers a powerful framework for unlocking the flexibility of electricity consumption. By enabling smarter, data-driven energy management, these technologies play a crucial role in shaping the future of sustainable and resilient energy systems.

Keywords: AI, IoT, smart grid, flexibility, energy management, demand response, renewable integration, virtual power plant

Jan Trosdorff is a research associate at the District Heating research team at the Hamburg University of Applied Sciences. He focuses on utilizing time series and geospatial data for district heating grid planning and operation, including data analysis, forecasting and grid routing.

Global deep learning model for high temporal and spatial resolution heat demand forecasting using real world monitoring and open data

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Heat demand forecasting is crucial for planning and operation of efficient integrated smart energy systems, especially district heating systems. Traditionally heat demand forecasts are used for optimizing the heat production, mainly on an hourly basis. In addition to the established use case, forecasts with high spatial and temporal resolution promise an improved grid integration of substations through simulation of innovative control concepts or model predictive controls. The highly resolved demand forecasts can be of help during the development stage of demand side management control strategies, but can also be part of grid operation.

A methodology for creating a data driven global forecasting model with deep learning architectures is proposed. One single global model is designed to predict the heat demand on building substation level for different buildings simultaneously, while being trained on a diverse dataset containing different building's data. By using a global model more generalized demand patterns can be identified and applied to forecasting problems. The model can be used to make predictions even for buildings not available in the training dataset and only one single model needs to be maintained. In contrast a local model approach would be designed to make forecasts for the same building it was trained on.

The model is designed to forecast the heat demand of multi family buildings on building substation level at 15 minutes temporal resolution utilizing real world monitoring data from multiple district heating systems in Hamburg, Germany. Additionally to real world monitoring data the model is fed with available open data, including cadastral data, LoD 3 3D building models and survey data.

Different deep learning architectures are compared to be used for highly resolved 24h ahead district heating demand time series prediction. Additionally a minimum set of input features is identified.

Keywords: heat demand forecasting, global model, deep learning, district heating, building substation level, 15 minute resolution, 3D building models, real world data, open data

Jana Reiter holds a master's degree in physics and a PhD in scientific computing from the University of Graz. She joined AEE INTEC in 2021, focusing on digitalization for industrial decarbonization, and lectures at FH Burgenland since 2022.

Dynamic Modelling and assessment of Alternative Fuel Supply Chains: Hydrogen, Ammonia, and Methanol Pathways for Maritime Applications

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The present work targets the evaluation of sustainable alternative fuel supply chains (fuel pathways) for powering multi-fuel solid oxide fuel cells in maritime applications. Evaluating hydrogen (H₂), ammonia (NH₃), and methanol (MeOH) production chains, this study introduces a comprehensive Fuel Pathway Tool designed to systematically design and evaluate these fuel pathways including production, transport, and storage.

The Python-based modular software framework encapsulates flexible, region-specific fuel supply chain modelling. The tool is based on a directed graph structure, where nodes represent production, storage, and transport units, and edges represent material and energy flows. Core functionalities include dynamic configuration of production routes, transport modes, and storage options. The tool operates fully time-dependent, utilizing an hourly timestep to simulate the dynamic behaviour of storages, production facilities, and transport systems. This structure enables sizing of storage, production and transport capacities across multi-step supply chains. Key performance indicators, such as well-to-wake energy efficiency and levelized cost of fuel, are utilized for evaluation and design of fuel supply pathways.

Use cases highlight comparative analyses of hydrogen produced via proton exchange membrane (PEM) electrolysis, ammonia synthesized through air separation and Haber-Bosch processes, and methanol derived from biogas upgrading. Insights into trade-offs between environmental and economic performance under varying energy system conditions are discussed.

This contribution outlines the methodology and structure of the Fuel Pathway Tool, presents a comparative evaluation of H₂, NH₃, and MeOH pathways for maritime applications, and discusses the broader implications for integrating sustainable fuel supply chains into future smart energy systems.

Keywords: hydrogen, ammonia, methanol, maritime fuels, sustainable transport, fuel supply chains, dynamic modelling, storage systems, solid oxide fuel cell

Jonathan Sejdija is a research associate and doctoral student at FH Aachen. He obtained a Master's degree in Business Informatics with a focus on energy management. Currently, he is researching and developing ways to evaluate decarbonization pathways with a simulation framework.

A Probabilistic Framework for Analyzing Uncertainty in Industrial Energy Supply and PPA Portfolios

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The increasing integration of renewable energy into power systems introduces significant uncertainty into energy supply scenarios, requiring probabilistic modeling to evaluate instruments like Power Purchase Agreements that aim to mitigate market-driven variability through long-term procurement.

While deterministic analysis remains common in practice, probabilistic models provide a critical advantage by explicitly quantifying uncertainties arising from renewable resource variability and market fluctuations. By incorporating stochastic representations of the supply (e.g., renewable generation profiles) coupled with actual demand time series data, this framework simulates diverse outcomes to assess cost and risk under uncertainty for robust scenario analysis and decision-making. In the context of Power Purchase Agreements, this can be used to assess the likelihood of different cost, risk, and performance outcomes under varying market and operational conditions. For example, probabilistic approaches can evaluate how often contractual energy volumes will be met, estimate the financial impact of deviations, and support the optimization of procurement portfolios to balance risk and return.

By applying probabilistic modeling to energy supply scenarios, this study demonstrates how uncertainty can be systematically incorporated into the analysis of Power Purchase Agreements. The approach enables the evaluation of both demand-side flexibility (such as bi-valent industrial processes) and supply-side strategies (such as diversified Power Purchase Agreement portfolios) under realistic, uncertain conditions. Scenario-based analyses compare current deterministic practices with optimized strategies that leverage probabilistic insights, providing a framework for evaluating energy procurement strategies.

Keywords: Simulation, Probabilistic modeling, uncertainty analysis, Power Purchase Agreements, flexibility

I am an industrial PhD student in computer science at Blekinge Institute of Technology, Sweden, and the Flemish Institute for Technological Research (VITO), Belgium, with a focus on intelligent fault detection and diagnosis in district heating building substations.

Generalising Fault Signatures for Robust District Heating Substation Monitoring

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District heating (DH) offers one of the most sustainable ways to meet urban thermal demand, yet it is highly susceptible to malfunctioning. A large number of substations operate sub-optimally due to faults. Left unaddressed, it can drive up return temperatures and undermine the integration of DH into smart energy systems. The transition to 4th-generation DH systems, which operate at lower supply temperatures and tighter margins for error, further emphasises the need for precise Fault Detection and Diagnosis (FDD). While traditional threshold-based and manual inspection methods identify some of the faulty substations, they are often too coarse, slow, and error-prone to capture the complex, dynamic behaviour of these networks; as a result, faults persist for extended periods. The introduction of smart heat meters enables data-driven FDD approaches that can detect emerging faults early. However, the volume of unlabelled data poses a major challenge for validating algorithms. We propose a one-class Convolutional Auto-Encoder (CAE) that learns the signature of normal operating DH substations. Once trained, any deviation manifests as an elevated reconstruction error, allowing us to flag faults without having seen a fault case. We enrich training via pseudo-labels and use two real-world datasets to test generalizability between DH networks (network A and B). First, we train our CAE on A and directly apply that model to B. We analyse the identified substations in B against known fault patterns and reverse training. We quantify performance via a hold-out test set and assess whether the learned fault signatures transfer reliably across networks. Preliminary results suggest that our CAE separates anomalous from normal behaviour to a high degree. These early observations demonstrate the feasibility of our approach. By demonstrating that the CAE can learn robust fault signatures, we aim to advance DH's FDD field, enabling more precise monitoring of DH networks.

Keywords: District Heating, Fault Detection and Diagnosis, Machine Learning, Cross-Network Generalisation

His professional interests include assessing efficiency and optimizing the use of renewable energy sources, with particular emphasis on geothermal energy in district heating. Mathematical and numerical modeling are tools commonly used in his work.

Utilization of a deep geothermal borehole heat exchanger HOCLOOP solution in cooperation with existing coal-fired district heating

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The work presents general results, remarks, and suggestions based on a case study of the utilization of a deep coaxial borehole heat exchanger located in a rock salt formation. The analyzed solutions may be helpful in decarbonizing the heating sector in a case of an existing district heating system based on conventional fuels. The analyzed case study is located in Poland in an area of rock-salt structure. Suggested BHE will cooperate with the existing DH system in Goleniów city. The case study evaluates the salt dome as potential targets for applying the closed-loop technology developed in the project with the acronym HOCLOOP. A temperature profile taken there shows that the average geothermal gradient for the whole profile in this area is about 3°C/100 m. This makes this formation particularly favorable for the exploitation of geothermal energy. The use of a deep horizontal well was assumed. The work is presenting estimations based on a numerical model of the underground and surface parts of the whole energy system. Numerical simulations of the BHE's operation made it possible to determine changes in the thermal parameters of the geothermal heat source over time and match them with the parameters of the surface installation. An analysis of the possibility of cascading heat from the working medium with an additional heat pump was also carried out, comparing the efficiency of such solutions. Analyzed DH system is characterized by high thermal power, much higher than a single unit of the HOCLOOP system. It helps to utilize the BHE units with a high load factor. Cooperation with a coal-fired system helps to gain additional financial profits related to the reduction of CO₂ emissions up to 50% and linked to its costs. The analyzed case study showed very promising technical and environmental results. The simulations enable to understand the potential benefits of HOCLOOP systems in combination with heat pumps or as stand-alone systems—utilizing additional heat exchangers.

Keywords: geothermal, coaxial borehole heat exchangers, decarbonisation, DHC

Lorenzo Mario Pastore is Assistant Professor at Sapienza University of Rome. His research fields are smart energy system modeling and planning at both national and district level, hydrogen energy and energy economy. He got his PhD in energy and environmental engineering.

On the role of hydrogen in 100% renewable energy systems: an assessment of applications, costs and infrastructure in Italy by 2050

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In the energy transition, hydrogen will be a key energy storage system and clean fuel for full decarbonisation. Yet, among various possible applications, only few will emerge as truly effective strategies. This paper assesses the role of hydrogen in a 100% renewable energy Italy scenario, investigating applications, costs and infrastructure. Three scenarios for fuel application in hard-to-abate sectors are evaluated, namely direct hydrogen, CO₂-electrofuels, and bio-electrofuels, focusing on heavy industry (steel, chemicals, furnaces) and heavy-duty transport (road, naval, aviation). Additionally, fuel cells' application in power sector for grid balancing are assessed. Each scenario optimises the size of renewable energy sources, electrolyser, and storage solutions (hydrogen and batteries) to minimise total system costs. The Levelized Cost of Hydrogen (LCOH) is analysed across production, storage, transmission, and distribution phases, along with electrofuel costs. Carbon Abatement Cost (CAC) compares cost-effectiveness of the different applications. Results show that hydrogen will be crucial in balancing renewables, covering around 25% of electricity consumption by 2050, however fuel cells in power sector are neither economically nor technically advantageous. Direct hydrogen use appears less cost-effective due to the infrastructure costs, with storage and distribution significantly increasing the overall LCOH. This is predominant in the transport sector, while in industry CAC values are very close. CO₂-electrofuels demonstrate economic viability but face challenges due to significant dependence on externally sourced CO₂, despite implementing carbon capture at industrial and thermal power plants. Bio-electrofuels offer the most cost-effective solution, efficiently balancing biomass and hydrogen streams without requiring CO₂ capture and storage. However, biomass consumption surpasses Italy's projected sustainability thresholds for 2050.

Keywords: 100% renewable energy systems, hydrogen energy, hard-to-abate sectors, electrofuels, national energy planning

Marius Reich works as a research assistant at the University of Applied Sciences Düsseldorf in the Center for Innovative Energy Systems. He focuses on topics related to the application of machine learning methods for analyzing energy systems.

Precomputed ML Surrogates for Energy System Design: Methodology and In-Depth Evaluation

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Designing energy supply systems involves computationally intensive simulations that limit their applicability in iterative design processes and optimization workflows. This paper presents and extensively evaluates a methodology for replacing such simulations with precomputed machine learning-based surrogate models, enabling fast and accurate optimization of system configurations. These surrogate models approximate the output of rule-based and mixed-integer linear programming (MILP)-based simulations, covering a range of complexities with respect to system parameters and boundary conditions. To decouple model training from user interaction, all surrogate models are generated a priori, prior to knowing any specific application case. Static and time-dependent boundary conditions are systematically varied during model generation to capture their influence on key performance indicators. In particular, time series inputs (e.g., heat demand profiles) are grouped into representative temporal classes. For each class, a dedicated surrogate model is trained using Gaussian Process Regression to map the system behavior under quantitative variations within that class. Once a user specifies their boundary conditions, the optimization framework selects the most appropriate surrogate model, enabling solution times in the order of seconds - even for structurally complex energy systems. The methodology is evaluated across a set of diverse test cases, encompassing both rule-based and MILP-based simulations of varying structural and operational complexity. The evaluation quantifies the approximation accuracy compared to direct optimization using full simulations with user-specific data, and it highlights the substantial computational speed-up achieved through this surrogate-based approach. In addition, it is demonstrated that the structure of the precomputed surrogate models intrinsically allows for efficient analysis under uncertainty.

Keywords: Energy supply systems, Design Optimization, Metamodeling, Time Series Data

Martina Capone is Assistant Professor at Politecnico di Torino. Her research focuses on the simulation and optimization of large-scale energy systems, such as district heating networks, multi-energy systems, and energy storage solutions.

A Simulation-Optimization Framework to Support the Transition of District Heating Systems

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District heating systems are essential for integrating renewable and low-carbon heat sources. As these systems evolve, they must adapt to changes in operational conditions, such as the integration of new energy sources or the transition to lower supply temperatures. To support this transition, it is crucial to have robust tools for simulating and optimizing system behaviour under different scenarios.

This paper presents a simulation and optimization framework developed to assess the operational performance of large-scale district heating networks. The model integrates both fluid-dynamic and thermal simulations based on the conservation equations of mass, momentum, and energy. The simulation model is formulated as a feasibility problem within an optimization environment, facilitating the inclusion of decision variables and enabling efficient exploration of operational scenarios without the need to repeatedly solve a direct simulation model. This approach allows for the assessment of improved operating conditions and makes it possible to evaluate various operational strategies under future conditions. The model was validated using real-world operational data, confirming its ability to accurately represent the system thermo fluid-dynamic behaviour. The simulation-optimization framework was implemented using Julia and solved with Gurobi, providing an efficient and scalable solution for large-scale systems.

The optimization problem analyzed in this study focuses on minimizing hydraulic power consumption by optimizing pumping control strategies, without necessitating modifications to the physical infrastructure. Preliminary results indicate that hydraulic pumping power could be reduced by more than 10%, achieved through operational adjustments. Additionally, the framework offers valuable insights into how the system can adapt to changing operating conditions, such as reduced supply temperatures, boosting the transition to next-generation district heating.

Keywords: Physical model, Simulation, Operational Optimization, District Heating Transition

Dr. Mathieu Patin is a post-doctoral researcher at the CEA-Liten (Chambery, France). His research focuses on the modelling and operation of decarbonized energy systems, his main current interest being hydrogen production systems.

Benchmarking Control Strategies for Multi-Stack Electrolyser Systems under Renewable Energy Variability

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The production of green hydrogen via electrolysis is a key enabler for the decarbonization of the industrial sector. However, it faces significant challenges due to the variability of renewable energy sources. Modular systems composed of multiple independent electrolyser stacks offer enhanced flexibility, making them particularly well-suited for integration with variable renewable energy. Nevertheless, depending on the control strategy applied, such systems can experience increased stack degradation and reduced overall efficiency.

To address these issues, numerous control strategies have been proposed in the literature. However, even in recent studies, these strategies are often benchmarked only against basic approaches such as daisy-chaining or equal power allocation. This limits the ability to assess and identify the most effective state-of-the-art methodologies.

Thus, we compare several control strategies on a representative use case. This framework is based on a dynamic model of a modular electrolyser system, accounting for both stack performance, degradation and the balance-of-plant operation. The model is implemented using the Modelica CEPL library and PEGASE co-simulation software. Representative profiles for renewable energy production and hydrogen demand are generated, and the system's dynamic behaviour is simulated under various control strategies.

We apply this framework to a diverse set of rule-based strategies from the literature, as well as to optimization-based approaches that differ in prediction horizon lengths and model precision. The strategies are further assessed under varying levels of uncertainty in system parameters and renewable generation forecasts.

The comparison relies on key indicators, including system efficiency, hydrogen production, and stack degradation, as well as economic metrics such as operating costs. This benchmarking provides an outlook on the current state of the art in control strategies for multi-stack electrolyser systems.

Keywords: Control strategies, Modelling, Electrolysis, Green hydrogen, Rule-based, Predictive control

Matteo Giacomo Prina holds a PhD in energy engineering. He is senior researcher at Eurac Research, institute for renewable energy, within the group of energy system modelling and e-mobility.

Evaluating Machine Learning Robustness as an EnergyPLAN Surrogate Model for Uncertainty Analysis

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Energy system modelling faces significant computational challenges that limit the depth and breadth of scenario, sensitivity and uncertainty analysis. This research addresses this critical constraint by examining the potential of machine learning as a surrogate model to reduce computational burden while maintaining solution reliability. The study develops an approach based on a machine learning technique to emulate the complex EnergyPLAN simulation process, which is then integrated within the EPLANopt model to enable capacity expansion optimization through a single-objective genetic algorithm. By comparing outputs and computational efficiency, the study explores the viability of using machine learning to accelerate energy system optimization and to study uncertainty. This approach allows for a more comprehensive understanding of system sensitivities and potential variations, which are typically constrained by computational limitations. The study aims to validate the machine learning surrogate model through multiple optimization iterations, comparing its performance against traditional methods such as using EnergyPLAN coupled with genetic algorithms, and particular swarm optimization. By rigorously testing the model's accuracy, consistency, and predictive capabilities, the research provides a critical assessment of the potential for machine learning to transform energy system modeling. The methodology is applied to a regional case study where global sensitivity analysis is performed, with particular emphasis on economic parameters to evaluate how cost uncertainties affect optimal system configurations and performance.

Keywords: Energy system modelling, Energy scenarios, Energy planning, Machine Learning, Surrogate Modelling

Matthias Posch completed a Bachelor's and Master's degree in Polymer Engineering and Science at Johannes Kepler University Linz, Austria. Currently, he is a PhD student in Polymer Engineering at the same institution, focusing on the ageing behaviour of polyolefins for renewable energy technologies.

Effect of hot air welding parameters on the ageing behaviour of polyethylene liners

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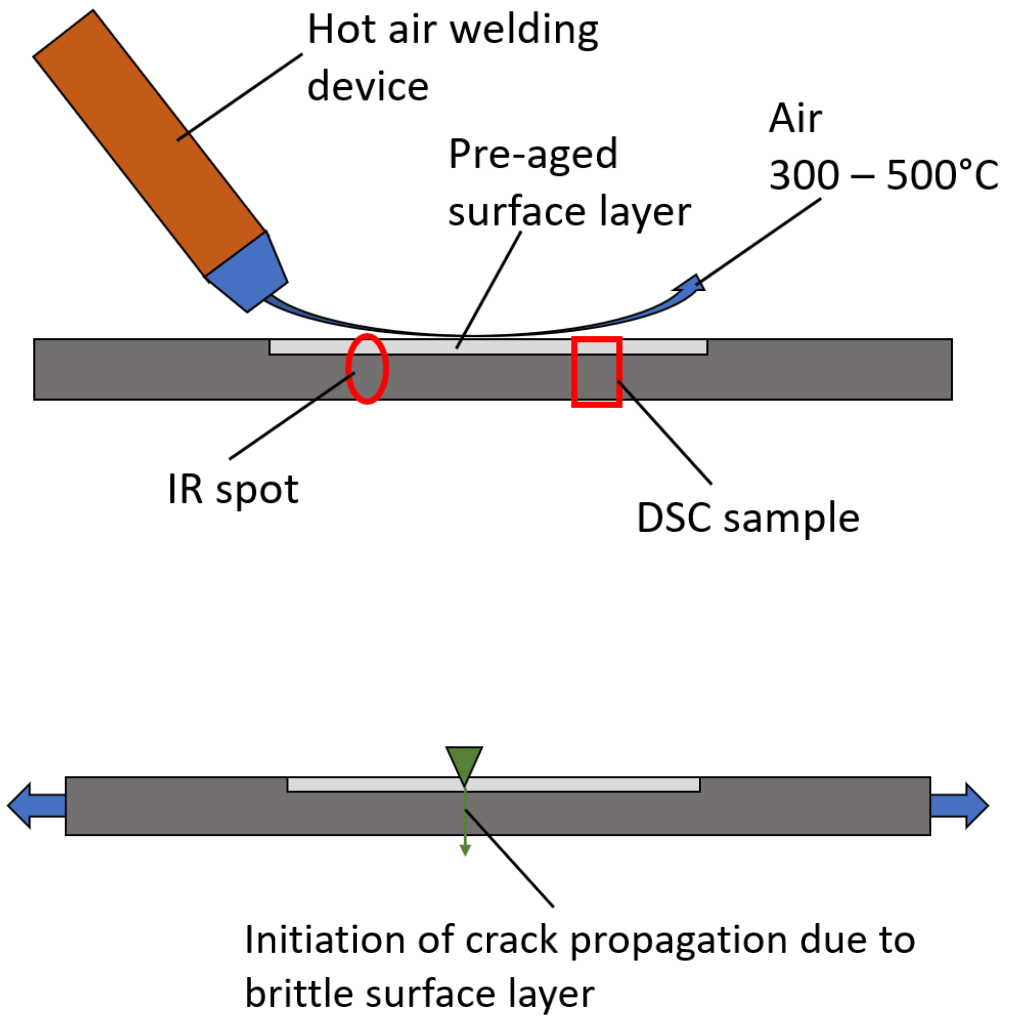
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Pit thermal energy storages (PTES) are gaining increasing market relevance, offering an efficient solution for storing excess energy for later use in district heating networks. To prevent water leakage, polymeric liners are applied as a barrier layer. These liners are extruded at thicknesses of 1.5 to 3 mm and welded on-site. Improper welding conditions lead to material degradation. The main objective of this study was to investigate the ageing behaviour of a well-established polyethylene liner under different preconditioning settings.

By systematic variation of the hot air temperature and heating time, polyethylene liners were preconditioned, but not welded. Subsequently, micro-specimens were manufactured, exposed to deionized water at elevated temperatures and removed at predefined intervals. The specimens were characterized by tensile testing, thermal analysis, and infrared (IR) spectroscopy. Mechanical failure was defined when the strain-at-break value dropped below strain-at-yield. The oxidation temperature threshold was defined as 220°C. A carbonyl index above 0.3 was considered as indicator for degradation.

As most sensitive ageing indicator, the strain-at-break values were identified. Both, oxidation temperature and carbonyl index were no reliable indicators. This was attributed to the localized degradation effect of hot air treatment limited to the surface of the liner. While thermal analysis and IR spectroscopy are probing the entire cross-section, local embrittlement of the specimen surface (see Figure) has a significant impact on the ultimate strain-at-break. Hence, by consideration of strain-at-break, critical hot air pretreatment conditions of 5 s at 450°C and 10 s at 360°C were deduced. Future research will deal with IR mapping allowing for analysis of degradation products close to the edge of the micro-specimen. Due to the trend to higher storage operating temperatures (e.g., PTES in Høje Taastrup), novel materials for liners are under development.

Keywords: thermal energy storage, polyethylene liner, hot air welding, polyolefin, degradation



Within his positions at two Fraunhofer Institutes since 2007, Dr. Krause has been responsible for projects focussing on energy efficient buildings and districts. His research addresses renewable energy systems like heat pumps and photovoltaics, HVAC systems and building automation and flexibility.

The impact of heat pumps on the electricity load: Evaluation of large sets of operational data including the simulation of future situations

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The expected ramp-up of heat pumps and electromobility as part of the energy transition will result in an increasing overall load on the electricity grid. To take this into account for grid planning, grid operators typically use simultaneity factors or simultaneity functions to determine the expected peak load. In the application case of decentralized heat pumps, the electricity load correlates strongly with the thermal demand for heating and domestic hot water. Reduced efficiency at low temperatures affects the electricity load additionally, the operation of heating elements at low outside temperatures implies a further challenge. In addition to the peak load, the daily profile of the electricity consumption of heat pumps is of major relevance for electricity balancing management. Typically, electricity providers use temperature-dependent standard load profiles for electricity consumers. However, the number of active customers, who will adjust their consumption depending on electricity prices or the availability of (renewable) generation capacity and grid capacity, will significantly increase in the future. Hereby, flexible operation will affect both the maximum peak load as well as the electricity consumption distribution over the days.

To assess all these aspects, a comprehensive study has been performed using large set of operational data derived from more than 6.000 installed heat pumps over up to 2.5 years as well as from scientific monitoring projects in Germany. To support the correlations derived from the operational data e.g. at very low temperatures, simulation models have been developed according to the respective buildings, system designs and operational behaviors. To evaluate the impact of flexible heat pumps, the operation has been simulated and optimized with respect to flexible tariffs for future heat pumps, electromobility as well as renewable energy market penetration.

Keywords: Heat pumps, operational assessment, flexibility, simulation, grid stability

Michel is assistant professor at the Politecnico di Torino, in the Energy Department, and visiting professor at SciencesPo – Paris School of International Affairs. He has several years of academic and professional experience on energy and transport systems analysis, scenarios and energy planning.

Evaluation of the hourly GHG intensity profiles of high-temperature heat pumps in industrial applications

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High-temperature heat pumps are increasingly being seen as a potential solution to decarbonize medium-temperature industrial applications. Some manufacturers are already providing solutions that can supply heat at 120°C, that could be of interest for a range of industries, with the aim of supporting the electrification of the sector. However, reliable performance indicators are required to estimate the actual emissions of this solution compared to the traditional options, to optimize their emission savings and penetration levels. In this analysis, we are evaluating the hourly emission factor of high-temperature heat pumps by integrating their operational profiles, which are also integrating the variable performance related to different operational temperatures and load factors, with the hourly emission factors from the electricity generation mix of the power grid. The comparison of various heat demand profiles from real data of industrial applications, along with the analysis of the electricity mix of different European countries, highlight the potential variability of greenhouse gas emissions along the supply chain for this solution. The results of the hourly analysis are also compared to average annual values to estimate the level of approximation of such a simplified approach. Our results can support energy system modellers as well as policy makers, by providing additional information of the performance of high-temperature heat pumps in real operating conditions that can be integrated in energy system models as a basis to improve the knowledge and reliability of decarbonization strategies and policies.

Keywords: High-temperature heat pumps, CO2 intensity, emissions, hourly profiles

Mikkel is a Consultant at the Danish Technological Institute. His expertise lies in the cross-section between artificial intelligence and engineering, including data-centric engineering, probabilistic forecasting, uncertainty quantification, surrogate models and Monte Carlo methods.

Data Compression for Time Series Modelling: A Case Study of Smart Grid Demand Forecasting

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Efficient time series forecasting is essential for smart energy systems, enabling accurate predictions of energy demand, renewable resource availability, and grid stability. However, the growing volume of high-frequency data from sensors and IoT devices poses challenges for storage and transmission. This study explores Discrete Wavelet Transform (DWT)-based data compression as a solution to these challenges while ensuring forecasting accuracy. A case study of a seawater supply system in Hirtshals, Denmark, operating under dynamic weather, operational schedules, and seasonal trends, is used for evaluation.

Biorthogonal wavelets of varying orders were applied to compress data at different rates. Three forecasting models—Ordinary Least Squares (OLS), XGBoost, and the Time Series Dense Encoder (TiDE)—were tested to assess the impact of compression on forecasting performance. Lossy compression rates up to $r = 0.999$ were analyzed, with the Normalized Mutual Information (NMI) metric quantifying the relationship between compression and information retention. Results indicate that wavelet-based compression can retain essential features for accurate forecasting when applied carefully.

XGBoost proved highly robust to compression artifacts, maintaining stable performance across diverse compression rates. In contrast, OLS demonstrated sensitivity to smooth wavelets and high compression rates, while TiDE showed some variability but remained competitive. This study highlights the potential of wavelet-based compression for scalable, efficient data management in smart energy systems without sacrificing forecasting accuracy. The findings are relevant to other fields requiring high-frequency time series forecasting, including climate modeling, water supply systems, and industrial operations.

Keywords: Demand forecasting, Time series modelling, Data compression techniques

Mirko Morini is associate professor at University of Parma since 2016. He coordinated international projects dealing with the smart management of integrated energy systems and he authored more than 150 papers about modelling, experimentation and management of fluid machinery and energy systems.

Predictive controller for optimal hydrogen generation and injection into the natural gas network

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Hydrogen is increasingly recognized as a key driver in the energy transition, as it has significant potential to support decarbonization of many sectors. However, the current hydrogen infrastructure is still underdeveloped, creating barriers to its widespread adoption. To facilitate its integration during the transitional phase, leveraging existing energy infrastructures presents a practical and cost-effective solution. For instance, by blending hydrogen with natural gas, the well-established pipeline infrastructure can be used to support hydrogen distribution without the immediate need for dedicated hydrogen pipelines. However, the hydrogen content within the gas mixture must be carefully regulated to maintain gas quality parameters standards and ensure the integrity of the pipeline system, as well as a proper operation of end-user appliances. In scenarios where multiple hydrogen injection points exist within the network, effective coordination becomes crucial to ensure compliance with safety and operational constraints. To address these challenges, this study presents the development and validation in Model-in-the-Loop of a controller based on Model Predictive Control. The proposed controller is designed to optimize and coordinate hydrogen injection in multiple points in the natural gas network while accounting for variations in gas composition as it flows through the infrastructure. The controller employs a multi-level optimization strategy, where different algorithms work in parallel to optimize various aspects of the problem. By using a holistic approach to energy management, the controller effectively monitors all energy exchanges and continuously tracks hydrogen concentration in real-time. The results show that the controller efficiently operate the Power-to-Gas systems, maximizing hydrogen injection while maintaining the gas quality parameters standards of the Italian legislation in the pipelines, also in networks with varying natural gas composition.

Keywords: Hydrogen blending, Model Predictive Control, Gas network, Hydrogen tracking

Nicholas Tedjosantoso is a research associate at HAW Hamburg/CC4E. His research focuses on energy systems, and he is currently pursuing a PhD in the field of district heating systems.

Tensor-Based Modeling Framework for District Heating Pipes

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Across multiple fields, there has been a noticeable increase in the use of tensor-based methods and the term "tensor" itself. This trend can be attributed to the growing complexity of data structures (e.g., multi-dimensional datasets) and advancements in hardware, such as specialized tensor GPUs. In engineering, tensors provide a powerful framework for modeling complex multi-dimensional relationships, which are fundamental to modern machine learning and control engineering, where tensor-based algorithms have enhanced controller efficiency. Previous studies have shown that tensor representations effectively model the dynamic behavior of heating systems and are suitable for HVAC systems. However, to the best of the author's knowledge, tensor-based models have not yet been applied to district heating systems.

To address this gap, this work aims to assess the feasibility of tensor-based methods for district heating pipes and to develop a corresponding tensor-based modeling framework. For this purpose, tensor representations of the conservation laws—namely, conservation of mass, momentum, and energy—are constructed. By modeling pipe flow implicitly, the empirical Darcy-Weisbach equation can be approximated using multilinear equations. The model is further extended using binary variables to enable the dynamic switching between laminar and turbulent flow regimes. The thermal behavior is modeled using a dynamic energy balance for an open system, spatially discretized into N segments ($N > 1$).

To validate the model, temperature response comparisons are made between the proposed model and an established pipe model from Modelica. The results show that the thermal behavior of the proposed model closely aligns with the reference model. For the momentum equation, direct comparison with the non-linear Darcy-Weisbach equation shows minimal deviations for both laminar and turbulent flow regimes. This demonstrates the potential of tensor-based approaches.

Keywords: Multilinear algebra, Tensor-based modeling, District heating, Pipe flow modeling, Dynamic simulation

Niklas Denter works on the optimisation of sector-coupled renewable heating systems, focusing on flexibility integration, waste heat utilisation, and techno-economic modelling. He is a research associate and PhD candidate at University of Applied Sciences Ingolstadt, Institute of new Energy Systems.

MODELLING BATTERY WASTE HEAT RECOVERY FOR SECTOR-COUPLED POWER-HEAT SYSTEMS IN DISTRICT HEATING PLANNING

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This contribution addresses a methodological gap in energy system modelling by developing an optimisation approach that dynamically integrates battery waste heat into sector-coupled power and heat systems. As the share of variable renewable electricity increases, flexibility technologies like batteries play a growing role—but also generate low-temperature waste heat that often remains unused.

The proposed framework extends existing models by representing batteries not only as electricity storage units but also as potential low-grade heat sources. In contrast to predefined waste heat profiles, thermal energy is generated endogenously as a byproduct of battery operation. This operation is optimised in response to electricity price signals and system constraints. The endogenous generation of the waste heat profile—and its consideration within the system design process—is a key advantage of the approach, enabling more realistic system representations and better integration of thermal dynamics into planning decisions. The model primarily performs system design optimisation, which is carried out under consideration of operational behavior through detailed dispatch modelling. Design decisions—such as battery sizing—determine the availability and usability of waste heat, which can then be either recovered or upgraded via heat pumps. Heat can be stored or directly injected into a district heating system—based on techno-economic trade-offs. The model builds on the open-source framework Calliope and is applied to a real-world planning context in Germany, where a system combining wind power, a heating network, and battery storage is under development.

While the initial focus lies on battery systems, the framework is extensible for integrating other low-temperature waste heat sources, such as electrolyzers and data centres. The analysis assesses cost-saving potential, explores strategies, and identifies conditions under which thermal integration is beneficial.

Keywords: battery waste heat, low-temperature waste heat, sector coupling, district heating, energy system planning, power-to-heat, optimisation model, calliope, energy flexibility

Nils Zimmerling is a research associate at the Professorship of Applied Thermodynamics at Chemnitz University of Technology and focuses his work on district heating networks.

Monitoring of district heating concrete ducts by measuring thermal parameters

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District heating allows for a reliable and cost-efficient supply. Furthermore, the networks allow the integration of renewable heat sources, which then can be distributed to the connected consumers. Eventually, this is the key to achieving environmental policies. These networks differ substantially regarding the system construction. Today, the use of preinsulated bonded pipe systems laid in the ground is preferred. However, a significant proportion of transmission pipelines in Germany consists of pipes laid in non-accessible concrete ducts.

Data, which describes the condition of the whole pipeline system in detail and locally resolved, is the basis for innovative maintenance strategies. For preinsulated pipes, for instance, through extensive research projects methods to estimate remaining service life have been developed. In contrast, the level of knowledge in the field of pipes in concrete ducts is relatively low. Through metrological monitoring, only the detection of leakage, for example, was possible. There are no insights available, that causes of slow processes based on measurements or a scientific theory were investigated.

The contribution describes a concept for thermal monitoring of DH pipes laid in concrete ducts. Two pipeline routes will be investigated with two monitoring systems in each case. A monitoring system contains multiple sensors at different locations. The recording of the weather is carried out by a weather station. Since many states and processes are not directly measurable or comprehensively determinable, numerical models or evaluation methods must be developed and used.

Furthermore, the article explains the planned data processing, which is also necessary for innovative maintenance. A measuring instrument undertakes the actual measurement. This instrument will be coupled with an edge device. There, later a decentralized evaluation of measured data can proceed, which informs the operator.

Keywords: district heating, pipe, insulation, concrete duct, condition assessment, system analyses, monitoring, data processing, methodologies

Ona Vassallo is a project specialist working in Sustainable Energy Systems -research group in HAMK - Häme University of Applied Sciences. Her research focuses on energy system analysis and smart energy applications, with special attention to district heating.

From combustion to conversion: Impact of heating demand decrease on district heating systems

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Ona Vassallo (presenter)

Due to climate change and increasing global temperatures, heating demand is expected to change in Finnish buildings, according to previous research and simulations, verified by the research group and outside operators. This study models small, middle and large sized district heating (DH) systems in Finland for the test reference years 2030 and 2050 with Representative Concentration Pathway (RCP) climate scenarios. High emission energy systems are in transition towards energy security and sustainable energy systems, while energy demand change may increase pressure for higher consumer energy cost. While national-level studies exist in Finland and Denmark, local-level analyses of climate change impacts on DH are lacking. As energy systems move towards sustainability, predicting emission and revenue changes help systems pivot if necessary. Modelling and identifying alternatives to high emission systems at local level reflects the national situation and the capacity to respond to the demands that national and European Union level planning has in store. Sustainable energy systems consume less emission intensive fuels and therefore promote national objectives for emission reductions. DH system modelling was done with current technologies and possible future integration of waste heat, electric boilers, and nuclear energy options. Using historic fuel prices, year 2023 was modelled as a baseline and later compared to future scenarios with scaled fuel prices. Modelling tool used for analysis was EnergyPRO with an operation strategy that prioritizes fuel prices. The results show that with a decrease of building heat demand, the current systems lose significant amount of revenue but can produce renewable heat at high rates. Future systems prioritize minimizing burning fuel to generate energy, achieving a fully renewable mix. Among scenarios, fully renewable systems with biomass-base lost the least amount of revenue, due to lack of emission costs and more consistent fuel prices.

Keywords: climate change, EnergyPRO, regional planning, sustainable energy systems, energy security

Paula Oberfeier (she/her) is a PhD at Fraunhofer ISE investigating the role of large-scale water-source heat pumps in district heating systems focusing on climate change uncertainties. She holds an M.Sc. in Business Administration and Engineering: Electrical Power Engineering from RWTH Aachen.

The role of reversible heat pumps in decarbonizing the heating sector under rising temperatures

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Climate change is driving significant shifts in building energy demands, with increasing temperatures leading to rising cooling needs while heating demand, though moderately declining, continue to be a crucial factor in overall building energy planning. Reversible heat pumps offer a promising solution for both demands. However, their integration into municipal energy systems and interactions with other components remain inadequately investigated. This study addresses this research gap by examining reversible heat pump integration into the regional energy system model DISTRICT – a mixed-integer linear optimization model for cost-minimizing planning of decentralized energy systems.

Building on established modeling approaches, we develop a mathematical formulation capturing operational characteristics of reversible heat pumps. The methodology includes temperature-dependent efficiency variations through linearized coefficient of performance functions and modeling of different operational modes (heating, cooling, domestic hot water production, and their combinations).

The case study examines scenarios with varying cooling demand intensities to identify optimal technology combinations, focusing on comparing reversible heat pumps with alternatives like district heating systems paired with decentralized air conditioning within a specific German municipality. By 2050, with a 2°C temperature increase, cooling demand is projected to reach 1.61GWh annually. Preliminary calculations show that meeting the cooling demand requires 236MWh of electricity (0.47% of municipal electricity consumption) using electrical chillers (EER 4.50), while reversible heat pumps (EER 7.11) consume only 150MWh (0.29% of municipal electricity consumption) – a 37% reduction. This study will evaluate economic implications of these savings by analyzing investment and operational costs, demonstrating conditions under which reversible heat pumps contribute to more efficient, lower-emission energy systems.

Keywords: reversible heat pumps, regional energy system modeling, district heating and cooling, municipal energy transition

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Philipp Herpich is a research associate and PhD candidate at TU Berlin (Workgroup for Infrastructure Policy) and EUF Flensburg (Department of Sustainable Energy Transition). His research includes energy system modelling, the heating transformation and fossil fuel phase-out in Germany.

Charting the EU Energy System Towards 2060 – Model results of the EU-EnVis-2060 scenarios

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The global energy transition requires a rethinking of how we generate, consume, and transform energy. To meet the EU's climate targets of net-zero emissions by 2045–2050, a strong push for electrification and renewables is needed. Yet, an unstable geopolitical landscape—globally and within Europe—adds complexity to this already ambitious task.

To explore future uncertainties, the “European Energy Vision 2060” (EU-EnVis-2060) scenarios were developed through expert workshops with academia, industry, and policy stakeholders. This process yielded four distinct qualitative storylines that reflect key drivers and uncertainties of the European energy transition.

These storylines were then translated into parameters for energy system modeling. Using the open-source Global Energy System Model (GENeSYS-MOD), we quantify Pan-European transition pathways. GENeSYS-MOD is a sector-coupled, linear cost optimization model covering electricity, buildings, industry, and transport. It simulates system evolution to 2060, delivering insights on investments, capacity expansions, dispatch, and flexibility needs.

Results highlight how Europe's energy system might evolve by 2060, identifying robust solutions to meet climate goals under diverse conditions. Key outputs include the required scale-up of renewables and flexibility options, as well as no-regret measures across scenarios. An iterative link between GENeSYS-MOD and regional/sectoral models ensures that detailed insights inform and refine broader system pathways for the ongoing EU Horizon Projects iDesignRES and ManOEUVre.

Ultimately, the scenarios aim to support the development and revision of National Energy and Climate Plans (NECPs), helping EU member states build sustainable, secure, and resilient energy systems for the future.

Keywords: Energy System Modelling, Europe, iDesignRES, Long-term scenarios, GENeSYS-MOD

Throughout his PhD, he has focused on enhancing the efficiency of district heating systems and developing smart solutions for building energy management. His primary research interests include energy flexibility and the application of AI in district heating systems.

Price-aware building thermal control using deep reinforcement learning: Simulation and experiment

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Mina Montazeri, Swiss Federal Laboratories for Materials Science and Technology

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While buildings are recognized as one of the main sources of global carbon emissions, they also present significant opportunities for decarbonization. Building energy systems are typically controlled using pre-defined schedules and rule-based strategies, which usually lack adaptability to dynamic conditions such as real-time energy prices, occupancy, and weather conditions. In this study, we develop a price-responsive Deep Reinforcement Learning (DRL) algorithm to autonomously control the indoor temperature of a building. DRL offers model-free control capable of learning optimal control strategies through interaction with the environment under dynamic conditions. The controller receives observation data and dynamic price as one of the external inputs and acts to minimize overall cost while maintaining thermal comfort. To improve learning efficiency, this study introduces Temporal-Weighted State Change, a novel method that compresses future price data into a single state observation for the controller, enabling forecast-aware decisions while reducing training complexity. The controller is developed and trained in a simulation environment using a physically consistent neural networks model. It is then implemented on a real-world residential unit in Dübendorf, Switzerland, and evaluated during the winter of 2025 using the dynamic electricity prices of the local utility company. Experimental results indicate that incorporating future price information leads to more informed decisions and improves the performance of DRL by 11.5% compared to only considering the current price. Findings also show that the controller sacrifices thermal comfort to reduce consumption costs at some hours. Accordingly, DRL could reduce heating costs by 66.1% at a cost of 6.8 Kh higher thermal discomfort compared to a rule-based controller. The findings highlight the developed controller as a promising solution for cost-efficient operation of buildings and enhanced grid flexibility.

Keywords: Deep reinforcement learning, Building energy management, Price-responsive thermal control, Smart buildings

Ruben van den Berg is a researcher at KWR in the Energy and Circular Systems team. He holds a degree in Civil Engineering and Water Management from Delft University of Technology. His work focuses on sustainable water and energy systems and life cycle analysis (LCA) to assess environmental impacts.

Driving decarbonization: evaluation of a case study of green hydrogen-based transport in Nieuwegein, the Netherlands

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- 2) *Tessa van den Brand, KWR Water Research Institute*
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Reducing emissions from the transport sector is essential for global climate goals. The EU aims for 14% renewable energy in transport by 2030. Hydrogen-powered transport, particularly for heavy-duty applications, offers a promising solution, overcoming battery-electric limitations with high energy density, fast refueling, and long ranges. It also addresses renewable energy intermittency by converting surplus solar and wind electricity into storable fuel and helps mitigate local grid congestion by reducing peak loads from simultaneous battery electric vehicles (BEVs) charging.

This study assesses the feasibility and environmental performance of a local green hydrogen value chain for road freight transport in Nieuwegein, the Netherlands. Green hydrogen is produced via proton exchange membrane water electrolysis (PEMWE) with an electrical capacity of 2.5 MW, operated under real-life conditions and meeting RED RFNBO criteria. The green hydrogen is used in fuel cell electric vehicles (FCEVs) and hydrogen internal combustion engine vehicles (HICEVs), with a focus on heavy-duty trucks.

A life cycle assessment (LCA) compares the environmental impacts of FCEVs and HICEVs with conventional diesel trucks and BEVs, using tonne-kilometer (tkm) as the functional unit. The analysis covers all relevant stages: fuel production, vehicle production and operation, infrastructure, and end-of-life.

Results show that FCEVs and HICEVs emit fewer greenhouse gases than diesel and BEV trucks using the Dutch electricity mix. FCEVs and HICEVs are more efficient in fossil resource use, but show higher environmental impacts in some indicators, such as human toxicity, due to the renewable energy needed for hydrogen production. Up to 31% of energy input for hydrogen production can be recovered as residual heat, which could support district heating and improve system efficiency. These findings highlight the role of green hydrogen in complementing electrification for a low-carbon transport system.

Keywords: green hydrogen production, PEMWE, road transport, LCA, fuel cell, renewable energy, electrolysis, greenhouse gas

Dr. Selim Mimaroglu is a Director of Data Science and Machine Learning at Oracle. He earned a Ph.D. in Computer Science from the University of Massachusetts Boston. Dr. Mimaroglu has published peer-reviewed articles on various topics in AI and holds five patents from the USPTO.

Disaggregating Electric Heating in Commercial Buildings with Deep Learning: U.S. Challenges and Opportunities

Selim Mimaroglu, Oracle

Anqi Shen, Oracle

Xiang Li, Oracle

Xiaoning Guo, Oracle

Dmitriy Fradkin, Oracle

Selim Mimaroglu (presenter)

At Oracle we have built vast amount of expertise in residential disaggregation. Our deep learning models help millions of customers annually to efficiently manage their energy needs. Our technology, which doesn't require any sensors and gadgets, is based on non-intrusive load monitoring and deep learning. Our models are trained and validated on millions of data points, and they have been in production for several years, continuously retraining and improving on new datasets.

We are expanding our disaggregation expertise by including small, medium, large businesses, and commercial buildings. Our aim is to provide similar benefits to all businesses and help them manage their electricity usage. Electric heating in businesses and commercial buildings is one of the largest expenses; an accurate estimation of this expense in the form of disaggregation helps energy management and efficiency.

We share our electric heating deep learning model building journey for businesses and commercial buildings in detail with accuracy metrics on several states and many cities. The training data set comprises real datasets, synthetically generated datasets, and surveys. We have firsthand experience with real datasets and surveys, and we also studied well known ComStock synthetic data from NREL (<https://comstock.nrel.gov/>) and appreciated its numerous benefits. ComStock data coverage in US is remarkable, and it includes various types and sizes of commercial buildings and businesses. We observed AI model building and validation on ComStock leads to remarkable results. But, testing the same models on real data in the same regions, we noticed performance degradations. We overcame this problem by various methods: selective sampling and boosting with real datasets. Instead of using ComStock as it is, we sampled data selectively to match with our commercial customers, which

led to better results. Another major improvement came from boosting ComStock with real datasets and surveys.

Keywords: Artificial intelligence in energy, Non-intrusive load monitoring (NILM), Energy disaggregation, Commercial buildings, Energy management, Energy efficiency

He works on large-scale energy system analysis using the Balmorel energy model, with a focus on sector coupling, flexibility options and global sensitivity analysis. His work also includes the integration of Life Cycle Assessment and Planetary Boundaries in energy model.

The role of flexibility in a sector-coupled European energy system

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Flexibility is key to integrate the high share of variable renewable energy (VRE) sources, like wind and solar, which is foreseen to achieve the green energy transition. Yet, the role of different flexibility providers, ranging from generation units, transmission lines, storage technologies and demand side management, remains highly uncertain .

In this study, we will quantify the need for flexibility in future sector-coupled European energy systems, using a large-scale energy system model, for the years 2030 and 2050. The energy system model performs a least-cost optimization of both investment and dispatch of energy technologies, and considers the main energy sectors and systems, such as electricity, heating, transport and hydrogen. We will apply global sensitivity analysis on specific techno-economic parameters followed by an advanced uncertainty assessment to evaluate the uncertainty space of the flexibility options.

Using this modelling framework, we investigate the internal market share of the different flexibility options, not only at the European level but also with a focus on regional distribution. Preliminary results show that sector coupling provides significant opportunities for flexibility provisions. Electricity and hydrogen transmission, hydrogen storage, heat pumps and electric vehicles are also identified as key players to provide flexibility. In addition, we will investigate the uncertainty space as well as the correlation of each flexibility option with specific parameters, such as correlation between VRE share and need for each flexibility option. Finally, we will analyze the effects of the overall system, with a focus on the total system cost, CO₂ emissions, and other indicators such as the electricity prices.

Keywords: Flexibility, Energy System modelling, Renewable energy integration, Sector coupling, Global Sensitivity Analysis

Tim Aidan Graulich is a PhD student in the section of Energy Economics and Modelling at Technical University of Denmark. His research focusses on linking and surrogate modelling of large scale and sector coupled energy system models, as well as uncertainty analysis.

Can surrogate modeling improve linking between sectoral energy system models?

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In the future, energy systems are expected to become increasingly integrated, with vectors such as electricity, gas and heat having the potential to synergistically couple various sectors. To model this energy transition, energy system models are becoming increasingly complex, seeking to incorporate higher temporal and spatial resolutions, more energy sectors, technologies and infrastructures and deal with inherent uncertainties related to future transition pathways. One possibility is to link existing sectoral energy system models together, utilizing existing and validated tools and possibly reducing computation times. While this method shows potential, it still faces issues in terms of performance and communication between modeling teams.

This study investigates the potential of machine learning based surrogate models to act as proxies for one of the linked sectors. Sensitivity analysis is used to identify key parameters that drive relevant outputs, thus reducing the input dimensionality and potentially the number of samples needed for successful training. Afterwards, machine learning models can be trained, using data generated by the underlying sectoral energy system model.

Using a toy example modeling hydrogen production in the Nordics, multiple sensitivity analysis methods are compared in terms of samples needed to identify key parameters. Subsequently different machine learning methods are compared on data sets with varying number of input parameters, to compare their accuracy in relation to training samples required. It is shown that reducing the input parameter space can result in more accurate proxies with fewer training samples, thus creating a tradeoff between surrogate model flexibility (number of input parameters included) and computational cost (number of training samples generated).

Keywords: Energy System Modeling, Sector Coupling, Model Linking, Machine Learning, Sensitivity Analysis

Tuomas Vanhanen is a doctoral researcher interested in smart energy cities, policy coherence, and sustainable transitions literature. He applies both qualitative and quantitative methods in the context of urban energy transitions.

Comparison of carbon neutrality strategies on the peak power demand of a Nordic city

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Smart energy cities with strict carbon neutrality must cope with infrastructure constraints, especially the electricity grid, as industries become electrified. Carbon capture, utilization, and storage technologies, including direct air capture together with uptake of heat pumps and electric vehicles place significant strain on the electricity grid, leading to doubling or tripling of peak electricity import.

This study applies bottom-up energy system modeling to assess trade-offs between different strategies for a Nordic city to reach carbon neutrality. By using dynamic coefficient of performance and considering the internal electric boiler function in HPs as model inputs, the analysis enhances the real-world applicability of the findings. The results provide insights into policy coherence and system efficiency under different scenarios, while underlining the importance of peak power management and system flexibility in strategic energy planning in cities.

Further research could employ GIS-based tools at the local scale to pinpoint electricity grid constraints within the smart energy city, rather than limiting assessments to transmission line capacities. This would inform more targeted infrastructure investments and enhance the transition to carbon neutrality.

Keywords: smart energy cities, energy transition, peak power demand, peak electricity import, coefficient of performance

Associate Professor with a demonstrated history of industrial cooperation and research project management. Key research areas: gas dynamics (vortex tube), waste heat recovery and storage, gas and hydrogen network safety.

Beyond conventional cooling - investigation of the impact of RHVT implementation into the Linde refrigeration cycle

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The study presents the possibility of integrating the Ranque-Hilsch Vortex Tube (RHVT) into refrigeration or heat pump cycles. RHVT is a device of simple design and construction, without moving parts, separating a compressed inlet flow into two expanded flows of different temperature (hot and cold), with adjustable share of the cold-to-inlet mass ratio. This study concerns a possible integration of RHVT into a refrigeration cycle by replacing the standard throttling valve and then managing the expanded, partially liquefied flows. However, it should be noted that the refrigeration agent has to be liquefied between the condenser and the evaporator. Based on the known thermal performance of RHVT for gases, obtained from an ongoing experimental and numerical research, a thermodynamic model was built to i) predict the outlet parameters from RHVT accounting for the phase change enthalpy, to ii) analyse the impact of RHVT valve position and the cold mass fraction on the two-phase flow performance, and to iii) evaluate the performance of selected refrigeration cycles using RHVT as the expansion element. The thermodynamic performance of the cycles was evaluated using the coefficient of performance (COP) as well as the exergy efficiency. The operation of the cycle was analyzed for the refrigeration and the heat pump mode. Attention has been paid to include supercritical CO₂ (R744) as a promising refrigeration agent. The findings of this study indicate the improvement potential of refrigeration cycle performance, and the directions of future developments.

Keywords: Vortex Tube, Ranque-Hilsch effect, Refrigeration, Coefficient of Performance

Yassine El Alali was trained as a biochemical engineer, and is currently applying his experience in thermodynamics, sustainability, biological processes and process engineering to the field of multi-energy systems and the urban energy transition.

Comparison of community-based and individualized energy scenarios in the urban energy transition using multi-objective optimization

Yassine El Alali; Jonathan Hachez; Svend Bram, Vrije Universiteit Brussel

Yassine El Alali (presenter)

The urban energy transition requires to facilitate access to a cheap, low-carbon energy supply. Multi-energy systems offer a portfolio of solutions to satisfy the needs in heating, cooling and electricity sustainably. In this work, we model the demands of a neighbourhood in Bari, Italy, as a case study. We consider three different scenarios: (1) a centralized energy hub with a district heating network, allowing heat, cold and electric exchanges between stakeholders. (2) a renewable energy community, where only electricity can be exchanged between stakeholders, at a certain cost. (3) as a benchmark, we consider individual solutions, where energy exchanges are not allowed. We present a multi-objective optimization approach to assess the economic and environmental performance of the different scenarios. The model uses mixed-integer linear programming and generates a set of Pareto efficient solutions. The results show that even with the higher initial investment costs of the centralized and energy community scenarios, there is still a significant preference for these systems due to economies of scale and the decreased dependency on the grid, which result in a lower environmental impact as well as a lower total annual cost. These community-based models for energy systems therefore not only provide social benefits, but also find solid basis in improving energy efficiency, reducing environmental impact, lowering costs and increasing self-sufficiency.

Keywords: Multi-Objective Optimization, District Heating, Energy Community, Sustainability, Renewable Energy, Positive Energy District, Energy Transition

Dr. Zhaoming Yang is assistant professor in China University of Petroleum, and his research focuses on smart energy system and energy system resilience. He has published more than 50 articles in Applied Energy, RESS, Energy, Journal of Cleaner Production et al. and top conference in energy system.

New generation natural gas pipeline system: for smart and resilient future

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This study addresses resilience assessment and smart development of natural gas pipeline systems (NGPS) by revealing self-organized criticality (SOC) through gas transmission-based disturbance analysis. The NGPS exhibits localized power-law distributions in disturbance scales/frequencies and self-limiting propagation mechanisms without cascading failures, supporting year-round emergency preparedness and universal preventive strategies. Innovatively, a smart NGPS-oriented performance flow algorithm and disturbance zone partitioning method were developed, aligning with operational scheduling strategies. A multi-dimensional resilience framework (global, threshold, temporal resilience) integrates flow structure sensitivity analysis—combining performance and asset flows—to enable disturbance prediction and decision optimization in design/operation phases. Validated in China's NGPS, the methodology advances intelligent resilient pipeline systems through algorithmic innovations and modular network analysis, providing theoretical and practical solutions for enhancing system functionality and disturbance resistance.

Keywords: Natural Gas Pipeline System, Gas Supply, Resilience, Smart Energy System, Complex Network

Smart energy infrastructure and storage options

Working in the field of mathematical optimization methods for the reliable, affordable, and sustainable design and operation of integrated energy systems. Focus on uncertainties including component failures and forecast errors, and seasonal storage.

Optimal real-time operation of smart energy systems with seasonal storage under uncertainty

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Achieving climate neutrality requires a significant expansion of renewable energies. Due to the intermittency of renewable energies, smart energy systems (SES) are expected to increasingly integrate seasonal storage for the affordable and reliable supply of residential to industrial consumers. To operate SES, operational optimization methods can be used. These methods require short computational times to be applicable in real-time. Existing methods ensure low computational times by either considering short forecast horizons or neglecting uncertainties. However, short forecast horizons hinder the seasonal storage operation, while the neglect of uncertainties can lead to high costs or undersupply.

To determine the optimal real-time operation of SES with seasonal storage under uncertainty, this work presents a novel operational optimization method. Our method combines stochastic rolling horizon optimization (SRHO), a widely used operating method, with stochastic dynamic programming. The SRHO considers weather forecasts for the next six days. At each hour, it reoptimizes the SES operation to account for updated forecasts. Stochastic dynamic programming determines the expected value of stored energy at the end of the six-day horizon. This expected value of stored energy considers a yearly operating period with seasonal uncertainties. We model seasonal uncertainties with Markov chains, which are based on typical days derived from historical data.

We evaluate our method by simulating the operation of an exemplary SES with heat, cold, and hydrogen storage over 45 years with varying weather conditions. On average, our method determines the optimal operation for the current hour in 3.0 seconds, enabling real-time application. Compared to SRHO without stochastic dynamic programming, our method reduces the average operational cost by 4.8%. This cost reduction highlights the relevance of considering yearly operating periods when operating SES with seasonal storage.

Keywords: Seasonal storage, operational optimization, uncertainty, forecasting

Curtis Meister is a Senior Research Associate and deputy team leader at the Competence Centre for Thermal Energy Storage at Hochschule Luzern (HSLU). He completed his PhD studies at Carleton University on an experimental full-scale seasonal thermal energy storage system for a low energy building.

Data-Driven Surrogate Models of Seasonal Thermal Energy Storage for MPC Applications – A Case Study on the Dronninglund Pit Storage

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This study explores the development of data-driven surrogate models for Seasonal Thermal Energy Storage (sTES) suitable for integration into Model Predictive Control (MPC) frameworks. Using measurement data from the Dronninglund pit storage system, a validated Modelica model serves as the foundation for generating training data for various surrogate modeling approaches. The objective is to assess whether data-driven models can provide a computationally efficient alternative to physics-based simulations while maintaining sufficient accuracy for control applications.

The study focuses on the surrogate model performance and its ability to replicate temperature stratification, heat losses, and ground temperature evolution. Multiple machine learning algorithms are evaluated based on predictive accuracy, generalization capability, and computational efficiency. The study also examines how different model structures and training strategies influence performance. Additionally, the feasibility of integrating the surrogate model within an MPC setup is analyzed, considering both computational requirements and control-relevant accuracy.

By systematically comparing surrogate models against the original Modelica-based approach, the study provides insights into the trade-offs between complexity, accuracy, and real-time applicability. The results contribute to the broader discussion on optimizing sTES operation through data-driven modeling, offering guidance on selecting appropriate methods for predictive control in large-scale thermal energy storage systems.

Keywords: surrogate modelling, data-driven modelling, machine learning, seasonal thermal energy storage, thermal energy storage, model predictive control

Janis Narbutis is a researcher focusing on solar-thermal building-envelope integration, designing and optimizing systems based on phase-change materials and innovative insulation solutions through experimental and numerical methods to minimize energy demand and carbon emissions.

Optimization of Thermal Energy Storage in Building Facades Using Phase Change Materials and Accumulation Tanks

Ruta Vanaga, Riga Technical University, Nikita Gortbatjuks, Riga Technical University, Jānis Narbutis, Riga Technical University

Jānis Narbutis (presenter)

The integration of energy storage into building envelopes using phase change materials (PCMs) represents an innovative solution for enhancing energy efficiency in buildings. By incorporating PCMs into facade systems, energy is stored and released in response to temperature fluctuations, reducing reliance on external heating and cooling. This approach is particularly crucial in light of rising energy demands and the global shift toward sustainable, self-sufficient buildings.

This study investigates the integration of PCMs within semi-transparent facade systems, with the aim of optimizing energy exchange in buildings through the addition of an accumulation tank. Small-scale laboratory testing was conducted using a 25x25x6 cm PCM container, paired with a 5-liter accumulation tank. The setup was designed to simulate the thermal buffering capabilities of a PCM-based facade, comparing the performance of two phase change materials — RT21HC and RT28HC — across two distinct seasons: summer and spring (northern climate).

The experimental testing was carried out using a small scale PASLINK test stand replicating indoor and outdoor environments. Test seasons were characterized by specific outdoor temperature and solar radiation parameters. In the experimental setup, the accumulation tank circulated water through the PCM-filled container, with temperature and flow rates closely monitored to assess the thermal response during both charging and discharging phases.

Each PCM was evaluated for its energy storage capacity, thermal transition behavior, and phase change efficiency under steady-state conditions. The results underscore the influence of seasonal variations on PCM behavior and demonstrate the added effectiveness of accumulation tanks in improving thermal regulation in building facades. These findings offer valuable insights for optimizing PCM-based thermal storage systems in smart energy applications.

Keywords: building thermal envelope, phase change materials, thermal energy storage, accumulation tank, PCM-based facade systems, laboratory testing

Martin Sollich is a PhD Fellow at KU Leuven in Belgium who is working on the optimal design of future-proof district heating networks. Currently, he is developing a first-of-a-kind tool that can automatically design fully renewable-based and low-temperature district heating networks.

Optimal Heat Storage Sizing for District Heating Networks to Maximize Electricity Revenue from Combined Heat and Power Units

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Short-term heat storage offers numerous advantages to district heating networks (DHNs), including improved integration of intermittent heat sources and peak demand shaving. In DHNs utilizing Combined Heat and Power (CHP) units, short-term storage enables temporal decoupling of electricity generation and heat delivery to consumers. This allows CHP units to operate primarily during periods of high electricity prices, thereby increasing revenues from electricity sales.

To support the cost-effective design of DHNs with integrated heat storage and CHP units, we have extended our automated, physics-based design tool for DHNs (PATHOPT). Specifically, the size and the charge/discharge operation of the heat storage are optimized using a time-dependent, nonlinear heat transport model. The objective is to maximize CHP electricity revenues while minimizing DHN operating and storage investment costs. The optimization is based on representative days to capture variations in heat demand, environmental conditions, and prices. The network and storage models account for heat losses and their effect on temperature; the storage considered is a cylindrical water tank.

Applied to an existing DHN in Belgium with an 8 MW peak heat demand, our results show that optimal integration of heat storage significantly improves the business case for the operator. Over 30 years, discounted electricity revenues increase by 25% - or EUR 1.4 million- while the investment cost for a 1000 m³ storage tank is around EUR 250,000. This real-world case highlights the potential for transforming existing CHP-based DHNs through optimized storage integration.

To further extend the capabilities of our design tool, we also present first results from a new methodology for modeling and optimizing seasonal heat storage in DHNs. This approach allows the use of representative days rather than full-year hourly data, while maintaining a physics-based, nonlinear optimization, thereby ensuring computational tractability.

Keywords: District heating network design, heat storage sizing, sector coupling, nonlinear optimization.

Mirjam Särnbratt is a PhD student at Lund University, focusing on integration of battery energy storage in the electricity system. She holds a M.Sc. in Environmental Engineering and has worked three years as a research engineer at IVL Swedish Environmental Research Institute.

Grid operators' perspectives on battery energy storage as an alternative to grid expansion: opportunities and barriers to deployment

Mirjam Särnbratt, Lund University, Department of Energy Sciences; Kerstin Sernhed, Lund University, Department of Energy Sciences; Martin Andersson, Lund University, Department of Energy Sciences

Mirjam Särnbratt (presenter)

Electricity networks are facing an unprecedented challenge in ensuring sufficient transmission and distribution capacity to support the ongoing electrification. Utilizing battery energy storage at strategic points in the electric grid is one solution that could alleviate the need for grid expansion, while offering a shorter timeframe to implementation and potentially lower system costs. However, timing of battery deployment is crucial: decisions made by grid operators today on whether to use batteries and other flexibility measures or to resort to traditional grid reinforcements will limit or enable the contributions from these alternatives. For batteries to play a part in the energy transition, network operators must deem the technology feasible and trustworthy enough to include this option in their planning processes. Therefore, the aim of our study is to explore the views of electric grid operators on battery energy storage as an alternative to grid expansion, in the short and long term, and how this is (or is not) currently reflected in their network development plans. The focus of the study is the SE4 grid area, a part of the Northern electricity network where capacity bottlenecks have already been a challenge in the past decade. Data is collected via interviews, both with distribution system operators who have integrated batteries in their grid and with operators with no prior experience of battery integration. A theoretical lens of socio-technical systems transitions is applied to provide a), an overview of current barriers for batteries to support the electric grid and b), recommendations on the next steps to overcome these barriers. The results improve our understanding of how incumbent actors such as grid operators interact with disruptive technologies at an early stage of technology deployment and could inform policy makers as well as energy actors on the road ahead.

Keywords: battery energy storage, batteries, flexibility, electrification, electric grid, grid operators, energy transition, socio-technical systems transitions, demand-side management

As a PhD researcher, he explores how energy-intensive swimming pool facilities can become energy flexibility assets by developing AI-based energy management strategies that optimize energy use while maintaining thermal comfort in complex indoor environments.

A Simplified Energy Balance Model to Estimate Thermal Energy Storage Potential in Swimming Pool Facilities

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Smart energy management in buildings is becoming increasingly important with the growing emphasis on energy flexibility and decarbonization. Swimming pool facilities, with their large volumes of water and continuous operation, present significant potential for thermal energy storage and load shifting/load shaving. This study presents a simplified energy balance model designed to estimate the thermal energy storage potential of indoor swimming pools by analyzing water temperature dynamics during controlled heating events.

The model is based on a first-order differential energy balance equation that captures the dominant heat exchange mechanisms in a pool environment, including convective, conductive, and evaporative losses, as well as external heat input from a heater or heat exchanger. By numerically solving the equation for various heater capacities and durations, the model estimates the corresponding temperature rise of the pool water.

Crucially, the change in water temperature is used to quantify the amount of thermal energy stored, based on the water mass and specific heat capacity. This allows facility managers and energy planners to evaluate the practical storage potential of the pool under different operating scenarios. The simplified model offers a fast and accessible tool for preliminary screening of energy flexibility strategies, particularly in demand response contexts.

While the model abstracts from some complexities of real-world systems, it provides a valuable foundation for estimating storage capacity and assessing the viability of swimming pools as energy flexibility assets. The framework may be extended in future work using detailed control methods and real-time data to enhance precision and operational impact.

Keywords: thermal energy storage, swimming pool flexibility, energy modeling, simplified heat balance, water temperature dynamics, demand response

Paul Volk is a Phd Fellow at the Institute for Thermal Engineering at the University of Kassel. His research focuses on the decarbonisation of heat supply in rural areas with a focus on solar thermal energy and seasonal heat storage.

Renewable district heating systems in rural areas considering seasonal storage & decreasing use of biomass

Paul Volk, Christoph Schmelzer, Oleg Kusyy, Janybek Orozaliev, Ulrike Jordan, Klaus Vajen, University of Kassel

Paul Volk (presenter)

The heat supply in (German) buildings in rural areas is currently mainly based on decentralized natural gas or oil boilers. To achieve CO₂ neutrality in this sector, either building-specific solutions such as heat pumps in combination with intensive building renovation can be used, or a centralized heat supply from renewable district heating networks can be implemented. In the past, these were largely based on the combustion of biomass. The analysis of existing case studies also shows that biomass-based heating networks continue to be favored in planning in Germany for cost reasons. As biomass is becoming scarce and prices for biomass are expected to rise in the future, various combinations of technologies are examined and compared in a simulation study to find scenarios in which the use of biomass can be decreased. Possible alternatives could include air-to-water heat pump technologies with and without the use of photovoltaic systems on site, river water heat pumps, solar thermal collector fields and the use of electricity from wind turbines in conjunction with heat pumps and power-to-heat systems. In addition, systems with and without seasonal heat storage are considered, as seasonal systems using surplus (mainly solar) energy from summer could reduce the use of biomass in winter. The simulations are performed with TRNSYS and optimized with numeric algorithms for the lowest possible heat production costs. In the simulations and optimizing process, a distinction is made as to whether the German subsidy for renewable heating networks applies or whether there is no subsidy in order to make the results internationally comparable.

Keywords: Renewable District Heating, Rural Areas, Seasonal Storage

Ralf-Roman Schmidt is working at AIT since 2009, where he is responsible for the development and management of projects in the field of district heating and integrated energy systems. He holds key positions in international networks and received a PhD in the field of thermo-fluid dynamics in 2013

Risk Assessment for Seasonal Thermal Energy Storage in District Heating Networks

Ralf-Roman Schmidt, Nyasha Greco, Gerhard Totschnig, Bernhard Mayr, Viktoria Illyés, Ina Maia-Novak, Abdulrahman Dahash; AIT Austrian Institute of Technology GmbH

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Seasonal thermal energy storages are a key element in decarbonising district heating networks. They can shift excess heat in summer from industrial waste heat, geothermal energy, heat pumps, and solar thermal energy to the winter and make an important contribution to covering the winter load and thus reducing the demand for fuels. However, seasonal thermal energy storages are capital intensive, and thus are subject to economic risks arising from uncertainties in future key factors, such as energy prices and availability.

This contribution describes the risks for seasonal thermal energy storage in district heating networks in a qualitative and quantitative way. The qualitative assessment is based on literature review and stakeholder discussions, and is considering technical, economic & financial, regulatory & legal, environmental & climate, social & stakeholder, integration & market risks. The qualitative assessment is done via a Monte Carlo Simulation (MCS) for a case study, considering uncertainties related to the future development of key factors such as prices and availability of electricity and green gases, demand side developments, and local, regional and national regulatory framework conditions.

Keywords: Seasonal Thermal Energy Storages, qualitative risks; quantitative risks

OPTIMAL INTEGRATION OF SEASONAL THERMAL ENERGY STORAGE WITHIN A THERMAL SOURCE NETWORK – THE PLANNING PHASE

1) Shariq Akbar, Simon Müller, David Schmitt, Tobias Schrag from Institute of New Energy Systems. 2) Abdulrahman Dahash from Austrian Institute of Technology

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Thermal Source Networks (TSNs), operating at low temperatures, are an essential component of future urban energy systems, enabling the integration of diverse renewable and waste heat sources. Seasonal Thermal Energy Storage (sTES) significantly enhances TSN flexibility by enabling inter-seasonal energy shifting and balancing fluctuating supply and demand. This paper investigates the optimal integration of sTES within TSNs, focusing particularly on the effects of storage insulation levels and the contribution of centralized heat pump (HP) operation to seasonal storage performance.

A detailed simulation framework is applied, coupling MATLAB Simulink-based network modeling with a physics-based Functional Mock-Up Unit (FMU) of a ground-coupled sTES developed in Modelica. A range of integration scenarios are analyzed, systematically varying key parameters such as storage volume, insulation quality, demand overlap, and energy source configurations. Special attention is given to evaluating how HP operation impacts storage charging and discharging dynamics under varying network conditions. Preliminary results indicate that high insulation levels substantially reduce thermal losses, especially under heating-dominated conditions, while optimized HP operation enhances the seasonal availability and utilization of stored energy.

The findings provide practical insights into the key design and operational factors affecting sTES integration in TSNs. They also contribute to supporting early planning decisions aimed at maximizing the efficiency, flexibility, and resilience of low-temperature networks characterized by dynamic prosumer activity.

Keywords: Thermal Source Network (TSN), Seasonal Thermal Energy Storage, Optimal Integration (sTES), Heat Pump (HP)

Thomas Haupt (Ansbach University of Applied Sciences) has been working on the topic of Home Energy Management Systems as part of his doctoral research since 2021.

Home Energy Management Systems (HEMS): Market Overview – Germany compared to Europe

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The intelligent integration of flexible consumers such as heat pumps, electric vehicles, and battery storage systems, combined with photovoltaic systems, dynamic tariffs, and smart grid participation, is a key element of the energy transition. Home Energy Management Systems (HEMS) serve as the central interface to enable this integration in single-family houses. The market for HEMS is rapidly growing, both in Germany and across Europe. In parallel with fast-paced technical developments, regulatory frameworks are also evolving. One of the greatest challenges lies in the grid-compatible integration of flexible assets like heat pumps, electric vehicles, and rooftop PV systems, particularly in the low-voltage distribution networks. This paper analyses the current HEMS market in Germany and compares it to developments across Europe. Data collection was conducted through a guided survey targeting HEMS providers (<https://database.hems-finder.org/>). The study addresses several core questions:

How do regulatory requirements and their implementations differ across countries?

What functions do HEMS offer in the energy management context?

How do different systems compare in the context of Europe?

First, the German and European HEMS markets were analysed. The results show that there are already around 50 HEMS providers active in Germany alone, with approximately 25% of them also operating in other European countries. Significant differences are observed in optimization targets, the structure and availability of dynamic electricity tariffs, the management of system interfaces, and the integration and connection to smart meters.

Keywords: HEMS

Self-consumption

Dynamic tariffs

Photovoltaic

Sector coupling

Special session on Nordic Hydrogen Valleys

Anne Neumann is full professor at the Department of Industrial Economics and Technology at NTNU, Director of Research for NTNU's Energy Transition Initiative (NETI), Adjunct Professor at NHH Bergen and MIT-CEEPR Affiliate.

Analyzing Regulatory Instruments for Emerging European Hydrogen Markets

Benjamin Fram, NHH

Anne Neumann, NTNU

Anne Neumann (presenter)

This abstract is submitted to be part of one of the proposed sessions of "Nordic Hydrogen Hubs". The research conducted in this proposed contribution consist of performing a comprehensive overview and analysis of existing regulatory instruments for hydrogen markets in Europe. These instruments could include international standards and definitions of units and measurement, carbon and particulate emissions standards, carbon border adjustment mechanisms (CBAM), and any other relevant policy instruments that could impact hydrogen production in Europe.

Keywords: hydrogen, regulation, Europe

His research as a PhD Fellow centres around Energy System Analyses, with focus on Macro-Energy Systems Modelling and Large-Scale System Integration of Green Hydrogen and E-fuels.

Nordic Hydrogen Hubs: A Multi-Model Framework for Regional Integration towards 2040

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Shamim Homaei, Norwegian University of Science and Technology.

Iva Ridjan Skov, Aalborg University.

Stian Backe, SINTEF Energy; Norwegian University of Science and Technology.

Konstantin Löffler, Technische Universität Berlin; Norwegian University of Science and Technology.

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Hydrogen and hydrogen derivatives are expected to play a pivotal role in decarbonising hard-to-electrify sectors by enabling sectoral integration in future energy systems. In the Nordic region, abundant renewable resources and ambitious climate targets provide a promising foundation for the development of hydrogen hubs where hydrogen is produced, used, and connected to broader infrastructure. This paper investigates how hydrogen hubs could be integrated into the Nordic energy system and linked to European hydrogen markets. The study applies a novel multi-model framework, coupling five complementary energy system models, encompassing demand models, the long-term capacity expansion model EMPIRE, and detailed operational models such as EnergyPLAN. The models are linked via the open-source SPINE toolbox, facilitating analysis across various sectors and temporal-spatial resolutions. Through a set of demand scenarios, the research evaluates potential pathways for hydrogen uptake in the Nordics toward 2040, examining investment needs, cross-sectoral interactions, country-level geographical distributions, and overall system impacts. The findings aim to inform strategic hydrogen planning by providing insights into essential infrastructure investments and the Nordic region's potential role within a broader European hydrogen network.

Keywords: Hydrogen hubs, Nordic Energy Systems, Energy Systems Modelling, Model Coupling

Frederik Fristed is a PhD candidate at the Technical University of Denmark. He researches the role of hydrogen and CO₂ infrastructure in decarbonising hard-to-abate transport, focusing on the Nordic shipping sector.

Hydrogen and CO2 infrastructures for Nordic maritime decarbonisation: a self-sufficiency perspective

Frederik Fristed, Rasmus Bramstoft, Marie Münster, Technical University of Denmark

Frederik Fristed (presenter) frefri@dtu.dk

Decarbonising Europe's maritime transport sector may require a substantial expansion of synthetic fuel production and supply chains for renewable electricity, hydrogen, and carbon sources. Such a transition demands extensive infrastructure for production, transport, and storage, yet the specific needs depend on the supply and demand characteristics of individual regions. This study examines infrastructure investments for marine fuel production in the Nordic region, incorporating port-level fuel demand and facility-level CO₂ sources and sequestration sites. We use a hard link between Balmorel, representing the sector-coupled energy system, and OptiFlow, a dedicated network flow model that captures PtX and CO₂ infrastructure investments and tracks energy and feedstock flows across conversion processes. We analyse maritime decarbonisation from 2030 to 2050 under three scenarios in which the aggregated Nordic system may (1) net-export, (2) remain net-neutral, or (3) net-import electricity, hydrogen, CO₂, and synthetic fuels. Fuel imports from outside Europe are included exogenously. Combining a large-scale energy system model with a network flow approach that integrates detailed spatial characteristics, we highlight the interactions between hydrogen and CO₂ infrastructures, the cost of regional self-sufficiency, and the impact of global fuel imports on the Nordic energy system.

Keywords: energy system analysis, renewable fuel infrastructures, shipping, carbon management

Johannes Giehl earned his PhD from TU Berlin in 2023, focusing on hydrogen infrastructure and business models. Now a postdoc at CSEI, he researches hydrogen value chains in the Nordics, using energy hub modelling to analyse infrastructure, market dynamics, and regulatory needs.

Power-to-X for Green Fuels: Techno-Economic Optimization of Energy Hubs Under Different Power Supply and Carbon Pricing Scenarios

Johannes Giehl, Dana Hentschel, Lucia Ciprian, Jens Weibezahn, Copenhagen School of Energy Infrastructure, Copenhagen Business School

Johannes Giehl (presenter)

The European ambitions for introducing green fuels call for the accelerated development and scaling of technologies and business models. The Nordics, as frontrunners in renewable energy integration, are well-positioned to contribute to and benefit from the establishment of integrated energy hubs. These hubs are key to producing sustainable fuels such as e-methanol, ammonia, and Fischer-Tropsch fuels.

To generate knowledge on specific operational details, system structure, and logistical requirements, an energy hub model is applied to several case studies, including a port at an island-based site and a floating fuel production concept, to explore the techno-economic feasibility of green fuel production. These case studies aim to capture specifics related to the operation, structure, and demands of the associated business models.

The model, built in the Spine environment using Mixed-Integer Linear Programming, is designed to optimize production as well as investments in units and storage. It incorporates detailed representations of efficiency variations (e.g., from electrolysis), water and sustainable carbon dioxide supply, and the potential utilization of by-products such as excess heat.

An integrated sensitivity analysis evaluates the impact of regulatory factors, including carbon pricing, on the economic viability of each case by calculating the levelized cost of the energy carrier. The determination of the required carbon price levels for competitiveness provides insights into a measure that could enable the large-scale development of energy hubs.

Results indicate the optimal investments in unit capacities, the levelized cost of green fuels, and the associated carbon price requirements, alongside the energy flows of each technology. Further development will focus on refining the representation of power storage and power supply contracts (e.g., PPAs), and on integrating the technological and socio-economic aspects identified by the Nord_H2ub project.

Keywords: Power-to-X, Synthetic Fuels, Energy Hub Model, Levelized Cost of Energy, CO2 emissions, Mixed Integer Linear Programming

Maria is an associate professor in energy systems analysis, focusing on future fuels and propulsion technologies for transport. Currently, she has a specific interest in the future role of hydrogen and electrofuels (fuels produced from electricity, water and carbon dioxide) for transport.

Under what circumstances can hydrogen become a cost-effective fuel choice for a future global fleet of heavy-duty trucks

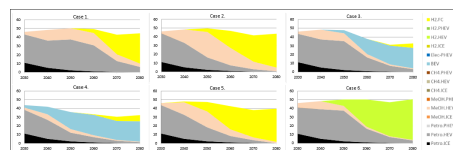
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The aim of this study is to assess under what circumstances hydrogen may be a cost-effective choice for trucks. We use the Global Energy Transition model, which is a linearly programmed energy systems model, generating the future fuel and propulsion technology mix that meets the demand (subject to the constraints) at lowest global energy systems cost. Global CO₂ emissions are constrained by carbon budgets consistent with either 1.5 or 2-degree climate targets. The model does not distinguish between fossil gasoline and diesel, which are lumped together as petro. A generic synfuel technology is used as a proxy for any liquid fuel other than petro, using data from the production of methanol (cheapest large-scale liquid energy carrier [1]). The synfuels may be generated from biomass, coal, natural gas, and hydrogen combined with CO₂ (e-fuels). CCS may be applied. Other energy carrier options are natural gas, hydrogen, and electricity. The model can choose between internal combustion engines (ICEs), mild hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell vehicles (FCVs). Cost data for vehicles are estimated from component costs (e.g. battery, hydrogen storage, and fuel cell stack). This approach ensures internal consistency between the cost assumptions for the different vehicle technologies. Cases are shown in Fig 1. Results are shown in Fig 2. Results show hydrogen benefits from more stringent climate targets (Case 2). No BEVs are seen in cases where EV range is assumed 400 km (Cases 1,2,5,6) but dominate when assuming 200 km (Cases 3,4). HEVs are seen more cost-effective than ICEs, where petro is quickly phased out in all cases, replaced by HEVs run on diesel, methanol or hydrogen (Case 6). An overarching conclusion is that hydrogen is shown to be a cost-effective solution for heavy-duty trucks, in all cases, regardless of designing them as beneficial to BEVs, hydrogen FCs or hydrogen ICEs.

Keywords: Hydrogen, scenarios, energy system, CO₂ reduction targets, future fuel mix, heavy-duty vehicles

	Fuel cell [\$/kW]	H2 storage tank [\$/GJ]	Fuel cell effi- ciency [%]	Battery [\$/kWh]	Driving range BEVs [km]	Carbon storage (CCS) [GtCO ₂]	Climate target
Base case (Case 1)	65	2500	55	150	400	600	2 °C
More stringent climate target (Case 2)	65	2500	55	150	400	600	1.5 °C
Moderate advantage BEVs (Case 3)	65	2500	55	150	200	600	2 °C
High advantage BEVs (Case 4)	65	2500	55	100	200	600	2 °C
Advantage H2-FC (Case 5)	35	2000	60	150	400	2000	1.5 °C
Advantage H2-IC (Case 6)	95	1000	45	150	400	2000	1.5 °C



Marie Münster is Professor in Energy System Analysis at the Technical University of Denmark. She has extensive experience within the field of energy system modeling with focus on international integrated energy systems and sector coupling.

Exploring the competition between e-fuels and negative emissions for decarbonizing international transport in the Nordics

Marie Münster, Frederik Fristed and Rasmus Bramstoft, Technical University of Denmark

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We need to decarbonize hard-to-abate sectors including long-distance shipping and aviation. This can be done to some extent by reducing fuel consumption and emissions related to shipping or flying, but to fully decarbonize, we need either to produce carbon-neutral fuels or compensate for fossil fuel consumption by negative emissions.

Both pathways are expected to have high costs and compete for low-cost renewable electricity and scarce carbon sources. The carbon-neutral pathway is associated with high production costs and concerns about fuel energy density and the need for extensive fleet retrofitting, while large-scale carbon offsetting requires large investments in transport and sequestration infrastructure. Broadly speaking, carbon-neutral fuels rely on carbon from 1) biomass or from hydrogen in combination with either 2) biogenic CO₂ from point sources or 3) atmospheric CO₂ or N₂ from direct air or ocean capture (DAC/DOC). In comparison, the negative emissions pathway relies on carbon capture and subsequent sequestration (CCS) from the same carbon sources.

This paper explores the potential competition between the use of carbon-neutral fuels and the combined use of fossil fuels and carbon offsetting, applying the Balmorel-OptiFlow framework in a case study of decarbonizing the Nordic shipping sector. The Balmorel-OptiFlow framework offers a highly detailed representation of renewable-fuel production and carbon management. The Nordics have a substantial shipping sector with both regional and international shipping and high ambitions in terms of reducing greenhouse gas emissions. The countries furthermore have good renewable resources (particularly wind, hydro and biomass) as well as good possibilities for sequestering CO₂ offshore. Through sensitivity analyses, we assess cost and resource thresholds to identify when each pathway becomes feasible and preferred over the alternative.

Keywords: Energy system analysis, bio-fuels, e-fuels, carbon management, negative emissions

Rasmus Bramstoft is an assistant professor at the Technical University of Denmark. His field of expertise is energy system planning (power, heat, gas, transport), with a special focus on sector-coupling, energy infrastructure, Power-to-X, and CCUS.

Nordic and European hydrogen production in an uncertain future

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Hydrogen is expected to play a key role in decarbonizing the hard-to-abate sectors, such as high-temperature industries, for high value chemicals and via Power-to-X to supply long-distance aviation and maritime sectors. While planning of electrolysis capacity and a potential hydrogen infrastructure is emerging, there are inherent uncertainties related to when, where and how much hydrogen there could be produced to support the energy transition.

This study sheds light on the uncertainty space of future hydrogen production by using a framework that combines a European sector-coupled energy system model with a comprehensive uncertainty assessment using Monte Carlo simulations. We explore the uncertainty ranges of hydrogen production at different geographical regions in Europe, and seek to identify main relationships, e.g., between main input drivers, such as variable renewable energy (VRE) generation and green hydrogen production.

Preliminary results show that it is important to consider the competition between green and blue hydrogen by 2030, as decisions made by 2030 can create lock-in effects for future investment decisions. By 2050, we explore the uncertainty range for green hydrogen production in pan-Europe, and we find that the highest green hydrogen is produced by mix of VRE sources in the west of Europe, followed by solar-based green hydrogen in the south, and

wind-based green hydrogen in the Nordic region. The uncertainty space for the Nordic region reveals green hydrogen production between 100 TWh and 400 TWh with a median at around 250 TWh, which emphasizes the potential role the Nordics can play as an exporting hydrogen hub, but also the large uncertainty.

Keywords: Energy system analysis, hydrogen, uncertainty analysis, global sensitivity analysis

Special session on Energy communities and positive energy districts

Annette Steingrube has been working as a researcher at Fraunhofer ISE for over ten years. Her main research focus is modelling and optimization of urban energy systems. Her academic background is mechanical engineering with a focus on renewable energies and she holds a PhD in engineering.

A practical assessment method for Positive Energy Districts

Dr. Annette Steingrube, Fraunhofer Institute for Solar Energy Systems

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The EU has set itself the goal that there should be 100 Positive Energy Districts (PEDs) by 2025. But what does Positive Energy District actually mean? In the last few years there have been various projects at EU level to develop definitions as well as assessment methods and in implementation projects districts were to be transformed into PEDs. And although 100 PEDS should have been implemented by this year, there is still not even one standardized definition and assessment method throughout the EU. In addition, the practical benefits are often still being questioned, especially from people in the field, for whom the concept is actually intended to help develop districts sustainably. In the presentation, the current status regarding the definition and assessment of PEDs is being presented. An analysis of them has shown that especially urban districts have problems becoming PEDs as it is often impossible for them to reach a positive energy balance, a prerequisite in many assessments. The reason is, that potentials for renewables are scarce and energy demand density is high in urban areas. But the concept of positive energy districts should work for all types of districts in all EU countries. Because of this Fraunhofer ISE has developed an assessment method which builds on the existing methods but takes the specific boundary conditions of urban districts into account. Instead of having a focus on a positive energy balance, the focus is on having a positive impact for the district as well as for the energy system of the city or region. In the presentation it will also be discussed, what the practical benefits of the concept of Positive Energy Districts can be and how it specifically helps districts in terms of climate neutrality, but also other criteria such as participation, grid stability, flexibility and much more.

Keywords: Positive Energy Districts, PED, district energy system, assessment method, urban districts

Jelena Nikolić is a mechanical engineer in the field of energy. Currently, she is a research assistant at Aalborg University, where she analyzes energy communities and positive energy districts to enhance energy decentralization, efficiency, and sustainability in urban environments.

Energy Cooperatives legal framework: Differences and similarities in Denmark, the Netherlands, and Norway

- 1) *Jelena Nikolic, Aalborg University*
- 2) *Karl Sperling, Aalborg University*
- 3) *Peter Sorknæs, Aalborg University*
- 4) *Henk-Jan Kooij, Radboud University Nijmegen*
- 5) *Martijn Gerritsen, Radboud University Nijmegen*
- 6) *Maja Louise Østed Clemmensen, EBO Consult A/S*

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Energy communities promote active citizen involvement in the energy sector and are recognized as essential components of the energy transition. Therefore, this paper analyzes the legal frameworks governing energy communities established by essential EU directives. The study investigates the extent to which national legislation in Denmark, the Netherlands, and Norway aligns with European standards, explores institutional arrangements, and identifies obstacles and incentives affecting the development of energy communities in practice. The paper aims to illuminate the challenges and opportunities that arise in translating legal norms into specific regulatory and social contexts. Additionally, it seeks to offer recommendations for enhancing the legislative framework to support the energy transition better and facilitate a more participatory model of energy production and consumption.

Keywords: energy communities, energy policies, legal framework

Mario Mihetec graduated from the Faculty of Mechanical Engineering in Zagreb with a thesis on vertical axis wind turbines. He worked at the Environmental Fund on energy efficiency and renewables. Since 2025, he's a lead researcher on EMERGE, METABUILD, and INITIATE projects at the same faculty.

Energy Communities and Smart Systems: Catalysts for a Rapid Renewable Energy Transition

Mario Mihetec dipl.ing.stroj., University of Zagreb, Goran Stunjek mag.ing.mech., University of Zagreb, izv. prof. dr. sc. Goran Krajačić, University of Zagreb,

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Energy communities (EC) and smart energy systems have a crucial role in fostering sustainable and decentralized energy solutions, particularly in light of the EU's "Clean Energy for All Europeans" package which empowers citizen participation in local renewable energy management. Potential of specific smart energy system configurations to significantly enhance the effectiveness of EC in achieving high levels of energy independence and resilience against external grid disruptions represent the motivation for this study. The hypothesis of this paper is that implementing peer-to-peer energy trading mechanisms between interconnected EC, facilitated by smart energy systems, will lead to a statistically significant increase in the overall efficiency of renewable energy use and improve the resilience of the regional energy network by enabling diversified energy exchange and reducing reliance on centralized generation. As a methodology a comprehensive review of existing literature has been done in order to synthesize the complementary aspects of EC and smart energy systems, focusing on how optimized configurations can lead to improved efficiency, cost reductions, and overall sustainability. The main result of this analysis reveals that the effectiveness of EC in achieving substantial energy independence and resilience is strongly dependent on the strategic integration of specific smart energy system components that optimize the use of local renewable resources and enable efficient energy exchange. Key findings indicate that smart energy systems, through advanced metering and control, enable EC substantial increase in self-consumption of locally generated renewable energy. While EC and smart energy systems offer a promising path towards a more sustainable energy future, their success in achieving energy independence and resilience is significantly enhanced by tailored smart energy system configurations.

Keywords: Energy community, smart energy system, peer-to-peer energy trading, renewable energy, energy efficiency

Postdoctoral researcher in strategic energy planning

Varieties of PEDs: Positive Energy Districts as building blocks for strategic energy planning at the local level

Martijn Gerritsen, Henk-Jan Kooij (Radboud University Nijmegen); Karl Sperling, Jelena Nikolic, Peter Sorknaes (Aalborg University); Maja Louise Ørsted Clemmensen (EBO Consult)

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Lowering energy needs and better aligning energy demand and supply in the built environment can enhance the sustainability of energy systems (Stoeglehner et al., 2011). Realizing such a transformation has implications for planning. Beyond allocating space to renewable infrastructures, sustainable energy system planning requires policy changes, new institutional arrangements, and integration with other land uses (Kempenaar et al., 2021). Yet, energy has historically played a minor role in spatial planning (Calvert et al., 2022; Kaza & Curtis, 2014; Kempenaar et al., 2021), and research linking strategic energy planning to comprehensive spatial planning remains limited (Sperling et al., 2011; Stoeglehner, 2020; Wretling et al., 2018). Scholars argue for a more proactive approach, with both short- and long-term strategic planning across governance levels (Koelman et al., 2024; Krog & Sperling, 2019; Olesen, 2023). This study engages with 'strategic energy planning' to examine institutional and organizational changes supporting sustainable energy transformations in different countries. We define strategic energy planning as systematically accounting for energy production, distribution, and consumption in spatial planning, and vice versa (Gerritsen, 2023), across national to local levels (Bale et al., 2012; Krog & Sperling, 2019). Our conference contribution focuses on local strategic energy planning by exploring how actors conceptualize and implement geographically-bounded transformations, particularly Positive Energy Districts (PEDs) (Derkenbaeva et al., 2022; Karvonen et al., 2025). We examine PED planning concepts and associated policy and ownership arrangements in Denmark, the Netherlands, Norway, and Portugal. Preliminary findings from Denmark and the Netherlands highlight the role of existing infrastructures: grid congestion in the Netherlands spurs new planning concepts, while Denmark's municipal climate and heating plans, and cooperatives, shape spatial plans.

Keywords: Strategic energy planning, energy system transformation, Positive Energy Districts

With MA in International Development and PhD in Psychology background, Dr. Minh Thu Nguyen uses qualitative and participatory research skills to engage with local communities in both Global North and South in co-creating energy support systems for more just and inclusive Positive Energy Districts.

Inclusive communication ecology for smart energy systems: Case studies from Positive Energy Districts across Europe

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Martijn Gerritsen, Mark Wiering, Radboud University;
Anders Horsbøl, Aalborg University;
Kristian Borch, Ruralis and Aalborg University;
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With the rise in electricity prices and the urgent need to tackle climate change in Europe, citizens are taking on more active roles in building smart energy systems such as Positive Energy Districts (PEDs), which enable communities to produce and consume their own energy efficiently at more affordable prices. As PEDs are often represented as complex technological configurations, citizens are dealing with fragmented information from commerce-driven market parties and local governments. This lack of a coordinated body of knowledge gives rise to the research need of energy support systems and information platforms wherein citizens are included. With a wide range of PED contexts from Portugal, the Netherlands to Denmark and Norway, this research contributes to an inventory of different platforms being used in European countries varying from state-based, market-based, to citizen-based. Thematic analysis of these platforms' framings showed that state-based systems are mainly concerned with technical-economic information and the regulatory framework for energy self-consumption while market-based platforms usually provide market tools and intelligent information systems to incentivize consumer/prosumer as individual or collective. Citizen-based platforms are concerned more with citizens' energy rights and duties and energy communities' practices. However, marginalized groups are often excluded or misrecognized from the decision-making processes and communications of PEDs, which furthers their vulnerability to energy poverty issue. Therefore, the research further aims to understand and improve the active participation of vulnerable groups in the peer-to-peer energy support systems and the wider communication ecology of PEDs. Through co-creation workshops or other participatory communication formats to include vulnerable groups, this research explores opportunities to address energy vulnerability for more inclusive and democratic smart energy systems.

Keywords: Smart energy systems, communication ecology, energy support system, energy vulnerability, positive energy districts

Peter Sorknæs is part of the Sustainable Energy Planning Research Group at Aalborg University, where he works with cross-sectoral energy system modelling of energy systems of different geographical scales with a focus on the heating sector.

North and South, what is the difference: Energy communities across the Europe

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Energy transition is one of today's main challenges. In this context, energy communities, established with the aim of democratizing and decentralizing the energy sector through the active participation of citizens, could be actors in the process of the energy transition. Since the concept of energy communities is still in development, it is necessary to understand their position and role in the specific energy frameworks of the countries in which they operate. In this we analyze different models of energy communities in Denmark and Portugal through the development of different archetypal models, taking into account specific factors that influence their functioning - energy consumption patterns, climatic conditions, regulatory policies, and economic parameters. In accordance with the current regulations and definitions of the Renewable Energy Community in these countries, the models include energy consumption in households, public buildings, and small and medium-sized enterprises. The goal is to identify universal and context-specific characteristics that shape the position and popularization of energy communities in different regulatory and economic environments.

Keywords: Energy communities, energy system analyses

Special session on Power-to-heat and thermal energy storage for faster and more affordable decarbonization

Hanne Kauko is a senior research scientist at SINTEF Energy Research. Her main fields of expertise include district heating, heat pump technologies and thermal energy storage, as well as modelling and optimization of integrated energy systems for neighbourhoods and industry.

Reducing grid impact of zero-emission passenger ports through power-to-heat and thermal energy storage

Hanne Kauko, SINTEF Energy Research; Erik Heggelund, SINTEF Energy Research; Stein Lønne, Tertnes Holding AS; Line Rydså, SINTEF Energy Research; Cecilia Gabriellii, SINTEF Energy Research

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Shipping plays an important role in transportation of goods and passengers, and domestic shipping accounts for around 10 % of Norway's total greenhouse gas emissions. Ports are central in the decarbonisation of the entire maritime industry, as they can facilitate the use of environmentally friendly energy sources in shipping, and function as energy hubs for different energy carriers and end-user sectors.

The decarbonization of ports and hence the entire maritime sector is heavily dependent on electricity due to shore power, charging of electrically driven ships, and potentially production of alternative fuels. However, in passenger ports, the thermal loads can constitute a substantial share of the total load, in particularly if cruise ships allow for waterborne heat supply from the port. The thermal demands account for up to 40 % of the total load of a cruise ship, and heat supply through district heating or efficient heat pumps could hence contribute to significantly reduce the grid impact of decarbonized port energy systems.

This study assesses the optimal energy system design for a planned zero-emission passenger port in south-west Norway. The port will provide shore power to cruise ships and medium-distance ferries, in addition to supplying heat and electricity to office buildings and a hotel on the site. The energy system includes local solar power production, seawater heat pumps providing heat at different temperature levels, batteries and thermal energy storage. The study demonstrates the potential of reduced grid impact through waterborne heat supply to cruise ships using heat pumps, and the flexibility obtained through coupling with thermal energy storage.

Keywords: Port decarbonization, thermal energy storage, power-to-heat, sector coupling, energy system modelling

Lill Mari Engan is a researcher at the Department of Energy Systems at SINTEF Energy Research, working with active distribution grids. She has a master's degree in Environmental Physics from the Norwegian University of Life Sciences from 2024.

Impact of Seasonal Thermal Energy Storage on the Power System at Different Latitudes

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Seasonal thermal energy storage (STES) systems enable storage of surplus energy as heat, which can help mitigate the seasonal mismatch between solar energy production in summer, and space heating demands in winter. While the techno-economic viability of STES has been investigated extensively, its potential benefits for the electric power grid have seen little research. Reducing seasonal variations may both lower the transmission capacity demand and avoid excessive power flow reversal, making better use of existing grid capacity and reducing the need for grid expansions. This paper presents a linear optimization model of a community with a shared solar-driven STES system, to study how it affects the use of the power grid. Results are compared to the same model using individual heat pumps and solar panels (PV) instead. The model is only subject to implicit flexibility, such as power market costs and grid tariffs. To study how latitude affects the grid impact of STES, the model is run using data from Norway, Germany, and Spain. All three countries see a 17-23% reduction in total electricity imports with STES, compared to individual heat pumps. Total electricity export is reduced by 15-50%, with Spain seeing the highest reduction, partly due to feed-in-tariff design. Peak import is reduced by 25% and 50% in Norway and Spain, respectively, while Germany slightly increases. In Norway and Germany, having STES incentivizes investing in more PV production, while still reducing peak power export by 8%. The results indicate that STES can help even out seasonal variations in power grid use, independent of latitude. This reduces grid capacity demands, particularly when distributed PV generation is involved. Importantly, the STES reduces load during hours of national peak load, especially in Norway. Grid operators and builders should consider the potential of STES systems to connect new consumers quicker, and make better use of the existing power grid.

Keywords: Seasonal thermal energy storage, Load shifting, Energy community, Power system, Distributed solar generation

Sebastian is a research associate at TU Wien's Energy Economics Group and a researcher at NTNU. His work focuses on open-source modeling for decarbonization pathways and sustainable energy systems. He also addresses resource management and system bottlenecks.

Defining Flexibility: A Key Performance Indicator Framework for District Energy Systems under Uncertainty

Simon Jordan, Technical University of Vienna;

Sebastian Zwickl-Bernhard, Technical University of Vienna

Sebastian Zwickl-Bernhard (presenter) zwickl@eeg.tuwien.ac.at

District energy systems represent a promising option for enhancing flexibility in electricity markets – an increasingly critical need given the rising frequency of both highly volatile and negative electricity prices. These price dynamics reflect a growing mismatch between electricity supply and demand. While price arbitrage between peak and off-peak periods – often associated with the so-called "battery wave" – has garnered attention, several barriers, including slow grid connection procedures, constrain the full integration of flexible resources into electricity markets. In this context, district energy systems are expected to play a vital role in providing flexibility and thereby formulating a future-proof business model since they are already implemented in field. This work proposes a systematic framework for assessing the flexibility potential of district energy systems in electricity markets. Central to this framework is a set of tailored Key Performance Indicators (KPIs) designed to capture the multifaceted contributions of district systems under uncertainty. The approach accounts for key sources of uncertainty, such as fluctuating electricity prices and weather-dependent operational constraints. Among others, the KPIs include: the utilization rate of available flexibility, the remaining flexibility reserve, electricity demand reduction compared to individual supply options, the difference in decision quality under uncertainty versus perfect foresight, and associated CO₂ savings. The KPI framework is embedded within a two-stage stochastic optimization model, enabling optimal investment and operation decisions under uncertainty. Its practical applicability is demonstrated through a case study of a district energy system in Trondheim, Norway. The results provide novel insights into evaluating and strengthening the role of district energy systems as flexible assets in evolving electricity markets.

Keywords: District Energy Systems, uncertainty, stochastic optimization, flexibility assessment, scenario analysis

He is a researcher in the Integrated Energy Systems group at SINTEF Energy studying the interaction between energy carriers in future energy systems using techno-economic analysis of markets and policy. He holds a Ph.D. in industrial economics and technology management from NTNU (2021).

Quantitative Impact of Flexible Thermal Energy Resources in Future European Energy System Pathways

Stian Backe, SINTEF Energy Research; Shweta Tiwari, SINTEF Energy Research; Dimitri Pinel, SINTEF Energy Research

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The integration of flexible thermal energy resources in future power grids can significantly enhance the resilience and efficiency of modern energy systems. In Europe, the heating and cooling sector accounts for approximately 50% of final energy demand, with heat demand in buildings often surpassing electricity demand. Energy system models, such as the global energy system model (GENeSYS-MOD), are essential tools for understanding the benefits of flexible heating and cooling resources. GENeSYS-MOD is a techno-economic model that optimizes cost-effective investment planning across various sectors, including potential sector coupling between energy carriers. In this study, several future pathways for how exogenous final energy service demand develops in Europe are analysed with GENeSYS-MOD. Investments in generation, transformation, trade, and storage capacities are compared with and without flexible thermal energy resources available towards 2050. Preliminary results show that flexible thermal energy storage can reduce the need for electrification of heating demand. The most cost-efficient option is heat storage connected to district heating systems, which increases the use of cheaper, non-electric heat sources like solar thermal collectors. This reduction in electricity use for heating decreases overall electricity demand, leading to fewer investments in expensive peak generators, such as combined cycle gas turbines with carbon capture and storage.

Keywords: Energy system modelling, thermal energy storage, flexible district heating, power-to-heat, sector coupling

Sverre Stefanussen Foslie is a research scientist at SINTEF Energy Research. His main fields of research are within energy efficiency in the industry, demand side flexibility and heat pumps and thermal storages, as well as modelling of the industry sector in energy system optimization models.

Decarbonizing industrial process heat demands using hybrid solar thermal and photovoltaic systems in combination with thermal energy storages.

Sverre Stefanussen Foslie, SINTEF Energy Research

Sverre Stefanussen Foslie (presenter)

Decarbonization of the industry sector is crucial for meeting the global emission reduction targets. The industry sector accounts for 25 % of global CO₂ emissions, requiring a diverse range of measures to be decarbonized. Industrial energy demand is primarily related to heating and cooling, and decarbonization of process heat is regarded as one of the most important tasks in decarbonizing the sector. At the same time, the increasing global energy demand is expected to be met particularly by solar energy, and finding ways to optimally integrate solar based energy systems into the industry sector may accelerate decarbonization of the sector.

Process heat at low to medium temperatures, up to 250°C, may be efficiently produced using solar thermal technologies, but reaching higher temperatures is challenging. Combining photovoltaic and solar thermal systems, together with power-to-heat-solutions, provides a flexible solution to decarbonize heat-intensive industry with demands over a range of temperatures. However, the variability of solar irradiation and availability of renewable electricity may challenge the reliability of supply of process heat based on such hybrid systems.

This study investigates the optimal energy system design of an industry facility requiring a combination of power and heat. Using the open-source energy system modelling tool EnergyModelsX, the study assesses the optimal combination of solar thermal, electric boilers and thermal energy storages to provide reliable energy supply to the variable energy demand of the processes. Additionally, the study investigates the potential for load shifting to adapt the energy demand to the availability of solar energy. The results demonstrate the potential of hybrid solar thermal and power-to-heat energy systems in industrial applications, and how thermal energy storages increase the potential for load shifting, thereby reducing overall demand for fossil fuels and increasing the uptake of renewable energy.

Keywords: Industrial decarbonization, solar thermal, power-to-heat, thermal energy storage, demand side flexibility

Till Holmes is a Junior Researcher at SINTEF Energy Research. His research focuses on thermal energy systems, their interaction with the electricity sector, and integrated energy system modelling.

The role of thermal energy storage in providing flexibility for the decarbonization of industrial process heat and district heating

Till Holmes, Stian Backe, Sverre Stefanussen Foslie, Hanne Kauko, all Sintef Energy Research

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The EU's target of net-zero emissions by 2050 requires a major transformation of the industrial sector, with industrial process heat representing 16% of the total energy demand in the European Union. This process heat is still predominantly generated from fossil fuels, presenting a significant opportunity for electrification and emissions reduction.

Electrification of industrial heating through electric boilers and heat pumps creates a coupling between the industrial heating and the electricity sector. While the coupling between heat and electricity sectors has been widely studied for buildings, the role of industrial heat demand across different temperature levels in a decarbonized energy system has received less attention.

This study explores the decarbonization of industrial process heat using sector-specific demand profiles that reflect multiple industries and temperature levels. These profiles are based on a newly developed methodology called IMPRO, which defines standard heat load profiles for various industrial sectors. This study presents the first application of these profiles in an energy system model. A linear optimization model with hourly resolution is used to investigate the role of thermal energy storage in decarbonized industrial heat systems. We compare cost-optimal solutions for decarbonizing industrial heat demand with and without integration into district heating networks, evaluating the added value of such connections.

Our findings highlight the importance of thermal energy storage in enabling flexibility on the thermal side of the system. Benefits include reduced curtailment of renewable electricity, improved grid utilization, increased cost-effectiveness, and greater system robustness during periods of low renewable availability. Preliminary results suggest that thermal energy storage can aid the uptake of renewable energy sources and reduce the need for electric battery storage in the grid.

Keywords: Industrial decarbonization, thermal energy storage, district heating, power-to-heat, sector coupling, energy system modelling

Whitney Trainor-Guitton is blends decision analysis, data science, spatial statistics and geophysical inversion. Before NREL, she earned her PhD from Stanford University, served as a staff scientist at Lawrence Livermore National Laboratory and assistant professor at the Colorado School of Mines .

Underground Thermal Energy Storage for Space Cooling: Reducing Electricity Grid Costs and Stress from National to District Scale

Whitney Trainor-Guitton (NREL), Scott Mello (NREL), Hyunjun Oh (NREL), Jonathan Ho (NREL), Yunzhi Chen (NREL), Ryan Cahalan (USGS), Jeff Pepin (USGS), Erick Burns (USGS)

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Space cooling in the United States accounts for 6% and 10% of total residential and commercial energy demand, respectively. This is expected to increase with more data centers. Three studies explore how space cooling can be done in ways to reduce grid costs or stress, either through district systems and/or underground thermal energy storage. The three studies are interconnected to consider three spatial scales: national to neighborhood (~30 buildings) to district (~7 buildings).

First, a capacity expansion model of the continental United States was used to identify states with the highest potential to reduce electrical grid costs, fuel consumption and emissions by replacing their existing sources of cooling. These state-scale results were used to choose a locations to represent in the district and neighborhood simulations. Specifically, URBANopt was used to model energy reductions through building networks and geothermal boreholes, while SUTRA was used to model subsurface cold storage to balance heat pump operations, which were modeled by GHEDesigner. URBANopt is a modular analytics platform that leverages physics-based building simulation investigate the design and operation multi-building energy systems including district thermal energy. URBANopt allowed for comparisons of energy uses by a neighborhood within Washington D.C. when the buildings were treated individually versus connected thermally as a district. Whereas SUTRA is a heat and fluid flow simulator used to model the geologic, seasonal storage and delivery of thermal energy. Our results from the 9 geographically and climatologically diverse locations identified in the national study, show how underground thermal energy storage provides multiple benefits to the electrical grid, like shaving peak summer loads at all locations.

Keywords: underground thermal energy storage, grid benefits, space cooling

Special session on Energy transition and decarbonisation in the district heating sector

Andrea Menapace, PhD in Sustainable Energy and Technologies, is a senior researcher at Eurac Research, Italy. He focuses on efficient, sustainable, and climate-resilient solutions for the energy and water sectors, with expertise in district heating and urban energy systems.

Unlocking Waste Heat Potential for District Heating Systems

Andrea Menapace, Institute for Renewable Energy, Eurac Research;

Daniele Anania, Institute for Renewable Energy, Eurac Research;

Giovanni Dalle Nogare, Institute for Renewable Energy, Eurac Research;

Rosanna Paradiso, Institute for Renewable Energy, Eurac Research;

Marco Cozzini, Institute for Renewable Energy, Eurac Research;

Diana Moreno, Department of Sustainability and Planning, Aalborg University;

Steffen Nielsen, Department of Sustainability and Planning, Aalborg University;

Peter Sorknæs, Department of Sustainability and Planning, Aalborg University.

Andrea Menapace (presenter) andrea.menapace@eurac.edu

The transition to climate-neutral energy systems by 2050, as mandated by the Energy Efficiency Directive, requires a profound transformation in how heating and cooling are produced and delivered. District heating and cooling networks (DHCNs) play a strategic role in this transition by enabling efficient sector coupling, supporting the integration of renewable and waste heat (WH) sources, and offering thermal flexibility and storage capacity. These features make DHCNs particularly effective in decarbonizing urban areas, enhancing overall energy efficiency, and increasing the share of renewables in the heating and cooling sector.

This work presents a geospatial methodology for mapping waste heat potential from both industrial and tertiary sectors, providing critical input for the modernization and expansion of existing DHCNs. The approach is based on a structured GIS framework that integrates open data, statistical analysis, and literature-based datasets to identify and quantify WH sources. Industrial WH mapping combines facility-level data, such as geographic location, NACE code, and number of employees, with the Danish WH dataset and a novel interpolation routine to estimate annual WH potential across three temperature levels. Urban WH mapping targets tertiary buildings, such as supermarkets, hospitals, swimming pools, and ice rinks, using GIS geometries and descriptive metadata. The estimation is based on gross floor area and category-specific coefficients derived from real-world energy use data and technical benchmarks.

The outcome is a harmonized spatial inventory of WH sources with hourly-resolution profiles, offering a robust foundation for energy system modelling, network design, and decarbonization scenario planning.

The described workflow is applied to a case study located in part of the Milan municipality, related to the HeatMineDH project, funded by the LIFE Programme under grant agreement N° 101120948.

Keywords: District heating, mapping, waste heat, energy recovery

Jacek Kalina is an associate professor at Silesian University of Technology. He has been working in the field of energy systems engineering for almost 30 years. His key expertise is in energy conversion systems, including district heating. He coordinates the EU-funded LIFE22-CET-SET_HEAT project.

What can we do in Bucharest? The issues of decarbonising large district heating systems.

Jacek Kalina

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The ambitious EU climate and energy policy sets rigorous targets and pushes towards decarbonization and climate neutrality in 2050 has placed District Heating (DH) systems at the forefront of urban energy transition. On the other hand, since DH is deeply embedded in the socio-economic system and built environment, the energy transition and decarbonisation of DH assets at the local level trigger serious technical, infrastructural, and socio-economic challenges.

In many European cities, the energy transition and decarbonisation of DH assets are largely untapped. This is due to the high complexity and multidimensionality of the process and insufficient availability of local resources (e.g. land, surface waters, waste heat, etc.).

The focal point of this study is the strategic planning of the decarbonization process for large DH systems. The announced strategies of such cities as Berlin, Amsterdam, Copenhagen, and Vienna revealed that depending on local conditions, the future primary energy mix may be highly diversified and DH systems become very complex structures. The case study in this work focuses on Bucharest, Romania. The Bucharest DH System is a second-generation system with a water network operating forward temperature ranging from 80 to 110 degC. The heating network has a total length of 3847 km and delivers heat to more than 500,000 individual households, 3611 industrial and 1122 other consumers. The current peak demand for heat is around 2.0 GW and the annual amount of heat delivered to the network is around 4500 GWh/year. The current input energy mix is not diversified. As for 2024, the DH system of Bucharest is entirely based on the combustion of natural gas. The key system components, i.e. production plants and networks, are worn out and in bad technical condition. Since the system has been underinvested for many years, the scale of the required renovation is enormous. A potential action plan is presented in the study.

Keywords: District heating, energy transition, decarbonisation, waste heat, renewable energy sources, strategic planning

PhD student at the Silesian University of Technology and a Technical Development Coordination Specialist at the ECO S.A. capital group. He works on integrating heat pumps and renewable energy sources into district heating systems.

Modernization of a Cogeneration-Based DH Network: Low-Temperature Heat Recovery and Dual Heat Pump Integration in Opole Poland.

Jendryasek Łukasz, Silesian University of Technology

Łukasz Jendryasek (presenter) lukasz.jendryasek@polsl.pl

This study presents a case for enhancing the sustainability and efficiency of an urban district heating (DH) network by optimizing low-temperature heat recovery from gas engine-based cogeneration units in Opole, Poland. The proposed retrofit approach aligns with the principles of 4th and 5th generation DH systems by integrating flexible, low-emission, and renewable-compatible technologies.

The optimization concept focuses on recovering low-temperature (LT) waste heat (45–55 °C) from engine cooling circuits and improving exhaust gas heat recovery. The system upgrade includes the installation of heat exchangers on three cogeneration units (total thermal output: 7.6 MW) and the implementation of a water-to-water heat pump, using LT waste heat as a source. Additionally, a second-stage economizer is considered to enable condensation-based recovery from exhaust gases currently discharged at 100–135 °C, aiming to significantly boost overall heat recovery efficiency.

Through the proposed modifications, the total heat output is expected to increase to 9–9.1 MW. During engine downtimes—anticipated to become more frequent due to increasing electricity market volatility—a cascade heat pump system will ensure continuous heat supply with a capacity of 0.8–1 MW. An air-to-water heat pump will also be integrated as a flexible, electricity-driven auxiliary source.

The study combines thermodynamic modeling with economic and environmental analysis to evaluate system performance, cost-effectiveness, and decarbonization potential. Results indicate substantial CO₂ emission reductions and operational cost savings, positioning the Opole DH network for a sustainable transition in line with EU climate targets.

By leveraging waste heat recovery and heat pump integration, this research demonstrates a replicable pathway for modernizing cogeneration-based district heating systems and advancing sector coupling in urban energy infrastructure.

Keywords: Heat Pump, waste-heat, gas-engine, sustainable heat supply, flexible energy systems

Marcel Barzantny is a young engineer, a PhD student working in the field of thermal technology. The topics he is working on include waste heat recovery, heat exchangers, energy storage and refrigeration cycles with a special focus on the Ranque-Hilsch Vortex Tube.

Cracking the code of PTES – the impact of atypical geological conditions on seasonal heat storage performance in Opole

Marcel Barzantny, Silesian University of Technology, Andrzej Sachajdak, Silesian University of Technology, Mariusz Tańczuk, Opole University of Technology, Wojciech Kostowski, Silesian University of Technology, Jacek Kalina, University of Technology

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Pit thermal energy storage (PTES) systems are increasingly recognized as effective solutions for sustainable heat retention. These systems require significant land area, especially for large-scale projects. Suitable locations with enough space to accommodate both the storage facility and the necessary infrastructure (like turbines, heat exchangers, and heat pumps) can be hard to find in dense urban environments. Large-scale PTES projects might compete with agricultural, residential, or protected natural areas. In some cities, using degraded post-industrial land may be an interesting option. Furthermore, the geological composition beneath the PTES installations plays a crucial role in influencing their thermal behavior and overall efficiency. This study explores the impact of specific geological conditions on a 200 000 m³ PTES performance, using Opole as a case study, accounting for the thermal properties of the local marl rock with its permeability and heat retention characteristics. A numerical model of a PTES reservoir is developed and simulated, incorporating site-specific parameters to assess thermal storage behavior. Model validation is performed using available data, and comparative analyzes are performed against other European PTES installations, to evaluate the role of different ground types. The results provide insight into how geological factors contribute to the efficiency and stability of PTES reservoirs over time. By examining variations in thermal dynamics at different locations, this study highlights the importance of geological composition in shaping storage performance. The findings indicate that site-specific considerations should be incorporated into the design and optimization strategies of the PTES, to ensure long-term feasibility with the local geological context. These observations enhance our understanding of how atypical post-mining ground conditions can impact the performance of PTES systems and their potential for future applications.

Keywords: PTES, District heating, Thermal storage, Geological conditions, Marl

He conducts research and didactic work in the area of district heating, distributed energy sources, thermodynamics, renewable energy sources and recovering waste energy. His job related skills are techno-economic optimization, waste energy utilization, small-scale CHP systems optimisation.

Integration of distributed waste heat sources into second-generation district heating systems – technical and economic challenge.

Mariusz Tańczuk, Opole University of Technology

Jacek Kalina, Silesian University of Technology

Łukasz Jendryasek, Energetyka Ciepłna Opolszczyzny SA

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The use of waste heat for heat production is one of the criteria for an efficient heating system according to the Energy Efficiency Directive (EED). The importance of waste heat available within district heating systems is constantly growing and is recognised as an effective way to decarbonise systems that are largely based on fossil fuels such as coal and natural gas. In order to determine the potential of waste heat sources in district heating, it is necessary to identify their parameters, such as the type of carrier, temperature and flow. It is also essential to know the operating time during the year. The technical factors outlined above determine the next steps in the integration of waste heat – balancing it with the heating system demand and developing technical solutions that allow it to be connected to the heating grid and control the interaction between the source and the system. This study addresses the issue of difficulties in integrating distributed heat sources, using the example of the district heating system in Opole, Poland. It is a second-generation system with a peak demand of approximately 180 MW, supplying approximately 70% of residential buildings and over 20% of industrial facilities. The study describes the technical and economic challenges that must be overcome in order to effectively and efficiently recover available waste heat, using several examples of dispersed industrial heat sources: a cement plant, an automotive manufacturing plant and a data center. All these cases share the problem of a properly structured business contract, which directly affects the price of the heat purchased/sold and the final price of heat for consumers. The results of preliminary economic analyses and proposals for technical and economic models of cooperation between the district heating system operator and waste heat suppliers are presented.

Keywords: waste heat, district heating, integration, technical challenge, economic challenge

Per Alex Sørensen has worked with design and implementation of district heating systems in more than 40 years. Especially systems including solar thermal, heat pumps and large scale thermal storages.

Know-how package and toolkit for transition of DHC systems using low temperature sources and heat pumps

Per Alex Sørensen and Niels Beck-Larsen, PlanEnergi

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In the EU-Life project SupportDHC a know-how package for transition of existing DHC systems using low-grade renewable energy and waste heat for district heating and cooling has been elaborated. The content is:

1. Transition of DHC systems. AGFWs guide to transition. Selected to give an overview of the transition steps and how to overcome them.
2. Mapping of low temperature sources. Examples of how to find and map low temperature sources. Selected because careful mapping is a must!
3. Reducing temperatures in the grid. Halmstad University's guide to lower grid temperatures and slides with examples. Selected to illustrate the importance of low flow and return temperatures to gain more efficient utilisation of RE and WH.
4. Technology description of heat pumps. Fact sheet F6 about heat pumps delivering up to 90 °C and F10 about heat pumps delivering up to 120 °C. From the IEA DHC project TS5. Selected because large scale heat pump will be part of systems utilising low temperature sources.
5. Spreadsheet for pre-feasibility calculations. Useful for screening of economic and environmental consequences of integration of large scale heat pumps in existing DH systems. Selected because the tool can be used to avoid detailed calculations of non-feasible solutions.
6. Examples of energyPRO calculations. Illustrates a methodology to set up energyPRO for all kinds of RE technology integration in an existing DH system. Selected to ensure correct energyPRO setup.
7. Best and worst practise from frontrunners. Fact sheets describing lessons learnt in frontrunner cases. Makes it possible for followers to learn from best practise and avoid repeating mistakes made by frontrunners.

The presentation is part of a special session for the SET_HEAT project

Keywords: Guide to transition, low temperature sources, reducing temperatures, heat pumps, feasibility calculations

Dr. Vilūnė Lapinskienė is an associate professor and researcher at the Department of Building Energetics, and vice-dean for studies. Her work focuses on building sustainability, HVAC efficiency, and renewable energy. She has authored 20+ publications and leads national and international projects.

Decarbonizing the Vilnius District Heating System: Modernization of the Heat Source in Naujoji Vilnia

V. Lapinskienė, J. Bielskus, G. Streckienė, A. Rogoža, V. Misevičiutė, VILNIUS TECH

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The Naujoji Vilnia district of Vilnius currently relies on aging biomass and gas boilers for heat supply, resulting in efficiency losses and high emissions. As part of the Vilnius district heating (DH) decarbonization effort, two modernization alternatives were evaluated to reduce fossil fuel use and improve system flexibility.

Alternative 1 retains the existing biomass boilers and one gas boiler, introducing a 5.2 MW air-to-water heat pump and a 3000 m³ thermal storage tank. Biomass boilers are assumed to be refurbished to extend their lifespan. The heat pump provides base load during most of the year, with gas and biomass boilers covering peaks and very low outdoor temperatures. The thermal storage balances supply and demand, enabling flexible operation based on electricity prices.

Alternative 2 mirrors Alternative 1 but increases the thermal storage tank to 6000 m³. The larger capacity improves load shifting and allows longer heat pump operation during low-demand periods. However, the overall system performance is only slightly improved compared to the first option.

Both alternatives were assessed using hourly modelling via energyPRO software. Results show that the heat pump could cover over 50% of the annual heat demand, cutting gas consumption by a factor of four. Biomass remains a key source, while the gas boiler becomes a backup. The study concludes that a combined solution of renewable heat, storage, and existing assets offers an effective and replicable pathway toward sustainable urban heating.

Keywords: Vilnius, district heating, decarbonization, biomass boilers, gas boilers, heat pump, thermal storage, energyPRO, renewable heat, system flexibility, emissions reduction.

Special session on Medium-duration thermal energy storage – Technologies, capacities and challenges

Dr Adriano Sciacovelli is Full Professor in thermo-mechanical energy storage systems at the Technical University of Denmark (DTU). He is an international leader in the field of Sustainable Thermal Energy Conversion and Storage, led/co-lead >30 research projects and published 170+ peer review papers

Carnot Batteries: Technological capabilities, challenges and emerging trends from IEA-ES task 44

Adriano Sciacovelli, Technical University of Denmark.

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Decarbonizing thermal and electrical energy is critical for achieving climate neutrality, yet industries, cities, and the transport sector still heavily rely on high-CO₂, fossil-fuel-based systems due to limited thermal energy flexibility. This dependency hinders the transition to electrified and renewable energy sources, posing a significant challenge to heat decarbonization.

To address this, advanced thermo-mechanical energy storage (TMES) solutions, also referred as Carnot Batteries (CB), must further evolve towards responsive and cost-effective solutions. Such capabilities and further innovations are essential to achieve a step-change in performance, enhance technology adoption, and improve value. Conventional CB systems, dominated by bulky, standardized designs, often struggle to meet such spatial, economic, and performance needs.

This talk presents the latest technological advancement in CB concepts combining fundamental insights into underpinning phenomena, technological optimization, and engineering science. Current CB technological landscape is presented as well as opportunities to unlock performance, overcoming limitations inherent in traditional systems. The talk will explore the distinct characteristics of CBs, emphasizing design and integration approaches that to improve charge/discharge performance and economic feasibility. Trends emerging from the work ongoing within IEA-ES task 44 will be also emphasized.

The presentation will highlight future research directions, unresolved challenges, and the potential role of emerging techniques in driving innovation in CBs solutions.

Keywords: Thermal Energy Storage, Carnot Batteries, Long-duration energy storage, techno-economic analysis

M.Sc. Tosatto Alice works since April 2019 as a Scientific Assistant at the Unit of Energy Efficient Building of the University of Innsbruck. Her research interests include the modelling of large thermal energy storage and the investigation of the hygrothermal performance of insulation materials.

Optimizing large-scale Thermal Energy Storage Envelope Design for Enhanced Energy and Exergy Efficiency in District Heating Systems

Alice Tosatto, Universität Innsbruck

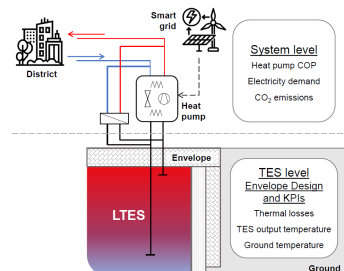
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Christoph Muser, Ingenieurbüro ste.p ZT-GmbH

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Large water-based thermal energy storage (LTES) systems are used to increase the share of renewable energy in district heating (DH) grids. DH grids require a certain flow temperature depending on the season, but the LTES thermal losses (TL) do not guarantee a constant LTES outlet temperature. Heat pumps (HPs) are used to provide the required power to reach the desired DH supply temperature and to increase the LTES capacity, but their COP depends on the LTES outlet temperature. Depending on the water temperatures and on the surrounding ground conditions, the LTES performance is influenced by its design and envelope quality. In the presence of specific constraints - such as high land costs, low space availability - the design choice tends to shift towards deeper and more compact tank-type LTES, as opposed to the more common and less expensive pit-type LTES. However, the greater depth can be challenging in presence of shallow groundwater (GW), which increases the LTES TL and, in turn, the temperature of the GW, which in some countries is limited by specific regulations. Thus, measures are required to limit these effects, consisting of the installation of thermal insulation and impermeable barriers to prevent direct GW flow to the LTES. The increased investment costs need to be considered in relation to the benefit in terms of LTES and DH performance and to the environmental requirements for the GW temperature.

The aim of this work is to study the influence of the LTES envelope design on the performance of the HP and on the ability to increase the district self-sufficiency. Different cases are studied with respect to the quality of thermal insulation of the LTES side walls, its position in relation to the structural wall and its depth. The influence on the energy and exergy efficiency of the LTES is analysed. Based on the LTES performance and its impact on the system – HP COP, electric energy demand and CO₂ emissions – a cost benchmark for the insulation is proposed.



Keywords: large-scale thermal energy storage, tank thermal energy storage, renewable energy, envelope design, thermal insulation, exergy efficiency, energy efficiency

Annelies Vandersickel is Professor 'Thermal Energy Storage' at the University Stuttgart and heads the department 'Thermal Process Technology' at the German Aerospace Center. The department develops thermal storage, power-to-heat and thermo-management solutions for industrial applications.

Beyond Grid Flexibility: Power-to-Heat and Carnot Batteries for Zero-Carbon Industrial Heat and Power Supply

Annelies Vandersickel, Kevin Ludwig, German Aerospace Center (DLR)

Annelies Vandersickel (presenter) annelies.vandersickel@dlr.de

As the global energy landscape transitions toward a high share of intermittent renewables, ensuring a stable and reliable power and heat supply, particularly for the heat-intensive industrial sector, is paramount. IEA-ES Task 44, "HiCBest: Power-to-Heat and Heat integrated Carnot Batteries for Zero-Carbon (industrial) Heat & Power supply," serves as an international collaboration platform dedicated to addressing this challenge.

Our mission is to advance the role of thermal energy storage and Carnot Batteries as key enablers for resilient grids and industrial decarbonization. The flexible coupling of both the electricity and heating sector using thermal storage solutions enables to simultaneously achieve cost-effective electricity storage for a resilient electricity sector, as well as a cost effective decarbonization of the heating sector.

This talk will provide a comprehensive overview of the Task's objectives, structure, and key findings. It will introduce the concept of Carnot Batteries—a technology that stores electricity as thermal energy and can convert it back to power—and highlight their unique capabilities for long-duration energy storage. A core focus of the Task is the integration of these systems for flexible waste heat recuperation and heat generation for districts and industrial processes. These aspects will be further explored by my colleagues, Adriano Sciacovelli and Silvia Trevisan, in their parallel presentations on technological capabilities and system opportunities.

By fostering a structured and collaborative environment, Task 44 aims to provide the necessary data, analysis, and recommendations to accelerate the deployment of these critical technologies, paving the way for a resilient and decarbonized energy system.

Keywords: Carnot Battery, Power-to-Heat, IEA

Gerald is an Associate Professor and project leader in the Section of Energy and Services at DTU Construct. His research focus is on thermal energy storage for flexible heating and cooling systems - including experimental development, testing and demonstration as well as system implementation.

Latent thermal energy storage for data center application

Gerald Englmaier, Technical University of Denmark; Mark Dannemand, Technical University of Denmark; Dominik Franjo Dominkovic, AI Energy ApS and Technical University of Denmark.

Gerald Englmaier (presenter) gereng@dtu.dk

Data centres - technical space that include computer systems and network infrastructure for data collection, storage, or telecommunication purposes - consume energy at almost constant rates. With the increasing reliance on solar and wind electricity via chiller, the demand for effective and compact energy storage solutions has become imperative. Latent Thermal Energy Storage (LTES) utilizing phase change materials can serve as an asset for flexible cold supply for buildings as well as for industry.

Solutions for flexible, secure, and reliable integrated cooling energy system for data centres have been investigated in the framework of the Danish research project "Cool-Data". To increase the operation flexibility of chillers for server room cooling via water to air heat exchangers, cold storage prototypes using salt hydrates and paraffin as phase change material were developed, tested and their suitability for hydronic server room cooling was elucidated. The measured energy storage density was 5-times higher in comparison to water tanks.

Flexible LTES for markets access of heating and cooling systems is currently investigated in the clean energy transition partnership "La-Flex". The main objective of the project is to optimize LTES by enhancing their controllability. A 200-kWh latent thermal energy storage for safer and flexible server cooling at DTU Campus is planned. This installation will be realized by the following project partners: DTU Construct, Campus Service, AI-Energy (Denmark) as well as Cartesian and Sintef Energy (Norway). Besides demonstration and learning from practice, the project further develops three main technologies: State-of-charge (SoC) determination technique, thermal power controller and model predictive control. SoC detection, i.e., a determination of the remaining capacity available in thermal energy storage, is crucial for optimized storage operation schedulers.

Keywords: Thermal Energy, cold storage, phase change materials, flexible cooling, data center.

Dr. Fan is a faculty member at DTU. With over 21 years of research experience in heat storage and solar heating systems, he has led or participated in more than 40 national/international research projects. He has authored over 173 SCI/EI-indexed journal articles and 39 conference papers and reports.

Water pit thermal energy storage for district heating system

Jianhua Fan, Technical University of Denmark; Pengcheng Wang, Technical University of Denmark

Jianhua Fan (presenter) jifa@dtu.dk

This paper presents the recent research on water pit thermal energy storage (PTES) as an outcome of the IEA Energy Storage TCP Task 41 'Economics of energy storage'. The long term operation of the 75,000 m³ PTES in Marstal and the 60,000 m³ PTES in Dronninglund were monitored in detail. Based on the monitoring data, the thermal performance of the PTES was evaluated. The charged /discharged energy, the heat loss, the energy and exergy efficiency of the PTES were determined. Advanced TRNSYS models of the PTES were developed and validated against the monitoring data. The PTES model was then used in a solar district heating system to investigate how best to integrate the PTES with solar collector fields, combined heat and power (CHP) generator, heat pump, etc. The monitoring data shows a gradual increase in heat loss from the floating lid of the Marstal PTES from 2013-2017. The PTES model was used to analyze the cause of the high heat loss from the PTES. Eventually, the economics of PTES for district heating were analyzed, using both the top-down approach and the bottom-up approach (for example, the levelized cost of heat, LCOH).

Keywords: Thermal energy storage, Large scale application, Water pit, District heating system, Techno-economic analysis, IEA ES Task 41

Dr. Ming Chen is a Full Professor at DTU Energy with 25+ years of research on energy conversion and storage, focusing on solid oxide cells for Power2X and thermal energy storage for Power2Heat applications.

Potentials of molten salt for medium duration thermal energy storage

Akhil Panicker and Ming Chen, Technical University of Denmark

Ming Chen (presenter) minc@dtu.dk

Decarbonization and green electrification are pivotal in addressing Europe's challenges of climate change and energy security. The industrial sector alone demands about 25–75% of medium-temperature heat¹, emphasizing the need for sustainable heat storage solutions. Molten salt-based thermal energy storage (TES) systems have emerged as a promising technology due to their high thermal stability, cost-effectiveness, and wide operating temperature range.

This work explores a two-tank molten salt TES system designed to supply steam at 120°C–450°C for industrial applications. Using molten salt as both heat transfer and storage medium, the system operates in charging and discharging phases. It consists of two tanks (hot and cold), a heat exchanger, pumps, valves, and a steam generator. During charging, molten salt from the cold tank is heated using renewable energy and stored in the hot tank. During discharging, the hot salt transfers heat to water in the steam generator, producing steam, while cooled salt returns to the cold tank. With sodium hydroxide as the chosen salt, the system operates between 323°C and 700°C. A Simulink model captures thermodynamic behavior, and cost functions evaluate CAPEX and OPEX, optimizing components for molten salt properties.

This work also investigates corrosion impacts on efficiency and cost. Corrosion affects durability of components such as tanks, heat exchangers, and piping, requiring strategic material selection, protective coatings, and design optimization to balance performance and cost. The study underscores the techno-economic feasibility of the system as a scalable, efficient solution for integrating renewables into industrial heat. Realizing its full potential requires further research into high-temperature, corrosion-resistant materials and the integration of TES with diverse renewable sources through advanced control and innovative design.

¹Naegler et al., *Int. J. Energy Res.* 2015, 39 (15), 2019–2030.

Keywords: Thermal Energy Storage, Heat Storage, Molten Salt, Power to Heat, Simulink, System Simulation

Special session on Medium-duration thermal energy storage – System perspectives

Frederick assists in various national energy system analyses of the Danish energy system. Additionally, he contributes to the research in various applications of molten salt storage at system level.

Effects of different uses of molten salt storages in the national energy system – A case study on Denmark

1.

Frederick Stender, Research Assistant in the Sustainable Energy Planning research group at Department of Planning at Aalborg University,

2.

Peter Sorknæs, Associate Professor in the Sustainable Energy Planning research group at Department of Planning at Aalborg University

3.

Frederik Botin Carøe Villum, (former) intern in the Sustainable Energy Planning research group at Department of Planning at Aalborg University

Frederick Stender (presenter) fsms@plan.aau.dk

Molten salt storages (MOSS) can in combination with an electric heater prove to have various purposes as goes for storage- and discharge of energy, effectively improving energy systems' ability to utilise increasing production of intermittent renewable electricity, relieving congestion issues in electrical grids, and provide dispatchable electricity generation. MOSS enacting as power-to-power operating units (effectively, Carnot batteries) This study will consider three distinct purposes of MOSS, all embedded in a model of the Danish energy system by 2045:

- 1) Retrofitting a soon-to-be decommissioned coal-fired power plant with MOSS enacting as Carnot batteries to provide non-fuel-based dispatchable electricity generation to the Danish energy system (plant).
- 2) Substituting gas- and biomass-based industrial process heat demands in Danish industries by implementing power-to-steam operating MOSS units (industry).
- 3) Combining large-scale onshore energy islands – consisting of large-scale, onshore renewable electricity production alongside PtX infrastructure such as electrolyzers and/or synthetic- and liquid fuel production – with MOSS enacting as power-to-power Carnot batteries (island).

Though the three above applications for MOSS varies, the following is considered for all of them:

- a) How does the necessary capacity of dispatchable electricity generation change to, and are there cheaper, more readily available alternatives?
- b) What change occurs in the total annual costs of the Danish energy system?

The modelling of the reference energy system of Denmark by 2045 alongside the three above distinct applications are all performed in the energy system analysis tool of EnergyPLAN.

Keywords: electrification, industrial process heat demand, molten salt storage, grid congestion, dispatchable electricity generation, EnergyPLAN, smart energy systems, retrofit, thermal storage

Michael Bayer is a research associate at the Lucerne University of Applied Sciences and Arts and a PhD student at TU Vienna. His research focuses on thermal grids, including the optimisation of existing district heating and the design and control of future district heating and cooling systems.

Cascading of sTES for optimal operation of DHC networks – Case study on a cooling dominated grid

Michael Bayer (1,2), Artem Sotnikov (1), Curtis Meister(1), Abdulrahman Dahash(3), Philipp Schuetz(1), Heimo Walter(2), Willy Villasmil(1)

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(3) Sustainable Thermal Energy Systems, Center for Energy, AIT Austrian Institute of Technology GmbH, 1210 Vienna, Austria.

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This study explores the cascading potential of seasonal thermal energy storage units (sTES) within a district heating and cooling (DHC) network, focusing on a cooling-dominated grid. The system comprises three stratified thermal storage pits operating at distinct temperature levels (10–30°C, 30–60°C, and 60–95°C) to enhance energy and exergy efficiency and optimize operational flexibility via heat pumps improving sector coupling.

The cooling grid is directly connected to the low temperature sTES (10–30°C), supplying cooling for applications such as data centers with stable baseloads and peak demands in summer. This storage is further cooled via a heat pump, further improving its cooling potential. The heat pump plays a dual role by directly supplying the heating grid and charging the medium-temperature sTES (30–60°C) during periods of low heat demand. The high temperature sTES (60–95°C) is primarily charged using solar energy during summer and serves as a additional heat source for peak load coverage in winter, utilizing its seasonal thermal storage potential.

The key objectives of this study are twofold: (1) to develop an optimal operational strategy for the integrated DHC network, maximizing energy and exergy efficiency and system flexibility, and (2) to assess the thermal interaction between the three sTES units when placed close to each other, determining insulation requirements to minimize thermal losses. Thanks to cascading the sTES units and dynamic heat pump operation, this research aims to tackle challenges in energy management and seasonal efficiency for sustainable heating and cooling networks.

Keywords: Seasonal Thermal Energy Storage (sTES), Modelica, District Heating and Cooling (DHC), Heat Pump Integration, Thermal Storage Cascading, Sector Coupling

Morten Herget Christensen is a Senior Consultant at Danish Technological Institute. His work focuses on the potential of thermal energy storages for cost-effective and resilient transition away from fossil fuels in district heating and industrial applications.

Heat pump and e-boiler hybrid systems for charging of thermal energy storages – Techno-economic analysis of district heating and industry applications

Morten Herget Christensen, Danish Technological Institute, Wiebke Brix Markussen, Danish Technological Institute

Morten Herget Christensen (presenter)

Decarbonization of the industry requires electrification of process heat. Electrification of process heat may be achieved via heat pumps or resistive electric heating. In this context thermal energy storages may decouple heat production and demand, and thereby add flexibility and possibilities for optimal operation scheduling, thereby potentially lowering the overall heat production costs.

In this work we consider the role that thermal energy storage plays in the optimal operation and configuration of “hybrid electrification systems”, systems that include both high-temperature heat pumps and electric boilers to produce high temperature heat and steam for industrial processes or heat for district heating transmission systems.

In this initial investigation we formulate a high-level optimization problem for the planning / hourly operation of the hybrid system subject to constraints that describe both the input-output electrical and thermal boundary conditions including:

Electricity prices, thermal load: temperature, pressure, mass flow; Simple models of the components for conversion and storage: electric boiler, high temperature heat pump, thermal storages, steam generator.

A method is proposed to analyze the performance of the hybrid system by varying the size, type, number and temperature levels of both storage and input heat technologies while covering all process heating demands at the lowest possible cost, expressed in economic KPI's such as the CAPEX, OPEX and LCOH of the hybrid system.

The method for techno-economic analysis is applied to the specific case of an industrial hub in Denmark and used to analyze the drawbacks and benefits of the size and configuration of thermal storages and heat input option

Keywords: Thermal Energy Storage, High Temperature Heat Pump, Industrial Decarbonization

Niels van der Veer is a mechanical engineer and energy planning consultant, specializing in techno-economic modelling and optimization of energy systems, and is involved in the feasibility and implementation of innovative energy solutions at the intersection of technology, policy, and market conditions.

Cost-effective and low-carbon heat supply using medium duration molten salt energy storage in the industry.

Magdalena Komoszynska, PlanEnergi

Niels van der Veer, PlanEnergi

Niels van der Veer (presenter)

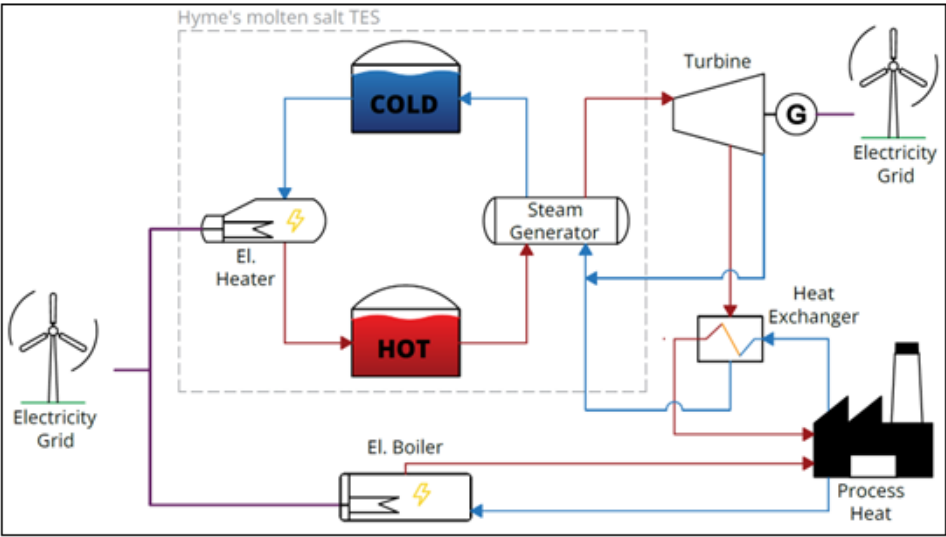
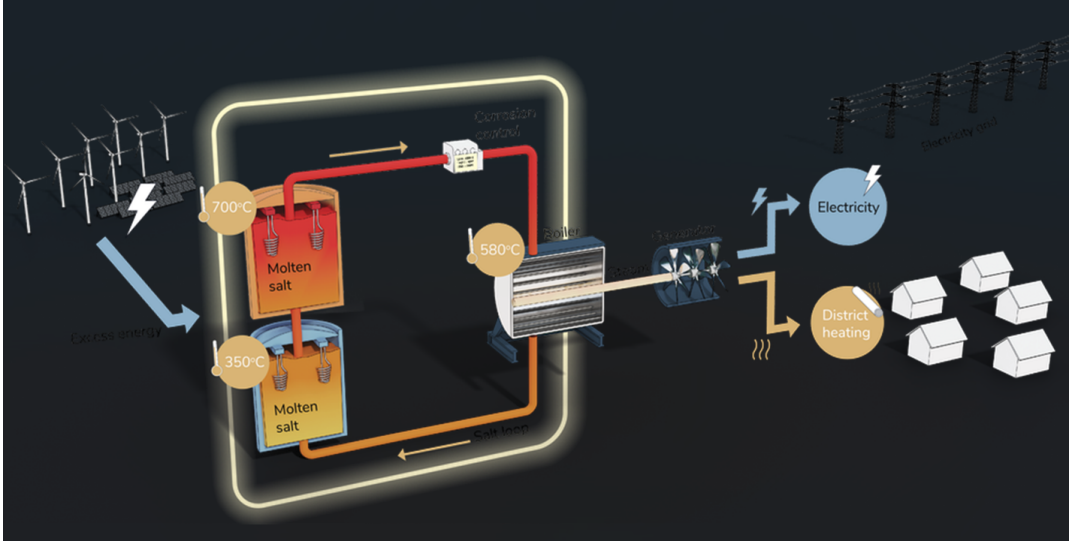
Industrial heat accounts for 25% of global final energy consumption, yet only 12% of this energy is derived from renewable sources. While other sectors benefit from renewable energy options, industrial applications require high-temperature heat, possible only through electrification which on the other hand requires energy storage to tackle the mismatch between the renewable generation and the heat demand.

To address this challenge, Hyme Energy's TES technology developed electricity driven molten salt energy storage to store and release heat efficiently and cost-effectively. Hyme uses a unique family of hydroxide salts that enable greater efficiency and cost savings compared to other salts in the thermal energy storage market.

This presentation explores their technology and assesses its economic feasibility through business case studies, utilising real production data.

PlanEnergi has performed a techno-economic optimisation of the storage system capacity for the most cost-effective industrial steam production and cogeneration. It analysed three main industrial users: Gas-to-Heat Transition, Power-to-Heat Co-Generation and Island Operation. The most cost-effective steam production is being sought in Hyme TES operating in different configurations: a) an exclusive standalone operation, b) a parallel operation with a boiler. This to serve different applications: 1. steam supply only and 2. both steam and electricity supply. The analysis was comprehensive and conducted at different boundary conditions, including historical and future electricity price prognosis as well changes to the investment costs, revenue streams and capital structures. The work revealed interesting and promising application possibilities for the Hyme molten salt storage as Power-to-Heat (-to-Power) technology revolutionising industrial fossil fuel-based high temperature heat dependence.

Keywords: Medium duration energy storage, TES, molten salt, Hyme, industrial heat



My research focuses on the development of cost-effective Thermal Energy Storage (TES) solutions to maximize the penetration of renewable energy while providing stability and flexibility to the energy sector.

Heat integrated Carnot Batteries for Decarbonized Industries – System Opportunities Mapping

Silvia Trevisan, KTH Royal Institute of Technology. Kevin Ludwig, German Aerospace Center. Wolfgang Weiss, AEE – Institute for Sustainable Technologies

Silvia Trevisan (presenter) trevisan@kth.se

The industrial sector is a major source of wealth, producing about one-quarter of the global gross product. However, industry is also a major emitter of CO₂ and it represents a key challenge toward achieving the worldwide CO₂ emission reduction targets. Flexible electrification, in the form of power to heat, thermal energy storage and, when need, heat to power units, has been recognized as a key technology toward decarbonizing the industrial sector. These systems can provide a multitude of services, among which: power and heating sector coupling, support to the grid (frequency regulation services), facilitate renewable integration and load shifting. Heat integrated Carnot Batteries can support the development of smart energy infrastructure and integrated systems together with the electrification of the industrial sector.

“Hi CBest - Power-to-Heat and heat integrated Carnot Batteries for Zero-Carbon (industrial) Heat & Power supply” (IEA ES TCP – Task 44) aim to support the global energy transition from a fossil fuel based to a zero-carbon energy system. This work stems from the Task’s activities and provides key insights and mapping technological solutions to main use cases. The presented mapping will not only communicate the unique selling points of Heat integrated Carnot Batteries (e.g. by integrating more clearly the services a system can deliver) and identify Best-Go cases but also highlight technically and environmentally promising use cases which should be further explored by research activities and that can be promoted and supported through policy & subsidies.

Keywords: Carnot Batteries, Industrial Decarbonization, Electrification, Thermal Energy Storage

Wim van Helden has worked at AEE INTEC since 2014, where he is a Senior Expert in Thermal Energy Storage. Next to that, he is working as an independent consultant in the area of thermal energy storage and solar thermal technologies. He has experience in leading national and international projects

Accelerating the Role of Large Thermal Energy Storages as Elements for Medium and Long Duration Flexibility

Wim van Helden, AEE Intec. Geoffroy Gauthier, PlanEnergi

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Large Thermal Energy Storage (LTES) technologies offer several opportunities to district heating and industrial heat networks. They increase the flexibility by connecting more and different heat sources, they increase the uptake of more variable renewable heat sources, they enable the coupling of different thermal processes in a system, and they provide grid flexibility through power-to-heat and medium-to-long term energy storage capacities.

Dependent on local geological conditions a suited LTES technology can be chosen, each having its own set of characteristics. The technologies are Aquifer, Borehole, Cavern, Mine, Pit and Tank thermal energy storages (respectively ATES, BTES, CTES, MTES, PTES and TTES). The technologies are the primary focus of IEA-ES Task 45 “Accelerating the uptake of Large Thermal Energy Storages”.

While the TTES technology is mature (TRL 9, with hundreds of installations worldwide), the other technologies aren’t quite as mature yet. PTES is the second most mature technology, with about 10 installations worldwide in 2025 (most of them in Denmark), a TRL between 8 and 9 and a dedicated EU-funded project “TREASURE” working on their further development and demonstration. Then come ATES and BTES technologies (at high temperatures, above 50-60°C), both with several pilot plants worldwide, and a few full-scale installations (TRL 7-8). Finally, CTES and MTES are still under development and at pilot-scale development (TRL 6-7). ATES, BTES, CTES and MTES are also being demonstrated within the EU-funded projects “Interstores”, “Uses4Heat” and “Push-IT”.

Due to their large storage capacity and in most cases large charge- and discharge powers, LTES are in a very good position to serve as medium duration flexible element in electricity grids (Medium Duration Energy Storage, or MDES). This generates advantages for the grid operator, having an additional demand-management element in the system and for the district or industrial heat network operator

Keywords: Thermal Energy Storage, Long Duration Energy Storage, Flexibility, Sector Coupling, Technology Development

Previous winners of the Best Presentation Awards

Best PhD/Postdoc Presentation:

2024: Simran Kaur Chaggar, FairHeat

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2021: Daniel Møller Sneum, Technical University of Denmark

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2019: Maria Jangsten, Chalmers University of Technology

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2017: Kanau Takahashi, Kyoto University

2016: Magnus Dahl, Aarhus University/AffaldVarme Aarhus

2015: Dorte Skaarup Larsen, Technical University of Denmark

Best Senior Presentation:

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2020: Matteo Giacomo Prina, EURAC Research

2019: Henrik Madsen, Technical University of Denmark

2018: Benedetto Nastasi, TU Delft

2017: Svend Svendsen, Technical University of Denmark

2016: Martin Crane, Carbon Alternatives Ltd

2015: Urban Persson, Halmstad University

Conference Chairs



Henrik Lund, Professor in Energy Planning at Aalborg University, Denmark

Henrik Lund is MSc Eng and Professor in Energy Planning at Aalborg University, Denmark. He holds a PhD in the Implementation of Sustainable Energy Systems (1990), and a Dr Techn in Choice Awareness and Renewable Energy Systems (2009). Henrik Lund is a highly ranked world-leading researcher. For more than 10 successive years, he is listed among ISI Highly Cited researchers, ranking him among the top 1% researchers in the world within engineering, and is on the Stanford list of top 2% scientists. He is member of The Danish Academy of Technical Sciences (ATV) and has been awarded the Royal Order of Chivalry of the Dannebrog. For 16 years, Henrik Lund was Editor-in-Chief of Elsevier's high-impact journal Energy and is now editor of conference relations and special issues. Moreover, he is the founding editor of the journal Smart Energy. He is the author of more than 500 books and articles including the book "Renewable Energy Systems". He is the architect behind the advanced energy system analysis software EnergyPLAN, which is a freeware used worldwide that have formed the basis of more than 300 peer-reviewed journal papers around the world..



Brian Vad Mathiesen, Professor in Energy Planning at Aalborg University, Denmark

Professor Brian Vad Mathiesen holds a PhD in fuel cells and electrolyzers in future energy systems (2008). His research focuses on technological and socioeconomic transitions to renewables, energy storage, large-scale renewable energy integration and the design of 100% renewable energy systems. He is one of the leading researchers behind the concepts of Smart Energy Systems and electrofuels. He has published 250 scientific articles and reports and is on the Clarivate Web of Science List of Highly Cited Researchers (since 2015), thus among the top 1% most cited researchers globally. In 2022 he was the most cited researcher in Danish media across all topics. Among other positions, he has been part of the EU Commission expert group on electricity interconnection targets and the Science Advice for Policy by European Academies (SAPEA) Expert Group on A Systemic Approach For the Energy Transition In Europe. He is the Research Coordinator of the Sustainable Energy Planning Research group and was the Principal Investigator (PI) of the RE-INVEST and sEnergies projects. He has been PI, work package leader and participant in more than 75 research projects. In 2012 he founded the MSc programme in Sustainable Cities at Aalborg University. Furthermore, he is an editorial board member of The Journal of Energy Storage (Elsevier) and The Journal of Sustainable Development of Energy, Water & Environment Systems; Associate Editor of Energy, Ecology and Environment (Springer) and Editor of the International Journal of Sustainable Energy .

Planning and Management. Recently he started the new Elsevier Journal Smart Energy. In addition, he is a member of The Danish Academy of Technical Sciences (ATV), a board member at The Danish Energy Technology Development and Demonstration Programme (EUDP), Radius Elnet and chairman of the Advisory Board of the CIP Foundation.



Poul Alberg Østergaard, Professor in Energy Planning at Aalborg University, Denmark

Poul Alberg Østergaard is Professor in Energy Planning at Aalborg University with a PhD in “Integrated Resource Planning” from 2000. He has a solid research and teaching experience within energy planning, with a main competence in the analysis of energy systems with large-scale integration of fluctuating renewable energy sources, optimisation criteria of energy systems analyses, sustainable energy scenarios for local areas, and drivers and barriers for renewable energy transition.

He has contributed to more than 100 scientific journal articles and is on the Stanford-Elsevier list of Top 2% scientists. He is editor-in-chief of the International Journal of Sustainable Energy Planning and Management and co-editor of a number of other journals. Furthermore, he is the Head of Study Board of Planning and Land Surveying at Aalborg University as well as the Programme Director of the M.Sc. programme in Sustainable Energy Planning & Management at Aalborg University.



Jakob Zinck Thellufsen, Associate Professor in Energy Planning at Aalborg University, Denmark

Jakob Zinck Thellufsen is an Associate Professor in Energy Planning and Energy System Analysis at Aalborg University. He holds a PhD in “Smart City Energy System Analysis”. His research concerns renewable energy, energy system analysis, and how system integration improves the renewable energy transition. Jakob Zinck Thellufsen has focused on research topics such as energy savings, CCUS, district heating and Power to X and how these are integrated and coupled in the

energy system. Jakob Zinck Thellufsen has contributed to more than 35 research papers and is currently leading research projects on CCUS in the energy system and has led work packages in important international projects regarding energy system analysis and model development. He is one of the main developers on the energy system analysis tool EnergyPLAN and currently teaches the program at both bachelors and PhD level. Furthermore, he is head of section at the Department of Sustainability and Planning at Aalborg University.



Hans Jørgen Brodersen, Senior Project Manager, Energy Cluster Denmark

Hans Jørgen Brodersen is present Senior Project Manager at Energy Cluster Denmark and formerly Project Director at Clean Cluster energy. He holds a Master of Science in “International Environmental and Energy Planning” from Aalborg University and has more than 30 years of Project management and teaching experience within Environmental, Technological and Energy Planning. He has held more Head of Center positions at and with Aalborg University within Waveenergy and Technology development. Centers that focus on Research and Technology

Innovation in cooperation with the private and public sectors. He has formerly also been Consultant in his own company and at Deloitte, where Energy and Environmental Management systems and organizational technology change in the private sector has been the drive of his work. He is external Examiner at Aalborg University. Among others, he has also been involved in the making of the Danish Society of Engineers’ proposal for a future 100% Renewable Energy Plan for Denmark, And before that chair and organizer of the International Europe Sustainability conferences with International business organisations like World Business Sustainability Council. He has during his career had a growing focus on the total value chain of connected technologies for power to fuel for wheels and wakes and system integration.

Plenary Keynote Speakers



ŞIIR KILKIŞ, IPCC WGIII Vice-Chair, will give the keynote speech: Smart Energy Systems Targeted Mitigation in Urban Areas for Avoiding Increments of Global Warming

Şiir Kılış has over two decades of experience in climate change mitigation, including its role in pursuing sustainable development. She is Vice-Chair of IPCC's Working Group III on the mitigation of climate change. She was a Lead Author of the Working Group III contribution to the Sixth Assessment Report, focusing on mitigation options, urban systems, and sustainable development linkages. She was in the Scientific Steering Committee of the scoping of the IPCC's Special Report on Climate Change and Cities and now acts as a Review Editor. She is a senior researcher and science adviser at The Scientific and Technological Research Council of Türkiye and is double affiliated to the Middle East Technical University in Ankara as professor. Her research focuses on the mitigation potential of urban areas, supply-demand interactions, global and local scales, and sustainable development. Through her publications, she takes place among the top 2% of scientists in energy, environmental sciences, and enabling/strategic technologies.

Abstract

Mitigation actions that can be aligned with supporting smart energy systems have an important role in shifting trajectories for our climate future. The global mean near-surface temperature reached 1.55 °C above pre-industrial levels on an annual basis in 2024 and at least 1.34 °C in estimates with longer timescales. Swift, targeted, and integrated mitigation actions continue to be necessary across spatial scales in coherent ways to enable the best chances of remaining with the long-term temperature goal of the Paris Agreement. This keynote will focus on the role of urban areas in supporting smart energy systems within ambitious mitigation pathways. A particular focus will be on the mitigation potential of 465 urban areas that can avoid up to 0.09 °C increments of global warming in 2050 when the transient climate response to cumulative CO₂ emissions is considered. Such a mitigation potential is possible when there are high levels of renewable energy deployment, sector coupling, and better urban planning. The avoided increments of global warming are in comparison to a less ambitious mitigation pathway that is aligned with the SSP1-2.6 scenario. Moreover, the vitality of decarbonizing urban infrastructure across sectors while addressing broader needs, such as ensuring access to renewable electricity and enabling cobenefits for improving air quality and protecting lives that are essential for sustainable development, are also emphasized. Actions that are aligned with supporting smart energy systems will be crucial from several dimensions. The plenary keynote will conclude with an outlook towards the Seventh Assessment cycle of the Intergovernmental Panel on Climate Change where points of emphasis in the agreed outline include those on the mitigation effects of system integration and actions for supporting net-zero targets.



ASBJØRN HAUGSTRUP, Chief External Relations Officer at Innargi, will give the keynote speech:

Outlook: Why is the heating of our homes attracting increased political attention and what is its role in Smart Energy Systems if we are to meet political targets?

Asbjørn Haugstrup is Chief External Relations Officer and a member of the Senior Management Team at Innargi A/S — a Danish company developing large-scale geothermal solutions for district heating in Germany, Poland, and Denmark.

Previously, Asbjørn Haugstrup has served as Special Political Advisor to several Danish ministers, including those for Climate, Energy and Buildings; Economic Affairs and the Interior; and Foreign Affairs.

Abstract

Cities are responsible for 70 % of global emissions, making them the front-line battlefield in the fight against climate change. In Northern European cities, 56 % of CO₂ emissions come from heating homes.

This makes the decarbonisation of heat one of the most impactful climate actions available to cities and communities.

Traditionally, heat in cities has been generated as a by-product of electricity production. This residual heat, most often produced by burning fossil fuels, has been effectively distributed through district heating networks.

Hopefully, the future is different. As energy systems transition to renewable sources such as solar and wind – which do not generate any waste heat – we will need new ways to generate heat in urban areas. Alternative approaches vary and may include the collection of waste heat, the introduction of geothermal, large scale heat pump solutions, burning of fossil fuels and biomass etc.

Until recently, heating has received relatively little attention in European energy policy compared to e.g. electricity and hydrogen. But this seems to be changing now. The new European Commission has announced plans for a strategy on heating and cooling as well as an action plan for geothermal energy.

Asbjørn Haugstrup will deliver a keynote addressing the role of heating in the decarbonisation of European cities, the importance of developing heating infrastructure, and the political drivers in the EU policy making that may shape the future of urban heating.



Philip Christiani, Partner at CIP, will give the keynote speech: Europe's Energy Pivot: A Strategic Blueprint for a Prosperous and Secure Energy Future.

Philip Christiani, Partner of CIP, based in Copenhagen, is co-heading the Energy Transition Fund platform. He is leading negotiations with offtakers and shaping the process for sales, building project teams, defining targets and milestones, setting priorities, and driving plans. Moreover, Philip Christiani is leading project development in Chile, Portugal, and Morocco. He has more than 20 years in Tier 1 consulting, most recently as a Senior Partner at McKinsey. In addition, he has been assisting global industry leaders on strategy, ESG compliance, recycling, and emissions reduction. Philip Christiani holds a MSc in Economics from the University of Copenhagen and a MS in Finance from the University of Reading.

Abstract

In an era marked by geopolitical tensions, market volatility, and urgent climate imperatives, Europe's energy landscape is at a critical crossroads. A recent white paper by Copenhagen Infrastructure Partners (CIP) in partnership with Oxford Economics and EA Energianalyse presents a vision for transforming Europe's energy system, emphasizing the pivotal role of low cost renewable energy sources. The underlying message is clear: Europe's future economic competitiveness and energy security depend on ambitious investments in renewable energy infrastructure, combined with strategic system integration and grid expansion. These renewable assets will form the backbone of Europe's future energy mix, with the ultimate goal of delivering over 90% of energy from clean sources by 2050.

The Context: Navigating a Volatile Global Energy Market

The global energy sector is experiencing unprecedented shifts. Political instability in key oil and gas-producing regions, fluctuating commodity prices, and the ongoing transition to decarbonized energy have created a landscape where traditional fossil fuel reliance is increasingly unsustainable and risky. Europe, heavily dependent on energy imports, particularly fossil fuels, finds itself vulnerable to global supply disruptions and price shocks.

The whitepaper underscores this vulnerability, revealing that Europe currently imports approximately 56% of its final energy demand at a cost of about EUR 450 billion annually. This dependency not only poses economic risks but also undermines energy sovereignty. To counter these challenges, we advocate for a strategic overhaul of the continent's energy system, grounded in accelerating the deployment of clean energy technologies



Lily Bermel, Research Advisor at the Massachusetts Institute of Technology Center for Energy and Environmental Policy Research, will give the keynote speech: The state of U.S. clean energy investment and policy

Lily Bermel is a Research Advisor for Brian Deese at the Massachusetts Institute of Technology Center for Energy and Environmental Policy Research (MIT-CEEPR). She works on a range of climate and industrial policy projects, including the Clean Investment Monitor and the Clean Energy Marshall Plan. Before joining MIT-CEEPR, Lily served for three years as a policy advisor on the U.S. State Department climate team, led by Special Presidential Envoy for Climate John Kerry. There, she negotiated on behalf of the United States in multilateral fora, integrated climate policy across the Department's operations, coordinated private sector engagement, and developed strategies to mitigate non-CO2 gases. Previously, Lily developed the sustainability department at Cornell Dining, wrote a series of policy proposals for the Kingdom of Tonga, and contributed to climate policy in Massachusetts at the state and local levels. Lily received a B.S. in Environment and Sustainability from Cornell University

Abstract

The U.S. clean energy transition tangibly accelerated after the enactment of the Inflation Reduction Act, which included comprehensive clean energy investment incentives. Indeed, investment in clean energy technologies nearly doubled, created hundreds of thousands of jobs, and is a growing share of the domestic economy. Following the 2024 election, Republicans are in the middle of changing – somewhere between reforming and repealing – the very energy tax cuts that are core to advancing American priorities of economic competitiveness and energy dominance, independence, and abundance. This keynote will provide the latest data on investment in clean energy technologies in the United States, the state of U.S. federal climate policy, and relevant lessons regarding climate politics.

List of special issue journal papers from previous SESAAU conferences

International Journal of Sustainable Energy Planning and Management, Vol 12 + 13 (2017)

Poul Alberg Østergaard, Henrik Lund: *Smart district heating and electrification*

Rasmus Lund, Dorte Skaarup Østergaard, Xiaochen Yang, Brian Vad Mathiesen: *Comparison of Low-temperature District Heating Concepts in a Long-Term Energy System Perspective*

Erik Trømborg: *Flexible use of electricity in heat-only district heating plants*

Anton Ivanov Ianakiev: *Innovative Delivery of Low Temperature District Heating System*

Jose Fiacro Castro Flores, Alberto Rossi Espagnet, Justin NingWei Chiu, Viktoria Martin, Bruno Lacarrère: *Techno-Economic Assessment of Active Latent Heat Thermal Energy Storage Systems with Low-Temperature District Heating*

Richard van Leeuwen: *Energy scheduling model to optimize transition routes towards 100% renewable urban districts*

Kerstin Sernhed: *Customer perspectives on district heating price models*

International Journal of Sustainable Energy Planning and Management, Vol 16 (2018)

Jürgen Knies: *A spatial approach for future-oriented heat planning in urban areas*

Daniel Møller Sneum, Eli Sandberg: *Economic incentives for flexible district heating in the Nordic countries*

Isabelle Best: *Economic comparison of low-temperature and ultra-low-temperature district heating for new building developments with low heat demand densities in Germany*

Georg Konrad Schuchardt: *Development of an empirical method for determination of thermal conductivity and heat loss for pre-insulated plastic bonded twin pipe systems*

International Journal of Sustainable Energy Planning and Management, Vol 20 (2019)

Poul Alberg Østergaard, Henrik Lund, Brian Vad Mathiesen: *Developments in 4th generation district heating*

Roberta Roberto, Raffaele De Iulio, Marialaura Di Somma, Giorgio Graditi, Giambattista Guidi, Michel Noussan: *A multi-objective optimization analysis to assess the potential economic and environmental benefits of distributed storage in district heating networks: a case study*

Anna Volkova, Eduard Latõšov, Vladislav Mašatin, Andres Siirde: *Development of a user-friendly mobile app for the national level promotion of the 4th generation district heating*

Lisa Brange, Kerstin Sernhed, Marcus Thern: *Method for addressing bottleneck problems in district heating networks*

Marco Pellegrini, Augusto Bianchini, Alessandro Guzzini, Cesare Saccani: *Classification through analytic hierarchy process of the barriers in the revamping of traditional district heating networks into low temperature district heating: an Italian case study*

Henrik Pieper, Vladislav Mašatin, Anna Volkova, Torben Ommen, Brian Elmegaard, Wiebke Brix Markussen: *Modelling framework for integration of large-scale heat pumps in district heating using low-temperature heat sources*

International Journal of Sustainable Energy Planning and Management, Vol 27 (2020)

Poul Alberg Østergaard, Rasmus Magni Johannsen, Henrik Lund, Brian Vad Mathiesen: *New Developments in 4th generation district heating and smart energy systems*

Anna Volkova, Eduard Latõšov, Kertu Lepiksaar, Andres Siirde: *Planning of district heating regions in Estonia*

Kristine Askeland, Bente Johnsen Rygg, Karl Sperling: *The role of 4th generation district heating (4GDH) in a highly electrified hydropower dominated energy system - The case of Norway*

Matteo Giacomo Prina, David Moser, Roberto Vaccaro, Wolfram Sparber: *EPLANopt optimization model based on EnergyPLAN applied at regional level: the future competition on excess electricity production from renewables*

Salman Siddiqui, John Macadam, Mark Barrett: *A novel method for forecasting electricity prices in a system with variable renewables and grid storage*

International Journal of Sustainable Energy Planning and Management, Vol 31 (2021)

Poul Alberg Østergaard, Rasmus Magni Johannsen, Henrik Lund, Brian Vad Mathiesen: *Latest Developments in 4th generation district heating and smart energy systems*

Johannes Röder, Benedikt Meyer, Uwe Krien, Joris Zimmermann, Torben Stührmann, Edwin Zondervan: *Optimal Design of District Heating Networks with Distributed Thermal Energy Storages – Method and Case Study*

Rasmus Lund: *Energy system benefits of combined electricity and thermal storage integrated with district heating*

Mathias Kersten, Max Bachmann, Tong Guo, Martin Kriegel: *Methodology to design district heating systems with respect to local energy potentials, CO₂-emission restrictions, and federal subsidies using oemof*

Alice Dénarié, Samuel Macchi, Fabrizio Fattori, Giulia Spirito, Mario Motta, Urban Persson: *A validated method to assess the network length and the heat distribution costs of potential district heating systems in Italy*

Karl Vilén, Sujeetha Selvakkumaran, Erik O. Ahlgren: *The Impact of Local Climate Policy on District Heating Development in a Nordic city – a Dynamic Approach*

Francesco Mezzera, Fabrizio Fattori, Alice Dénarié, Mario Motta: *Waste-heat utilization potential in a hydrogen-based energy system - An exploratory focus on Italy*

Markus Groissböck: *Energy hub optimization framework based on open-source software & data - review of frameworks and a concept for districts & industrial parks*

Ulrich Trabert, Mateo Jesper, Weena Bergstraesser, Isabelle Best, Oleg Kusyy, Janybek Orozaliev, Klaus Vajen: *Techno-economic evaluation of electricity price-driven heat production of a river water heat pump in a German district heating system*

Kelly D'Alessandro, Paul Dargusch, Andrew Chapman: *Disruption, Disaster and Transition: Analysis of Electricity Usage in Japan from 2005 to 2016*

Bente Johnsen Rygg, Marianne Ryghaug, Gunnar Yttri: *Is local always best? Social acceptance of small hydropower projects in Norway*

Obadia Kyetuza Bishoge, Godlisten Gladstone Kombe, Benatus Norbert Mvile: *Energy Consumption Efficiency Behaviours and Attitudes among the Community*

Rahmat Adiprasetya Al Hasibi: *Multi-objective Analysis of Sustainable Generation Expansion Planning based on Renewable Energy Potential: A case study of Bali Province of Indonesia*

Wesley Bowley, Ralph Evins: *Energy System Optimization including Carbon-Negative Technologies for a High-Density Mixed-Use Development*

International Journal of Sustainable Energy Planning and Management, Vol 34 (2022)

Poul Alberg Østergaard; Rasmus Magni Johannsen, Neven Duić, Henrik Lund: *Sustainable Development of Energy, Water and Environmental Systems and Smart Energy Systems*

Felipe Del-Busto, María Dolores Mainar-Toledo, Víctor Ballestín-Trenado: *Participatory Process Protocol to Reinforce Energy Planning on Islands: A Knowledge Transfer in Spain*

Igor Balen, Danica Maljković: *A step towards decarbonised district heating systems: Assessment of the importance of individual metering on the system level*

Henrik Pieper, Kertu Lepiksaar, Anna Volkova: *GIS-based approach to identifying potential heat sources for heat pumps and chillers providing district heating and cooling*

Nelli Putkonen, Tomi J. Lindroos, Eimantas Neniškis, Diāna Žalostība, Egidijus Norvaiša, Arvydas Galinis, Jana Teremranova, Juha Kiviluoma: *Modeling the Baltic countries' Green Transition and Desynchronization from the Russian Electricity Grid*

Anna Volkova, Aleksandr Hlebnikov, Aleksandr Ledvanov, Tanel Kirs, Urmas Raudsepp, Eduard Latõšov: *District Cooling Network Planning. A Case Study of Tallinn*

Mostafa Fallahnejad, Lukas Kranzl, Marcus Hummel: *District heating distribution grid costs: a comparison of two approaches*

Juha-Antti Rankinen, Sara Lakkala, Harri Haapasalo, Sari Hirvonen-Kantola: *Stakeholder management in PED projects: challenges and management model*

Tekla Szép, Tamás Pálvölgyi, Éva Kármán-Tamus: *Indicator-based assessment of sustainable energy performance in the European Union*

International Journal of Sustainable Energy Planning and Management, Vol 38 (2023)

Poul Alberg Østergaard (Journal manager), Rasmus Magni Johannsen, Neven Duić, Henrik Lund, Brian Vad Mathiesen, Maria Isabel Rebelo Teixeira Soares, Paula Fernanda Varandas Ferreira: *Sustainable Energy Planning and Management*

Diego Viesi, Md Shahriar Mahbub, Alessandro Brandi, Jakob Zinck Thellufsen, Poul Alberg Østergaard, Henrik Lund, Marco Baratieri, Luigi Crema: *Multi-objective optimization of an energy community: an integrated and dynamic approach for full decarbonisation in the European Alps*

Anna Volkova, Einari Kisel, Olavi Grünvald, Andres Veske, Sreenath Sukumaran, Jaanus Purga: *Estonian Energy Roadmap to carbon neutrality*

Hermann Edtmayer, Lisa-Marie Fochler, Thomas Mach, Jennifer Fauster, Eva Schwab, Christoph Hochenauer: *High-resolution, spatial thermal energy demand analysis and workflow for a city district*

Mattia Pasqui, Guglielmo Vaccaro, Pietro Lubello, Adriano Milazzo, Carlo Carcasci: *Heat pumps and thermal energy storages centralised management in a Renewable Energy Community*

Dr Helen Turnell, Dr Caterina Marques, Phil Jones, Chris Dunham, Dr Akos Revesz, Professor Graeme Maidment: *Driving success towards zero carbon energy targets for UK's Local Authorities*

Vita Brakovska, Ruta Vanaga, Girts Bohvalovs, Leonora Fila, Andra Blumberga: *Multiplayer game for decision-making in energy communities*

International Journal of Sustainable Energy Planning and Management, Vol 44 (2025)

Noémie Jeannin, Jérémy Dumoulin, Alejandro Pena-Bello, David Wannier, Christophe Ballif, Nicolas Wyrsh: *A spatiotemporal analysis of photovoltaic electricity storage potential in electric vehicles*

Energy - The International Journal, Vol 110 (1 September 2016)
Special issue on Smart Energy Systems and 4th Generation District Heating

Selected papers from 1st International Conference on Smart Energy Systems and 4th Generation District Heating

Edited by Henrik Lund, Neven Duic, Poul Alberg Østergaard and Brian Vad Mathiesen

Henrik Lund, Neven Duic, Poul Alberg Østergaard, Brian Vad Mathiesen: *Smart energy systems and 4th generation district heating*

Benedetto Nastasi, Gianluigi Lo Basso: *Hydrogen to link heat and electricity in the transition towards future Smart Energy Systems*

Dietmar Schüwer, Christine Krüger, Frank Merten, Arjuna Nebel: *The potential of grid-orientated distributed cogeneration on the minutes reserve market and how changing the operating mode impacts on CO₂ emissions*

Christoffer Lythcke-Jørgensen, Adriano Viana Ensinas, Marie Münster, Fredrik Haglund: *A methodology for designing flexible multi-generation systems*

Weiming Xiong, Yu Wang, Brian Vad Mathiesen, Xiliang Zhang: *Case study of the constraints and potential contributions regarding wind curtailment in Northeast China*

Xiaochen Yang, Hongwei Li, Svend Svendsen: *Decentralized substations for low-temperature district heating with no Legionella risk, and low return temperatures*

Dorte Skaarup Østergaard, Svend Svendsen: *Replacing critical radiators to increase the potential to use low-temperature district heating – A case study of 4 Danish single-family houses from the 1930s*

Jelena Ziemele, Armands Gravelsins, Andra Blumberga, Girts Vigants, Dagnija Blumberga: *System dynamics model analysis of pathway to 4th generation district heating in Latvia*

M.Köfinger, D.Basciotti, R.R.Schmidt, E.Meissner, C.Doczekal, A. Giovannini: *Low temperature district heating in Austria: Energetic, ecologic and economic comparison of four case studies*

Jacek Kalina: *Complex thermal energy conversion systems for efficient use of locally available biomass*

Urban Persson, Marie Münster: *Current and future prospects for heat recovery from waste in European district heating systems: A literature and data review*

Rasmus Lund, Urban Persson: *Mapping of potential heat sources for heat pumps for district heating in Denmark*

J.N.W. Chiu, J. Castro Flores, V. Martin, B. Lacarrière: *Industrial surplus heat transportation for use in district heating*

Sven Werner: *European space cooling demands*

Valery A. Stennikov, Ekaterina E. Iakimetc: *Optimal planning of heat supply systems in urban areas*

Stefan Petrović, Kenneth Karlsson: *Ringkøbing-Skjern energy atlas for analysis of heat saving potentials in building stock*

Energy - The International Journal (last update 21 September 2018)
Special issue on Smart Energy Systems and 4th Generation District Heating

Selected papers from 2nd International Conference on Smart Energy Systems and 4th Generation District Heating

Edited by Henrik Lund

Henrik Lund, Neven Duic, Poul Alberg Østergaard, Brian Vad Mathiesen: *Smart Energy and District Heating: Special Issue dedicated to the 2016 Conference on Smart Energy Systems and 4th Generation District heating*

Fabian Levihn: *CHP and heat pumps to balance renewable power production: Lessons from the district heating network in Stockholm*

Gerald Schweiger, Jonatan Rantzer, Karin Ericsson, Patrick Lauenburg: *The potential of power-to-heat in Swedish district heating systems*

M. Rämä, S. Mohammadi: *Comparison of distributed and centralised integration of solar heat in a district heating system*

Ashreeta Prasanna, Viktor Dorer, Nadège Vetterli: *Optimisation of a district energy system with a low temperature network*

Sven Werner: *International review of district heating and cooling*

- Lisa Brange, Patrick Lauenburg, Kerstin Sernhed, Marcus Thern: *Bottlenecks in district heating networks and how to eliminate them – A simulation and cost study*
- Jelena Ziemele, Armands Gravelsins, Andra Blumberga, Dagnija Blumberga: *Combining energy efficiency at source and at consumer to reach 4th generation district heating: Economic and system dynamics analysis*
- Raimonda Soloha, Ieva Pakere, Dagnija Blumberga: *Solar energy use in district heating systems. A case study in Latvia*
- Carlo Winterscheid, Jan-Olof Dalenbäck, Stefan Holler: *Integration of solar thermal systems in existing district heating systems*
- Gerald Schweiger, Per-Ola Larsson, Fredrik Magnusson, Patrick Lauenburg, Stéphane Velut: *District heating and cooling systems – Framework for Modelica-based simulation and dynamic optimization*
- Henrik Lund, Poul Alberg Østergaard, David Connolly, Brian Vad Mathiesen: *Smart energy and smart energy systems*
- Torben Ommen, Jan Eric Thorsen, Wiebke Brix Markussen, Brian Elmegaard: *Performance of ultra low temperature district heating systems with utility plant and booster heat pumps*
- Tomasz Z. Kaczmarczyk, Grzegorz Żywica, Eugeniusz Ichnatowicz: *The impact of changes in the geometry of a radial microturbine stage on the efficiency of the micro CHP plant based on ORC*
- M. Jangsten, J. Kensby, J.-O. Dalenbäck, A. Trüschel: *Survey of radiator temperatures in buildings supplied by district heating*
- Hanne Kauko, Karoline Husevåg Kvalsvik, Daniel Rohde, Armin Hafner, Natasa Nord: *Dynamic modelling of local low-temperature heating grids: A case study for Norway*
- Julio Efrain Vaillant Rebollar, Eline Himpe, Jelle Laverge, Arnold Janssens: *Sensitivity analysis of heat losses in collective heat distribution systems using an improved method of EPBD calculations*
- Mikko Wahlroos, Matti Pärssinen, Jukka Manner, Sanna Syri: *Utilizing data center waste heat in district heating – Impacts on energy efficiency and prospects for low-temperature district heating networks*
- Yasameen Al-Ameen, Anton Ianakiev, Robert Evans: *Thermal performance of a solar assisted horizontal ground heat exchanger*

Energy - The International Journal (Last update 9 November 2018)
Special issue on Smart Energy Systems and 4th Generation District Heating

Selected papers from 3rd International Conference on Smart Energy Systems and 4th Generation District Heating

Edited by Henrik Lund

Martin Leurent, Pascal Da Costa, Miika Rämä, Urban Persson, Frédéric Jasserand: *Cost-benefit analysis of district heating systems using heat from nuclear plants in seven European countries*

Juan Pablo Jiménez Navarro, Konstantinos C. Kavvadias, Sylvain Quoilin, Andreas Zucker: *The joint effect of centralised cogeneration plants and thermal storage on the efficiency and cost of the power system*

Matteo Giacomo Prina, Marco Cozzini, Giulia Garegnani, Giampaolo Manzolini, Wolfram Sparber: *Multi-objective optimization algorithm coupled to EnergyPLAN software: The EPLANopt model*

Hanmin Cai, Shi You, Jiawei Wang, Henrik W. Bindner, Sergey Klyapovskiy: *Technical assessment of electric heat boosters in low-temperature district heating based on combined heat and power analysis*

Anna Volkova, Vladislav Mašatin, Andres Siirde: *Methodology for evaluating the transition process dynamics towards 4th generation district heating networks*

Samuel Letellier-Duchesne, Shreshth Nagpal, Michaël Kummert, Christoph Reinhart: *Balancing demand and supply: Linking neighborhood-level building load calculations with detailed district energy network analysis models*

Annelies Vandermeulen, Bram van der Heijde, Dieter Patteeuw, Dirk Vanhoudt, Lieve Helsen: *A theoretical benchmark for bypass controllers in a residential district heating network*

I. Andrić, J. Fournier, B. Lacarrière, O. Le Corre, P. Ferrão: *The impact of global warming and building renovation measures on district heating system techno-economic parameters*

Kerstin Sernhed, Kristina Lygnerud, Sven Werner: *Synthesis of recent Swedish district heating research*

Hanne Kauko, Karoline Husevåg Kvalsvik, Daniel Rohde, Natasa Nord, Åmund Utne: *Dynamic modeling of local district heating grids with prosumers: A case study for Norway*

Kristina Lygnerud, Sven Werner: *Risk assessment of industrial excess heat recovery in district heating systems*

Fabian Bühler, Stefan Petrović, Fridolin Müller Holm, Kenneth Karlsson, Brian Elmegaard: *Spatiotemporal and economic analysis of industrial excess heat as a resource for district heating*

Wiebke Meesenburg, Torben Ommen, Brian Elmegaard: *Dynamic exergoeconomic analysis of a heat pump system used for ancillary services in an integrated energy system*

Natasa Nord, Elise Kristine Løve Nielsen, Hanne Kauko, Tymofii Tereshchenko: *Challenges and potentials for low-temperature district heating implementation in Norway*

Yasameen Al-Ameen, Anton Ianakiev, Robert Evans: *Recycling construction and industrial landfill waste material for backfill in horizontal ground heat exchanger systems*

Jelena Ziemele, Einars Cilinskis, Dagnija Blumberga: *Pathway and restriction in district heating systems development towards 4th generation district heating*

Eftim Popovski, Tobias Fleiter, Hugo Santos, Vitor Leal, Eduardo Oliveira Fernandes: *Technical and economic feasibility of sustainable heating and cooling supply options in southern European municipalities-A case study for Matosinhos, Portugal*

B. Zühlsdorf, W. Meesenburg, T.S. Ommen, J.E. Thorsen, W.B. Markussen, B. Elmegaard: *Improving the performance of booster heat pumps using zeotropic mixtures*

Ieva Pakere, Dace Lauka, Dagnija Blumberga: *Solar power and heat production via photovoltaic thermal panels for district heating and industrial plant*

Ruta Vanaga, Andra Blumberga, Ritvars Freimanis, Toms Mols, Dagnija Blumberga: *Solar facade module for nearly zero energy building*

Gowri Suryanarayana, Jesus Lago, Davy Geysen, Piotr Aleksiejuk, Christian Johansson: *Thermal load forecasting in district heating networks using deep learning and advanced feature selection methods*

C. Marguerite, G.B. Andresen, M. Dahl: *Multi-criteria analysis of storages integration and operation solutions into the district heating network of Aarhus – A simulation case study*

Ina De Jaeger, Glenn Reynders, Yixiao Ma, Dirk Saelens: *Impact of building geometry description within district energy simulations*

M. Köfinger, R.R. Schmidt, D. Basciotti, O. Terreros, I. Baldvinsson, J. Mayrhofer, S. Moser, R. Tichler, H. Pauli: *Simulation based evaluation of large scale waste heat utilization in urban district heating networks: Optimized integration and operation of a seasonal storage*

Asad Ashfaq, Anton Ianakiev: *Investigation of hydraulic imbalance for converting existing boiler based buildings to low temperature district heating*

Søren Djørup, Jakob Zinck Thellufsen, Peter Sorknæs: *The electricity market in a renewable energy system*

Gerald Schweiger, Richard Heimrath, Basak Falay, Keith O'Donovan, Peter Nageler, Reinhard Pertschy, Georg Engel, Wolfgang Streicher, Ingo Leusbrock: *District energy systems: Modelling paradigms and general-purpose tools*

Henrik Lund, Neven Duic, Poul Alberg Østergaard, Brian Vad Mathiesen: *Future district heating systems and technologies: On the role of smart energy systems and 4th generation district heating*

Energy - The International Journal (Last update 27 February 2020) **Special issue on Smart Energy Systems and 4th Generation District Heating**

Selected papers from 4th International Conference on Smart Energy Systems and 4th Generation District Heating

Edited by Henrik Lund

Tobias Sommer, Stefan Mennel, Matthias Sulzer: *Lowering the pressure in district heating and cooling networks by alternating the connection of the expansion vessel*

Elisa Guelpa, Vittorio Verda: *Compact physical model for simulation of thermal networks*

Urban Persson, Eva Wiechers, Bernd Möller, Sven Werner: *Heat Roadmap Europe: Heat distribution costs*

C.H. Hansen, O. Gudmundsson, N. Detlefsen: *Cost efficiency of district heating for low energy buildings of the future*

Anna Volkova, Igor Krupenski, Henrik Pieper, Aleksandr Ledvanov, Eduard Latõšov, Andres Siirde: *Small low-temperature district heating network development prospects*

Sara Månsson, Per-Olof Johansson Kallioniemi, Marcus Thern, Tijs Van Oevelen, Kerstin Sernhed: *Faults in district heating customer installations and ways to approach them: Experiences from Swedish utilities*

Sonja Salo, Juha Jokisalo, Sanna Syri, Risto Kosonen: *Individual temperature control on demand response in a district heated office building in Finland*

Gašper Stegnar, D. Staničić, M. Česen, J. Čížman, S. Pestotnik, J. Prestor, A. Urbančič, S. Merše: *A framework for assessing the technical and economic potential of shallow geothermal energy in individual and district heating systems: A case study of Slovenia*

Souman Rudra, Yohannes Kifle Tesfagaber: *Future district heating plant integrated with municipal solid waste (MSW) gasification for hydrogen production*

Johannes Pelda, Stefan Holler: *Spatial distribution of the theoretical potential of waste heat from sewage: A statistical approach*

Elisa Guelpa, Ludovica Marincioni, Stefania Deputato, Martina Capone, Stefano Amelio, Enrico Pochettino, Vittorio Verda: *Demand side management in district heating networks: A real application*

Armands Gravelsins, Ieva Pakere, Anrijs Tukulis, Dagnija Blumberga: *Solar power in district heating. P2H flexibility concept*

Benedikt Leitner, Edmund Widl, Wolfgang Gawlik, René Hofmann: *A method for technical assessment of power-to-heat use cases to couple local district heating and electrical distribution grids*

Joseph Maria Jebamalai, Kurt Marlein, Jelle Laverge, Lieven Vandeveldel, Martijn van den Broek: *An automated GIS-based planning and design tool for district heating: Scenarios for a Dutch city*

Nicolas Lamaison, Simon Collette, Mathieu Vallée, Roland Bavière: *Storage influence in a combined biomass and power-to-heat district heating production plant*

Andra Blumberga, Ritvars Freimanis, Indra Muizniece, Kriss Spalvins, Dagnija Blumberga: *Trilemma of historic buildings: Smart district heating systems, bioeconomy and energy efficiency*

Nadine Aoun, Roland Bavière, Mathieu Vallée, Antoine Arousseau, Guillaume Sandou: *Modelling and flexible predictive control of buildings space-heating demand in district heating systems*

Britta Kleinertz, Götz Brühl, Serafin von Roon: *Heat dispatch centre – Symbiosis of heat generation units to reach cost efficient low emission heat supply*

Henrik Lund, Neven Duic, Poul Alberg Østergaard, Brian Vad Mathiesen: *Perspectives on Smart Energy Systems from the SES4DH 2018 conference*

O. Terreros, J. Spreitzhofer, D. Basciotti, R.R. Schmidt, T. Esterl, M. Pober, M. Kerschbaumer, M. Ziegler: *Electricity market options for heat pumps in rural district heating networks in Austria*

Energy - The International Journal (Last update 17 July 2020)
Special issue on Smart Energy Systems

Selected papers from 5th International Conference on Smart Energy Systems and 4th Generation District Heating

Edited by Henrik Lund

Hanmin Cai, Andreas Thingvad, Shi You, Mattia Marinelli: *Experimental evaluation of an integrated demand response program using electric heat boosters to provide multi-system services*

Zhikun Wang, Jenny Crawley, Francis G.N. Li, Robert Lowe: *Sizing of district heating systems based on smart meter data: Quantifying the aggregated domestic energy demand and demand diversity in the UK*

Paolo Leoni, Roman Geyer, Ralf-Roman Schmidt: *Developing innovative business models for reducing return temperatures in district heating systems: Approach and first results*

Francesco Neirrotti, Michel Noussan, Marco Simonetti: *Towards the electrification of buildings heating - Real heat pumps electricity mixes based on high resolution operational profiles*

Morten Herget Christensen, Rongling Li, Pierre Pinson: *Demand side management of heat in smart homes: Living-lab experiments*

Monica Arnaudo, Monika Topel, Björn Laumert: *Techno-economic analysis of demand side flexibility to enable the integration of distributed heat pumps within a Swedish neighborhood*

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