Book of Abstracts

10th International Conference on Smart Energy Systems

Lund, Henrik; Mathiesen, Brian Vad; Østergaard, Poul Alberg; Thellufsen, Jakob Zinck; Brodersen, Hans Jørgen

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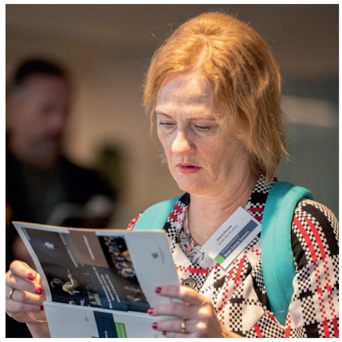



Book of Abstracts 2024

International Conference on Smart Energy Systems

10th Anniversary Edition

AALBORG UNIVERSITY

#SESAAU2024

energy CLUSTER DENMARK

10th International Conference on Smart Energy Systems
10-11 September 2024

Conference Booklet

Aalborg University
Department of Sustainability and Planning
Rendsburggade 14
DK - 9000 Aalborg

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Preface and welcome

It is a great pleasure to welcome you to **SESAAU2024 - the 10th anniversary edition of the International Conference on Smart Energy Systems**, which takes place in Aalborg on 10-11 September and with technical tours on 9 and 12 September 2024. The conference is organised by Aalborg University and Energy Cluster Denmark. We thank the sponsors for their contribution to this year's conference: Grundfos, Aalborg Forsyning, Kamstrup, Kingspan, CIP, COWI, Danfoss, Euroheat & Power, Gradyent, NORLYS Energy Trading, PlanEnergi, Ørsted, and Aalborg Portland.

We look forward to meeting participants from academia and industry from around the world in person. The conference this year is in Aalborg Kongres og Kultur Center in central Aalborg and the conference dinner venue is located next to the landmark Aalborg Tower.

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 6 to 13 September to all attendees, whether attending online or in person.

Like last year, the conference has a focus on the deployment of renewable energy and energy efficient technologies in the light of the unprovoked Russian attack on Ukraine. The series of events since the initial attack on 24 February 2022 have underlined that energy security must be a pivotal part of energy policy. A reliance on Russia for natural gas, oil, coal, and biomass supplies has demonstrated serious flaws in European energy policies, and the events unfolding have renewed a focus on self-reliance – amongst others, on locally deployed renewable energy technologies.

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 10th 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. Once again, we welcome more than 300 participants from 25 countries around the world – to a programme with seven strong keynote profiles and more than 200 session presentations as well as technical tours. The keynotes will focus on Smart Energy Systems and heat pumps as well as energy security in Europe in the light of the continuing logistical challenges and the war in Ukraine on the first day. On the second day, focus will be on the role of hydrogen in the green transition with insights from India, China and Germany.

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

Conference Chairs

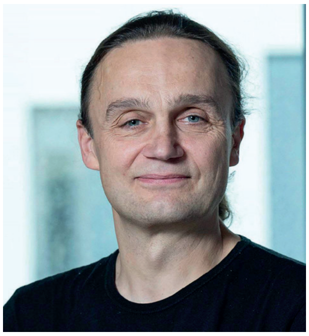
Henrik Lund, Professor in Energy Planning at Aalborg University, Denmark

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 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 15 years, Henrik Lund has been Editor-in-Chief of Elsevier's high-impact journal Energy with annual 15000+ submissions, and 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 electrolysers 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 (2015-2022), thus among the top 1% most cited researchers globally. In 2022 her 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 sEEnergies 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.

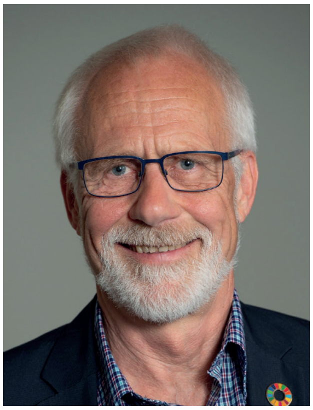


Poul Alberg Østergaard, Professor in Energy Planning at Aalborg University, Denmark

Poul Alberg Østergaard is Professor in Energy Planning at Aalborg University. He holds a PhD in "Integrated Resource Planning" (2000) and has more than 20 years of research and teaching experience within Energy Planning. His research competence includes analysis of energy systems with large-scale integration of fluctuating renewable energy sources; optimisation criteria of energy systems analyses, and sustainable energy scenarios for local areas. Poul A. Østergaard has led and been involved in multiple research projects focusing on renewable energy scenarios, integration of renewable energy sources into the energy system and framework conditions for renewable energy scenarios. He has contributed to more than 100 scientific journal articles in highly reputed journals in addition to reports and other non-peer reviewed work. 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, Poul A. Østergaard is the Head of Study Board of Planning and Land Surveying at Aalborg University as well as the Programme Director and a distinguished teacher 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 have 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 s one of the main developers on the energy system analysis tool EnergyPLAN and currently teaches the program at both bachelors and PhD level.



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.

10TH EDITION

International Conference on Smart Energy Systems

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

CALL FOR ABSTRACTS

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

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

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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

Conference fees

Early registration (for presenters with accepted abstracts):

- **375 EUR** (attendance in Aalborg)
- **275 EUR** (virtual attendance)

Normal fee:

- **475 EUR** (attendance in Aalborg)
- **375 EUR** (virtual attendance)
- Conference dinner (Aalborg): **110 EUR**

Aim and Organisers

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 (4GDH), electrification of heating and transport sectors, electrofuels and energy efficiency. This 10th edition of the conference cements it as a main venue for presentations and fruitful debates on subjects that are pertinent to the development and implementation of smart energy systems to fulfil national and international objectives. The conference is organised by Aalborg University and Energy Cluster Denmark.

Format

Again in 2024, we look forward to welcoming our participants to a hybrid conference with the possibility to attend either online or in person – this time at AKKC in central Aalborg. In Aalborg, you can attend the conference sessions in person, while the online conference platform enables you to attend the conference virtually. Via the platform you will have access to watch all 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 Aalborg.

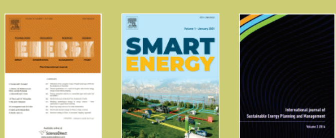
Important dates 2024

15 April	**Deadline abstract submission** (Upgrade to paper is optional)
25 April	**Reply on acceptance of abstracts**
25 April - 31 May	**Early registration**
1 June - 15 August	**Normal registration**
9 September	**Technical tour**
10 - 11 September	**Conference**
12 September	**Technical tour**

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 2024. 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 **15 April 2024.**



Submitted abstracts will be reviewed by a scientific and an industrial committee. Authors of approved abstracts may be invited to submit papers to special issues of Energy, Smart Energy and IJSEPM. Abstracts may be presented at the conference without uploading a full paper, as this is not a requirement.

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

International Scientific Committee

Prof. Abdul Ghani Olabi, University of Sharjah, UAE
Prof. Alexandros Flamos, University of Piraeus, GR
Prof. Anna Volkova, Tallinn University of Technology, EE
Prof. Anthony Patt, ETH Zürich, CH
Prof. Aoife Foley, University of Manchester, UK
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Dr. Ralf-Roman Schmidt, Austrian Institute of Technology, AT
Dr. Richard Büchele, Energieinstitut Vorarlberg, AT
Dr. Robin Wiltshire, Building Research Establishment, UK

International Industrial Committee

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Anders Dyrelund, Senior Market Manager at Rambøll, DK
Anders N. Andersen, Head of Dept. at EMD International, DK
Ard de Reus, Solution Consultant at Gradyent, NL
Carsten Østergaard Pedersen, BD Director at Grundfos, DK
David Kodz, Senior Product Manager at MAN Energy Solutions, CH
Dietrich Schmidt, Deputy Head of Department at Fraunhofer, DE
Dirk Vanhoudt, Senior Researcher at VITO, BE
Fabian Levihn, Head of R&D at Stockholm Exergi, SE
Gareth Jones, Managing Director at Fairheat, UK
Jan Eric Thorsen, Director, Danfoss DCS Global Applications, DK
Jesper Høstgaard-Jensen, CTO at Aalborg Forsyning, DK
Jesper Møller Larsen, Division Director, Verdo, DK
John Bøgild Hansen, Senior Advisor at Haldor Topsøe, DK
Martin Jakob, Executive Partner at TEP Energy, CH
Morten Abildgaard, CEO at Viborg Fjernvarme, DK
Morten Dalum, Norlys Energy Trading, DK
Morten Stobbe, CEO at VEKS, DK
Peter Jorsal, Product and Academy Manager at Kingspan, DK
Steen Schelle Jensen, Head of Business Dev. at Kamstrup, DK
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 Aalborg as well an overview of the recorded presentations which can be accessed via the online conference platform in the period 6-13 September 2024.

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 password sent to you on 6 September 2024.

Nominate your favourite candidate for the Best Presentation Awards
Remember to nominate your favourite presentation for the Best Presentation Awards which will be announced and awarded a prize at the plenary closing session. You nominate the candidates via the online conference platform.

HOW TO NAVIGATE THE ONLINE BOOK OF ABSTRACTS
- Open the Bookmark menu
- Under each topic, you will find the presenters of abstracts in alfabetical order
- Click the name and you will see the abstract

PROGRAMME AALBORG

TUESDAY 10 SEPTEMBER 2024

08:00-09:00	**Registration and breakfast**	**Main entrance**

Europahallen

09:00-11:00 **Plenary opening session**

09:00-09:10 **Professor Poul Alberg Østergaard and CEO Glenda Napier:** Opening speech

Plenary keynotes: Smart Energy Systems and Heat Pumps - chaired by Professor Poul Alberg Østergaard

09:10-09:30 **Professor Henrik Lund, Aalborg University, 10th anniversary keynote**: New insights into Smart Energy Systems: Theory, Concepts and Applications

09:30-09:45 **Raymond Decorvet, Senior Account Executive MAN Energy Solutions:** 21st Century - The age of the mega heat pumps

09:45-10:00 Questions and debate

Plenary keynotes: Energy security in Europe - chaired by Professor Brian Vad Mathiesen

10:00-10:20 **Assistant Professor Vera van Zoest, Swedish Defence University**: Energy security in Europe: Are we at risk?

10:20-10:40 **Research Fellow Francesco Sassi, Observatory of International Politics of the Italian Parliament and Ministry of Foreign Affairs and Cooperation**: The looming tensions between energy security and transition in the post EU-Russia energy order

10:40-11:00 Questions and debate

11:00-11:15	**Short break**

11:15-13:00 Parallel sessions 1-7

11:15-13:00 Room 1.10

Session 1: Smart energy systems analyses, tools and methodologies

Chaired by David Kodz

Session keynote Vittorio Verda: Integration of large-scale heat pumps in high temperature district heating systems

Maarten Blommaert: Balancing Centralized and Decentralized Heat Pump Solutions for Heating Networks Using Design Optimization

Martin Sollich: Integrating short-term storage in optimal heating network design to reduce back-up capacity and increase renewable heat supply

Umberto Tesio: Operation optimization of a Multi Energy System with a District Heating Network

Jinze Li: Optimization and techno-economic analysis of a hybrid renewable energy system for covering energy and water needs in remote island

Laura Kuper: Heating network topology design by price-collecting Steiner trees

11:15-13:00 Room 1.09

Session 2: Smart energy infrastructure and storage options

Chaired by Thomas Helmer Pedersen

Session keynote Richard van Leeuwen: Development and implementation of a Smart Energy System for local energy communities to improve sustainability and decrease electricity grid loads

Martin Hartvig: Pathway 2.0: Sector coupling is a driver for offshore shore hubs and spokes

Jes Donneborg: Energy on Demand - A Renewable Sector-Coupling Energy Park

Fabian Borst: Managing Complexity in Industrial Heating and Cooling Systems: A Local Energy Market Framework for Transactive Control with Technical Constraints

Hamza Abid: Techno-economic analysis of offshore energy hubs: Enabling Europe's energy transition

Kristina Haaskjold: Value of energy storages in ancillary and energy markets in the Norwegian low-carbon energy transition towards 2050

11:15-13:00 Room 1.08

Session 3: Integrated energy systems and smart grids

Chaired by Paula Ferreira

Session keynote Tijs Van Oevelen: Peak load reduction in a district heating network by means of demand response and supply temperature control: Evaluation of test results

Dabrel Prits: Demand side management (DSM) key performance indicators as a value driver for large scale DSM implementation in district heating networks

Faran Ahmed Qureshi: Comparing and evaluating different predictive control configurations in a district heating network – Simulation study

Costanza Saletti: Coordination of multi-energy prosumers with demand side management

Abdul Azzam: Development and Evaluation of a model predictive control strategy for an operational analysis in district energy systems

11:15-13:00 Room 1.07

Session 4: Institutional and organisational change for smart energy systems and radical technological change

Chaired by Gareth Jones

Session keynote Kristina Lygnerud: Increased district energy competitiveness through social sustainability

Bernhard Mayr: Introducing the concept of an integrated decision-making framework for sustainable heating (and cooling) technologies

Lucy Sherburn: Establishing Key Performance Indicators for heat networks for use within the UK's Heat Network Technical Assurance Scheme

Daniel Møller Sneum: Making district heating bankable: District heating as an asset class

Søren Djørup: A Framework for Heating Technology Characterisation and its Relevance to Energy Policy Design

Lisa Hjerrild: Experiences with economic compensation to neighbors of large-scale renewable energy farms

11:15-13:00 Room 1.03

Session 5: Energy savings in the electricity sector, buildings, transport and industry

Chaired by Lieve Helsen

Session keynote Cameron Downing: Comparison of the Thermal Experience & Controllability of Gas Boilers and Air Source Heat Pumps

Naomi Adam: Co-design of Thermal Systems in a Collective Low-Carbon District

Mazarine Roquet: Decarbonation of an Existing Building Asset Energy Supply: A Case Study on Low Temperature Thermal Network

Philipp Althaus: Intelligent control using flexible controller architecture for improved energy efficiency of room heating: Design and evaluation in a living lab

Wen Liu: The impacts of behavioral variables on heat demand in the built environment and on the economic consequences of energy efficiency measures investment

Vassilis Stavrakas: Advancing integrated and smart renovation packages for efficient, sustainable, and inclusive energy use: Modelling of real-life residential buildings

11:15-13:00 Room 1.02

Session 6: 4th generation district heating concepts, future district heating production and systems

Chaired by Tobias Schrag

Session keynote Lars Skytte Jørgensen: Advancing Sustainable Energy Solutions: Aalborg Forsyning's Strategic Green Transition Initiatives

Simon Müller: Modern benchmark of adaptive thermal source network at industrial site – The Incampus

Ulrich Trabert: Optimised Operation of Industrial Prosumers in District Heating Systems

Afraz Mehmood Chaudhry: A framework for optimizing prosumer-based thermal networks in urban communities: robust design approach with uncertain energy markets

Giulia Manco: Design optimization for solar thermal prosumers in district heating networks

11:15-13:00 Room 1.01

DHC+ Platform Special Session: Experiences and outlooks on digitalisation of district heating & cooling

Session keynote Matteo Pozzi: Fostering Digitalisation to enhance DHC Systems: progresses and perspectives by the DHC+ platform

Steen Schelle Jensen: Leveraging End-User Engagement for Enhanced District Heating Systems

Ard de Reus: Real-time dynamic pressure and temperature control of a District Cooling system

Luca Scapino: A Real-Case Study on Dynamic Operational Optimization of Thermal Energy Storage with an end-to-end Live Digital Twin

Open discussion with the audience and members of the DHC+ Digitalisation Working Group

13:00-14:15 Lunch and networking — Restaurant ground floor and 1st floor

14:15-15:45 Parallel sessions 8-14

14:15-15:45 Room 1.10

Session 8: 4th generation district heating concepts, future district heating production and systems

Chaired by Jan Eric Thorsen

Session keynote Anders Nielsen: Intelligent heat management and distribution are crucial in a district heating network

Orestis Angelidis : A Scottish Case Study: Can 5th Generation District Heating and Cooling Facilitate Holistic Decarbonisation in Clyde Gateway?

Tom Burton: Heat Network Optimisation Guidance: Standardising the approach to improving the performance of legacy systems

Aya Heggy: Decarbonising the UK's Heat Networks: A Framework for Archetype-Based Strategies and Case Study Analysis

Jelena Ziemele: Synergies between heat production, distribution, and consumption for decarbonizing strategy of urban district heating system

14:15-15:45 Room 1.09

Session 9: 4th generation district heating concepts, future district heating production and systems

Chaired by Richard van Leeuwen

Session keynote Brian Vad Mathiesen: Heat Roadmap Europe: Electrification versus low temperature district heating for heating buildings

Enric Gonzalez Gonzalo: Heat Roadmap Europe: Key findings across five EU countries comparing district heating options compared to EU27

David Kodz: Grid Stabilization with Mega Heat Pumps

Martina Capone: Enhancing District Heating Transition through the Integration of Groundwater Heat Pumps

Jake Adamson: Optimising thermal storage volume to reduce the electric peaking plant capacity

14:15-15:45 Room 1.08

Session 10: 4th generation district heating concepts, future district heating production and systems

Chaired by Anna Volkova

Session keynote Dagnija Blumberga: Multi-energy Hub Forwards to Decarbonisation

Nirav Patel: Optimizing District Heating Supply for Positive Energy Districts

Johan Dalgren: Circulation flows in District Heating Systems – A comparison between necessary, demanded and real flows

Carolin Ayasse: Heating System Optimization considering Technology, Temperature, and Retrofit Flexibility Model-endogenously

Mieczysław Dzierzgowski: Sustainable district heating in Łomża - on the road to decarbonisation

14:15-15:45 Room 1.07

Session 11: Integrated energy systems and smart grids

Chaired by Hans Jørgen Brodersen

Session keynote Nicholas Long: Ambient loop network and capacity expansion modeling case study in the USA and Austria

Nils Namockel: Wholesale electricity market modeling with distribution grid constraints

Nicolas Vasset: Optimal control for gas distribution networks with flexibility and biomethane injection targets

Christian Møller Jensen: Delay compensated peak shaving in district heating zones by automatic setpoint scheduling

14:15-15:45 Room 1.03

Session 12: Renewable energy sources and waste heat sources including PtX for district heating

Chaired by Ralf-Roman Schmidt

Session keynote Hanne Kauko: Electrolysis waste heat utilization towards district heating – a case study for Norway

Sina Dibos: Impact Analysis of Electrolyzer Waste Heat on Low Temperature District Heating and Cooling Networks

Leander Kimmer: Decarbonising district heating with hydrogen: A comparison of business and economic optimums

Anna Billerbeck: Increasing the spatial resolution of climate-neutral district heating supply in European energy system models

Dan Staunton: How large-scale ASHP deployed on DH networks can decarbonise challenging urban environments

14:15-15:45 Room 1.02

Session 13: Smart energy system analyses, tools and methodologies

Chaired by Steen Schelle

Session keynote Stefan Holler: Building Supply Temperature Cadastre (BSTC) for analysing low-temperature feasibility of residential buildings

Julia Eicke: Simplified representation of buildings in district heating network models – a data driven approach

Samanta Alena Weber: Feature Engineering for Machine Learning to predict heat networks on the end-user level

Amin Darbandi: Machine Learning for Prediction of Heat Demand and Applying Reinforcement Learning to Schedule Energy Hubs

Dominik Stecher: Data Set & Fault Signature Generation for District Heating with Generative and Transformative Neural Networks

14:15-15:45 Room 1.01

Session 14: Electrification of transport, heating and industry

Chaired by Iva Ridjan Skov

Session keynote Mirko Morini: Trends in smart energy in airports

Peiyao Guo: Equilibrium Analysis of Coupled Energy Sharing Community and Transportation Network: A Game-theoretic Approach

Lucas Verleyen: The battery – A blessing or a curse for Positive Energy Districts?

Wellington Alves: A Data-Driven Exploration of End-of-Life Scenarios for Lithium-ion Batteries in Electric Vehicles

Noémie Jeannin: Using electric vehicle as flexibility asset for photovoltaic electricity production: A geographical approach

15:45-16:15 Coffee break — 1st floor

16:15-17:45 Parallel sessions 15-21

16:15-17:45 Room 1.10

Session 15: 4th generation district heating concepts, future district heating production and systems

Chaired by Stefan Holler

Session keynote Jan Eric Thorsen : Aftercooling concept for 4th generation district heating substations

Carles Ribas Tugores: Enabling Return Temperature Reduction in Austrian District Heating System: Absorption Heat Exchanger Integration and Impact Analysis

Jens Møller Andersen: Comparison of direct and indirect district heating systems in Denmark

Michele Tunzi: Enhancing Temperature Optimization and Economy in a Danish District Heating Network through Domestic Hot Water Substation Renovation

Ana Catarina Marques: A district heating network with heat recovery from waste water treatment plant

16:15-17:45 Room 1.09

Session 16: Electrification of transport, heating and industry

Chaired by Vittorio Verda

Session keynote Oddgeir Gudmundsson: Economic comparison of hydronic based heating and multi-split A2A heat pumps – using a case study

Julian Hermann: A surrogate model for residential heat pump COP estimation in the context of energy system optimisations

Christopher Graf : Domestic Hot Water Systems in existing residential buildings: A Comparative Simulation Study on Efficiency and Hygiene Challenges

Antoine Laterre: Comparing Carnot batteries and chemical batteries for residential heat and electricity management: a prospective life-cycle assessment

16:15-17:45 Room 1.08

Session 17: Smart energy systems analyses, tools and methodologies

Chaired by Hironao Matsubara

Session keynote Paula Ferreira: Energy Demand Forecasting for Developing Economies in Sub-Saharan Africa

Andrew Lyden: Exploring sector-coupled flexibility in energy markets with locational pricing

Tuomas Vanhanen: Energy System Modeling of Sector Coupling in a Sustainable City: A Policy Scenarios Approach

Miguel Chang: Assessing operationally robust long-term capacity expansion plans – A model coupling approach

August Brækken: Integrated port energy systems for decarbonized maritime industry

16:15-17:45 Room 1.07

Session 18: GIS for energy systems, heat planning and district heating

Chaired by Steffen Nielsen

Session keynote Urban Persson: Data categories and selection criteria for an evaluation of the potential for solar district heating with pit thermal energy storage in Sweden

Stanislav Chicherin: Improving design of the 5th generation district heating and cooling systems (5GDHC) systems: a robust GIS-driven approach

Johannes Pelda: MEMHIS 2.0 - Spatial identification and evaluation of the temporal availability and economic assessment of waste heat sources

Abdulraheem Salaymeh: Assessing the Thermal Potential and Sustainable Water Withdrawal Rates from German Waterbodies for District Heating

Britta Kleinertz: Spatial prioritization of heat supply systems – experience from literature and practise combined in a practical guideline

16:15-17:45 Room 1.03

Session 19: Smart energy systems analyses, tools and methodologies

Chaired by Dirk Vanhoudt

Session keynote Gideon Mbiydzenyuy: Practical Considerations for Bi-directional Long Short-Term Memory Anomaly Detection in District Heating Networks

Dennis Lottis: Benchmarking optimization problem formulations for Model Predictive Control of District Heating systems with a Software-in-the-Loop approach

Chris Hermans: Gaussian Process Based Fault Detection in District Heating Substations

Edison Guevara Bastidas: Prioritisation of faults in district heating substations: towards predictive maintenance and optimised operation

Jonne van Dreven: Optimizing Fault Detection and Diagnosis in District Heating: The Impact of Data Source and Sampling Frequency

16:15-17:45 Room 1.02

Session 20: Smart energy systems analyses, tools and methodologies

Chaired by Ingo Leusbrock

Session keynote Ralf-Roman Schmidt: A techno-economic and investment risk analysis of ambient and waste heat supply technologies considering future uncertainty for a case study in Poland

Gerhard Totschnig: Optimal supply portfolio in a decarbonised district heating system - results of a model-based investigation for two case studies

Jonathan Riofrio: Towards Sustainable Energy Transition: Guidelines for Wind Energy Expansion and Power-to-X Integration in Small Island States

Ali Kök: Modelling Uncertainties in District Heating Supply Modelling

Mohammad Kiani Moghaddam: A double-layer many-objective stochastic optimization model to handle many uncertainties in the operation of smart energy systems

16:15-17:45 Room 1.01

Special session: IEA Annex 84

Chaired by Peter Sorknæs

Session keynote Anna Cadenbach: Novel Concepts and Technologies for Demand Side Management in Thermal Networks – A review of selected Case Studies

Anna Marszal-Pomianowska: Demand Response application – A survey with district heating professionals

Yangzhe Chen: Flexibility potential analysis with quantifiable KPI assessment for energy sector coupling leveraging advanced thermal storage solutions

Zeng Peng: Critical Review of Digital Infrastructures on the Interoperability between Buildings and 4th Generation District Heating System

17:45-18:45 Break

18:45 Joint walk to conference dinner venue. If you wish to join, we meet outside the main entrance to AKKC

19:30 Conference dinner at Skydepavillonen, Søndre Skovvej 30, 9000 Aalborg

PROGRAMME AALBORG WEDNESDAY 11 SEPTEMBER 2024

09:00-10:45 Parallel sessions 22-28

09:00-10:45 Room 1.10

Session 22: CCUS and PtX technologies and the production and use of electrofuels in future energy systems

Chaired by Marie Münster

Session keynote Thomas Helmer Pedersen: Direct Air capture cost reduction and market development via process intensification. Establishing the DAC insetting concept

Lars Schwarzer: Carbon management in a volatile energy system – DTI's research in flexible carbon capture, utilization, and storage

Alexandros Flamos: Bidirectional soft-linking of open-source energy models to evaluate the feasibility of transition pathways to carbon neutrality in the power sector

Jens Weibezahn: Fueling the Future: Optimizing Power-to-X Production in Renewable Energy Hubs through Flexible Operating Units

Lissy Langer: Conditions on electricity purchasing: More (emission reduction) bang for your buck?

Christine Brandstätt: Incentives for pipeline decomissioning and repurposing in regulated grids

09:00-10:45 Room 1.09

Session 23: Components and systems for district heating, energy efficiency, electrification and electrofuels

Chaired by Peter Jorsal

Session keynote Anna Volkova: Decarbonisation options of district heating peak loads

Poul Alberg Østergaard: District heating in Denmark – Dynamically reshaping the composition of heat supply

Maya Neyhousser: Adaptive Control for Decentralized Feed-in of Solar Heat into District Heating Networks Based on Reinforcement Learning

Johannes Nicolás Wildfeuer: Continuous commissioning of hot water installations using a digital twin

Sadia Ferdous Snigdha: AI based heat pump controller for power grid resilience enhancement

Simran Chaggar: Assessing the suitability of existing buildings to operate at lower temperatures via in field temperature lowering testing

09:00-10:45 Room 1.08

Session 24: Smart energy infrastructure and storage options

Chaired by Dietrich Schmidt

Session keynote Geoffroy Gauthier: Large Thermal Energy Storages (LTES) are a key element of the future energy system

Julio Vaillant Rebollar: Operational assessment of Large-Scale Ground Source Heat Pump and Borehole Thermal Energy Storage System

Ali Pour Ahmadiyan: Simulation and optimization of high temperature waste heat storage and recovery through a city scale borehole storage field

Dmitry Romanov: Techno-economic analysis of utilization of waste heat from a data center combined with a borehole thermal energy storage

Daniel Friedrich: Short Borehole Thermal Energy Storage cycles charged with otherwise curtailed wind energy

Henning Rahlf: Analysis of bidirectional EV charging infrastructures within industrial DC grids

09:00-10:45 Room 1.07

Session 25: 4th generation district heating concepts, future district heating production and systems

Chaired by Kristina Lygnerud

Session keynote Ieva Pakere: District heating resilience under high energy price shocks

Aadit Malla: Assessing the Economic Viability of Thermal Source Networks: The Role of Temperature Sensitivities

Nicolas Oliver Marx: Techno-Economic Feasibility of District and Individual Heating & Cooling Solutions – A Preliminary Assessment of Selected Case Studies

Denis Divkovic: Optimising heat planning: Cost effective refurbishment for enabling low carbon district heating

Luca Casamassima: Comparative study of LTDH distribution systems in urban heating: a cost-effectiveness and sustanaibility analysis

Nina Dungworth: Impact of technical assurance on reducing heat network capital cost by addressing oversizing in design

09:00-10:45 Room 1.03

Session 26: Planning and organisational challenges for smart energy systems and district heating

Chaired by Poul Thøis Madsen

Session keynote Andra Blumberga: Overcoming sociotechnical challenges: How to model the probability of investing in climate-friendly energy technologies

Bent Ole Gram Mortensen: Framework for Energy Data Spaces - Let's share energy data for a greener future

Alwina Kaiser: Bridging the Implementation Gaps: A Multi-Criteria Decision Support Approach for Enhancing Municipal Heat Supply and Social Acceptance

Adithya Ramachandran: Unveiling Consumer Behavior in District Heating Network: A Contrastive Learning Approach to Clustering

Nermina Abdurahmanovic: Enhancing Energy Efficiency through User Engagement and Behaviour Change: A review on gamification approaches and serious games in energy systems

Nina Kicherer: Three heat marketplaces for the cost-efficient integration of renewable heating plants into district heating systems

09:00-10:45 Room 1.02

Session 27: GIS for energy systems, heat planning and district heating

Chaired by Urban Persson

Franz Mauthner: Agent-based simulation of energy transition pathways in urban environments

Ruihong Chen: GIS-based landscape scenicness estimation using machine learning for visual impact assessment of wind projects deployment in Europe

Alexander Rehbogen: Spatial Energy Planning for Heat Transition - Steering Transition by Information

Eva Wiechers: German and Danish Case Studies undertaken on the Citiwatts platform replacing the Hotmaps platform

Annette Steingrube: The potential role of island heating networks in decarbonizing heating supply of districts. A case study for the district of Freiburg Waldsee

09:00-10:45 Room 1.01

Sino-Danish Special session: Harvesting waste heat sources and better understanding heat demands patterns for 4th generation district heating in China and in Denmark

Chaired by Allan Bertelsen

Siyue Guo: Waste heat recovery for urban heating in northern China

Zanyu Yang: Intermittent and Fluctuating Waste Heat Characteristics in Steel Plants: Recovery Optimization Study

John Tang Jensen: Heat source pricing - District Heating Networks

Lipeng Zhang: Insights from Danish Heating Metering and Billing: Implications for China's Clean Heating Development

Zhaoyang Liu: Aligning Heat Demand with Sources Based on Heat Intensity: A Heat Roadmap for China

Panel discussion and Q&A

10:45-11:15 Coffee break 1st floor

11:15-13:00 Parallel sessions 29-35

11:15-13:00 Room 1.10

Session 29: Smart energy system analyses, tools and methodologies

Chaired by Ard de Reus

Session keynote Daniel Rohde: Dynamic Energy System Optimization: A unique methodology for simultaneous sizing and optimal operation

Michael Frank: Algorithm-Supported Operation and Investment Planning of Decentralized Energy Infrastructure at Production Sites

Saltanat Kuntuarova: Operational Flexibility of Integrated Power and District Heating Systems: Modeling of Heat Flow Directions

Anas Algarei: Evaluating Tools for Integrating District Cooling into Wider Energy Models

Alena Lohrmann: Go with the flow: a new approach to levelized cost estimation to account for water use in power generation

11:15-13:00 Room 1.09

Session 30: CCUS and PtX technologies and the production and use of electrofuels in future energy systems

Chaired by Alexandros Flamos

Session keynote Anders Borup: Depending on your neighbor - Sector coupling challenges of the future

Marie Münster: Why do we see differences in results when modeling hydrogen in integrated energy systems?

Hossein Nami: Optimizing Regional Electrolysis Capacity

Henrik Wenzel: Local Energy Parks in Northern Fun

Meng Yuan: Beyond Borders: Alternative Renewable Energy Export Strategies

Leon Schumm: Offtaker regulation: Impacts on New Zealand hydrogen export ambitions

11:15-13:00 Room 1.08

Session 31: Smart energy systems analyses, tools and methodologies

Chaired by Graeme Maidment

Nora Yusma Mohamed Yusop: Optimal Decarbonisation Pathways for Malaysia's Energy System: Mapping a Long-Term Transition to Net Zero Emissions by 2050

Jan Stock: Construction of large district heating networks based on open-source data and demonstration of possible transformation measures

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

Ryoga Ono: The analysis of a woody biomass-to-X model based on high-resolution dataset by 1,741 municipalities in Japan

Henrique Lagoeiro: FAST DHC project: initial findings on the development of a decision support tool for the techno-economic evaluation of low-temperature DHC networks

11:15-13:00 Room 1.07

Session 32: Planning and organisational challenges for smart energy systems and district heating

Chaired by Bent Ole Gram Mortensen

Session keynote Hironao Matsubara: Challenges in Planning and Implementing Decarbonized Advanced Areas in Japan

Gianmarco Preso: Scenario analysis for efficient transition of a district heating network – Case study in Göttingen

Max Guddat: The Municipal Heat Planning Toolbox - Conceptual Approaches to Heat Planning, Based on Danish Practical Experience

Stine Bülow: Decision Making under Uncertainty in Coupled Multi-Energy Systems

Gareth Jones: Upcoming changes to heat network regulation in the UK – overview of the Heat Network Technical Assurance Scheme

11:15-13:00 Room 1.03

Session 33: Smart energy infrastructure and storage options

Chaired by Matteo Pozzi

Session keynote Martin Stroleny: Innovations in District Heating and Cooling: ground-breaking projects reshaping the DHC landscape

Dietrich Schmidt: Digitalization of district heating systems – Transforming heat networks for a sustainable future

William Delgado-Diaz: Hybrid seasonal heat storage systems using phase change materials: Economic and Environmental Optimization

Jonathan Hachez: Building load profile synthesis: a stochastic approach to model building energy consumption timeseries

Michael Bayer: Methodological Development of a Reduced-Order Data-Driven Model from Detailed Numerical Simulations for Seasonal Thermal Energy Storage (STES)

Sreenath Sukumaran: Enhancing the Sustainability of District Cooling Networks Through Integration of Snow Storage Systems: A Case Study of Tallinn, Estonia

11:15-13:00 Room 1.02

Session 34: 4th generation district heating concepts, future district heating production and systems

Chaired by Dagnija Blumberga

Session keynote Femke Janssen: Integrated Design and Operational Optimisation for District Heating Networks: Seasonal Subsurface Storage and Heat pumps

Kobus van Rooyen Integral Heating and Cooling Optimization; Design and Operation

Gerrid Brockmann: Economic and ecological investigation of a heating network in the suburban area Leeste in Germany

Michela Romagnosi: A modelling tool for dynamic simulations of a 5th generation district heating and cooling system applied to Italian case studies

Daniel Muschick: Implementation results from an optimization-based, predictive supervisory controller for a district heating network in Austria

Els van der Roest: Collective or individual heating solutions - the case of Utrecht (NL)

11:15-13:00 Room 1.01

Special session: IEA DHC Annex TS5 - Integration of Renewable Energy Sources into Existing District Heating and Cooling Systems

Chaired by Thomas Pauschinger

Session keynote Ingo Leusbrock: Transformation of large district heating and cooling systems to higher shares of renewable energy sources

Alice Dénarié: Decentral integration of renewables in existing district heating networks - results and lessons learned from IEA DHC Annex TS5

Mohammad Saeid Atabaki: A systematic approach to analyze methodologies for renewables-based district heating potential assessments – A categorization and literature review

Giulia Spirito: A GIS-based tool to optimally plan and operate renewables-based DH systems

Frederik Feike: Modeling heat loads and return temperatures of buildings connected to a district heating network using a neural network

Poul Thøis Madsen: The involvement of stakeholders when decarbonizing larger existing DHC plants. A guide for politicians, planners, and operators of DHC plants

13:00-14:00	**Lunch and networking**	**Restaurant ground floor and 1st floor**

Europahallen

14:00-15:45 **Plenary closing session**

Plenary keynotes: The role of hydrogen in the green transition - chaired by Professor Henrik Lund

14:00-14:20	**Professor Jyoti Parikh, Executive Director IRADe**: The Relevance of Hydrogen for India
14:20-14:40	**Professor Xiliang Zhang, Tsinghua University:** The role of hydrogen energy in achieving China's carbon neutral goal
14:40-15:00	**Professor Michael Sterner, OTH Regensburg**: The hydrogen and Power-to-X economy in Germany: Insights on generation, imports, backbones, storage and demands
15:00-15:20	Questions and debate
15:20-15:35	Best Presentation Award Ceremony by Professor Poul Alberg Østergaard
15:35-15:45	Closing by Professor Brian Vad Mathiesen and Hans Jørgen Brodersen, Senior Project Manager

PROGRAMME AALBORG - TECHNICAL TOURS

MONDAY 9 SEPTEMBER AND THURSDAY 12 SEPTEMBER 2024

Technical Tour: Power-to-X - Navigating the practical challenges in hydrogen and methanol production

Monday 9 September 2024
14:30 - 17:30

Facing climate change and the urgent demand for sustainable energy solutions, we stand on the brink of a green energy revolution. Power-to-X offers a path forward, yet with this new horizon come practical challenges that we cannot overlook. Among the most prominent are the production of hydrogen and methanol – key components in this transition. How do we navigate these challenges to unlock the potential of Power-to-X? Port of Aalborg and Aalborg University have set up a CCUS-Hub demonstration testsite for the whole PtX value chain. The demonstration site includes various necessary technical units from grid or RE production of high-voltage power supply, storage solutions, electrolyser production of H_2, CO_2 connections and supply, methanol production and more. The tour includes a presentation at the Port of Aalborg and a visit to the CCUS Hub.

More information at [conference website]

Technical Tour: Aalborg Portland cement factory goes for Carbon Capture solutions

Thursday 12 September 2024
8:30 - 11:30

Aalborg Portland is committed to reducing CO_2 emissions per ton of cement by 30% by 2030. At the factory, more visions and missions have resulted in an ambitious action plan with an innovative approach, and the target is to reach up to 73% in CO_2 reduction in total in 2030. One innovative approach to the reduction target is to set up a large demonstration and pilot carbon capture plant facility to the production emmisions. The tour includes a presentation on how the factory will capture 400,000 t of CO_2/year and a visit to the latest Carbon Capture installed unit at the factory.

More information at [conference website]

Smart energy systems analyses, tools and methodologies

Anas Algarei: Evaluating Tools for Integrating District Cooling into Wider Energy Models

Markus Auer: Optimising District Heating Substation Bypass Flow Control: a Practical Approach Combining Simulation- and Case-Study

Edison Guevara Bastidas: Prioritisation of faults in district heating substations: towards predictive maintenance and optimised operation

Maarten Blommaert: Balancing Centralized and Decentralized Heat Pump Solutions for Heating Networks Using Design Optimization

August Brækken: Integrated port energy systems for decarbonized maritime industry

Miguel Chang: Assessing operationally robust long-term capacity expansion plans – A model coupling approach

Amin Darbandi: Machine Learning for Prediction of Heat Demand and Applying Reinforcement Learning to Schedule Energy Hubs

Jonne van Dreven: Optimizing Fault Detection and Diagnosis in District Heating: The Impact of Data Source and Sampling Frequency

Julia Eicke: Simplified representation of buildings in district heating network models – a data driven approach

Paula Ferreira: Energy Demand Forecasting for Developing Economies in Sub-Saharan Africa

Aoife Foley: From Contentious to Consensus - Expert Consultation and Perspectives on the Net Zero Energy Transition Applied to Northern Ireland

Michael Frank: Algorithm-Supported Operation and Investment Planning of Decentralized Energy Infrastructure at Production Sites

Lilli Frison: Comparison of different transformer based neural network architectures for load forecasting in district heating networks under changing conditions

Chris Hermans: Gaussian Process Based Fault Detection in District Heating Substations

Stefan Holler: Building Supply Temperature Cadastre (BSTC) for analysing low-temperature feasibility of residential buildings

Laura Kuper: Heating network topology design by price-collecting Steiner trees

Saltanat Kuntuarova: Operational Flexibility of Integrated Power and District Heating Systems: Modeling of Heat Flow Directions

Ali Kök: Modelling Uncertainties in District Heating Supply Modelling

Henrique Lagoeiro: FAST DHC project: initial findings on the development of a decision support tool for the techno-economic evaluation of low-temperature DHC networks

Jinze Li: Optimization and techno-economic analysis of a hybrid renewable energy system for covering energy and water needs in remote island

Alena Lohrmann: Go with the flow: a new approach to levelized cost estimation to account for water use in power generation

Dennis Lottis: Benchmarking optimization problem formulations for Model Predictive Control of District Heating systems with a Software-in-the-Loop approach

Andrew Lyden: Exploring sector-coupled flexibility in energy markets with locational pricing

Gideon Mbiydzenyuy: Practical Considerations for Bi-directional Long Short-Term Memory Anomaly Detection in District Heating Networks

Mohammad Kiani Moghaddam: A double-layer many-objective stochastic optimization model to handle many uncertainties in the operation of smart energy systems

Ryoga Ono: The analysis of a woody biomass-to-X model based on high-resolution dataset by 1,741 municipalities in Japan

Marius Reich: Harnessing Machine Learning for Rapid Optimization: Integration of Time Series Data into Prior Approximation of Energy System Simulations

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

Jonathan Riofrio: Towards Sustainable Energy Transition: Guidelines for Wind Energy Expansion and Power-to-X Integration in Small Island States

Daniel Rohde: Dynamic Energy System Optimization: A unique methodology for simultaneous sizing and optimal operation

Ralf-Roman Schmidt: A techno-economic and investment risk analysis of ambient and waste heat supply technologies considering future uncertainty for a case study in Poland

Martin Sollich: Integrating short-term storage in optimal heating network design to reduce back-up capacity and increase renewable heat supply

Dominik Stecher: Data Set & Fault Signature Generation for District Heating with Generative and Transformative Neural Networks

Jan Stock: Construction of large district heating networks based on open-source data and demonstration of possible transformation measures

Umberto Tesio: Operation optimization of a Multi Energy System with a District Heating Network

Gerhard Totschnig: Optimal supply portfolio in a decarbonised district heating system - results of a model-based investigation for two case studies

Nora Yusma Mohamed Yusop: Optimal Decarbonisation Pathways for Malaysia's Energy System: Mapping a Long-Term Transition to Net Zero Emissions by 2050

Tuomas Vanhanen: Energy System Modeling of Sector Coupling in a Sustainable City: A Policy Scenarios Approach

Vittorio Verda: Integration of large-scale heat pumps in high temperature district heating systems

Volodymyr Voloshchuk: Digital twin-based smart heating system with a condensing boiler

Marie Therese Warnecke: Analysing and Monitoring Building Energy Efficiency via Web Scraping of Property Listings

Samanta Alena Weber: Feature Engineering for Machine Learning to predict heat networks on the end-user level

ONLINE PROGRAMME SESSION PRESENTATIONS - ACCESSIBLE FROM 6 TO 13 SEPTEMBER 2024

Planning and organisational challenges for smart energy systems and district heating

Nermina Abdurahmanovic: Enhancing Energy Efficiency through User Engagement and Behaviour Change: A review on gamification approaches and serious games in energy systems

Andra Blumberga: Overcoming sociotechnical challenges: How to model the probability of investing in climate-friendly energy technologies

Stine Bülow: Decision Making under Uncertainty in Coupled Multi-Energy Systems

Max Guddat: The Municipal Heat Planning Toolbox - Conceptual Approaches to Heat Planning, Based on Danish Practical Experience

Gareth Jones: Upcoming changes to heat network regulation in the UK – overview of the Heat Network Technical Assurance Scheme

Alwina Kaiser: Bridging the Implementation Gaps: A Multi-Criteria Decision Support Approach for Enhancing Municipal Heat Supply and Social Acceptance

Nina Kicherer: Three heat marketplaces for the cost-efficient integration of renewable heating plants into district heating systems

Hironao Matsubara: Challenges in Planning and Implementing Decarbonized Advanced Areas in Japan

Bent Ole Gram Mortensen: Framework for Energy Data Spaces - Let's share energy data for a greener future

Gianmarco Preso: Scenario analysis for efficient transition of a district heating network – Case study in Göttingen

Adithya Ramachandran: Unveiling Consumer Behavior in District Heating Network: A Contrastive Learning Approach to Clustering

Vedant Sinha: Industrial Load Flexibility in California: Challenges and Opportunities to Unlocking Cost And Carbon Savings

Smart energy infrastructure and storage options

Hamza Abid: Techno-economic analysis of offshore energy hubs: Enabling Europe's energy transition

Ali Pour Ahmadiyan: Simulation and optimization of high temperature waste heat storage and recovery through a city scale borehole storage field

Michael Bayer: Methodological Development of a Reduced-Order Data-Driven Model from Detailed Numerical Simulations for Seasonal Thermal Energy Storage (STES)

Fabian Borst: Managing Complexity in Industrial Heating and Cooling Systems: A Local Energy Market Framework for Transactive Control with Technical Constraints

William Delgado-Diaz: Hybrid seasonal heat storage systems using phase change materials: Economic and Environmental Optimization

Jes Donneborg: Energy on Demand - A Renewable Sector-Coupling Energy Park

Daniel Friedrich: Short Borehole Thermal Energy Storage cycles charged with otherwise curtailed wind energy

Geoffroy Gauthier: Large Thermal Energy Storages (LTES) are a key element of the future energy system

Jonathan Hachez: Building load profile synthesis: a stochastic approach to model building energy consumption timeseries

Martin Hartvig: Pathway 2.0: Sector coupling is a driver for offshore shore hubs and spokes

Kristina Haaskjold: Value of energy storages in ancillary and energy markets in the Norwegian low-carbon energy transition towards 2050

Richard van Leeuwen: Development and implementation of a Smart Energy System for local energy communities to improve sustainability and decrease electricity grid loads

Simon Nießen: Hydrogen as a key technology in modern energy systems

Henning Rahlf: Analysis of bidirectional EV charging infrastructures within industrial DC grids

Julio Vaillant Rebollar: Operational assessment of Large-Scale Ground Source Heat Pump and Borehole Thermal Energy Storage System

Dmitry Romanov: Techno-economic analysis of utilization of waste heat from a data center combined with a borehole thermal energy storage

Dietrich Schmidt: Digitalization of district heating systems – Transforming heat networks for a sustainable future

Martin Stroleny: Innovations in District Heating and Cooling: ground-breaking projects reshaping the DHC landscape

Sreenath Sukumaran: Enhancing the Sustainability of District Cooling Networks Through Integration of Snow Storage Systems: A Case Study of Tallinn, Estonia

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

Ruihong Chen: GIS-based landscape scenicness estimation using machine learning for visual impact assessment of wind projects deployment in Europe

Stanislav Chicherin: Improving design of the 5th generation district heating and cooling systems (5GDHC) systems: a robust GIS-driven approach

Britta Kleinertz: Spatial prioritization of heat supply systems – experience from literature and practise combined in a practical guideline

Franz Mauthner: Agent-based simulation of energy transition pathways in urban environments

Johannes Pelda: MEMHIS 2.0 - Spatial identification and evaluation of the temporal availability and economic assessment of waste heat sources

Urban Persson: Data categories and selection criteria for an evaluation of the potential for solar district heating with pit thermal energy storage in Sweden

Alexander Rehbogen: Spatial Energy Planning for Heat Transition - Steering Transition by Information

Abdulraheem Salaymeh: Assessing the Thermal Potential and Sustainable Water Withdrawal Rates from German Waterbodies for District Heating

Annette Steingrube: The potential role of island heating networks in decarbonizing heating supply of districts. A case study for the district of Freiburg Waldsee

Eva Wiechers: German and Danish Case Studies undertaken on the Citiwatts platform replacing the Hotmaps platform

ONLINE PROGRAMME SESSION PRESENTATIONS - ACCESSIBLE FROM 6 TO 13 SEPTEMBER 2024

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

Anders Borup: Depending on your neighbor - Sector coupling challenges of the future

Christine Brandstätt: Incentives for pipeline decomissioning and repurposing in regulated grids

Alexandros Flamos: Bidirectional soft-linking of open-source energy models to evaluate the feasibility of transition pathways to carbon neutrality in the power sector

Lissy Langer: Conditions on electricity purchasing: More (emission reduction) bang for your buck?

Marie Münster: Why do we see differences in results when modeling hydrogen in integrated energy systems?

Hossein Nami: Optimizing Regional Electrolysis Capacity

Anne Neumann: Regulatory framework for hydrogen hubs: Taking stock and looking ahead

Thomas Helmer Pedersen: Direct Air capture cost reduction and market development via process intensification. Establishing the DAC insetting concept

Kirill Resnikow: Modelling Electrolyser Systems – The research project BOOST

Leon Schumm: Offtaker regulation: Impacts on New Zealand hydrogen export ambitions

Lars Schwarzer: Carbon management in a volatile energy system – DTI's research in flexible carbon capture, utilization, and storage

Jens Weibezahn: Fueling the Future: Optimizing Power-to-X Production in Renewable Energy Hubs through Flexible Operating Units

Henrik Wenzel: Local Energy Parks in Northern Fun

Meng Yuan: Beyond Borders: Alternative Renewable Energy Export Strategies

Renewable energy sources and waste heat sources including PtX for DH

Anna Billerbeck: Increasing the spatial resolution of climate-neutral district heating supply in European energy system models

Sina Dibos: Impact Analysis of Electrolyzer Waste Heat on Low Temperature District Heating and Cooling Networks

Hanne Kauko: Electrolysis waste heat utilization towards district heating – a case study for Norway

Leander Kimmer: Decarbonising district heating with hydrogen: A comparison of business and economic optimums

Dan Staunton: How large-scale ASHP deployed on DH networks can decarbonise challenging urban environments

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

Søren Djørup: A Framework for Heating Technology Characterisation and its Relevance to Energy Policy Design

Lisa Hjerrild: Experiences with economic compensation to neighbors of large-scale renewable energy farms

Kristina Lygnerud: Increased district energy competitiveness through social sustainability

Bernhard Mayr: Introducing the concept of an integrated decision-making framework for sustainable heating (and cooling) technologies

Lucy Sherburn: Establishing Key Performance Indicators for heat networks for use within the UK's Heat Network Technical Assurance Scheme

Daniel Møller Sneum: Making district heating bankable: District heating as an asset class

Sino-Danish Special session: Harvesting waste heat sources and better understanding heat demands patterns for 4th generation district heating in China and in Denmark

Siyue Guo: Waste heat recovery for urban heating in northern China

Zanyu Yang: Intermittent and Fluctuating Waste Heat Characteristics in Steel Plants: Recovery Optimization Study

John Tang Jensen: Heat source pricing - District Heating Networks

Lipeng Zhang: Insights from Danish Heating Metering and Billing: Implications for China's Clean Heating Development

Zhaoyang Liu: Aligning Heat Demand with Sources Based on Heat Intensity: A Heat Roadmap for China

Special session: IEA DHC Annex TS5 - Integration of RES into existing DHC systems

Ingo Leusbrock: Transformation of large district heating and cooling systems to higher shares of renewable energy sources

Alice Dénarié: Decentral integration of renewables in existing district heating networks - results and lessons learned from IEA DHC Annex TS5

Mohammad Saeid Atabaki: A systematic approach to analyze methodologies for renewables-based district heating potential assessments – A categorization and literature review

Giulia Spirito: A GIS-based tool to optimally plan and operate renewables-based DH systems

Frederik Feike: Modeling heat loads and return temperatures of buildings connected to a district heating network using a neural network

Poul Thøis Madsen: The involvement of stakeholders when decarbonizing larger existing DHC plants. A guide for politicians, planners, and operators of DHC plants

ONLINE PROGRAMME SESSION PRESENTATIONS - ACCESSIBLE FROM 6 TO 13 SEPTEMBER 2024

Integrated energy systems and smart grids

Faraedoon Ahmed: The complementary role of interconnector and demand side unit in facilitating grid transition towards achieving 80% RES in the I-SEM system by 2030

Abdul Azzam: Development and Evaluation of a model predictive control strategy for an operational analysis in district energy systems

Christian Møller Jensen: Delay compensated peak shaving in district heating zones by automatic setpoint scheduling

Valentin Kaisermayer: A Distributed Demand Response Approach for Heating Networks

Nicholas Long: Ambient loop network and capacity expansion modeling case study in the USA and Austria

Nils Namockel: Wholesale electricity market modeling with distribution grid constraints

Nicola Cesare Di Nunzio: District cooling system: energy, economic and environmental analysis of a case study in Tunisia

Tijs Van Oevelen: Peak load reduction in a district heating network by means of demand response and supply temperature control: Evaluation of test results

Dabrel Prits: Demand side management (DSM) key performance indicators as a value driver for large scale DSM implementation in district heating networks

Faran Ahmed Qureshi: Comparing and evaluating different predictive control configurations in a district heating network – Simulation study

Costanza Saletti: Coordination of multi-energy prosumers with demand side management

Nicolas Vasset: Optimal control for gas distribution networks with flexibility and biomethane injection targets

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

Naomi Adam: Co-design of Thermal Systems in a Collective Low-Carbon District

Philipp Althaus: Intelligent control using flexible controller architecture for improved energy efficiency of room heating: Design and evaluation in a living lab

Cameron Downing: Comparison of the Thermal Experience & Controllability of Gas Boilers and Air Source Heat Pumps

Wen Liu: The impacts of behavioral variables on heat demand in the built environment and on the economic consequences of energy efficiency measures investment

Mazarine Roquet: Decarbonation of an Existing Building Asset Energy Supply: A Case Study on Low Temperature Thermal Network

Vassilis Stavrakas: Advancing integrated and smart renovation packages for efficient, sustainable, and inclusive energy use: Modelling of real-life residential buildings

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

Simran Chaggar: Assessing the suitability of existing buildings to operate at lower temperatures via in field temperature lowering testing

Maya Neyhousser: Adaptive Control for Decentralized Feed-in of Solar Heat into District Heating Networks Based on Reinforcement Learning

Sadia Ferdous Snigdha: AI based heat pump controller for power grid resilience enhancement

Anna Volkova: Decarbonisation options of district heating peak loads

Johannes Nicolás Wildfeuer: Continuous commissioning of hot water installations using a digital twin

Poul Alberg Østergaard: District heating in Denmark – Dynamically reshaping the composition of heat supply

Electrification of transport, heating and industry

Wellington Alves: A Data-Driven Exploration of End-of-Life Scenarios for Lithium-ion Batteries in Electric Vehicles

Christopher Graf : Domestic Hot Water Systems in existing residential buildings: A Comparative Simulation Study on Efficiency and Hygiene Challenges

Oddgeir Gudmundsson: Economic comparison of hydronic based heating and multi-split A2A heat pumps – using a case study

Peiyao Guo: Equilibrium Analysis of Coupled Energy Sharing Community and Transportation Network: A Game-theoretic Approach

Julian Hermann: A surrogate model for residential heat pump COP estimation in the context of energy system optimisations

Noémie Jeannin: Using electric vehicle as flexibility asset for photovoltaic electricity production: A geographical approach

Antoine Laterre: Comparing Carnot batteries and chemical batteries for residential heat and electricity management: a prospective life-cycle assessment

Mirko Morini: Trends in smart energy in airports

Lucas Verleyen: The battery – A blessing or a curse for Positive Energy Districts?

Special session: IEA Annex 84

Anna Cadenbach: Novel Concepts and Technologies for Demand Side Management in Thermal Networks – A review of selected Case Studies

Anna Marszal-Pomianowska: Demand Response application – A survey with district heating professionals

Yangzhe Chen: Flexibility potential analysis with quantifiable KPI assessment for energy sector coupling leveraging advanced thermal storage solutions

Zeng Peng: Critical Review of Digital Infrastructures on the Interoperability between Buildings and 4th Generation District Heating System

ONLINE PROGRAMME SESSION PRESENTATIONS - ACCESSIBLE FROM 6 TO 13 SEPTEMBER 2024

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

Jake Adamson: Optimising thermal storage volume to reduce the electric peaking plant capacity

Jens Møller Andersen: Comparison of direct and indirect district heating systems in Denmark

Orestis Angelidis : A Scottish Case Study: Can 5th Generation District Heating and Cooling Facilitate Holistic Decarbonisation in Clyde Gateway?

Carolin Ayasse: Heating System Optimization considering Technology, Temperature, and Retrofit Flexibility Model-endogenously

Dagnija Blumberga: Multi-energy Hub Forwards to Decarbonisation

Gerrid Brockmann: Economic and ecological investigation of a heating network in the suburban area Leeste in Germany

Tom Burton: Heat Network Optimisation Guidance: Standardising the approach to improving the performance of legacy systems

Martina Capone: Enhancing District Heating Transition through the Integration of Groundwater Heat Pumps

Luca Casamassima: Comparative study of LTDH distribution systems in urban heating: a cost-effectiveness and sustanaibility analysis

Afraz Mehmood Chaudhry: A framework for optimizing prosumer-based thermal networks in urban communities: robust design approach with uncertain energy markets

Johan Dalgren: Circulation flows in District Heating Systems – A comparison between necessary, demanded and real flows

Denis Divkovic: Optimising heat planning: Cost effective refurbishment for enabling low carbon district heating

Nina Dungworth: Impact of technical assurance on reducing heat network capital cost by addressing oversizing in design

Mieczysław Dzierzgowski: Sustainable district heating in Łomża - on the road to decarbonisation

Enric Gonzalez Gonzalo: Heat Roadmap Europe: Key findings across five EU countries comparing district heating options compared to EU27

Aya Heggy: Decarbonising the UK's Heat Networks: A Framework for Archetype-Based Strategies and Case Study Analysis

Mu Huang: Energy performance assessment of heat pump systems in three existing multi-family buildings in Europe based on field measurement

Femke Janssen: Integrated Design and Operational Optimisation for District Heating Networks: Seasonal Subsurface Storage and Heat pumps

Lars Skytte Jørgensen: Advancing Sustainable Energy Solutions: Aalborg Forsyning's Strategic Green Transition Initiatives

David Kodz: Grid Stabilization with Mega Heat Pumps

Aadit Malla: Assessing the Economic Viability of Thermal Source Networks: The Role of Temperature Sensitivities

Giulia Manco: Design optimization for solar thermal prosumers in district heating networks

Ana Catarina Marques: A district heating network with heat recovery from waste water treatment plant

Nicolas Oliver Marx: Techno-Economic Feasibility of District and Individual Heating & Cooling Solutions – A Preliminary Assessment of Selected Case Studies

Brian Vad Mathiesen: Heat Roadmap Europe: Electrification versus low temperature district heating for heating buildings

Daniel Muschick: Implementation results from an optimization-based, predictive supervisory controller for a district heating network in Austria

Simon Müller: Modern benchmark of adaptive thermal source network at industrial site – The Incampus

Anders Nielsen: Intelligent heat management and distribution are crucial in a district heating network

Ieva Pakere: District heating resilience under high energy price shocks

Nirav Patel: Optimizing District Heating Supply for Positive Energy Districts

Els van der Roest: Collective or individual heating solutions - the case of Utrecht (NL)

Michela Romagnosi: A modelling tool for dynamic simulations of a 5th generation district heating and cooling system applied to Italian case studies

Kobus van Rooyen: Integral Heating and Cooling Optimization; Design and Operation

Christina Rosan: How Can District-Wide Heat Pumps be used to meet Climate and Equity Goals in U.S. Cities? Translating Lessons from Europe

Jan Eric Thorsen : Aftercooling concept for 4th generation district heating substations

Ulrich Trabert: Optimised Operation of Industrial Prosumers in District Heating Systems

Carles Ribas Tugores: Enabling Return Temperature Reduction in Austrian District Heating System: Absorption Heat Exchanger Integration and Impact Analysis

Michele Tunzi: Enhancing Temperature Optimization and Economy in a Danish District Heating Network through Domestic Hot Water Substation Renovation

Jelena Ziemele: Synergies between heat production, distribution, and consumption for decarbonizing strategy of urban district heating system

Theda Zoschke: Survey of optimal dispatch methods of decentralised production units in district heating networks: A technical review

DHC+ Platform Special Session: Experiences and outlooks on digitalisation of district heating & cooling

Matteo Pozzi: Fostering Digitalisation to enhance DHC Systems: progresses and perspectives by the DHC+ platform

Steen Schelle Jensen: Leveraging End-User Engagement for Enhanced District Heating Systems

Ard de Reus: Real-time dynamic pressure and temperature control of a District Cooling system

Luca Scapino: A Real-Case Study on Dynamic Operational Optimization of Thermal Energy Storage with an end-to-end Live Digital Twin

Plenary Keynote Speakers

Professor Henrik Lund will give the 10th anniversary keynote speech New insights into Smart Energy Systems – Theory, Concepts and Applications

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 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 15 years, Henrik Lund has been Editor-in-Chief of Elsevier's high-impact journal Energy with annual 15000+ submissions, and 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.

Raymond Decorvet, Senior Account Executive, will give the keynote speech 21st Century – The age of the mega heat pumps

Raymond Decorvet oversees Global Business Development of Heat Pumps and Power Storage ETES at MAN Energy Solutions in Zurich. His role is integral to the company's dedication to advancing sustainable heating solutions and decarbonization strategies. Decorvet's knowledge in innovative technologies and his ability to foster networking and collaboration strongly supports MAN Energy Solutions' shift towards sustainable energy solutions. With his support, the company has embarked on pivotal projects in Esbjerg and Aalborg, Denmark. Here, the deployment of high-capacity sea water heat pumps marks a milestone in integrating the heat pump business into the company's decarbonization strategy; "Moving big things to zero." His prior experience in the computer industry, including various leadership roles at ABB's Data Center business, has enriched his broad skill set and strategic approach to business development. Decorvet possesses an academic background in general management and economics.

Dr Vera van Zoest will give the keynote speech Energy security in Europe: are we at risk?

Dr Vera van Zoest is assistant professor at the Swedish Defence University focusing on modelling and simulation of critical infrastructures. She has a background in spatio-temporal statistics, data analysis and machine learning, with interests in method development, energy crisis resilience and energy security. Currently, she leads the "Resilient Electricity Supply in Sweden: Towards a National Crisis Energy system" (RESISTANCE) project funded by the Swedish Energy Agency. This project focuses on energy system resilience through a socio-technical approach, by on the one hand modelling and simulation of vulnerabilities in the electricity network, and on the other hand, studying the behavior of people in times of an energy crisis. Her previous project, predicting the effects of the pandemic on electricity consumption patterns using a large dataset of smart energy meters, also funded by the Swedish Energy Agency, has been listed in IVA's 100-list 2023, highlighting projects which are deemed to have a high societal impact. She is affiliated researcher at Uppsala University and member of the interdisciplinary Uppsala Smart Energy Research (USER) group.

Research Fellow Francesco Sassi will give the keynote speech The looming tensions between energy security and transition in the post EU-Russia energy order

Francesco Sassi (Ph.D.) is a research fellow with the energy security unit of the Italian Parliament and the Italian Ministry of Foreign Affairs and International Cooperation. He holds a Ph.D. (with honour) in Geopolitics – Political Science at the University of Pisa. Francesco's research has been published in several international peer-reviewed journals and book chapters related to the study of energy geopolitics and the interactions between government actors and market-based ones in highly politicised contexts. His main analytical interests are energy geopolitics dynamics in Eurasia, China and Russia energy diplomacy and security strategies, the political and economic effects of the globalisation of the natural gas market, the state-market-companies nexus in the energy field and the power relationship in energy interdependencies. Also, Francesco is a consultant and research fellow at RIE – Ricerche Industriali ed Energetiche, where he works on the implications of energy security and diplomacy strategies on investment trends and global energy scenarios. He is also the coordinator of the energy geopolitics programme at RivistaEnergia.it, the online magazine of ENERGIA, the main Italian quarterly publication on energy policy and economy.

Professor Jyoti K. Parikh will give the keynote speech Relevance of Hydrogen for India

Professor, Dr Jyoti K. Parikh, Executive Director of Integrated Research and Action for Development (IRADe), was a member of the former Prime Minister's Council on Climate Change, India, and is a recipient of the Nobel Peace Prize awarded to IPCC authors in 2007. She has participated on global platforms such as the Global Commission on Adaptation set up by the UN Secretary-General, the advisory group "Friends of COP26, and the Global Agenda on Decarbonization of the Energy Sector of the World Economic Forum. Dr Parikh was invited as a Global Leadership Fellow by the School of Global Policy Studies of The University California, San Diego. She has served as an energy consultant to the World Bank, the US Department of Energy, the European Commission, and UN agencies such as UNIDO, FAO, UNU, and UNESCO, and as an environment consultant to UNDP, World Bank and UNEP. She has served in a number of international advisory panels and as an advisor to various ministries for the Government of India. She was in the Board of directors of the Indian Renewable Energy Development Agency Ltd (IREDA) 2001-2004 and the National Institute of Urban Affairs (NIUA). Dr Parikh is the author of more than 250 publications, including 28 books.

Professor Xiliang Zhang will give the keynote speech The role of hydrogen energy in achieving China's carbon neutral goal

Dr. Zhang Xiliang is a professor of management science and engineering and director of the Institute of Energy, Environment and Economy at Tsinghua University. Professor Zhang is a member of the National Experts Panel on Climate Change, the President of the China Carbon Emissions Trading Association, the Chair of the Energy Systems Engineering Committee of China Energy Research Society, and the Editor-in-Chief of Energy and Climate Management. He was granted the Leading Talent Award by the Ministry of Ecology and Environment and the First Award for Humanity and Social Science Research by the Ministry of Education in 2020. His current research interests include low-carbon energy economy transformation, climate change economics, and climate change policy design. Professor Zhang holds a PhD in Systems Engineering from Tsinghua University.

Professor Michael Sterner will give the keynote speech The hydrogen and Power-to-X economy in Germany: Insights on generation, imports, backbones, storage and demands

Michael Sterner is a Professor at OTH Regensburg in the fields of energy storage, hydrogen and energy system technology and head of the associated research centre. As one of the inventors of Power-to-Gas and Power-to-X, he develops energy concepts for companies and advises the German government and the EU Commission. He is a member of the National Hydrogen Council. In addition to numerous scientific publications, the engineer is editor of the standard work "Energiespeicher" (SpringerNature) and co-author of the Intergovernmental Panel on Climate Change (IPCC). He is also author of the Spiegel bestseller "How to save the climate" and has given over 1000 keynotes on the energy transition. His entire life has also been characterised by extraordinary voluntary work. The passionate musician and composer lives in Regensburg with his wife and three children.

Plenary Keynote: Henrik Lund

Professor at Aalborg University

New insights into Smart Energy Systems – Theory, Concepts and Applications

Abstract
This presentation includes new insights into the concept, theory, and application of smart energy systems. The concept was introduced in 2012 and shortly after received a scientific definition. As opposed to, for instance, the smart grid concept, which puts a sole focus on the electricity sector, smart energy systems include the entire energy system in its approach to identifying suitable pathways to the green transition.

Based on the 3rd edition of "Renewable Energy Systems", a theory of two smart energy systems hypotheses has been formulated. First, that one must take a holistic and cross-sectoral smart energy system's approach to be able to identify the best solutions for an affordable and reliable transition of the energy system into a carbon neutral society. Second, that subsector studies (no matter if they consider the role of a specific technology or the role of a region or country) should aim at identifying the role to play in the context of the overall system transition rather than aim at decarbonising the sub-sector on its own.

The concept and theory have been applied to the analysis of the need for energy storage and electricity balancing in a future climate-neutral society. In five Smart Energy System Integration Levels (SESIL), progressing from a sole electricity sector focus to a fully integrated system of electricity, heating, cooling, industry, transport, and materials, optimal investments in storage and resulting levels of curtailment are identified. It is illustrated how an overall least-cost solution is only identified in a fully integrated smart energy system, with affordable types of energy storage and little curtailment that cannot be found in a sole electricity sector approach.

Plenary Keynote: Raymond Decorvet

Senior Account Executive at MAN Energy Solutions in Zürich

21st Century – The age of the Mega heat pumps

Abstract

50% of global energy consumption is used for heating, heat & cold production. Most of this energy is still coming from fossil fuels. But in the light of the climate targets set for 2030 and beyond, most of the processes <200°C already could be decarbonized today. And the best and sustainable technology for this are heat pumps. The technology is available and ready. But large-scale Mega heat pumps will not only be important for the heat transition but also for the overall energy transition. Learn how we can take advantage of synergies among different market participants. How to balance and stabilize the power grid. And how to leverage power overcapacities and reduce the power consumption and cost. Which available other sources can we take advantage of?

Plenary Keynote: Vera van Zoest

Assistant Professor at Swedish Defence University

Energy security in Europe: are we at risk?

Abstract

We are facing several crises simultaneously: we have not yet seen the end of the effects of the pandemic, we are in the middle of a climate crisis and now we face an energy crisis because of the war in Ukraine, in turn leading to an economic crisis. The European energy system has a high resilience, but can be vulnerable when the four pillars of energy security collapse: availability, accessibility, acceptability, and affordability. The availability pillar may be at risk of collapsing when the war in Ukraine spreads further into Europe. During the war in Ukraine, we have seen that energy has become a prioritized war target to destabilize society. The accessibility pillar is at risk when electricity can no longer be transported, or when the system is out of balance. With climate change, the risk of natural hazards increases. Simultaneously, the increased use of smart devices increases the risk of cyber-attacks. Smart devices could, in the hands of a third party, be steered to bring the entire energy system out of balance for a short period of time. Finally, polarization in Europe may lead to instability in the last two pillars of energy security: acceptability and affordability. Already now, we see a strong polarization in many countries, which is further fed by the ongoing economic crisis. When polarization increases to a level where the European Union is scattered, countries may become egocentric and international agreements may not be met. This, in combination with decreased availability and accessibility, and an increased demand for electricity as a result of decarbonisation efforts, could lead to an increase in electricity prices. We can thus conclude that the four pillars of our resilient energy infrastructure are in need of guarding, through a strong Europe with tempered polarization, a strong cyber security including awareness amongst users of smart energy devices, a decreased dependency on large centralized power production, and local mapping of risks related to natural hazards, including predictions for climate change.

Plenary Keynote: Francesco Sassi

Research Fellow, Observatory of International Politics of the Italian Parliament and Ministry of Foreign Affairs and Cooperation

The looming tensions between energy security and transition in the post EU-Russia energy order

Abstract

In the post EU-Russia global energy order, tensions between energy security and transition are rising. This trend poses a tremendous challenge to the Net-Zero transition, as much as to the security of global energy systems. This is why we need, along with the discussion of energy security and transition, renew our approach and conceptualisation of the relevance of energy interdependencies in the understanding of today's global energy systems. Moreover, without understanding how energy interdependencies work, it won't be possible for Europe to advance its own interests in a fragmented and turbulent global economy and deeply globalised energy markets.

In fact, since the beginning of Russia's invasion of Ukraine, the EU-Russia energy interdependency has started to crumble. After decades of oil and natural gas trade, EU authorities have implemented a strategy to phase-out the dependency over imports from Russia. The two strategies have achieved different results and Russian gas flows still reach Europe and influence the internal market. As a security strategy, European authorities have therefore been looking to import massive amounts of LNG. This has also been done with the clear intent to slash the interdependency while stopping Moscow's invasion of Ukraine. However, results have been uncertain for European stakeholders, import dependency and the invasion of Ukraine. Moreover, the EU strategy had wider implications, way beyond the same energy markets and the EU borders. Energy security and transition policies in Asian countries such as China and India have been affected. Within the same context, the competition is also rising between China, the US and Europe in the manufacturing of green technologies with looming effects also for the politicisation of green interdependencies and critical raw materials, essential to foster the European energy transition. In this sense, we profoundly need to re-adapt the way we think about our security and transition strategies, considering the influence of energy interdependencies.

Acknowledging the relevance of the intended and unintended consequences of power dynamics, how they work and how power is fungible in energy interdependencies should become an essential component of every working smart energy system.

Plenary Keynote: Jyoti K. Parikh

Professor and Executive Director of Integrated Research and Action for Development (IRADe), New Delhi

Relevance of Hydrogen for India

Abstract
India has committed to reach net zero emissions by 2070 at the COP26 Glasgow meeting. Therefore, India is seriously examining the hydrogen options in 3 ways: A) The Government of India has committed itself by setting up a green hydrogen mission with a production target of 5 million tonnes (MT) by 2030, and 25 Mt by 2045, with an outlay of US$ 2.2 billion by 2030 as an incentive, to encourage the private sector to enter into various aspects of hydrogen supply and utilisation chain. The private sector, especially associated with petroleum and gas, is taking the benefit from these incentives and coming up with prototypes and pilot projects. B) In addition, the private sector is also active. Because their exports and competitiveness depend on how soon they can adopt green technologies. The EU has also thrown challenges to the exporters, especially to steel, aluminium, fertilisers, cement and power by announcing CBAM. This has increased their efforts. C) Moreover, the Department of Science and Technology (DST) has R&D programme that funds and has set up 3 Hydrogen Valley platforms so that various laboratories and the private sector can experiment with green and grey hydrogen and test their prototypes and possibly develop start-ups.
In addition to summarising the current effoerts, IRADe modelling work will be discussed. The Hydrogen option is a part of the IRADe model that covers the entire energy system of India with various supply technologies and end us sectors in the net zero pathway framework, observes that the green hydrogen would require substantial electricity generation capacity based on RE. This capacity is limited which is also shared by othee sectors, such as power sector, Electric Vehicle, DRE and hard-to-abate- industries
The talk will describe India's plans for the development of hydrogen and its priorities, private sector engagements and R&D efforts. It will also include observations from IRADe modeling work that gives breakeven price of Hydrogen that decides competition with other options in power and industries sectors.

Plenary Keynote: Xiliang Zhang

Professor and Director of the Institute of Energy, Environment and Economy, Tsinghua University

The role of hydrogen energy in achieving China's carbon neutral goal

Abstract
This presentation will firstly give an introduction to the current status of hydrogen production and use in China. The second part will provide an overview of China's energy system transformation toward carbon neutrality of which hydrogen energy development serves as an important element. Then it will present an outlook for the hydrogen production from renewable electricity and nuclear energy and the uses in transport, steel manufacturing, chemical production, and district heat and electricity generation. The presentation will also discuss the infrastructure and institutional barriers to the hydrogen production, transport, and uses in the context of China. The last part of the presentation will be on the policy interventions and institutional reforms needed to address those barriers.

Plenary Keynote: Michael Sterner

Professor at OTH Regensburg

The hydrogen and Power-to-X economy in Germany: Insights on generation, imports, backbones, storage and demands

Abstract
Germany is trying to ramp up the hydrogen economy by governmental support of research and industry. German ideas and concepts like Power-to-X and H2Global spread successfully around the world, but German perfectionism is hindering the transfer from research to application and thus climate and hydrogen goals can still fail. What can be generated inside the country, what needs to be imported, is there a hydrogen backbone soon, where is the first application and the highest demand at what efficiencies and can we still meet the goals? This is discussed on a scientific basis in this keynote.

Smart energy systems analyses, tools and methodologies

They are a PhD student at the University of Edinburgh specializing in sustainable energy systems and the role of district heating and cooling within them. They hold a master's degree in the field and have five years of experience in construction project management.

Evaluating Tools for Integrating District Cooling into Wider Energy Models

Anas Algarei, The University of Edinburgh

Anas Algarei (presenter) anas.algarei@gmail.com

Developing space heating and cooling systems is key to building climate-resilient, sustainable cities and ensuring comfort amid unpredictable temperature fluctuations due to seasonal changes and climate change. While district heating has traditionally received considerable attention, leading to the development of numerous modeling tools and frameworks, the increasing imperative for sustainable cooling solutions in the face of global warming and urbanization growth has spotlighted district cooling. As an energy-efficient alternative to conventional cooling methods, district cooling stands out for its potential in reducing energy consumption and carbon emissions. However, the exploration of district cooling, particularly through modeling and simulation, lags behind.

This research focuses on evaluating the capabilities of current modeling tools in integrating district cooling systems within the broader energy system. The assessment covers the following tools: EnergyPlus, EnergyPlan, EnergyPro, TRNSYS, URBANopt, nPro, tespy, pandapipes, and DisHeatLib. These tools vary in their approach to energy system modeling, from detailed building simulation to urban-scale energy planning. While these tools offer robust functionalities for modeling various aspects of energy systems, including district heating and electricity grids, their capabilities to integrate and optimize district cooling systems within a wider energy system framework are often limited or underdeveloped.

For instance, many of these tools lack the ability to accurately simulate the interactions between district cooling operations and renewable energy sources, or they may not provide detailed cost-benefit analyses for planning of district cooling under varying urban conditions. This gap not only hinders the optimization and widespread adoption of district cooling solutions but also limits the tools' effectiveness in supporting urban planners, engineers, and policymakers in making informed decisions regarding sustainable urban cooling strategies.

The research underscores the need for the development of advanced modeling frameworks that can accurately simulate district cooling systems, integrate them into the broader energy system, and evaluate their impact on overall energy consumption and carbon footprint.

Keywords: District Cooling, Energy System, Modelling

Markus Auer is a research associate at the Lucerne School of Engineering and Architecture in Switzerland. His research focuses on thermal grids including optimisation of existing district heating and design and control of future district heating and cooling systems.

Optimising District Heating Substation Bypass Flow Control: a Practical Approach Combining Simulation- and Case-Study

Markus Auer (1), Artem Sotnikov (1), Marco Belliardi (2), Vinicio Curti (2), Willy Villasmil (1)
(1) Institute of Building Technology and Energy, Lucerne University of Applied Sciences and Arts
(2) University of Applied Sciences and Arts of Southern Switzerland

Markus Auer (presenter) markus.auer@hslu.ch

Temperature reduction in existing high-temperature district heating grids (3rd generation DH, 3GDH) is a necessity to improve efficiency and enable integration of renewable energy sources. Elimination of excess bypass flow is a cost-effective solution for temperature reduction, supporting the transition from 3rd to 4th generation DH.
Thermal bypass valves are currently state of the art to maintain required temperature at customer substations, mainly in summer. However, a practical design and robust control strategy for bypass flow needs to be developed. Appropriate temperature setpoints and correct placement of temperature sensors are required. Current bypass control leads to unnecessary bypass flow, which increases return temperatures.
We have developed a method to quantify the impact of constant and thermal bypass valves on grid and consumers in terms of energy- and mass-flow. A practical applicable guideline shows how bypass valves can be controlled to minimise bypass flow while ensuring adequate supply temperatures.
The case study, an existing 3GDH wood grid in Switzerland was analysed using design grid data and 5-minute measured operational data. This grid type can be deemed representative of the nearly 800 wood DH grids out of a total of round 1'200 thermal grids in Switzerland. A thermo-hydraulic model of the DH grid including ground-coupled pipes and bypass valves was developed with Modelica and calibrated using measured data.
The case study has a total of seven thermal bypass valves at terminal substations set at 60 °C, resulting in high return temperatures during summer operation. The developed model allowed simulation of mass flows, temperatures, and heat losses, representing realistic grid conditions.
A controller was developed to optimise the performance of bypass valves as a function of pipe length, line density and temperature requirement, by regulating valve opening, pump speed and operation of heat generation units. The parametric study allowed the definition of bypass control setpoints for minimal supply temperature in respective grid strings . Guidelines were developed for practical application to other grids.

Keywords: District Heating, Thermal Grids, Third-Generation District Heating, Temperature Reduction, Bypass Valves, Control, Modelica, Dynamic Simulation, Modelling

Edison Guevara B. works as Research Associate in the department of Energy Informatics at the Fraunhofer Institute for Energy Economics and Energy System Technology. There he works on developing data-driven methods for anomaly detection and automatic fault detection with focus on heating systems.

Prioritisation of faults in district heating substations: towards predictive maintenance and optimised operation

Edison Guevara Bastidas, Fraunhofer Institute for Energy Economics and Energy System Technology - IEE;
Stefan Faulstich, Fraunhofer Institute for Energy Economics and Energy System Technology - IEE;
Holger Dittmer, Fraunhofer Institute for Energy Economics and Energy System Technology - IEE;
Gowtham Sakthivel Mohan, Fraunhofer Institute for Energy Economics and Energy System Technology - IEE;
Martin Neumayer, Institut für nachhaltige Energieversorgung GmbH - INEV;
Kibriye Sercan-Calismaz, German Heat and Power Association - AGFW;
Thilo Glenewinkel, Enercity Netz GmbH;
Karsten Fischer-Florschütz, YADOS GmbH;
Anna Marie Dagmar Cadenbach, Fraunhofer IEE

Edison Guevara Bastidas (presenter) edison.guevara@iee.fraunhofer.de

Effectively detecting and handling faults in district heating substations is vital to ensure the security of heat supply and improve system efficiency. However, utilities face challenges in efficiently operating and maintaining the growing number of substations due to limited monitoring and service personnel. The digitalisation of the demand side presents an opportunity to develop data-driven methods for automatic fault detection, offering scalability to utilities to serve multiple customers and optimise maintenance interventions. A variety of different faults can occur in substations, which can reflect differently on operational data. It is then necessary to prioritise faults to develop adequate detection methods and to support operators in their Operation and Maintenance (O&M) processes. Failure Modes and Effects Analysis (FMEA) is a widely used methodology to prioritise potential failures and their effects on the reliability of systems based on a Risk Priority Number (RPN). It is a useful methodology to identify design or process improvements to increase the reliability of the systems but misses aspects relevant to O&M. In this study, we propose an adaptation of the original FMEA for the prioritisation of faults with focus on O&M optimisation. The methodology uses a Maintenance Priority Number (MPN) for the ranking of faults, which adopts two factors of the FMEA's RPN: severity of fault and occurrence. Contrary to the FMEA's RPN, the third factor in the new MPN reflects the handling capability on the fault in terms of: the potential of the fault to be detected through monitoring and the capability to prevent or correct the fault through maintenance measures. Severe and frequent faults, which have a potential to be monitored and maintained yield the highest MPNs and should be in focus from an O&M perspective. The proposed methodology is demonstrated on district heating substations in cooperation with a German utility, a substation manufacturer and the German Heat and Power Association (AGFW). It identifies the relevant failure modes for developing automatic fault detection and diagnosis methods, which are the basis for utilities to implement predictive maintenance strategies and op-erations optimisation.

Keywords: district heating substations, predictive maintenance, operation optimisation, fault detection methods, monitoring, FMEA, prioritisation of faults

Prof. Maarten Blommaert is an assistant professor at KU Leuven's Mechanical Engineering department at Geel campus, and is associated with EnergyVille. His research group IDEAL investigates generative design techniques for the design optimisation of thermal energy components and heating networks.

Balancing Centralized and Decentralized Heat Pump Solutions for Heating Networks Using Design Optimization

Maarten Blommaert, KU Leuven, Belgium; Dries Peeters, KU Leuven, Belgium; Martin Sollich, KU Leuven, Belgium; Yannick Wack, KU Leuven, Belgium; Robbe Salenbien, Flemish Institute for Technological Research (VITO), Belgium; Martine Baelmans, KU Leuven, Belgium

Maarten Blommaert (presenter) maarten.blommaert@kuleuven.be

In recent years, much attention has been going to low-temperature and ultra-low temperature heating networks, because of their ability to maximally incorporate waste heat, limit energy losses, and service heating and cooling demands simultaneously. Nevertheless, they require more expensive heat pump substations and require bigger pipes and pumping power because of the low operational temperature drop. This in turn increases both investment (CAPEX) and operational (OPEX) costs of the network. The decision to invest in a heating network with a central or decentralized heat pump configuration, or possibly a combination of both, is therefore a complex design exercise that requires balancing different cost factors.

In this contribution, we adapted the recently developed PATHOPT code for nonlinear model-based topology optimization of heating networks to be able to automatically select standard or heat pump substations for each consumer in the optimal design of heating networks. Using this optimal design tool, we analyse the optimum designs for different source and demand temperatures. The physics-based model hereby allows assessing the feasibility of the proposed designs when exploring different operational temperatures and temperature drops within the network. First conclusions are drawn from the studied academic cases.

Keywords: District heating network design; nonlinear optimization; heat pump substation; low-temperature heating networks

August Brækken is a research scientist at SINTEF Energy Research. He has a master's degree in Energy and environmental engineering from the Norwegian University of Science and Technology (NTNU). He specialises in modelling of integrated energy systems and building performance simulation.

Integrated port energy systems for decarbonized maritime industry

August Brækken, SINTEF Energy Research; Erik Heggelund, SINTEF Energy Research; Line Rydså, SINTEF Energy Research; Hanne Kauko, SINTEF Energy Research

August Brækken (presenter) august.brakken@sintef.no

Shipping is considered one of the most environmentally efficient means to transport large volumes of goods and passengers. Norway has a clear goal to move goods transport from road to sea in the pursuit of reducing its greenhouse gas (GHG) emissions, with the aim of 50 % reduction by 2030. Domestic shipping accounts for around 10 % (4.3 million tons) of Norway's total GHG emissions, out of which approximately 1.2 million tons are generated in ports. Ports will play a crucial role in the decarbonization of the entire maritime industry, while they also serve as an important link between offshore and onshore energy systems.

Electrification of both the port activities and the ships that visit the ports is one of the primary measures to reach the decarbonization targets. However, electricity is becoming a scarce resource, and the power grid capacity is already limited in many areas of Norway. It is therefore of utmost importance to limit the use of electricity and consider other energy carriers when relevant, as well as to exploit the flexibility available from integration of different energy carriers and sectors.

This study evaluates two Norwegian industrial ports that are both working towards zero-emission operation, with emphasis on different energy carriers. Port A is a large cargo port, with significant expansion plans and ambitions for electrification of cranes and providing onshore power supply to all visiting ships. To accommodate the increased electricity demand, the port is planning to install large-scale PV production in combination with battery storage. Port B is a large offshore supply base, with future ambitions for large-scale production of hydrogen. Port B has an existing heating network it wishes to exploit to accommodate the port's heating demands, utilizing either surplus heat or a seawater heat pump. Surplus heat from the planned hydrogen production could also be used for land-based fish farming or desalination.

This study will perform techno-economic assessments of different energy system scenarios for both ports using the optimization tool Integrate. This will give valuable insights into how the

energy system in the two case ports, and ports in general, should be designed to achieve net zero emissions.

Keywords: Integrated energy systems, port energy systems, techno-economic modelling, maritime industry, sector coupling

Miguel works as a Research Scientist at the Department of Energy System Analysis, Institute for Energy Technology, Norway

Assessing operationally robust long-term capacity expansion plans – A model coupling approach

Miguel Chang, Institute for Energy Technology
Iva Ridjan Skov, Aalborg University
Pernille Seljom, Institute for Energy Technology
Ugur Halden, Institute for Energy Technology

Miguel Chang (presenter) miguel.chang@ife.no

Climate change poses significant planning challenges as the energy system grapples with weather fluctuations and reoccurring extreme weather events, while the system becomes increasingly dependent on variable renewable energy. Energy system models are used to assess how such systems could be optimally designed and inform planning decisions for the energy transition. However, the analysis with these models is often based on data for representative time periods or a specific weather year, and narrow focus of all sectors. Methodological trade-offs also emerge in terms of the planning perspective of said models. For instance, favoring a long-term perspective to investigate cost-optimal capacity expansion options for energy conversion, transmission and storage using coarse operational detail, or utilizing finer temporal detail to represent the hourly operations of the energy system for a snapshot year. Therefore, this study provides a methodology that links both perspectives to test the operational feasibility of long-term capacity expansion options and assess how resilient the resulting system design is to extreme weather conditions taking Norway as a case. To this end, two contrasting weather years are considered as inputs: one portraying a representative year, and an extreme case with a long period of unavailable variable renewable production. The IFE-TIMES-Norway model is used to identify cost-optimal capacities and demand options across all sectors for different scenarios, while considering different temporal resolutions. To supplement the analysis and test the system feasibility, the IFE-TIMES-Norway model is linked to hourly simulations of the system conducted using the EnergyPLAN tool. The proposed methodology and analysis can show the trade-offs in modelling approaches and provide insight into how resilient future energy system scenarios are, and the role of sector coupling in improving the resilience of the system.

Keywords: energy system modelling, model coupling, sector coupling, TIMES, EnergyPLAN

Amin Darbandi is an Associate Researcher at Hermann-Rietschel Institute in Technical University of Berlin. He is interested in data analysis and machine learning and seeks to leverage data to gain more meaningful and actionable insights in the energy sector.

Machine Learning for Prediction of Heat Demand and Applying Reinforcement Learning to Schedule Energy Hubs

1. *Amin Darbandi, Technical University of Berlin*
2. *Shixin Ni, Technical University of Berlin*
3. *Gerrid Brockmann, Technical University of Berlin*
4. *Karim Shawky, Technical University of Berlin*
5. *Martin Kriegel, Technical University of Berlin*

Amin Darbandi (presenter) a.darbandi@tu-berlin.de

Energy systems are experiencing substantial transitions to maintain an environmentally friendly yet economically feasible energy supply through renewable energy sources. However, demand fluctuations and uncertainties in renewable energy production increase the operational complexity of energy hubs.

To address these challenges, an Encoder-Decoder LSTM model is first developed to predict the heat demand, while minimizing dependencies on both auxiliary and predetermined features. A comprehensive study is conducted to compare the suggested method with several traditional models such as support vector machine (SVM), random forest regression (RFR), and extra gradient boosting regression (XGB). The results demonstrate that the Encoder-Decoder LSTM algorithm effectively captures the non-linearity in the heat load data with remarkable accuracy (~R2=97 %, compared to 88 % on average for other algorithms), while the mean absolute percentage error is less than 7.5 % (compared to 26 % on average).

Afterwards, the predicted demand is provided to a multi-objective energy management system (EMS) proposed in this work. The EMS is developed using a model-free Deep Reinforcement Learning (DRL) method, specifically Soft Actor-Critic (SAC). The DRL model employs a weighted cost function to incorporate not only the operation costs but also emitted emissions, allowing for the examination of trade-offs between different operating strategies. Subsequently, weight factors are adjusted to identify the operational Pareto space for managing energy hubs. The DRL model successfully identified energy dispatch strategies capable of reducing operational costs and emissions by up to 60 % without compromising on generated heat.

This work was funded by the German Federal Ministry for Economic affairs and Climate Protection (BMWK) under the funding code 03EN3062A.

Keywords: Machine Learning, Reinforcement Learning, Heat Demand Forecast, Heat Dispatch Scheduling, Energy Management System

Jonne van Dreven is 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.

Optimizing Fault Detection and Diagnosis in District Heating: The Impact of Data Source and Sampling Frequency

Jonne van Dreven, Blekinge Institute of Technology and VITO. Abbas Cheddad, Blekinge Institute of Technology. Sadi Alawadi, Blekinge Institute of Technology. Ahmad Nauman Ghazi, Blekinge Institute of Technology. Jad Al Koussa, VITO. Dirk Vanhoudt, VITO.

Jonne van Dreven (presenter) jonne.van.dreven@bth.se

The district heating (DH) field is undergoing a significant digital transformation, with an increasing focus on leveraging data-driven techniques, such as Machine Learning (ML), for enhanced operational efficiency and reliability. A critical aspect of this digitalization phase is adopting intelligent fault detection and diagnosis (FDD) systems designed to identify and diagnose faults promptly. However, the effectiveness of these FDD systems is heavily dependent on the availability and quality of data from DH substations. Therefore, it is crucial to understand the impact of different types of data and their collection frequencies on the accuracy of FDD models.

This study aims to systematically explore the implications of using only primary side data, combined primary and secondary side data, and combined ancillary information, primary and secondary side data on the performance of FDD models. We seek to determine the optimal data collection frequency to ensure high accuracy and reliability of FDD. This study uses labeled data from a generic DH substation emulation for five fault scenarios (minor/large valve leak, stuck valve, high heat curve, and deviating temperature sensor) and a typical operation scenario as a baseline. We develop and evaluate various ML models under three experimental conditions: (1) models trained on only primary side data, (2) models trained on both primary and secondary side data, and (3) models trained on ancillary information and primary and secondary side data. In each experiment, we assess the impact of data sampling rates, comparing frequencies up to 1-hour intervals.

Preliminary findings suggest that the frequency of data significantly impacts FDD performance. We anticipate that integrating secondary side or combined ancillary data will substantially elevate the accuracy of FDD models beyond those trained solely on primary side data.

This research underscores the importance of strategic data collection and utilization in developing effective FDD systems for DH networks. By identifying the optimal types and frequencies of data for FDD, the study contributes to the broader goal of digitalization and automatic FDD in the DH sector, offering a roadmap for enhancing operational efficiency and reliability using data-driven approaches.

Keywords: Data Collection, Digitalization, District Heating, Fault Detection and Diagnosis, Machine Learning

After graduating in mechanical engineering, Julia started her PhD at the Institute for Technical Thermodynamics at the Technical University of Darmstadt. Her research focuses on physical modelling of district heating networks. Her goal is to contribute to the decarbonisation of the heating sector.

Simplified representation of buildings in district heating network models – a data driven approach

Julia Eicke, Frank Dammel, Peter Stephan; Technical University of Darmstadt

Julia Eicke (presenter) eicke@ttd.tu-darmstadt.de

District heating plays a crucial role in supplying heat to buildings while ensuring efficient energy use, as it can combine heat from different sources. So far, the full potential of district heating networks (DHNs) is not exploited due to high network temperatures and inflexible operational strategies. Modeling of DHNs can help to understand the influence of operational parameters and to evaluate operational strategies. For this, it is important that the models map realistic system behavior. At the same time, a low level of complexity is desirable so that the modeling effort and required computation time are appropriate in relation to the scope of the research.

One of the main factors influencing the network parameters is the interaction between the connected buildings and the network via substations. Substations, which act as intermediaries between the primary (network) and secondary (building) sides, add complexity to the modeling effort, since substation characteristics, such as heat transfer area and material resistance, must be considered, as well as the operation of the secondary side. As a result, it is difficult to build DHN models that represent the network parameters without modeling buildings individually, including specific substation characteristics. In addition, secondary side measurement data is not always available.

In our work, we apply a data-driven approach to identify similarities and differences among the network-building interactions within our university's DHN. The network topology includes a classical linear network as well as a loop and is fed by different heat sources at several locations. Thus, there are various options and possibilities to analyze the operational parameters and network parameters in different contexts. The investigations in this work are based on primary side measurement data to avoid dependence on secondary side data. By grouping buildings based on their network interaction characteristics, including demand and temperature profiles, it provides insights for simplifying building models and reducing the number of necessary representations within network simulations. This can help to design lean network models that still represent real-world dynamics.

Keywords: district heating, model simplification, grouping of buildings, network-building interaction

Associate Professor at the School of Engineering, University of Minho and Researcher at ALGORITMI Research Centre (Portugal). Her research interests are in energy economics, energy planning and just energy transition.

Energy Demand Forecasting for Developing Economies in Sub-Saharan Africa

Budareld Mbuma, Algoritmi Research Center/LASI, University of Minho, Portugal, Géremi Gilson Dranka, Department of Electrical Engineering, Federal Technological University of Paraná (UTFPR), Pato Branco, Brazil, Paula Ferreira, Algoritmi Research Center/LASI, University of Minho, Portugal

Paula Ferreira (presenter) paulaf@dps.uminho.pt

In Sub-Saharan Africa, millions lack access to reliable electricity, hindering socio-economic progress. Addressing this challenge requires effective power generation expansion planning to bridge this electricity access gap and narrow the socioeconomic disparities in the region. Nonetheless, a challenge remains since traditional demand forecasts often overlook "suppressed demand" for power planning. Suppressed demand refers to unmet or latent demand for electricity that arises from the incapability to meet minimum service levels due to various constraints, such as lack of infrastructure and poverty. In other words, the lack of electricity infrastructure, for instance, stops consumers from performing a series of activities, including income-generating ones, which translates into higher disposable income and further electricity consumption at a household level.
This paper focuses on Angola, a Sub-Saharan country that is undergoing a process of modernization of production capacity and transmission networks. Additionally, there is a large electricity access gap between the rural and the urban populations, which encompass 20.3% and 60.1% of population access to electricity, respectively. A bottom-up approach will be employed to forecast demand in association with available household-level data and recognizing that future energy demand in developing countries is highly dependent on the economic and social contexts and subject to large uncertainties. Therefore, scenarios for linear demand projections across consumer segments will be defined, integrating national and regional plans to estimate market penetration rates of domestic appliances (household demand), industrial and services growth rates (industrial demand), and social economy (e.g. schools and health units demand) along with climate projections. Future electricity demand will be forecasted based on socio-economic development, demographics, and minimum service level requirements, then disaggregated by sector. These findings will directly inform the development and analysis of energy plans for Angola, ultimately promoting sustainable electrification of the country.

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Keywords: Electricity demand, Developing countries; Socioeconomic context

Professor Aoife M. Foley is the Chair in Net Zero Infrastructure | School of Engineering, The University of Manchester, UK. She is Managing Executive Editor in Chief, Renewable & Sustainable Energy Reviews, and Editorial Board of Nature Scientific Reports - Mechanical Engineering

From Contentious to Consensus - Expert Consultation and Perspectives on the Net Zero Energy Transition Applied to Northern Ireland

Ché Cameron, School of Mechanical and Aerospace Engineering, Queen's University Belfast, Belfast, United Kingdom, Faraedoon Ahmed, School of Engineering, University of Manchester, Manchester, United Kingdom, Dlzar Al Kez, School of Engineering, University of Manchester, Manchester, United Kingdom, Barry Johnston, School of Mechanical and Aerospace Engineering, Queen's University Belfast, Belfast, United Kingdom, Alastair Brown, School of Mechanical and Aerospace Engineering, Queen's University Belfast, Belfast, United Kingdom, Harrison Hampton, School of Mechanical and Aerospace Engineering, Queen's University Belfast, Belfast, United Kingdom, Christopher Lowans, School of Mechanical and Aerospace Engineering, Queen's University Belfast, Belfast, United Kingdom, Dylan Furszyfera, School of Mechanical and Aerospace Engineering, Queen's University Belfast, Belfast, United Kingdom, and Aoife Foley, School of Engineering, University of Manchester, Manchester, United Kingdom.

Prof. Aoife Foley (presenter)

This study examines key considerations of the net zero energy transition and identifies policy dilemmas using an evidence base gathered by a modified Delphi study. Contentious issues are identified through divergent opinions, but consensus subset groups are discovered through agglomerative clustering. The extracted groups are examined along sectoral and industry lines, and their internal consensus presents a new approach to building societal agreement for decarbonisation by structuring productive debate between groups instead of individuals. The study consists of one remote survey completed by 29 participants, followed by an in-person sandpit discussion event with 32 attendees. Northern Ireland's energy system decarbonisation strategy is developed by the Department for the Economy using a scenario-based approach. The policy-makers apply five policy lenses of decarbonisation, equity, security, macroeconomic benefit, and efficiency. Regional planners across government departments use sectoral strategies to drive the heat, power, and transport sectors to net zero by 2050. The study results are accommodated in the real-world policy dimensions, the planners' three sectoral boundaries, and contextualised as technology readiness levels (TRLs) and societal readiness levels (SRLs). The findings show that expert opinions rank environment as the top priority in the energy trilemma and prioritise spreading net zero transition costs fairly. Investigation of power sector decarbonisation found that the most favoured action of large-scale renewable installation is at odds with the current UK government policy, which effectively prohibits new on-shore wind deployment. For the heat sector, improved insulation is the top priority; and in the transport sector, electrification is favoured over hydrogen.

Keywords: Net Zero; Policy; Delphi study; Consensus; TRL; SRL

Michael Frank, M.Sc., born in 1997, studied mechanical engineering at the Technical University of Darmstadt. He has been working as a research assistant at the Institute of Production Management, Technology and Machine Tools at TU Darmstadt since 2022.

Algorithm-Supported Operation and Investment Planning of Decentralized Energy Infrastructure at Production Sites

Michael Frank, Fabian Borst, Lukas Theisinger, Matthias Weigold, Technical University of Darmstadt Institute for Production Management, Technology and Machine Tools

Michael Frank (presenter) m.frank@ptw.tu-darmstadt.de

The industrial sector accounts for 25 % of the German GDP and 28 % of the total final energy consumption. Therefore, this sector is environmentally and economically meaningful. With a share of only 6.3 % of renewables in final energy production (in 2022, industrial sector), the environmental necessity for transformation measures in the energy infrastructure is high. To stay globally competitive, energy productivity of related production processes must be maintained. This results in highly complex planning tasks, which require algorithm-supported approaches.

In this article, we argue that investments in decentralized energy infrastructure (DEI) at production sites offer great potential for the transformation of the German industrial sector towards reduced greenhouse gas emissions. Furthermore, they inherently mitigate problems of transformation approaches solely focused on the central energy infrastructure (CEI) of production sites.

Concretely, due to the proximity of DEI to production processes no adaptions to existing CEI are necessary. Therefore, offering less intrusive and generally easier to apply transformation measures. Second, decentralization leads to a distributed energy system, characterized by higher resilience. Third, close to process located transformation measures allow the combined optimization of energy and product flows, resulting in higher energy productivity.

Our findings are based on experiments with a MINLP formulation of a representative, multi-sector energy system of a production site. We combine the mathematical programming approach with a detailed simulation of discrete and continuous production processes. This allows us to evaluate decentral transformation measures on a process level, therefore maxing out the energy efficiency potential, and develop heuristic solution approaches to incorporate domain knowledge in the solving process. To plausibilize our optimization outcome we generate Pareto frontiers for different constraint configurations.

The energy system is modelled in oemof. As a solver, Gurobi 11 is used. The capability to solve non-linear, non-convex problems to global optimality is investigated by comparison with linearization approaches. For the simulation of the production processes the modelling language Modelica is used.

Keywords: simulation, mathematical programming, MINLP, dispatch and investment planning, decentralization, production sites, multi-sector, energy productivity

Dr. Lilli Frison leads the 'Cognitive Buildings' team at the Fraunhofer ISE focusing on applying AI to enhance the energy efficiency of buildings. Her academic background includes studies in computer science and mathematics in Paderborn, London, Lausanne, and a PhD from the University of Heidelberg.

Comparison of different transformer based neural network architectures for load forecasting in district heating networks under changing conditions

Lilli Frison, Fraunhofer Institute for Solar Energy Systems ISE, Fabian Höldin, Fraunhofer Institute for Solar Energy Systems ISE, Simon Gölzhäuser, Fraunhofer Institute for Solar Energy Systems ISE, Christian Wolff, Fraunhofer Institute for Solar Energy Systems ISE, Axel Oliva, Fraunhofer Institute for Solar Energy Systems ISE

Lilli Frison (presenter) lilli.frison@ise.fraunhofer.de

As district heating networks become increasingly complex, smart control of these networks is essential for efficient operation under the influence of varying boundary conditions such as weather, user behavior, energy availability, and power grid requirements. Accurate heat generation control based on forecasted demand is critical for enhancing energy efficiency, allowing operators to manage their energy production and distribution more effectively. To achieve this, precise information about forecasted demand, including uncertainty estimates, is essential for robust predictive and optimal control algorithms. Transformer neural networks have recently gained prominence for their superior capacity to handle sequential data and capture long-range dependencies, which is crucial for forecasting tasks in dynamic systems like district heating networks.

In this contribution, we rigorously evaluate a spectrum of Transformer-based neural network architectures, ranging from state-of-the-art models from the literature such as the Temporal Fusion Transformer to light-weight custom-designed Transformer structures, assessing their predictive performance for heat demand forecasting. Our analysis is particularly concentrated on the applicability of these models in a real-world district heating network scenario, which is subject to limited data availability ongoing changes, for instance, the integration of additional heat consumers during the expansion of the network and the change in heat demand during the renovation of buildings. Therefore, we evaluate networks on their ability to adapt to new data quickly. A final critical requirement is to supply the network operator and control algorithm with accurate uncertainty estimates regarding the forecasted demand. Providing a clear description of the confidence intervals for these predictions is crucial. We will elaborate on this aspect in detail. The evaluation is conducted in the Weil am Rhein heating network serving currently around 70 buildings, with the intention to integrate a robust model predictive control algorithm. The network's irregular demand and scarce high-quality data highlight the challenge of achieving precise forecasting with existing methods, motivating the need for novel, robust techniques.

Keywords: District heating networks, smart control, demand forecasting, artificial neural networks, artificial intelligence

Dr. Chris Hermans is a senior researcher in the Algorithms, Modeling and Optimization (AMO) team at VITO. The majority of his research is situated in the space of machine learning and optimization, with a particular focus on time series forecasting and optimal control.

Gaussian Process Based Fault Detection in District Heating Substations

Chris Hermans, Jad Al Koussa, Tijs Van Oevelen, Dirk Vanhoudt @ VITO/EnergyVille

Chris Hermans (presenter)

Recent years have seen an increased interest in fault detection for district heating customer installations, which consist of the substation and the secondary side downstream the substation (space heating and domestic hot water). At the same time, as more customer data have become available, it is now possible to use advanced fault detection and diagnosis algorithms to detect anomalies in these installations. Faulty or sub-optimal substations result in an increase in the district heating return temperature and in the volume flow in the network, and as such in a decrease of the efficiency of the DH network on the production, distribution and the consumption sides. In this work, we have developed a novel data-driven fault detection method that automatically detects anomalies in district heating substations, based on the data from a single substation's energy meter. Our method employs an ensemble of stochastic models, trained on a fixed amount of data at different points in time. These stochastic models are hybrid models, consisting of a black-box deterministic model, combined with a superimposed Gaussian process to model the uncertainty and thus establish confidence intervals. By comparing the predictions of the models to the observed measurements at the substation, we can detect anomalies indicative of a fault. Quantifying the uncertainty through the use of a Gaussian process has several advantages over the more common modelling of the error as a one-dimensional Gaussian distribution, which is a common implicit assumption in literature. As such it is possible to combine the traditional interpretability of a Gaussian distribution on a per point basis with detecting recurring patterns in the error distribution, such as seasonality or other trends. Our approach has been tested on multiple sources of data, including labeled datasets from the lab, and unlabeled or only partially labeled data from the a real DH network. This method could be applied to a large number of substations as it does not require knowledge about the building and its usage, and it does not require the use of extra sensors which could be intrusive in many cases. During the conference, the method will be explained and the testing and validation will be presented and discussed.

Keywords: Decarbonization; optimization; fault detection; analytics; district heating substations; Gaussian processes

Stefan Holler is a professor in energy and environmental technology. He teaches energy technology and energy management. His research areas include DHC and RES with a focus on system transformation. He has a long experience in managing national and international research projects.

Building Supply Temperature Cadastre (BSTC) for analysing low-temperature feasibility of residential buildings

Stefan Holler, HAWK University of Applied Sciences and Arts
Abdulraheem Salaymeh, HAWK University of Applied Sciences and Arts
Tanja Mehring, HAWK University of Applied Sciences and Arts
Irene Peters, HafenCity University Hamburg
Erik Bertram, HAWK University of Applied Sciences and Arts
Sebastian Föste, HAWK University of Applied Sciences and Arts

Stefan Holler (presenter) stefan.holler@hawk.de

In practice, not every building is ready for renewable energy integration and connection to low temperature district heating (LTDH). Often it is the high temperatures required in the heating system that blocks the switch. This study analyses the minimum flow temperature required for different levels of efficiency in existing buildings. We propose the definition of a Building Supply Temperature Cadastre (BSTC) as an indicator of the minimum required flow temperatures and hence the feasible or suitable heating systems in existing buildings. The cartographic representation of a BSTC in combination with Heat Cadastres allows the allocation of energy-related measures for the building technology and the building envelope as well as suitable heat supply concepts in energy districts (e.g. LTDH, ambient heat networks, decentralised heat pump systems) with high spatial resolution and in chronological order.
Our first results for the German federal state of Lower Saxony show that about 15 % of residential buildings are currently ready for low-temperature heat supply (≤ 55 C) or can be made low-temperature-ready by means of a few targeted insulation measures and/or improvements to the heat distribution system. If current refurbishment rates continue until 2045, this share will increase to 65 %. If all buildings are fully refurbished according to the German standard for energy efficiency in buildings, the share of the residential building stock that is low temperature ready can be forecasted to be 78 %. If future building refurbishment is carried out to the Passive House standard by 2045, this proportion can be increased to 96 %. Full refurbishment to Passive House standard means that every house will be low-temperature ready and could be supplied by LTDH.

Keywords: Building Supply Temperature Cadastre, Low-Temperature District Heating, Heat Cadastre, Refurbishment, Residential Building Stock

Laura Kuper is pursuing her PhD with Siemens AG in cooperation with TU Darmstadt, researching the design of urban energy infrastructure for heating in consideration of sector coupling effects. She earned her master's degree in energy engineering at RWTH Aachen University.

Heating network topology design by price-collecting Steiner trees

Laura Kuper, Siemens AG Technology Sustainable Energy and Infrastructure and Technical University of Darmstadt Chair for multimodal energy systems.
Michael Metzger, Siemens AG Technology Sustainable Energy and Infrastructure.
Paul Stursberg, Siemens AG Technology Sustainable Energy and Infrastructure.
Stefan Niessen, Siemens AG Technology Sustainable Energy and Infrastructure and Technical University of Darmstadt Chair for multimodal energy systems.

Laura Kuper (presenter) laura.kuper@siemens.com

Heating networks are pivotal for the transition of the heat supply infrastructure towards more sustainability. To ensure an economically efficient transition, the design of heating network topology needs to balance the costs for network construction and the benefits of connected consumers. The decision, whether to connect a specific consumer, influences the topology of the pipe network and thus may affect the costs for connecting other consumers.

Most approaches in the literature for the topology design of heating networks rely on mathematical programming, with a particular emphasis on mixed-integer linear problem formulations. This approach performs well on small problems but reaches practical limits when considering several thousand customers due to increasing calculation times. This paper thus proposes to apply combinatorial graph algorithms and exploits the computational efficiency of these algorithms. We leverage the underlying graph structure of the problem in which the graph edges represent the connections by pipes and the vertices represent consumers and road intersections. To include economic aspects, we model the topology design problem as a price-collecting Steiner tree problem: Price-collecting Steiner trees aim to identify the subgraph with the highest profit by balancing the costs for building edges and the benefits of connected vertices. This modelling approach sacrifices detail with respect to the network's physical behavior but in turn enables us to apply efficient algorithms from the literature tailored to this problem. Some of these algorithms grow the network iteratively and thus offer the possibility to derive not only a target topology but also to evolve topologies of expansion phases using the intermediate algorithm steps. Evolving topologies of expansion phases cannot easily be achieved using mixed-integer linear programming approaches without increasing the size of the formulation. We conduct a comparison study between the price-collecting Steiner tree and the mixed-integer linear formulation for varying system sizes in the order of 100 to

10000 edges and discuss the advantages and disadvantages of both approaches regarding economic results, topology design and computational efficiency.

Keywords: district heating, network topology design, combinatorial graph algorithms, computational efficiency, phased expansion

Saltanat Kuntuarova is a research associate and doctoral candidate at the Technical University of Munich (TUM). The primary research focus pertains to the heat energy market and innovative solutions in the coupling of thermal and electrical grids.

Operational Flexibility of Integrated Power and District Heating Systems: Modeling of Heat Flow Directions

Saltanat Kuntuarova, Technical University of Munich, Vedran Perić, Aarhus University

Saltanat Kuntuarova (presenter) saltanat.kuntuarova@tum.de

The electrical power sector is increasingly utilizing renewable energy sources, while the heating sector still heavily depends on fossil fuels. Integrated electricity and district heating (DH) systems offer a solution by combining renewable energies with alternative heat sources while leveraging the operational flexibility of DH networks.

In this study, we explore the integration of DH systems with electrical power systems under variable mass flow and variable temperature, while evaluating the potential benefits of incorporating the flow directions into the optimization model, which traditionally are predetermined for simplicity. The enhanced flexibility is quantified by comparing the total operational costs of systems with bidirectional mass flow versus unidirectional ones. Using a case study of an integrated 6-bus electricity and 3-node DH network, we conceptually demonstrate how mass flow directions may enhance system performance and efficiency.

The optimization incorporates heat flow physics, which is characterized by hydraulic and thermal equations. Furthermore, the model uses quadratic relaxation methods for modeling the heat flow as a function of the pressure drops. It uses linearization techniques and McCormick relaxations for convexifying bilinear terms, resulting in a Mixed Integer Second Order Cone Programming (MISOCP) and Mixed Integer Linear Programming (MILP). The selected relaxation is improved by tightening its feasible region.

Keywords: district heating systems, optimal heat flow direction, bidirectional flow, integrated energy systems, multi-energy systems, flexibility, mixed-integer linear program

Ali Kök is a research associate and PhD candidate at Energy Economics Group (EEG), Vienna University of Technology (TU Wien). His research focuses on energy system modeling to assess decarbonization pathways of the district heating sector.

Modelling Uncertainties in District Heating Supply Modelling

Ali Kök, TU Wien. Lukas Kranzl, TU Wien.

Ali Kök (presenter) koek@eeg.tuwien.ac.at

District heating (DH) systems are recognized as essential elements in European energy policies aimed at substantially integrating renewable and excess heat sources to meet stringent decarbonization targets. Specific policy objectives include an annual increase of 2.1% in renewable energy and excess heat contributions to DH systems. Despite these clear targets, the pathways to achieve them remain underdefined, emphasizing the need for advanced modeling techniques. Addressing this, understanding and integrating uncertainty becomes pivotal, as it directly influences planning and policy decisions.

This research critically examines the application of multistage optimization techniques in DH supply modeling, contrasting these with traditional scenario-based approaches. Traditional methods often operate under a limited number of fixed scenarios and do not fully capture the dynamic uncertainties inherent in the future energy landscape—such as variable DH demand and fluctuating energy prices.

Our study begins with an evaluation of existing DH supply models and their methods of incorporating uncertainty, which might arise from factors like new building constructions, demolitions, renovations, and varying climatic conditions. We extend our review to capacity expansion models from other energy sectors, exploring methods that might be adapted to DH systems. Through a comparative analysis of models from Khojaste et al. (2023) on Markov decision processes, Mitjana et al. (2023) on multistage stochastic models for decarbonization, and Hole et al. (2023) on hydroelectric system capacity planning using stochastic dual dynamic programming, we investigate diverse approaches to managing uncertainty across energy systems.

The contribution of this paper is twofold: firstly, it provides an in-depth review of uncertainty modeling techniques across energy sectors with a focus on their applicability to DH supply. Secondly, it introduces a multistage stochastic optimization model for DH supply, developed through this cross-disciplinary review, and demonstrates its application in a case study based on a DH system from a central European country. This model aims to enhance DH supply models' strategic relevance and applicability in supporting investment decisions.

Keywords: District Heating, Supply Modeling, Multistage Optimization, Stochastic Modelling

Henrique is a research fellow at London South Bank University, where he carries out research on sustainable heating and cooling across residential, commercial and industrial applications. His main interests are related to low-grade waste heat integration into DHC systems and large-scale heat pumps.

FAST DHC project: initial findings on the development of a decision support tool for the techno-economic evaluation of low-temperature DHC networks.

Henrique Lagoeiro, London South Bank University
Catarina Marques, London South Bank University
Graeme Maidment, London South Bank University
Nicolas Marx, Austrian Institute of Technology
Ralf-Roman Schmidt, Austrian Institute of Technology
Alessandro Maccarini, Aalborg University
Oddgeir Gudmundsson, Danfoss Climate Solutions

Henrique Lagoeiro (presenter) roscoeh2@lsbu.ac.uk

The Feasibility Assessment Tool for District Heating and Cooling (FAST DHC) project, funded through the IEA DHC Annex XIV, aims to develop and demonstrate a simple, freely available, web-based decision support tool for the techno-economic performance evaluation of 4th generation district heating (4GDH) and thermal source networks (TSNs), whilst also enabling their comparison to individual heating and cooling (H&C) solutions. The TSN concept is in its early stage of development and there is a lack of understanding of its relative merits against traditional DHC concepts, i.e. how do 4G and TSN systems compare and what are their competitive advantages to individual H&C systems. The FAST DHC tool will enable users (e.g. local authorities, designers and energy planners) to perform early-stage feasibility studies and easily compare the potential benefits of the latest DHC typologies, providing greater clarity on how/where each system may be best applied. The goal is to assist the development of the DHC sector by equipping users with a reliable initial estimate of proper system setup, therefore maximising benefits to DHC developers, operators and end users. This presentation introduces the concept for the FAST DHC tool, highlighting its planned features, and shares some initial project outcomes, which includes the development of a techno-economic database for levelised cost calculations.

Keywords: District heating and cooling, techno-economic evaluation, planning tools, 4th generation (4GDH), thermal source networks (TSNs), low-temperature networks.

Jinze Li works as a project manager at Research Institute of Petroleum Exploration and Development and leads research projects in the field of energy systems engineering, energy system modelling and optimization.

Optimization and techno-economic analysis of a hybrid renewable energy system for covering energy and water needs in remote island

Jinze Li,Research Institute of Petroleum Exploration and Development. Pei Liu, Tsinghua University. Guosheng Zhang, Research Institute of Petroleum Exploration and Development.

Jinze Li (presenter) lijz2022@petrochina.com.cn

Reliable, economic and sustainable power and freshwater supply are essential for the development of remote offshore areas. Supplying these requirements to island residents has been severely constrained due to limited access to the utility networks. Meanwhile, heavy dependence on extensive use of imported fossil fuels, especially diesel for power generation are costly, and inconsistent with environmental protection and low-carbon transition. The implement of hybrid renewable energy systems (HRES) provide opportunities for addressing reliance on submarine cable interconnection and fossil-based power system. This study aims to conduct an optimization and comprehensive techno-economic analysis of a HRES for island energy and freshwater supply, via a case study of a remote island in China. The most cost-competitive configuration is identified by using Hybrid Optimization of Multiple Energy Resources (HOMER), which taking into account PV panels, wind turbines, diesel generator, batteries and hydrogen storage systems. In addition, sensitivity analysis are performed to reveal the impact of variations of resources availability and economics on system application, whilst considering energy and water demand growth due to future development and increasing touristic demands. Results indicated that the proposed HRES enhances the economic viability of island power and water supply, whilst presents wide capability in multiple scenarios and consistency of long-term decarbonization targets.

Keywords: Hybrid renewable energy system, remote island, China

Dr. Alena Lohrmann is a postdoctoral researcher for the Chair of Energy Systems Analysis at ETH Zürich, Switzerland. She received her doctoral degree at LUT University in Finland. Her research is focused on the water footprint assessment of energy systems and water- and energy-intensive technologies

Go with the flow: a new approach to levelized cost estimation to account for water use in power generation

Alena Lohrmann, ETH Zürich
Javier Farfan, Åbo Akademi University

Alena Lohrmann (presenter) alohrmann@ethz.ch

The currently used electricity generation technologies require a considerable amount of water for their operation and, thus, rely heavily on water availability. As water resources become increasingly unreliable globally due to climate change, competition for water resources and water prices are expected to grow significantly in the upcoming decades.
Despite this fact, water costs for power generation, including water transportation and water treatment costs, are usually overlooked in calculations of the levelized cost of electricity (LCOE). To address this research gap, this study introduces a novel method for calculating the levelized cost of water (LCOW) for power generation, which is proposed to be included in the widely used LCOE formula by scholars. Using the proposed method, we assess the water use at 13,863 thermal power plant units worldwide, which have a total active capacity of 4,182 GW. In particular, we estimate, on a per country-level, the average cost for water transportation from the nearest water source (e.g., river, lake, or even seawater shoreline—for power plants using seawater) to the location of the power generation unit. We also estimate the average costs of water cost at source and water pre-processing, which, in turn, depends on the type of water used and its quality. In addition to the assessment of the water use costs for thermal power generation, the study considers other power generation technologies that require water for their operation, such as solar photovoltaic (PV) power plants, which are typically overlooked in water studies, but which require water for regular cleaning of PV panels.
The study's contribution is twofold. First, we present a novel universal methodology for assessing the LCOW for power generation, which can be included in the LCOE calculations in future studies. Second, we present our estimations of the LCOW for different power generation technologies, both globally and on a per-country level. These estimations, considering the average costs for water transportation and water costs, are not only globally relevant but also provide valuable insights for local energy planning, water management, resources conservation and policymaking.

Keywords: Water-energy nexus, levelized cost of electricity, levelized cost of water

Dennis Lottis is a research associate at Fraunhofer IEE in Kassel, specializing in thermo-hydraulic simulations and mathematical optimization in the field of district heating. He is also involved in the planning and construction of a district heating test facility.

Benchmarking optimization problem formulations for Model Predictive Control of District Heating systems with a Software-in-the-Loop approach

Dennis Lottis, Fraunhofer IEE
Anna Cadenbach, Fraunhofer IEE
Philipp Härtel, Fraunhofer IEE & University of Kassel

Dennis Lottis (presenter) dennis.lottis@iee.fraunhofer.de

The fourth generation of district heating (4GDH) is characterized by various generation technologies, particularly renewable energy and waste heat, and heat storage to use renewable heat when available, regardless of demand. Hence, efficient and predictive operational planning is becoming important. Model predictive control (MPC) is commonly proposed for this purpose. When modeling the optimization problems within the MPC, the individual components are often linearized. This enables a fast and unambiguous solution at the expense of accuracy. By contrast, the use of non-linear formulations can lead to a significant increase in complexity and thus reduce computational tractability, which impairs real-time capability. Given this trade-off between accuracy and computational challenges, there is a need to benchmark the performance of different model formulations against each other and against traditional control strategies.

In this work, a benchmarking approach using a complex transient thermo-hydraulic system simulation model (CTM) in real-time software-in-the-loop (SIL) operation is demonstrated. The flexible heating grid of the research facility “District LAB” at Fraunhofer IEE serves as the demonstration object. First, the CTM is implemented in the simulation environment Simscape, including a control structure to represent the reference case of rule-based heat storage charging control. Then, two different optimization problems are formulated using the Pyomo library in Python: a mixed-integer linear programming (MILP) formulation based on energy balances and a mixed-integer nonlinear programming (MINLP) formulation based on mass balances. Subsequently, a bidirectional data exchange between simulation and optimization is established.

Benchmarking is performed in SIL operation using input parameters from different seasons. The performance scores are the main outcome of this work, and it is expected that both optimization methods outperform the reference case. Furthermore, a quantification of the performance benefits is possible, which can serve as decision support for grid operators in the transformation process towards 4GDH. To further substantiate the results, additional experimental investigations at the District LAB facility are planned beyond this work.

Keywords: Fourth Generation of District Heating, Model Predictive Control, Software-in-the-Loop, Benchmark

Dr Andrew Lyden is a Lecturer in Energy System Economics. He is working on research and consultancy projects related to net-zero electricity markets, integrated multi-energy (electricity, heat, transport) systems, decarbonised district heating and cooling, and long-term energy storage technologies.

Exploring sector-coupled flexibility in energy markets with locational pricing

1) Andrew Lyden, University of Edinburgh, 2) Lavin Jafaripour, University of Edinburgh, 3) Anas Algarei, University of Edinburgh

Dr. Andrew Lyden (presenter) andrew.lyden@ed.ac.uk

The integration of renewable energy sources into the power grid necessitates innovative strategies to manage variability and intermittency. Potential strategies include sector-coupled flexibility and electricity market reform, such as increased use of more granular, locational pricing. This talk will focus on the interaction and synergies between sector-coupled flexibility and locational pricing.

Sector-coupled flexibility, harnessing synergies across energy sectors, can bolster grid stability and further decarbonisation. Energy vectors like electricity, hydrogen, and heat can be coordinated to meet demand while accommodating renewable generation fluctuations.

Locational pricing mechanisms in the UK and EU electricity markets aim better reflect real-time balance of supply and demand across different regions, resulting in more efficient resource allocation and grid management. In the UK and EU locational pricing is a topic of fierce debate in current electricity market reform discussions.

The adoption of locational pricing has the potential to increase the effectiveness of sector-coupled flexibility strategies, facilitating a more responsive and sustainable energy system. This talk will explore this interaction and assess synergies.

Integrated planning across energy domains is crucial for realising renewable potential. Supportive policies and market structures are needed to incentivise flexible infrastructure investment and complementary electricity market reform. The study highlights the importance of assessing electricity market reform along with future developments in sector-coupling.

Keywords: Sector coupling, electricity market reform, locational pricing

Dr. Gideon Mbiydzenyuy is a Senior Lecturer in Informatics at the University of Borås, specializing in Industrial AI. He actively researches and teaches courses on data analytics, optimization and software development on both undergraduate and graduate levels.

Practical Considerations for Bi-directional Long Short-Term Memory Anomaly Detection in District Heating Networks.

gideon.mbiydzenyuy@hb.se

Gideon Mbiydzenyuy (presenter) gideon.mbiydzenyuy@hb.se

Building energy systems rely on anomaly detection for optimal performance and efficiency. This study explores the practical application of Bi-directional Long Short-Term Memory (BiLSTM) networks for anomaly detection in multivariate time series data from building heat systems. These systems include features like flow rate, supply and return temperatures, temperature differentials, and energy consumption.

While Long Short-Term Memory (LSTM) networks have shown promise in time series anomaly detection, research lacks consensus on best practices for data preprocessing (scaling techniques), network architecture (complexity and parameters), and training/validation (loss function selection). This limits real-world adoption of these techniques.

This article addresses this gap by analyzing the strengths and weaknesses of design choices in these dimensions. We use experimental results from a multivariate time series dataset representing a district heating network in Sweden. While not providing definitive answers, this study sheds light on crucial considerations for implementing BiLSTM-based anomaly detection in building energy systems.

Keywords: Anomaly Detection, BiLSTM Networks, Multivariate Time Series, District Heating

He is a knowledgeable, capable, and committed researcher with a nice teamwork ability. Highly experienced in research, design, and application of complex mathematical models for use in the analysis of energy systems.

A double-layer many-objective stochastic optimization model to handle many uncertainties in the operation of smart energy systems

Mohammad Kiani-Moghaddam, AAU Energy, Aalborg University, Denmark; Mohsen N. Soltani, AAU Energy, Aalborg University, Denmark; Saltanat Kuntuarova, Munich Institute of Integrated Materials, Energy and Process Engineering, Technical University of Munich Munich, Germany; Ahmad Arabkoohsar, Department of Civil and Mechanical Engineering, Technical University of Denmark, Copenhagen, Denmark.

Mohammad Kiani Moghaddam (presenter) mkm@energy.aau.dk

With rising interactions and interdependencies among diverse energy carriers, higher renewable energy penetration, heightened cybersecurity risks, evolving energy market rules and decentralized energy models, electrification of transportation, and applying new government policies, regulations, and environmental standards, the operation of smart energy systems (SESs) faces new and increased uncertainties. Traditional techniques, which rely on sufficient information on uncertainties (e.g., probability distribution functions) to examine their impacts, are often insufficient because it is difficult and even impossible to access such information in practical cases. To address these challenges, this study introduces a double-layer many-objective stochastic optimization model to handle many uncertainties in the operation of SESs effectively. The upper layer of the model simultaneously optimizes the horizon of these uncertainties considering their interactions, while also applying Information-gap decision theory to evaluate adverse and beneficial impacts on SES operations using robustness and opportunity functions, respectively. Uncertainties include electrical, heating, and cooling power demands, the price of electricity and gas, and the photovoltaic production capacity. The boundaries set by minimum and maximum limits for the horizon of all uncertainties, along with the entirety of the lower-layer optimization problem, serve as constraints for the upper-layer many-objective optimization problem. Furthermore, the study applies the non-dominated sorting genetic algorithm III to tackle the upper-level many-objective optimization problem and find the six-dimension set of Pareto efficient solutions. To determine the optimal solution within Pareto efficient solutions, a combination of the fuzzy satisfying method and the conservative, min-max formulation, methodology is used. In the lower layer, a computational core for the upper layer, the operation of the SES is formulated using mixed-integer nonlinear programming to minimize the operation and emission costs subject to technical and logical constraints of the SES. The results prove the model's ability to handle many uncertainties in the operation of the SES.

Keywords: Double-layer many-objective stochastic optimization, operation, non-dominated genetic algorithm-III, smart energy system, many uncertainties.

Ph.D student in Tohoku University, Japan.
He works on the design of wood biomass energy systems from data analysis and model simulation using Python and GIS. His current focus is on the construction and integrated evaluation of Biomass-to-X models based on high-resolution woody biomass energy data.

The analysis of a woody biomass-to-X model based on high-resolution dataset by 1,741 municipalities in Japan

Ryoga Ono, Remi Delage, Toshihiko Nakata. Department of Management Science and Technology, Graduate School of Engineering, Tohoku University

Ryoga Ono (presenter)

Biomass energy is expected to be useful fuel, as well as heat and electricity source to archive carbon-neutral society. In this study, the high-resolution woody biomass energy potential and demand for alternative energy sources were estimated for 1,741 municipalities in Japan. This energy potential was calculated through bottom-up estimation using the method of an aggregation approach, which considers forest growth and supply chain. The datasets were based on each forest information and heuristic model. A woody Biomass-to-X (B2X) model was developed that accounts for the energy conversion process from a woody biomass source to each energy demand and solved as a mixed integer programming problem with cost minimization as the objective function. Additionally, the B2X model includes inter-regional energy transport between neighboring communities and storage for each energy form. Bio-derived fuels are less expensive than electrofuels, which is derived from renewable energy sources and comes in a variety of forms. This global optimized solution from the B2X model provides a pathway for utilization of biomass fuel toward a carbon-neutral society.

Keywords: Biomass-to-X, bottom-up estimation, high-resolution analysis, Forest supply chain, Optimal solution

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.

Harnessing Machine Learning for Rapid Optimization: Integration of Time Series Data into Prior Approximation of Energy System Simulations

Marius Reich, Patrick Rathjen and Mario Adam, University of Applied Sciences Düsseldorf - Centre of Innovative Energy Systems

Marius Reich (presenter) marius.reich@hs-duesseldorf.de

Energy supply systems, designed to operate over decades, must meet high standards, especially with the advent of high-efficiency technologies and increasing renewable energy sources. These trends demand systematic design optimization tools, specifically directed at a non-scientific audience. With this target audience it is of high importance for the tool to be intuitive, fast and with a high informational gain. Instead of formalizing and solving a mixed integer linear problem for determining an optimal design, the authors utilize machine learning to approximate the input-output-relation of rule-based simulations of energy supply systems (e.g. learning the total annualized cost of a photovoltaics systems depending on its size and orientation for given boundary conditions) and utilizing this approximation in metaheuristic optimization. By not only incorporating seizing parameters but also (time-dependent) boundary conditions into the machine learning modeling process as inputs, it is possible to decouple this rather time demanding process from the user interaction, leaving the user only with the very fast approximation to be used in diverse analyses (e.g. optimization). The usually user-specific boundary conditions, e.g. the district's heat load profile or the weather data, can be integrated in two ways prior to the user's interaction: Either by building approximations with typical profiles and assigning the users case to the most fitting approximation or by generating a latent space of time series data using deep learning techniques and incorporating this latent space in the machine learning process. Both approaches are compared and evaluated in terms of computational efficiency and accuracy for optimizing a test case, demonstrating their effectiveness in prior approximation of energy system simulation.

Keywords: Energy supply systems, Rule based simulation, Design Optimization, Metamodeling, Time Series Data

Lukas Richter is a research associate at the Deutsches Biomasseforschungszentrum in the field of energy system modeling and simulation, especially in the area of the cellular approach and biomass-based hybrid systems.

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

Lukas Richter, Deutsches Biomasseforschungszentrum gemeinnützige GmbH;
Volker Lenz, Deutsches Biomasseforschungszentrum gemeinnützige GmbH;
Martin Dotzauer, Deutsches Biomasseforschungszentrum gemeinnützige GmbH;
Joachim Seifert, Dresden University of Technology

Lukas Richter (presenter) lukas.richter@dbfz.de

Managing energy resources in a decentralized and renewable energy system is becoming increasingly challenging. This system is characterized by individual prosumers who are primarily motivated by self-interest, self-sufficiency, and profit. Prosumers only engage with the energy grid when they require power or have surplus to offload. This behavior contributes to inefficiencies and elevated costs within the system. Consistency in prosumer behavior can result in excess energy during periods of high renewable generation, which may require expensive mechanisms for use or curtailment. Conversely, it can lead to shortages during times of limited renewable output. To address this imbalance, significant investment in storage infrastructure, non-volatile energy generation assets, or a fundamental restructuring of the energy framework towards a more cooperative and communicative distribution of renewable energy may be required.
This study analyzes the impact of solid biomass-based hybrid systems (SBBS) on a multimodal, cellular-structured energy grid. The research employs an iterative optimization approach that considers investment and operational considerations with mutual interference. The algorithm combines a multi-agent system with the adaptability of SBBS, providing insights into the optimal configuration of decentralized energy assets within district-level frameworks. The model also incorporates a local electricity market that facilitates the exchange of electricity between buildings. This analysis is essential in determining the appropriate scale of decentralized energy installations. It ensures a secure supply and mitigates grid constraints caused by excess capacities.
The approach was tested in a rural area of Saxony, Germany, using real demand data. A cellular structured multimodal energy system was used to model the district consisting of up to 30 buildings. The study aimed to explore the feasibility of integrating SBBS into a cellular structured energy grid to optimize decentralized energy systems at the district level. This approach addresses the challenges posed by individual consumer behavior while ensuring grid stability and security of supply.

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

PhD fellow at DTU's Wind and Energy Systems, researching water electrolyser integration in modern power systems. MSc in Electrical Engineering from BME, Hungary and BSc from UPS, Ecuador.

Towards Sustainable Energy Transition: Guidelines for Wind Energy Expansion and Power-to-X Integration in Small Island States

Jonathan Riofrio ,Elisabeth Andreæ, Asger Nyholm, Chresten Træholt, Tilman Weckesser, Shi You - Technical University of Denmark (DTU), and Helma Maria Tróndheim-Power Company SEV.

Jonathan Riofrio (presenter) aurio@dtu.dk

Small Island States (SIS) historically relied heavily on imported fuels for energy, but are shifting towards harnessing renewable energies (REs) to combat climate change, bolster resilience, and secure long-term energy independence. Ambitious plans for RE-based energy systems are underway in various SIS globally. However, integrating increasing shares of solar and wind energy into SIS power systems poses operational challenges, such as surplus energy leading to curtailment and the lack of kinetic energy storage resulting in low inertia systems. Power-to-X (PtX) facilities offer a promising solution, converting curtailed RE energy into green hydrogen (GH2), with inverter-based electrolysers providing grid services. Technical planning and precise sizing are crucial for effective PtX integration, addressing expansion planning and operational needs. This paper provides guidelines for feasible wind energy expansion and PtX sizing in SIS, considering energy demand, infrastructure, and geography. Monte Carlo simulation generates expansion scenarios, with subsequent analysis assessing system reliability against frequency events, utilizing alkaline electrolysers for frequency regulation. The Faroe Islands' bulk power system serves as a case study, aligning with local initiatives to increase wind energy share by 2030. Preliminary results suggest AELs rated at 9.8 MW can provide adequate frequency response, potentially avoiding curtailment of 15.7 MW of wind energy compared to 2023. The paper's structure includes an introduction to the Faroese power system, considerations for wind power expansion, PtX facility insights, simulated frequency support scenarios, and main findings of PtX inclusion in SIS.

Keywords: Alkaline electrolyser (AEL), frequency support, low-inertia system, Monte Carlo simulation, Power-to-X (PtX), Small Island States (SIS).

Daniel Rohde has more than ten years of experience with energy system analysis, especially dynamic simulation and optimization of integrated energy systems with Modelica. After many years in research, he now works at Modelon and is involved in R&D as well as commercial projects and support.

Dynamic Energy System Optimization: A unique methodology for simultaneous sizing and optimal operation

Daniel Rohde, Modelon
Arne Köppen, Modelon
Friedrich Gottelt, Modelon
Moritz Hübel, Modelon

Daniel Rohde (presenter) daniel.rohde@modelon.com

The energy transition from fossil-based to renewable energy systems has led to an increase in system complexity, which makes system analysis more challenging. In addition, uncertainties regarding future technology and market developments as well as governmental regulations can impede necessary long-term investments in smart energy systems. It is therefore crucial to mitigate risks and enable informed decisions by generating meaningful result data. Many tools and methodologies for energy system analysis exist and it is important to match the capabilities to the problem statement at hand.

In this contribution, we present a unique methodology that was recently released in the library Energy Systems. It enables techno-economic optimization of hybrid energy systems, covering the sectors electricity, heat, and fluids (fuels, hydrogen, CO2). The library is written in Modelica and is fully compatible with dynamic optimization based on Optimica. Dynamic optimization is a proven methodology for simultaneous optimization of design (component size, capacity, etc.) and operation (component power, flow, etc.). The gradient-based solver allows for fast convergence and this advanced methodology – previously applied successfully in several projects - is now available to non-experts.

The scope of the Energy Systems library are utility-scale energy systems with a typical use case being the decarbonization of industrial sites. Key components are modeled individually, e.g., solar panels, heat pumps, electrolyzers, storages, etc. Auxiliary equipment is neglected, as the library follows a flow-based approach without spatial resolution. The implemented equations allow setting operational limits and defining prices for energy and fluid flows. The resulting cash flows as well as the user-defined investment costs for each component are automatically summed, conveniently showing the system's economic performance. Scaling of components can be activated and makes it possible to find the optimum distribution of a given budget or to

minimize the total cost of ownership. Time series data for load profiles, prices and weather are inputs that can be used to generate different scenarios. The optimization methodology allows a fair comparison of all scenarios and thus generates useful insights.

Keywords: Techno-economic optimization, Hybrid energy system, Optimal design, Optimal operation

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

A techno-economic and investment risk analysis of ambient and waste heat supply technologies considering future uncertainty for a case study in Poland

Nyasha Grecu; Ralf-Roman Schmidt, Stefan Strömer, Bernhard Mayr, Nicolas Marx, Klara Maggauer, AIT Austrian Institute of Technology GmbH

Ralf-Roman Schmidt (presenter)

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District heating (DH) networks can play a key role in heat decarbonization since they enable 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, such as ambient heat (AH) and waste heat (WH).

The use of heat pumps (HPs) allows for the integration of lower temperature AH and WH sources that could not be used otherwise. Further on, they can provide greater flexibility by increasing the coupling of the electricity and heat sectors. The decarbonization of DH systems using AH and WH requires large investments in sustainable heat supply technologies including heat exchangers, HPs, and piping infrastructure, as well as storages etc.

Different temperature AH and WH sources have different benefits and risk factors. For AH sources, there is high certainty they will still be available in the future. However, they have low temperatures, especially in the winter, and therefore rely on HPs. This results in low COPs, higher investment costs due to the HP, and increased dependence and vulnerability to electricity prices. High temperature WH from industrial processes have relatively low investment and operation costs as no HP is necessary. However, there is greater uncertainty surrounding its future availability as there is a chance that industrial activities change (i.e., with industry decarbonization) or are discontinued (i.e., if the company relocates). Medium temperature WH such as from service sector cooling also requires a HP, and therefore has higher investment cost. However, COPs are higher than for AH sources and, depending on the source, future availability may be more certain compared to high temperature sources.

This contribution will analyze different heat supply portfolios, considering both, the levelized cost of heat and the system's resilience in the face of future uncertainties (i.e. energy markets and WH cessation scenarios. This will be done for a case study in Poland, understanding the potential role of AH and WH in the resilient decarbonization of the local DH network.

Keywords: Resilience, district heating, decarbonization strategies, ambient heat, waste heat, drop out scenarios, uncertainties, Monte-Carlo-Simulation

Martin Sollich is a PhD student 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 achieve fully renewable-based and low-temperature heating networks.

Integrating short-term storage in optimal heating network design to reduce back-up capacity and increase renewable heat supply

Martin Sollich, KU Leuven, Belgium; Anouk Robbeets, KU Leuven, Belgium; Yannick Wack, KU Leuven, Belgium; Robbe Salenbien, Flemish Institute for Technological Research (VITO), Belgium; Martine Baelmans, KU Leuven, Belgium; Maarten Blommaert, KU Leuven, Belgium.

Martin Sollich (presenter) martin.sollich@kuleuven.be

A major challenge in district heating networks is the presence of a morning peak demand due to night setbacks, as this requires high peak capacity of the heat supply compared to the average daily demand, and thus high investment costs. Short-term heat storage can alleviate this problem by allowing some of the required heat to be "pre-produced" and stored. To support the design of cost-effective heating networks with integrated heat storage, we have extended our automated design tool for district heating networks (PATHOPT). Specifically, the charge/discharge operation of the storage is optimized based on a time-dependent, non-linear heat transport model to reduce the required heat production capacity and lower the overall investment cost of the heating network. The physics-based model accounts for heat losses and their impact on the storage temperature. For a realistic use case, we show that significant economic benefits are obtained by optimal integration of heat storage. For this case, the optimal integration of heat storage allows a reduction of the required heat production capacity by 20%, resulting in a total investment cost reduction equivalent to 18% of the heat production investment when storage is not considered in the design.
To extend the capabilities of the tool towards integrating intermittent renewable and waste heat sources, we also show first results of a new methodology to capture daily and seasonal variations by optimizing the heating network and heat storage design, based on the simulation of a limited number of representative days. With these capabilities, the tool automatically decides on the optimal storage operation for those representative days, while simultaneously optimizing the temperature, heat supply and capacity of heat producers, pipe layout and sizes, and network operation. This enables the optimization of renewable-based heating networks and provides cost and energy efficient network designs. Moreover, the integration of heat storage improves the flexibility of the network planners and economic gains due to the increased accessibility of intermittent heat sources. We show for a use case how the optimal integration of heat storage can increase the heat supply from a solar thermal field, thereby reducing CO_2 emissions and costs.

Keywords: District heating network design, heat storage, renewable energy integration, nonlinear optimization

After completing a B.Sc. and M.Sc. in Computer Science, he started working on research projects using machine learning in industrial applications. He is currently working on fault detection in district heating networks as part of his PhD.

Data Set and Fault Signature Generation for District Heating with Generative and Transformative Neural Networks

Dominik Stecher, Technical University of Applied Science Rosenheim
Martin Neumayer, Institut für nachhaltige Energieversorgung GmbH
Andreas Maier, Friedrich-Alexander-University Erlangen-Nürnberg
Dominikus Bücker, Institut für nachhaltige Energieversorgung GmbH
Jochen Schmidt, Technical University of Applied Science Rosenheim

Dominik Stecher (presenter) dominik.stecher@th-rosenheim.de

The rise of digitalization in heat meters coupled with the evolution towards 4th generation district heating has sparked a surge in utilizing data streams from individual district heating substations for anomaly or fault detection. This trend is driven by the prospect of enhanced customer satisfaction, improved operational efficiency, reduced operating costs, and optimized maintenance and repair schedules. However, our investigation for SESAAU 22 reveals that existing literature predominantly relies on unlabeled datasets for anomaly detection purposes. Moreover, many studies resort to employing simulated faults or entirely synthetic datasets. Among the surveyed publications, a mere two out of 25 incorporate labeled, real-world datasets. Furthermore, we observe inconsistency in fault labeling practices, ranging from Boolean to numerical values, depending on the severity of the fault.

We have created a labelled data set covering 3.5 years from 2019 to 2022 in a German district heating network. The data consists of hourly measurements of supply and return temperature as well as flow rate for the primary side of individual district heating substations. The annotations consist of reviewed customer complaints including root cause, as well as anomalies which did not result in a customer complaint but were deemed important by district heating experts during manual review and labelling of the time series data.
Using this data set, we evaluate fault and anomaly detection algorithms ranging from unsupervised threshold-based and statistical frameworks – for which we can now calculate performance metrics – to supervised classifiers such as support vector machines and neural networks including RNN, LSTM, and CNN in order to determine general performance as well as the influence of individual substations and fault types. Furthermore, we discuss and evaluate use-case-specific performance indicators such as time savings due to early fault detection and prediction certainty within the limits of our data set.

We aim to demonstrate the feasibility of fault detection using supervised learning methods as well as current limitations and considerations for future development.

Keywords: Fault Detection, Anomaly Detection, District Heating, Substation, Supervised Learning, Neural Network,

After completing his studies at RWTH Aachen, Jan Stock started as a research associate at Forschungszentrum Jülich. His field of research is the transformation of existing district heating systems with a focus on lowering supply temperatures and the integration of sustainable heat sources.

Construction of large district heating networks based on open-source data and demonstration of possible transformation measures

Jan Stock, Forschungszentrum Jülich, Institute of Energy and Climate Research, Energy Systems Engineering (IEK-10); Till Schmidt, Forschungszentrum Jülich, Institute of Energy and Climate Research, Energy Systems Engineering (IEK-10); André Xhonneux, Forschungszentrum Jülich, Institute of Energy and Climate Research, Energy Systems Engineering (IEK-10); Dirk Müller, Forschungszentrum Jülich, Institute of Energy and Climate Research, Energy Systems Engineering (IEK-10)/RWTH Aachen University, E.ON Energy Research Center, Institute for Energy Efficient Buildings and Indoor Climate

Jan Stock (presenter) j.stock@fz-juelich.de

Transforming existing district heating (DH) systems to provide efficient and climate-neutral heat supply to buildings is a huge challenge. Large DH systems in densely populated cities are particularly complicated to transform, as the building stock in such cities is very heterogeneous. The rapid evaluation of transformation measures or the identification of synergies with other energy sectors in the vicinity of DH systems is hindered by the fact that detailed information on the dimension of the network, the supplied buildings or historical measurement data is usually not readily available.
Therefore, we present a holistic approach to generate DH models of existing DH systems using several open-source data sets with the intention of using the resulting model to analyse possible transformation measures in the region where the DH system is located.
The model is constructed using various publicly available data sets, e.g. the general network topology available from the operator, geo-referenced building data in the vicinity of the DH network, a DH connection rate per building block or survey data on the year of construction of buildings. In addition, open-source tools are used to construct a comprehensive DH model, such as a network graph management tool and a demand profile generator. Since the obtained model uses many comprehensive datasets, the resulting model represents the real existing DH system with a high degree of accuracy and can therefore be used to analyse possible transformation options.
In this work, we apply the developed approach to the DH system of a large German city, which supplies more than a thousand buildings. In the first step, the model generation is shown. The DH model is then used to demonstrate a possible stepwise transformation process by separating the existing DH network with a previously developed optimisation model. The stepwise transformation of the separated DH network includes the utilisation of a nearby

sustainable heat source and the reduction of the supply temperature in the separated network in combination with the installation of supporting heat pump systems.

Keywords: District Heating, Modelling, Transformation, Existing Networks, Open-Source

Umberto Tesio is a PhD student at the Energy Department of Politecnico di Torino (Italy). His main research activity is aimed at developing methodologies for the simulation and optimization of Multi Energy Systems and District Heating Networks.

Operation optimization of a Multi Energy System with a District Heating Network

Umberto Tesio, Politecnico di Torino.
Elisa Guelpa, Politecnico di Torino.
Vittorio Verda, Politecnico di Torino.

Umberto Tesio (presenter) umberto.tesio@polito.it

The combined production of the main energy vectors (electricity, heating and cooling) is one of the most promising options for an efficient and sustainable generation, able to satisfy the demand of both residential and industrial loads. In the context of the energy transition, the distributed generation involving different technologies fed by fossil fuels or renewable sources, and energy storages is becoming a reality. A Multi Energy System is composed by many components interacting between them to produce multiple energy vectors and can represent both a centralized and distributed configuration. In these systems, the infrastructures for the energy transportation are a key element, not only because they allow the power transfer between generators and consumers, but because they can influence the operation of the MESs themselves. In fact, they do not only pose boundaries to the systems operation, but they also increase their flexibility. This is particularly true for the thermal networks of medium-high size, such as the District Heating Networks. Another important aspect for increasing the flexibility of a MES, as well as its performance and economic savings, is the energy storage. The inclusion of these elements in the MES simulation and optimization represents a very interesting field of investigation. The computational times required to find the best solution must be affordable in practical terms, and this aspect is among the priorities to be fulfilled when optimization models are built. In addition, the fact that the computational cost is usually directly dependent on the accuracy of the simulation and optimization introduces an additional element of complexity, leading to the necessity of reaching a trade-off. Few works can be found in the scientific literature with similar objectives and their analyses are heavily influenced by the simplifications assumed at the beginning of the development of the models. With these motivations, the present analysis proposes a model for the integration of a detailed and realistic integration of a thermal network in the operation optimization of an energy system.

Keywords: Multi Energy System, District Heating Network, Optimization, Energy Storage, Flexibility

Gerhard Totschnig has been working for the AIT, since 2018 as a research engineer. He holds a Master's Degree in Theoretical Physics of the TU Vienna and obtained a Ph.D. at the Institute of Chemical Engineering, Fuel and Environmental Technology of TU Vienna.

Optimal supply portfolio in a decarbonised district heating system - results of a model-based investigation for two case studies

Gerhard Totschnig, Ralf-Roman Schmidt, Demet Suna, Philipp Ortmann, Fabian Leimgruber, Clovis Seragiotto
AIT Austrian Institute of Technology GmbH

Gerhard Totschnig (presenter) Gerhard.Totschnig@ait.ac.at

The majority of urban district heating networks is still supplied via fossil fuels. This share of the generation portfolio must be decarbonised to achieve the targeted EU climate neutrality by 2050. The aim of this contribution is to show which technologies can make up the future generation portfolio of a decarbonised district heating system.
The investigations are based on the results of a model-based optimisation of a future generation portfolios for various assumptions of the available potentials for different technologies (geothermal energy, waste incineration, waste heat, storages and others).
To answer the central question, the district heating network, including the generation and consumption structures, was modelled. The expansion and deployment planning of the optimised technology portfolio is defined as a linear mixed-integer optimisation problem
The minimisation of the discounted total system costs of the generation park is defined as an objective function of the model. The model horizon extends until 2050.
This methodology was applied for two different case studies.
This contribution is part of the IEA DHC Annex TS5 special session

Keywords: district heating, decarbonization strategies, invest optimization, operational optimization

Dr. Nora Yusma (bt. Mohamed Yusoff) is a senior researcher and director of the Institute of Energy Policy and Research. Her experience includes working as a national consultant and researcher for Malaysia and the international level.

Optimal Decarbonisation Pathways for Malaysia's Energy System: Mapping a Long-Term Transition to Net Zero Emissions by 2050.

1) Nora Yusma Mohamed Yusoff, Insititute of Energy Policy and Research, Universiti Tenaga Nasional; 2) Abdelhalim Abobker Adam Ahmed, Insititute of Energy Policy and Research, Universiti Tenaga Nasiona; 3) Alif Imran Mohd Shuhaimi, Universiti Tenaga Nasional; 4) Azlina Mohammad Jais, Energy Commission of Malaysia and 5) Salmi bin Samsudin, TNB Fuel Services Sdn. Bhd.

Nora Yusma Mohamed Yusop (presenter) nora@uniten.edu.my

Malaysia has set ambitious goals for its energy future, with a focus on achieving 70% renewable energy capacity and reaching net zero emissions by 2050. The country's energy transition roadmap outlines these targets. Our analysis utilises the EnergyPLAN model, a robust tool for energy system analysis. It emphasises the strategic replacement of coal-fired power plants with renewable energy sources and advanced technologies. We conducted a comprehensive analysis of different scenarios, which included the Reference Case for 2022 and the Advanced Technology Scenarios (ATS). The results showed a substantial rise in installed power capacities, possibly reaching an impressive 63,952 MW. The projections indicate that renewable energy will contribute significantly to the total capacity, with solar energy leading the way with a 48% share, culminating in a total capacity of 66%. Projections indicate that natural gas will emerge as the primary green energy source, contributing 19% to the total. Following closely behind is green hydrogen, at 12.9%, with nuclear power trailing at 2%. Additionally, we anticipate significant growth in Carbon Capture and Storage (CCS) and Battery Energy Storage Systems (BESS), with CCS capacity significantly increasing and BESS reaching 12,525 MW. These developments are crucial for enhancing grid resilience and managing the intermittency of solar power. An economic analysis identifies challenges, particularly those related to ATS's projected average generation cost. This necessitates a comprehensive evaluation of technologies such as CCS and PHES. Our study highlights the critical need for prompt action to secure a long-term and sustainable energy supply for Malaysia. It emphasises the importance of striking a harmonious balance between environmental goals and economic feasibility.

Keywords: Decarbonisation, National Energy Transition Roadmap, Advanced Technology, EnergyPLAN, Net Zero Emission

Tuomas Vanhanen is a doctoral researcher at Tampere University, Finland. His research focuses on the regulatory and policy aspects of sector coupling in urban settings.

Energy System Modeling of Sector Coupling in a Sustainable City: A Policy Scenarios Approach

Tuomas Vanhanen, Tampere University; Arnau Aliana, ETH Zürich; Valtteri Seppälä, Tampereen Energia Oy

Tuomas Vanhanen (presenter) tuomas.vanhanen@tuni.fi

Cities often incorporate the concepts of sustainability and smartness into their goals. To achieve these goals, the electrification of energy end-use sectors— referred to as sector coupling—is considered crucial. Professionals routinely utilize Bottom-up Energy System models (ESMs) to assess the impact of the energy domain on various techno-economic indicators in future scenarios. However, despite policies being essential tools for guiding smart and sustainable city development, the representation of policy instruments and policy mixes in ESM studies is often unnecessarily limited. Therefore, the aim of this study is to quantitatively address the challenge faced by policymakers in designing an urban-scale policy mix and selecting suitable indicators for impact assessment.

To achieve this aim, we create urban energy system scenarios with a focus on the sustainability dimension, thereby concentrating the scope of our analysis. We include large-scale energy storage to utilize the excess heat from applications of sector coupling. Additionally, we create plausible policy scenarios in the context of a representative medium-sized city in Northern Europe. We then use the ESM tool EnergyPLAN to calculate policy-relevant insights at the city scale while also considering system-level effects.

Our study demonstrates that, in addition to technical energy system scenarios, policy scenarios significantly influence sustainable city development indicators. We discuss recommendations for scholars and other professionals engaged in urban policymaking. As an increasing number of municipalities adopt policies for sustainable development, future research could employ multiple-case study research designs to create empirical evidence on the effectiveness of various policy mixes across different policy regimes.

Keywords: Energy system integration, sector coupling, strategic energy planning, energy policy

Full professor at Energy Department of Politecnico di Torino. His research activity is mainly focused on district heating and thermal energy storage

Integration of large-scale heat pumps in high temperature district heating systems

Vittorio Verda, Politecnico di Torino

Vittorio Verda (presenter) vittorio.verda@polito.it

Integration of heat pumps in district heating networks is a quite recent trend, which is pursued in order to increase the share of renewables. This option is easier to apply in low temperature district heat systems, but presents issues when high temperature systems are considered. This paper investigates the energy and economic results that can be obtained in an existing large-scale district heating network, where heat pumps can be installed in distribution networks which operating temperature can be smartly handled along the heating season without affecting the operation of the other portions of network.

This particular installation allows one to manage the distribution network by applying a variable set-point in the supply temperature, depending on the specific requirements of the buildings connected in the area and thus optimize the contribution of the heat pump.

Both the energy and economic analysis are performed considering all energy contributions, including the effects of the heat pump installations on the pumping power. To properly consider for the various terms along the heating season, exergy is used as a criterion for energy accounting. Results show in a quantitative way the various advantages that arise from such integration.

Keywords: heat pumps, district heating

Volodymyr Voloshchuk is a Professor of the Department of Automation of Energy Processes. The scientific activity is devoted to development and implementation of mathematical and computer modelling of thermal processes, exergy-based design, assessment, optimisation and control of thermal systems.

Digital twin-based smart heating system with a condensing boiler

Volodymyr Voloshchuk, Inna Bilous, Pavlo Novikov, Oleksandr Stepanets, Anastasiya Zakharchenko, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

Volodymyr Voloshchuk (presenter) vl.volodya@gmail.com

Condensing boilers can achieve significantly higher efficiency than conventional ones due to possibility to recover latent heat of vaporization from the flue gas. But it can be achieved when return temperature of heating system is sufficiently low (below the dew temperature of the flue gas), which directly depends on thermal modes of the heating system. Real-time monitoring energy efficiency and performance degradation of condensing boilers are of high priority too. So, development of methods and tools that can use data in real-life and have possibilities to find the most efficient modes, to detect performance changes timely is crucial for efficient operation of such system. Implementation of these methods should be based on mathematical models or simulation of the system. The model should be automatically fitted to current measurements from a real operating system.

The paper presents development of a digital twin-based smart heating system, which includes a condensing boiler.

The model taking system dynamics over the entire operating range has been developed. The proposed framework of a digital twin takes advantage of the latest technologies in IT, which could be applied for experience-based real-time information interchange between the physical system and the digital twin to achieve energy efficient operation modes of the investigated system.

It has been found that the biggest increase in boiler efficiency (by 6.6 %) can be achieved by switching to low-temperature heating systems. Applying intermittent heating is in second place in terms of the possibility of increasing boiler efficiency (up to 3.5 %). Insulation of the house also increases boiler efficiency, but less than the previous two solutions (up to 2.7%).

Keywords: Keywords: condensing boiler, heating system, dynamic model, internet of things, database, real-time measurements

Marie Therese Warnecke, a master's student in "Green Engineering" and a student assistant, specializes in district heating concepts, renewable energies, energy transition, and achieving climate-neutral building stock.

Analysing and Monitoring Building Energy Efficiency via Web Scraping of Property Listings

Abdulraheem Salaymeh 1,2), Marie Therese Warnecke1), Bilal El Haj 3), Irene Peters 2), Stefan Holler 1)
1)HAWK University of Applied Sciences and Arts
2)HafenCity University Hamburg
3)FH Aachen

Marie Therese Warnecke (presenter) marie.warnecke1@stud.hawk.de

In the contemporary digital landscape, data is evolving into a key asset in various markets. Particularly, online real estate platforms serve as significant repositories, furnishing extensive datasets encompassing key property attributes such as price and size. These datasets can be invaluable for energy efficiency analyses of buildings, addressing limited documentation and database inadequacies at high spatial resolution.

This article examines web-scraping techniques in recording real estate ads for energy analyses, aiming to open up new data sources and close data gaps. It evaluates data utilisation, efficacy, and discusses the associated challenges.

In our analyses, we utilise a database comprising more than 5 million records, aggregated from multiple property portals since 2015, containing key attributes on buildings including construction year, living space, heating systems, energy sources, and energy performance classes. This database continues to be supplemented with data on new properties on offer. To accomplish this task, we utilise a Node.js script leveraging the Puppeteer API to systematically retrieve data from real estate platforms. This script traverses through the web pages of real estate advertisements, extracting specific information from distinct sections of the website, denoted in the code as "siteBox", "sizeBox", "priceBox", and "energyBox". Subsequently, the extracted data is stored in JSON files, each named according to city names, ensuring all data is organized in a machine-readable format.

The findings indicate that certain users on real estate platforms neglect to furnish information regarding the energy performance certificate, particularly evident in cases of “worst-performing buildings” such as (G, H), despite legal mandates requiring its disclosure in real estate advertisements. Moreover, challenges stemming from the inconsistent terminology

used for energy sources and heating systems on these platforms were underscored. Additionally, employing web scraping techniques offers significant time-saving benefits in data collection compared to traditional survey methods such as interviews, facilitating the acquisition of up-to-date data on an ongoing basis.

Keywords: Web Scraping, Real Estate, Energy Efficiency

Samanta Alena Weber is a researcher in sustainable thermal energy systems, with a focus on enhancing energy efficiency. She currently works on the application of Machine Learning in the context of heat systems to identify potentials for flexibilization and optimization with data-driven approaches.

Feature Engineering for Machine Learning to predict heat networks on the end-user level

Samanta Alena Weber, Institute for Energy Process Engineering and Fuel Technology, Clausthal University of Technology, 38678 Clausthal-Zellerfeld, Germany

Michael Fischlschweiger, Chair of Technical Thermodynamics and Energy Efficient Material Treatment, Institute for Energy Process Engineering and Fuel Technology, Clausthal University of Technology, 38678 Clausthal-Zellerfeld, Germany

Dirk Volta, Energy and Life Science, University of Applied Sciences Flensburg, 24943 Flensburg, Germany

Jens Geisler, Energy and Life Science, University of Applied Sciences Flensburg, 24943 Flensburg, Germany

Samanta Alena Weber (presenter)

Modeling of heat networks with enhanced predictive quality enables tailored sector integration and raising system flexibility. For instance, it opens the potential for lowering the supply temperature, which implicates heat savings and leads to increased exploitation of low-value heat sources while costs of energy distribution are decreased. With sufficient data and the most suitable input variables, data-driven models have been proven very effective for heat load prediction in the past. However, establishing data-driven models is particularly case-specific. This requires an individual application-specific approach, which typically leads to excessive iterative processes. To further overcome the challenge of time and resource-intensive working steps, in this work, we propose an approach that rests on the automation of data preparation and hyperparameter optimization in the context of heat network modeling. Therefore, domain knowledge of thermal energy systems is combined with Statistical and Machine Learning-based estimators to determine the most sophisticated set of predictors for forecasting the supply parameters: volume flow, supply, and return temperature, on the end-user level. This is exemplified based on reference data obtained from a model region in northern Germany. Furthermore, based on the identified predictors and the reference data from the model region, an optimized Long Short-Term Memory (LSTM) model is applied. This allows the discussion of limits and chances of Statistical and Machine

Learning-based feature engineering in heat network predictions on the end-user level based on LSTMs. This work further contributes to the fundamental understanding of heat systems and their influencing factors, as well as the prediction of network parameters such as demand. This knowledge is essential for the further development and implementation of smart energy system integration, and it helps to identify potentials for flexibility and optimization that lead to increased efficiency.

Keywords: Data-driven modeling, Thermal energy systems, Deep Learning, District heating

Planning and organisational challenges for smart energy systems and district heating

Nermina Abdurahmanovic is a research associate and PhD candidate at Fraunhofer Institute for Energy Economics and Energy System Technology focusing on optimisation and digitalisation of district heating systems through simulation modelling and customer engagement strategies.

Enhancing Energy Efficiency through User Engagement and Behaviour Change: A review on gamification approaches and serious games in energy systems

Nermina Abdurahmanovic, Fraunhofer Institute for Energy Economics and Energy System Technology (IEE), Anna Cadenbach, Fraunhofer Institute for Energy Economics and Energy System Technology (IEE)

Nermina Abdurahmanovic (presenter) nermina.abdurahmanovic@iee.fraunhofer.de

District heating systems (DHS) are crucial for achieving the goals of the Paris Agreement on climate change, as they can transition to carbon-neutral, renewable energy systems and play a significant role in climate neutrality efforts. By incorporating renewable energy sources, advanced technologies, and digitalisation, DHS have the potential to become significant contributors to sustainable energy systems. However, it is important to recognize that purely technical solutions are insufficient to optimize DHS. End-user behaviour has a significant impact on the system and can affect its performance. Thus, prioritising customer engagement strategies and fostering cooperation with consumers are crucial to realizing the full potential of DHS and achieving climate neutrality in the heating sector.

This study explores the potential of gamification as an effective method for engaging end users and optimising district heating systems. While gamification has demonstrated success in various fields for education and engagement, its potential in district heating systems requires further investigation. To address this, the study conducts a comprehensive literature review on gamification in different technical fields, focusing on its application in smart energy systems and district heating systems.

The study examines various gamification elements and techniques and analyses case studies and examples of gamification implementation in energy systems. Furthermore, it evaluates the potential impact and benefits on user engagement and energy consumption patterns in heating systems, including increased energy efficiency, reduced costs, and enhanced user satisfaction . Additionally, the study identifies the challenges and limitations associated with implementing gamification in district heating systems and explores the use of technologies like artificial intelligence and machine learning to overcome them. These technologies enhance user engagement by analysing and predicting user behaviour and preferences.

By doing so, this research aims to identify research gaps and potential advancements in gamification techniques for district heating systems, to optimise system performance and enhance digitalisation.

Keywords: Gamification, district heating systems, user engagement, behaviour change, energy efficiency

Professor Andra Blumberga works for the Institute of Energy Systems and Environment, Riga Technical University. Her main research interests are energy efficiency, both from the technical and policy sides, and system dynamics modelling.

Overcoming sociotechnical challenges: How to model the probability of investing in climate-friendly energy technologies

Andra Blumberga, Pal I.Davidsen, Ritvars Freimanis, Dagnija Blumberga, Girts Bohvalovs
Institute of Energy Systems and Environment, Riga Technical university

Andra Blumberga (presenter) andra.blumberga@rtu.lv

The energy transition toward carbon neutrality is highly complex. The smart energy system has to replace traditional linear energy system by integrating various sectors, and involving a significant number of stakeholders. Many well-established energy modelling tools exist to advise policymakers on energy transition. Energy research needs to be complemented by a perspective of social sciences and humanities to ensure the diffusion of renewable energy resources (RES) and energy efficiency (EE) technologies. Their research adds up behavioral motivations, the boundaries of social acceptance of the energy transition, and a decision-making structure based on traditions, values, habits, attitudes, and beliefs. Changes in energy behavior are critical to supporting a societal transition towards a low-carbon and sustainable future. Barriers to EE and RES prevent energy consumers from adopting EE and RES technologies and changing their behavior as people might be seen as obstacles rather than creators of EE. Many policies to overcome these barriers have been adopted and implemented worldwide. Although most current policy tools focus on the context of decision-making, such as technology market development and market failures, the behavioral aspects are as important as cost-related issues and should be addressed by the policies. Therefore, policy interventions should be developed by a diverse range of experts based on a multi-faceted approach to the sociotechnical challenge.

In this study, psychological studies and theories about pro-environmental behavior and energy consumers' behavior were used as the basis for the energy model structure supplementation with the decision-making structure. This study investigated the probability of investing in RES or EE in the Bass diffusion model. A system dynamics model was built in Stella Architect to reflect non-linearity, delays, and feedback present in the real-life system. The structure of the model was filled with data from non-renovated and renovated buildings in the residential sector. Results show how the model's structure proposed in the study may help to address behavioural factors in the simulation models and assess their impact on the diffusion of EE and pathway towards energy neutrality.

Keywords: energy modelling, energy consumers' behaviour, system dynamics, technology diffusion

Stine Bülow is finalizing her Master of Science in Engineering degree in sustainable energy and energy systems analysis at the Technical University of Denmark. Her key areas of interest are integrating renewable energy sources and optimizing energy systems using mathematical modeling.

Decision Making under Uncertainty in Coupled Multi-Energy Systems

Stine Bülow, Technical University of Denmark.
Thea Elisabeth Hein Petersen, Technical University of Denmark.
Henrik Madsen, Technical University of Denmark.
Georgios Tsaousoglou, Technical University of Denmark.

Stine Bülow (presenter) stinebulow@hotmail.com

Smart energy systems provide a foundation for a sustainable and efficient future society. By considering the integrated operation of multiple energy carriers, these systems can enhance their efficiency and ability to adjust to uncertainties like weather conditions and user behavior. However, making informed decisions in smart energy systems with complex operational interdependencies can be challenging, especially when dealing with the unpredictability of renewable energy production. Moreover, energy systems are critical and socio-technical systems, necessitating safety, transparency, and explainability of operational decisions. This paper considers a coupled multi-energy system, including electricity, heat, gas, and hydrogen, where operational decisions must be made sequentially and under uncertainty. The solution concept takes the form of a policy, i.e., a method for making operational decisions in the system as new information about the uncertainty becomes available. To approximate optimal and accountable decisions, the paper presents a stochastic look-ahead policy where the system's uncertainty is simulated through a probabilistic forecast and captured and clustered into a finite set of scenarios that can be used in a multi-stage stochastic program. The policy's performance is evaluated empirically on a realistic case-study system.

Keywords: Decision Making under Uncertainty, Coupled Multi-Energy Systems, Economic Dispatch, SDG 7 - Affordable and Clean Energy, Stochastic Optimisation, Sequential Decision Making

Max Guddat works for PlanEnergi as a consultant in energy planning and district heating. Originally from the Danish Minority in Northern Germany, Max is involved in projects in energy planning in Denmark, Germany and European cooperations.

The Municipal Heat Planning Toolbox - Conceptual Approaches to Heat Planning, Based on Danish Practical Experience

Max Gunnar Ansas Guddat, Per Alex Sørensen, both PlanEnergi, Denmark

Max Guddat (presenter) mgag@planenergi.dk

Current approaches to heat planning often focus on small districts. Whilst this obviously is great for project development on the short run, not having an overview of the greater picture in a city or a region, may lead to suboptimal investments, when developing heating infrastructure. Municipal heat planning addresses this issue and has been practiced in Denmark since the 1970's. This has led to high shares of district heating and low socioeconomic costs in the heat supply.
Only few other countries have the same history for heat planning and the thresholds for starting a heat planning process may be large. To inspire local authorities in how to approach heat planning, a toolbox has been developed focusing not only on the available tools for (thermal) energy planning, but also the core boundary conditions to put in place like organizational aspects (within the project group, stakeholder identification and split of work between the project partners and external partners) and the establishment of the planning process in the organization to ensure the plan does result in project development and iterations, rather than just ending it's life on a shelf.
The heat planning process described in the toolbox is split into four phases: 1) Preparing the Ground, 2) Mapping, 3) Scenario Analyses and 4) Plan and Implementation. Core results of this structure are to a) have the necessary local capacity building and organizational aspects of new planning processes addressed (phases 1 and 4), but also to ensure process and make sure that the calculations proceed even though better/perfect data may be still be "around the corner", as it sometimes may be better to have a plan than metered data for five years for every single dwelling (may be expensive and exhaustive and hence have the opposite effect).
The original aim for the toolbox was to give an overview of existing tools for energy planning, but during discussions it became clear that the need for explaining concepts and processes was more important than what tool to use for the calculation part. The toolbox has originally been developed for the regional energy agencies in Baden-Württemberg (DE) but has since been presented to other municipalities and authorities in Germany (incl. dena) and other European countries.

Keywords: Heat Planning, Organization, Stakeholder Involvement

Gareth is Managing Director of FairHeat, a leading energy consultancy in the UK, with wide experience of the UK heat network market. Recently, he has been acting as Lead Technical Author for the Heat Network Technical Assurance Scheme in the UK, working on behalf of the UK & Scottish Governments.

Upcoming changes to heat network regulation in the UK – overview of the Heat Network Technical Assurance Scheme

1) Gareth Jones, Managing Director at FairHeat; and 2) Lucy Sherburn, Senior Engineer at FairHeat

Gareth Jones (presenter) gareth.jones@fairheat.com

Heat networks are a key part of the UK Government's strategy to reach net zero emissions by 2050. The heat network market is expected to grow rapidly, and the Government is supporting its growth with financial support and a new regulatory regime.

This new regulatory regime puts UK heat networks on a trajectory to become a regulated utility in 2025, similar to gas and electricity. This includes regulation of heat networks by Ofgem, the introduction of minimum technical standards, consumer protection measures and the introduction of heat network zones. These are very significant changes for the heat network sector in the UK.

It is essential that the new regulatory framework is underpinned by robust technical standards to ensure high performance and good consumer outcomes. Over the last 18 months, work has been undertaken to develop a Heat Networks Technical Assurance Scheme that will provide the necessary governance, structures, procedures, and standards required to assess and certify heat networks in the UK.

In summary, the scheme (HNTAS) is a performance based assurance scheme, with impartial assessment of claims made by a responsible party as to whether minimum standards will be achieved or have been achieved, in order to ensure that certain performance outcomes are achieved through the design and construction process and maintained during operation.

The scheme covers all types of heat networks (communal, district, 4th generation, 5th generation and cooling), and will assess and certify identifiable elements of a heat network. The heat network elements are the following: Energy Centre, District Distribution Network, Substation, Communal Distribution Network, Consumer Connection, and Consumer Heat Systems.

Assessment will occur throughout the development of a heat network, with 8 assessment stages from feasibility, design through construction and into operation, with Certification at the end of commissioning and again 2 years into operation.

In summary, this work provides an overview of the upcoming regulation within the heat network sector in the UK and work to date in developing the Heat Network Technical Assurance Scheme.

Keywords: Heat networks, district heating, certification, assurance scheme, regulation, industry standards, key performance indicators

Alwina Kaiser is an environmental and civil engineer specializing in sustainable heat supply systems. She focuses on integrating stakeholder input into decision-making processes, advancing municipal heat transition strategies under Germany's Heat Planning Act.

Bridging the Implementation Gaps: A Multi-Criteria Decision Support Approach for Enhancing Municipal Heat Supply and Social Acceptance

Alwina Kaiser, 1 University of Kassel 2 Fraunhofer Institute for Energy Economics and Energy System Technology, Friedrich Krebs, 1 University of Kassel 2 Fraunhofer Institute for Energy Economics and Energy System Technology, Anna Marie Cadenbach, Fraunhofer Institute for Energy Economics and Energy System Technology

Alwina Kaiser (presenter) alwina.kaiser@iee.fraunhofer.de

The challenge Germany faces in its heat transition is not only the implementation of efficient political measures and the creation of financial incentives but also overcoming local social and structural barriers. These barriers significantly hinder acceptance and implementation speed, especially due to uncertainties, information deficits, and the exclusion of citizens from decision-making processes. In accordance with the german Heat Planning and Decarbonization of Heat Networks Act (WPG), we present a practice-oriented decision support tool that enables a transparent evaluation and comparative assessment of alternative heat supply solutions for city quarters. The purpose of the tool is to contribute a comprehensible fact base for a participation process involving all relevant stakeholders, including citizens.

The decision support tool draws on methods from Multi-Attribute Decision-Making such as the Simple Additive Weighting (SAW) method, among others, and was developed in an ongoing research project. In a first step we identified relevant criteria of heat provision scenarios in collaboration with stakeholders. A structured dataset and evaluation framework has been established for criteria such as geotechnical data, building data, economic data, and land dimensions on both qualitative and quantitative bases. The criteria include economic and ecological factors as well as qualitative aspects such as operational comfort or regional value creation. All criteria are rated on a five-point scale, with quantitative data normalized and qualitative data systematically categorized. This methodology allows the comparison of alternative heat provision scenarios based on the defined criteria and their systematic assessment against the current status quo. Preliminary results indicate that in the project area, low-temperature heat networks and combined solutions of decentralized plants and heat networks perform best in the overall evaluation. These evaluation results are intended to be iteratively adjusted through specific weightings during the stakeholder dialogue during an upcoming stakeholder workshop. Subsequently, processes are to be bundled and automated in a tool to achieve profound improvements in decision-making in the domain of municipal heat supply.

Keywords: Heat Transition, Decision Support Tool, Multi-Attribute Decision-Making, Multi Criteria Decision Analysis, Social Acceptance, Municipal Heat Supply

Nina Kicherer is a research associate at the District Heating research team at the Hamburg University of Applied Sciences. Within the research team, she focuses on transformation strategies for existing district heating systems as well as economic and organizational aspects of the transformation.

Three heat marketplaces for the cost-efficient integration of renewable heating plants into district heating systems

Nina Kicherer, Hamburg University of Applied Sciences; Olessya Kozlenko, Hamburg University of Applied Sciences; Peter Lorenzen, Hamburg University of Applied Sciences

Nina Kicherer (presenter) nina.kicherer@haw-hamburg.de

The green transition of district heating systems (DHSs) leads to a diversified and more distributed heat production which poses technical, economic, and organizational challenges for their future operation. To tackle these challenges, the research project "Integrierte Wärmewende Wilhelmsburg – IW3" developed a market-based approach for a cost-effective integration of heating plants into DHSs. The presented approach can be used as a novel optimization method to combine long-term investment and short-term operational planning processes considering physical network restrictions such as temperature and pressure in the price formation.

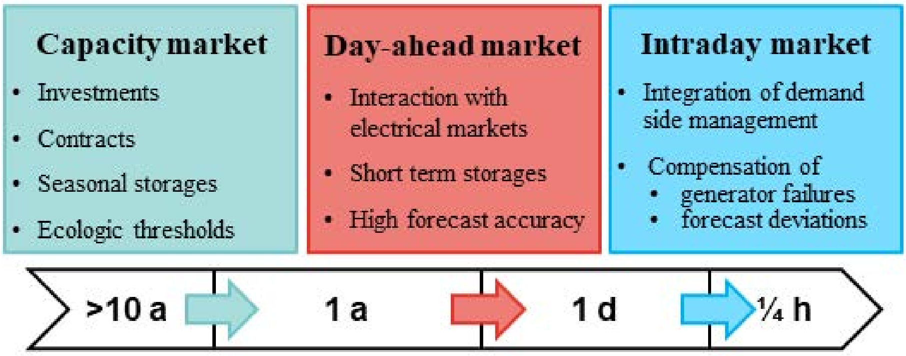
The implementation of the heat market is based on a market cascade that includes three connected marketplaces: a Capacity Marketplace for the long-term planning and a Day-ahead and an Intraday Marketplace for the short-term dispatch.

The Capacity Marketplace contains five steps from determining and tendering the necessary capacities to choosing the technically feasible and most cost-efficient heating plants and designing the contracts. The individual steps are supported with digital tools, such as an OpenSource heat planning tool for the first layout of the DHS supply and a simulation tool to identify viable concepts for the DHS.

The Day-ahead and Intraday Marketplaces are implemented as a smart market approach, considering physical impacts of the heating plants and the network. Most importantly, the impact of heat grid losses, temperature and pressure on the DHS has been included in the price clearing for a more accurate representation of the overall costs of the heat supply. A bid generator has been developed to determine prices for the bids of different heating plant types depending on temperature level and amount of the delivered heat.

The presented heat market demonstrates an alternative approach for a cost-efficient allocation of heating plants in DHSs taking into consideration the specific conditions and restrictions of a grid-based heat supply. It can serve both long-term planning to secure a renewable, secure supply and a cost-effective short-term dispatch of the available heating plants.

Keywords: district heating systems, heat market, smart market, optimization



Dr. Hironao MATSUBARA is chief researcher of Institute for Sustainable Energy Policies(ISEP) in Tokyo, Japan. His research fields are statistics database, scenario study, policy framework and business model of renewable energy in Japan.

Challenges in Planning and Implementing Decarbonized Advanced Areas in Japan

Hironao Matsubara, Makoto Tajima, Tetsunari Iida, Institute for Sustainable Energy Policies

Hironao Matsubara (presenter) matsubara_hironao@isep.or.jp

While various measures are being implemented in Japan to achieve carbon neutrality by 2050, 74 regions have been selected by the national government (Ministry of the Environment) by the end of 2023 as areas that will achieve decarbonization by 2030, and the implementation of smart energy systems has begun. The implementation of smart energy systems has begun. This report discusses the current status and efforts of regions in Japan to decarbonize, measures to achieve this goal, and future prospects for each region, and examines trends and challenges in each region. As specific target areas for decarbonization and realization of regional issues, this report will report on the implementation of plans in Ogata Village, Akita Prefecture and Sosa City, Chiba Prefecture. In Ogata Village, a district heating system that utilizes rice husks, a local biomass resource, as fuel and a solar power using PPA scheme, etc. are planned and introduced by a regional energy company. In Sosa City, Chiba Prefecture, plans are also underway for on-site PPA using solar power and batteries, and off-site PPA through an agrivoltaics system centered on a regional energy company.

Keywords: Smart energy system, Decarbonization, PPA, District Heating, Agrivoltaics, community power

Bent Ole Gram Mortensen is a professor of energy and environmental law. His research focuses on the regulation of energy and utility companies, district heating and cooling, power supply, renewable energy.

Framework for Energy Data Spaces - Let's share energy data for a greener future

Bent Ole Gram Mortensen, University of Southern Denmark. Lisa Hjerrild, University of Southern Denmark

Bent Ole Gram Mortensen, Lisa Hjerrild (presenter) bom@sam.sdu.dk

Energy data can play a crucial role in informing policy decisions, guiding investments, optimizing energy systems, and promoting sustainable development, security of supply and climate goals. To policymakers, regulators, and industry, data analytics has become a trusted partner in decision making throughout the energy sector.

But how do legal frameworks support access to better data analytics? Or will the legal frameworks be a barrier to further developments in the energy sector?

This abstract explores the legal complexities surrounding energy data spaces and open energy data spaces including issues related to data privacy, security, and interoperability. It examines the challenges posed by existing legal frameworks, such as the General Data Protection Regulation (GDPR) and the recent European data acts, such as NIS II.

First, with the increasing use of smart meters and home energy monitoring systems, detailed information about households' energy consumption patterns can be collected. This data may reveal personal habits, routines, and lifestyle information, raising concerns about privacy hence the potential (ab)use of the data by third parties. Furthermore, energy data collected from smart grids or energy devices may include location information, such as the geographic coordinates of a residence. This can potentially reveal personal details about individuals' whereabouts and daily activities. The complexity of energy data space concerns of the legal basis or appropriate anonymization techniques when consumption, and personal location data is accessible through energy data spaces.

Second, Access to energy is a crucial element of our daily life and is by the EU considered to be a key and critical infrastructure along with transport, digital infrastructure, drinking water, health etc. It's will therefore be necessary to consider which energy data to be relevant for (open) energy data spaces . With the NIS II-directive a baseline is set out for cybersecurity risk-management measures and reporting obligations across the sectors that fall within its scope. Data quality and liability is a key factor to reliable data spaces. Though the general mean accountability we investigate different options of ownership to energy data spaces and how pitfalls can be avoided.

Keywords: Energy data, open data, AI, artificial intelligence, NIS II, EU, privacy, security, interoperability, purpose

Gianmarco Preso is a Phd Student at the Energy Department of Politecnico di Torino. His research focus on modelling and optimization of district heating network, with the goal of converting existing networks as efficiently as possible.

Scenario analysis for efficient transition of a district heating network – Case study in Göttingen

Gianmarco Preso, Politecnico di Torino
Elisa Guelpa, Politecnico di Torino
Vittorio Verda, Politecnico di Torino
Dmitry Romanov, HAWK University
Stefan Holler, HAWK University
Johannes Pelda, HAWK University

Gianmarco Preso (presenter) gianmarco.preso@polito.it

District heating networks are essential for modern urban planning as cities aim to enhance energy efficiency and decrease carbon emissions. These networks efficiently distribute heat to both residential and non-residential buildings. To achieve this, the networks must be integrated with renewable energy sources, waste heat, residual heat from industries, and efficient CHP systems. This study uses a modeling approach to perform a scenario analysis of a real network in the north campus of the Göttingen University. The goal is to guide decision-making in prioritizing consumer refurbishment within district heating systems, aiming for a more efficient to lower supply and return temperatures. The study establishes a range of scenarios, starting with the district heating network's current configuration. Additional scenarios are then developed, integrating renewable energy sources into the network. The district heating network's behavior and performance are simulated under various scenarios using detailed network modeling. This analysis considers factors such as variations in consumer demand and reductions in supply temperature to generate a range of plausible future scenarios. The findings offer valuable guidance for decision-makers and stakeholders involved in managing and planning the transition of district heating networks. This enables them to make informed choices and develop resilient strategies for the future.

Keywords: modelling, consumers refurbishment, renewable energy sources, pumping power, heat losses, district heating transformation, heat supply system

Adithya Ramachandran is a doctoral researcher at the Pattern Recognition Lab at FAU, Germany. His research focuses on developing innovative AI-based solutions and approaches within the field of utilities to enhance efficiency, reliability, and sustainability.

Unveiling Consumer Behavior in District Heating Network: A Contrastive Learning Approach to Clustering

1) Pooja Basak, Adithya Ramachandran, Andreas Maier, Siming Bayer 2) Friedrich Alexander University, Erlangen

Adithya Ramachandran (presenter) adithya.ramachandran@fau.de

The rapid integration of Information and Communication Technology (ICT) and the widespread adoption of smart meters in District Heating Networks (DHNs) offer significant potential for optimizing heat demand and operational efficiency. This study delves into the effectiveness of Contrastive Learning, a self-supervised representation learning technique, in addressing the need for clustering end-consumers within DHNs based on their heat consumption behaviors, departing from conventional strategies centered on property types. Although segregating consumers by property type may appear intuitive, it overlooks the role of demand-based factors, making it suboptimal for resource management and operational planning tasks. Leveraging weekly load profiles derived from smart meter data and contrastive learning, we uncover subtle differences in behavioral patterns among end-consumers by learning similarities and dissimilarities in the representational space. Using the heat consumption data of end-consumers from a Danish District Heating Network, we demonstrate the ability of contrastive learning models to learn representations of consumption patterns in latent space for the downstream task of end-user clustering. Additionally, we examine the resulting user clusters based on consumption patterns alongside property type clusters to identify end consumers exhibiting deviations from expected consumption behaviors associated with their respective property types. Quantitative evaluation metrics of precision, recall, and F1-score are employed to interpret obtained clusters. Through qualitative analysis, we advocate the need to complement existing knowledge of consumer groups with data-driven approaches to gain deeper insights into consumption patterns, Our methodology contributes to more efficient and sustainable energy management practices within DHNs, with profound implications for improved pricing policy formulation, optimized end-consumer engagement, and accurate heat forecasting.

Keywords: Contrastive Learning, Clustering, Heat Consumption, end consumers, behavioral analysis

Vedant is a final year MS Energy Systems student in UC Davis' Energy Graduate Group. He has worked on load flexibility, clean power procurement, and carbon abatement economics as a researcher in Professor Kelly Kissock's industrial decarbonization research group.

Industrial Load Flexibility in California: Challenges and Opportunities to Unlocking Cost And Carbon Savings

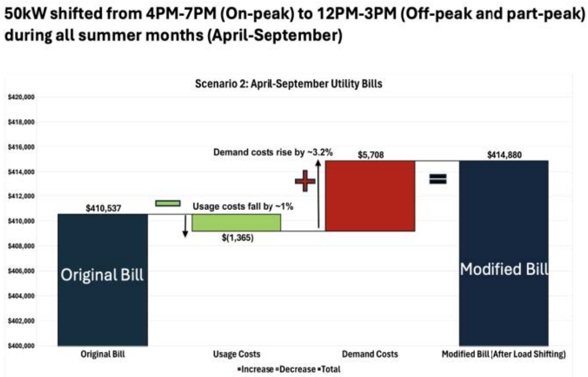
Vedant Sinha, University of California Davis. Kelly Kissock, University of California, Davis.

Vedant Sinha (presenter) vedsinha@ucdavis.edu

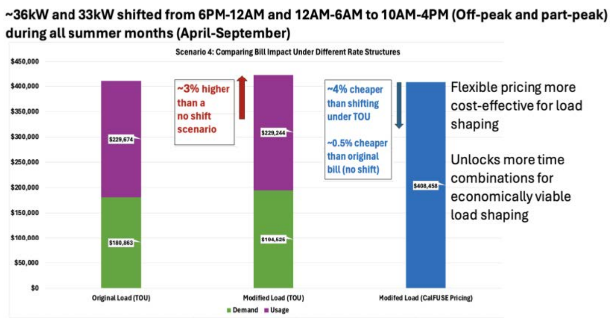
This study examines the barriers preventing California's industrial facilities from realizing the avoided electricity cost and abated scope 2 emissions benefits of demand response (load shifting and shaving). The structuring of demand charges ($/kW) in industrial time-of-use (TOU) rate schedules undermines the economic incentive for industrial demand management to reduce on-peak electricity consumption and shaping load to match hours of renewable surplus. We used Pacific Gas & Electric (PG&E's) representative load profile and rate structure of a medium industrial facility to model load shifting decisions. We then show the utility bill (cost) and carbon emissions impact of these decisions. We modeled two scenarios using the status quo TOU rate structure and two scenarios using a dynamic rate structure to show the cost and carbon benefits of switching from a TOU electricity pricing regime to a dynamic one. Our results indicate that load shifting under more flexible pricing mechanism leads to cheaper bills than TOU rates and abates up to 2 to 6 times more scope 2 emissions than shifting load under a TOU structure.

Our analysis will begin with a brief introduction to California's duck curve trend, the expected load growth from electrification of end uses and the potential cost and carbon savings as the motivation for load flexibility. Additionally, we highlighted California's policy targets and distributed energy resources as the enablers for load shifting. Following the motivations and background for our study, we described our methodology for modeling load shifting scenarios and calculating their impacts on utility bills and carbon savings using a TOU and a dynamic rate structure. In our first two scenarios, we we show how a TOU structure limits the number of possible cost-effective and high carbon abatement time combinations of load shifting. For the second scenario, we zoom into the bill for the month of June to see what drives up demand charge payments ($/kW) and wipes out the usage cost savings ($/kWh) from shifting load to low electricity cost and low carbon intensity hours. In scenario 3 and 4, we show the load shifting flexibility, cost savings, and carbon abatement that is unlocked by a dynamic pricing structure.

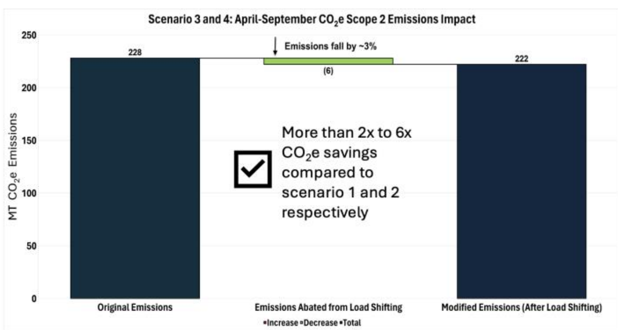
Keywords: Load flexibility, industrial load shifting, industrial demand response, time-of-use electricity rates, demand charges, scope 2 emissions, real-time pricing, dynamic pricing



Scenario 2: Higher bills when shifting under TOU rate structure



Scenario 3: Cost Savings When Shifting Under Flexible Billing Methods



Smart energy infrastructure and storage options

He is a PhD researcher in the sustainable energy planning research group in Copenhagen. His work focuses on the holistic understanding of energy systems and in particular the role of hydrogen and electro fuels in sector coupling

Techno-economic analysis of offshore energy hubs: Enabling Europe's energy transition

Hamza Abid, Aalborg University; Brian Vad Mathiesen, Aalborg University; Poul Alberg Østegaard Aalborg University

Hamza Abid (presenter) hamzaa@plan.aau.dk

Effectively integrating large amounts of renewable energy in future energy systems forms the basis of the energy transition goals in Europe. The North-sea in Europe is a large renewable offshore wind resource that can supply both renewable electricity and renewable fuels to power the energy transition. The study analyses the different pathways of utilizing offshore energy either in the form of direct electricity onshore or via hydrogen pipelines to be supplied onshore to fulfill future hydrogen demand potentials. The results are presented for three geographical levels: Denmark, Northern-Europe, and Europe. A techno-economic feasibility of offshore energy hubs is performed and their significance in the future European energy systems is quantified.

Keywords: Energy systems, Hydrogen, electrofuels, Offshore energy hubs, energy islands, Denmark, Northern Europe, Europe

Ali Pour Ahmadiyan is a PhD candidate at NTNU, Department of Energy and Process Engineering. He is presently engaged in the design and control optimization of borehole thermal energy storage for seasonal storage of high-temperature waste heat.

Simulation and optimization of high temperature waste heat storage and recovery through a city scale borehole storage field

1) Ali Pour Ahmadiyan, Natasa Nord
2) Department of Energy and Process Engineering, Norwegian University of Science and Technology, Norway

Ali Pour Ahmadiyan (presenter) ali.p.ahmadiyan@ntnu.no

Decoupling of district heating (DH) systems from the electricity grid and integration of renewable energy sources are prerequisites for the development of resource-efficient and environmentally friendly heating systems. Waste incineration is the main source of DH in Nordic countries, especially in Norway, where it accounts for 48% of the total. Nevertheless, a significant portion of the heat generated by incineration is wasted as it is produced continuously throughout the year, while the heat demand decreases during the summer. Accordingly, a seasonal storage is required to address this mismatch by storing the surplus heat in summer and supplying in winter. Borehole thermal energy storage (BTES) has been proved to be a viable option given its favorable storage potential, flexibility is design and scalability. In this paper the feasibility of integrating a city-scale BTES field with DH network is studied. The main objective is to determine optimum design of BTES to enhance storage potential and heat recovery capability. The Nyhavna district in Trondheim, Norway, is investigated as the as the case study. The BTES charging source is the Trondheim waste incineration plant, where about 120 GWh of heat is dissipated annually due to the demand and supply mismatch. The proposed system includes waste heat incineration as the heat source, BTES as a heat sink/source of DH network in charging/discharging mode, heat pump for storage temperature elevation if required, and hourly heat demand of the residential area. A dynamic simulation model is developed to capture thermal interactions among the components under variable load conditions. The long-term thermal response of the BTES is obtained using the Python toolbox ‘pygfunction’, which is based on finite line source method. The model is further adjusted for transient analysis of BTES, taking into account the thermal resistance and capacity of water-filled BTES, which is commonly used in Nordic countries. The developed thermal model is employed to analyze different BTES field designs and charging/discharging schemes to optimize storage and recovery efficiency. The result provided enhanced design and operation parameters to achieve lower return charging flow temperature and reduced heat loss during the inter-seasonal period.

Keywords: District heating, Borehole thermal energy storage, Waste heat utilization, Thermal interactions, Borehole field design, Storage efficiency

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.

Methodological Development of a Reduced-Order Data-Driven Model from Detailed Numerical Simulations for Seasonal Thermal Energy Storage (STES)

Michael Bayer (1,2)
Curtis Meister (1)
Artem Sotnikov (1)
Abdulrahman Dahash (3)
Philipp Schuetz (1)
Heimo Walter (2)
Willy Villasmil (1)

(1) School of Engineering and Architecture, Lucerne University of Applied Sciences and Arts, Technikumstrasse 21, 6048, Horw, Switzerland
(2) TU Wien, Institute for Energy Systems and Thermodynamics, Getreidemarkt 9/302, 1060 Vienna, Austria
(3) Sustainable Thermal Energy Systems, Center for Energy, AIT Austrian Institute of Technology GmbH, Giefinggasse 2, 1210 Vienna, Austria

Michael Bayer (presenter) michael.bayer@hslu.ch

As district heating systems transition to 4th and 5th generations, the cost-effective integration of seasonal thermal energy storage (STES) becomes crucial. These storage systems require robust controls to efficiently utilize renewable energy sources and effectively stabilize heat supply. This research presents a methodology for developing a data-driven model derived from numerical, multi-physical simulations, specifically tailored for optimizing seasonal thermal energy storage. By employing a grey-box modeling approach, this work merges empirical data from detailed multi-physics outputs with physical principles of energy systems. This hybrid model captures the complex dynamics involved in STES while maintaining computational efforts as minimum, making it suitable for real-time control.
The model simplifies complex multi-physics data into a more manageable and interpretable form, maintaining essential dynamics for accurate predictions. It is integrated into a Modelica environment, enabling dynamic interaction with various components of district heating networks and facilitating system simulations. This integration helps adapt to the fluctuating demands of energy systems and supports the extensive simulations needed by modern infrastructures.

Validation of this model against the original multi-physics data confirms its accuracy under diverse operational conditions. The validation process involves the comparison of model outputs with detailed, multi-physics results in key STES metrics, ensuring that the model accurately reflects real-world behavior and can predict system dynamic responses effectively.
The development, integration, and validation of this model provide a systematic approach to improving computational strategies for energy storage systems. This paper discusses the methodology used in model development, the integration technique into existing simulation platforms, and its validation.

Keywords: STES, seasonal thermal energy storage, reduced-order modelling, modelica,
grey-box modelling, data-driven modelling

Fabian Borst, M. Sc., born in 1996, studied Mechanical Engineering at the TU Darmstadt. Since 2020 he has been working as a research assistant at the Institute for Production Management, Technology and Machine Tools in the field of energy-optimized industrial heating and cooling systems.

Managing Complexity in Industrial Heating and Cooling Systems: A Local Energy Market Framework for Transactive Control with Technical Constraints

Fabian Borst, Michael Frank, Lukas Theisinger, Matthias Weigold, Institute of Production Management, Technology and Machine Tools at Technical University of Darmstadt (Germany)

Fabian Borst (presenter) f.borst@ptw.tu-darmstadt.de

The global efforts on decarbonizing the industrial sector poses major challenges for energy-intensive companies. Here, companies with large heating and cooling demands are particularly affected, as these demands are mainly covered by fossil fuels. This leads to the integration of renewable energy converters, storages and waste heat sources, increasing the complexity of industrial heating and cooling systems. Subsequently, the number of possible operating states rises, which challenges developing an energy-optimized and resilient control strategy while meeting requirements on scalability and implementation effort. For power systems, these challenges are faced by decentralized, transactive concepts. Here, multi-agent systems based on local energy markets enable the self-coordinating and ressource-efficent system operation. As we see similiar challenges in industrial heating and cooling systems in the future, we aim at transferring this approach. Furthermore, current research lacks holistic approaches which consider, in addition to the market design, the bid creation phase and the execution of clearing results considering technical constraints. Therefore, we present a local energy market framework to model the subsystems of industrial heating and cooling systems as market participants using consistent design patterns. After the initial definition of the system structure, a supervisory control strategy based on a market-driven multi-agent system is instantiated automatically. The resulting framework enables then the autonomous trading of multiple products as well as the execution of market clearing results using different energy forecasting and risk models. For validating our control concept, the market framework is implemented within Python enabling the interaction with virtual as well as real environments. The validation is then carried out both virtually using a dynamic simulation model and in real-world experiments for a small-scale thermal energy system of the ETA Research Factory at the Technical University of Darmstadt. Apart from defining the energy system structure, our approach almost eliminates the implementation effort compared to the benchmark of a centralized supervisory control concept.

Keywords: transactive energy, local energy market, energy market design, supervisory control, field test, dynamic simulation

William Delgado-Diaz is part of the Competence Center Thermal Energy Storage (CCTES) at HSLU and PhD Student at the Laboratory of Renewable Energy Science and Engineering (LRESE) at EPFL. His current research focuses on latent heat thermal energy storage at both component and system level.

Hybrid seasonal heat storage systems using phase change materials: Economic and Environmental Optimization

William Delgado-Diaz, Lucerne University of Applied Sciences and Arts (HSLU), Swiss Federal Institute of Technology in Lausanne (EPFL)
Marcel Troxler, Lucerne University of Applied Sciences and Arts (HSLU)
Willy Villasmil, Lucerne University of Applied Sciences and Arts (HSLU)
Reto Hendry, Lucerne University of Applied Sciences and Arts (HSLU)
Philipp Roos, Lucerne University of Applied Sciences and Arts (HSLU)
Rebecca Ravotti, Lucerne University of Applied Sciences and Arts (HSLU)
Anastasia Stamatiou, Lucerne University of Applied Sciences and Arts (HSLU)
Jörg Worlitschek, Lucerne University of Applied Sciences and Arts (HSLU)
Sophia Haussener, Swiss Federal Institute of Technology in Lausanne (EPFL)

William DELGADO-DIAZ (presenter) williamorlando.delgadodiaz@hslu.ch

The increasing implementation and integration of renewable energy sources into the global energy system requires a substantial enhancement in renewable energy-based heat production and seasonal heat storage capabilities to mitigate reliance on the grid. Considering that thermal grids and district heating networks are primary but limited solutions, our research explores innovative strategies for locations beyond the reach of these systems.

This study focuses on optimizing a Seasonal Hybrid Thermal Energy Storage (SHTES) system that combines water and encapsulated Phase Change Materials (PCMs) integrated with photovoltaic (PV) panels and a heat pump (HP) to provide services for a multifamily house, aiming to maximize thermal self-sufficiency while minimizing both the Levelized Cost of Heat (LCOH) and Global Warming Potential (GWP).

Our research utilized numerical modeling and a black-box optimization routine (NOMAD) to analyze system configurations under various scenarios, ensuring a thorough assessment of the performance of system parameters such as storage volume, PCM capsule configuration, PV peak power, and heat pump power. The study explored various storage tank scenarios as viable storage concepts, each providing distinct advantages in terms of cost, installation complexity, and environmental sustainability.

Employing Pareto fronts and statistical methods, we clarified the influential factors in system performance and highlighted the pivotal role of storage capacity, PCM configuration, PV peak power, and heat pump capabilities in influencing system performance, cost-efficiency, and environmental impact.

Our findings underscore the potential of hybrid thermal storage systems in providing a scalable and economically feasible alternative pathway to traditional heat storage methods. As technology and market conditions evolve, the efficiency and viability of these systems are expected to improve, further supporting the transition to renewable energy sources.

Keywords: Seasonal Hybrid Heat Storage, Phase Change Materials, Photovoltaic Systems, Heat Pumps, Global Warming Potential, Levelized Cost of Heat.

Jes Donneborg is Senior Vice President at Aalborg CSP and has worked within the renewable industry for more than 20 years, developing various renewable project installations ranging from solar thermal system and PV plants over air collector systems to domestic hot water and heat pump installations.

Energy on Demand - A Renewable Sector-Coupling Energy Park

Jonas Ilum Sørensen, Aalborg CSP A/S.
Jes Donneborg, Aalborg CSP A/S

Jes Donneborg (presenter) jdo@aalborgcsp.com

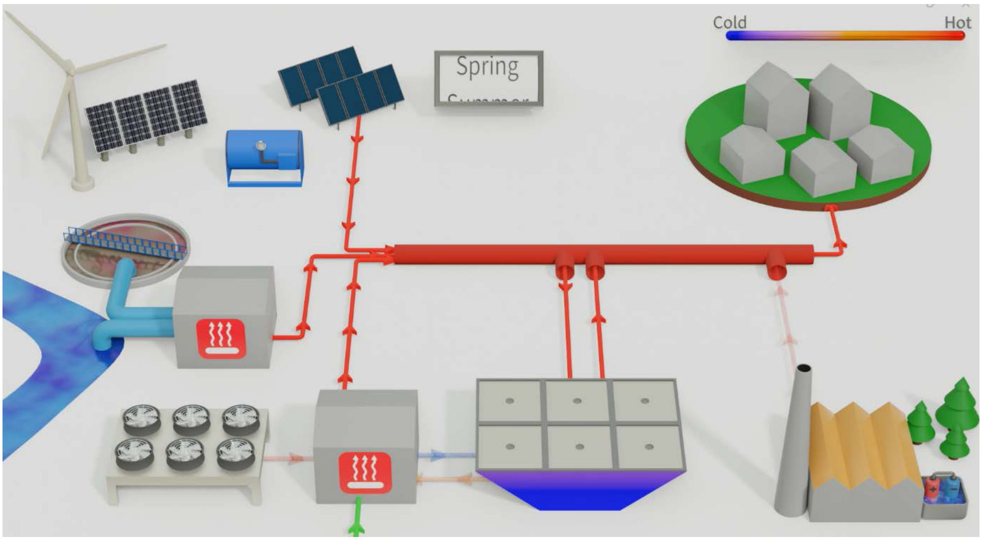
District heating networks are being revolutionized through the implementation of renewable energy sources and the capture of waste or excess heat, utilizing sector-coupling between electricity and heat. District heating companies aim at providing their consumers with both low-cost and green heat on demand, ensuring both security of supply and resilience against volatile fuel prices.
Renewable sector-coupled energy parks emerge as the key solution to this changing energy landscape, utilizing available local heat sources and integrating them to supply the heating grid with on-demand heating energy.
A renewable energy park as such requires deployment and utilization of various renewable technologies for both heating and electricity capacities, including:

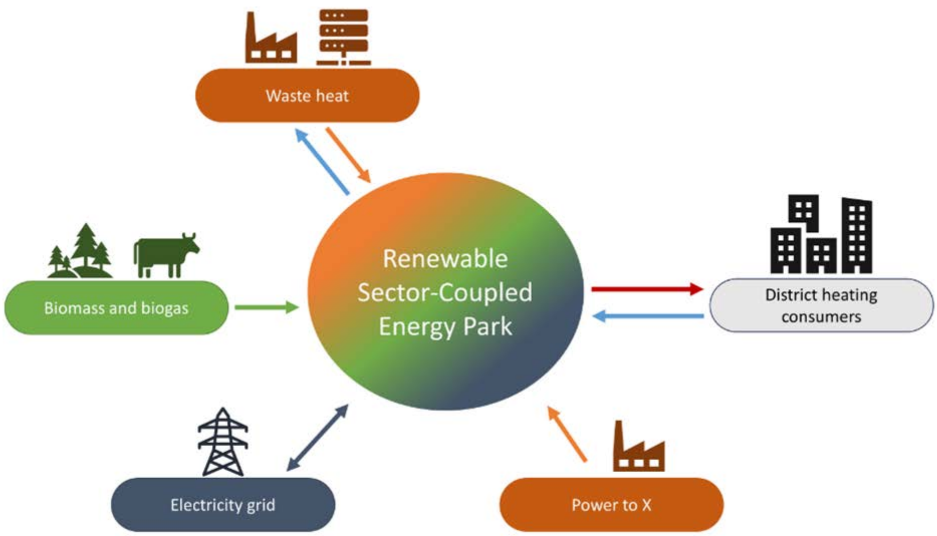
- Heat storage: Daily/weekly/seasonal
- Power-to-Heat: Electric heat pumps and boilers
- Solar thermal
- Waste heat: Industry, datacenters etc.
- Combustion: Biomass, biogas, waste incineration
- Photovoltaic panels
- Wind turbines
- Etc.

Working with renewable heat necessitates bridging gaps between periods of sunshine/no sunshine, wind/calm, and waste heat availability/production downtime. Energy storages will bridge these gaps. Renewable energy parks combining energy storage and renewable technologies is the missing link between today's fossil heating of district heating grids and the renewable heating of tomorrow.
At the heart of the energy park is the Pit Thermal Energy Storage (PTES).
The essence of this development lies not in the technology itself, but in the integration of these technologies and the imperative to eliminate fossil fuels in the heating sector.
The transition to low-cost green heat supply is achieved by defining the right energy utilization strategy and optimizing interconnectivity between different technologies, thereby delivering the lowest possible cost of energy.

When constructed correctly, the renewable energy park can supply the district heating grid on demand with precisely the amount of heat needed, including peak load, as the storage creates a temporal link between heat supply and demand. The flexibility provided by the energy storage allows for the constant use of the most cost-effective heat source.

Keywords: Renewable energy, energy on demand, sector coupling, energy parks, district heating, Pit Thermal Energy Storages, PTES, solar thermal, heat pumps, waste heat, PV, wind turbines, biomass, biogas





Daniel Friedrich is Professor of Energy Systems in the Institute for Energy Systems in the School of Engineering at the University of Edinburgh. His current focus is on the integration of thermal energy systems into the wider energy system to achieve a net zero society.

Short Borehole Thermal Energy Storage cycles charged with otherwise curtailed wind energy

Daniel Friedrich and Thibaut Desguers, University of Edinburgh

Daniel Friedrich (presenter) d.friedrich@ed.ac.uk

To reach net zero it is crucial to achieve the complete decarbonisation of heat and to significantly increase renewable electricity generation. Long-term Thermal Energy Storage (LTES) systems can provide benefits for both the district heating customers and operation as well as the wider energy system. However, it is not trivial to achieve these benefits due to the complex interactions between different systems and stakeholders. This contribution presents modelling tools for short Borehole Thermal Energy Storage (BTES) cycles and their application to case study designs of electrified District Heating Networks (DHN) with BTES systems charged with otherwise curtailed wind energy.
BTES systems are traditionally used with solar thermal collector arrays to store abundant solar energy from the summer for winter use. By coupling the DHN with the wider electricity system and, in particular, with otherwise curtailed wind energy the BTES system needs to be charged and discharged more frequently. An example DHN with BTES system achieves high efficiencies (up to 200% due to high efficiency of heat pumps and short cycles), curtailed wind fractions above 40%, and operating costs and emissions significantly lower than for gas-reliant systems. However, the results also show a trade-off between efficiency and grid services which requires careful market and incentive design to benefit both consumers and grid operators.
A detailed numerical analysis of the BTES performance for different charge/discharge cycles shows that shorter cycles lead to increased recovery factors, energy density and storage capacity. For example, recovery factors which are around 50% for seasonal operation, can be increased to around 85% for cycle durations of several days to a couple of weeks. Improved modelling tools are needed to account for this changed operation. An analytical model is developed based on the physical processes plus a correction factor for the cycle length to account for temperature gradients and reduced heat conduction distances. This model shows excellent agreement with the numerical result for cycle durations down to a few days. The analytical model is integrated into a linear energy system model which enables the exploration of BTES systems as part of the wider energy system.

Keywords: Borehole thermal energy storage (BTES), short-cycles, system integration, whole system modelling;

Geoffroy is a French engineer, specialized in modelling, analysis and design of renewable thermal energy systems including means of heat production (solar, waste heat, heat pump, etc.) and thermal energy storage. He has been working in Denmark at PlanEnergi since 2019

Large Thermal Energy Storages (LTES) are a key element of the future energy system

Geoffroy Gauthier, PlanEnergi; Per Alex Sørensen, PlanEnergi; Wim van Helden, AEE Intec

Geoffroy Gauthier (presenter) gg@planenergi.dk

Heating and cooling accounts for half of the energy consumption in Europe and worldwide. Currently, fossil fuels dominate the thermal energy sector (accounting for about 2/3 of the heating energy worldwide1). At the same time, thermal energy (heating or cooling) is:
- Easy to produce
- Easy to store at large scale (GWh and above)
- Easy to store over long periods
- Inexpensive to store (at large scale)

Large Thermal Energy Storages (LTES) offer more flexibility in district heating systems, also adding operational flexibility to power plants and industrial processes. Furthermore, they enable a higher share of renewables and waste heat, and they can provide peak shaving functionality for electricity grids through Power-to-Heat, thus enabling sector coupling of the power and heating sector. During periods with high production of renewable electricity, heat or cold can be generated through heat pumps or electric boilers, stored, and later be reused during peak demand for heating or cooling, avoiding extra electricity demand. LTES are used by large-scale heat producers, District Heating Network (DHN) operators, as well as some industrial actors. They store heat and deliver it to a DHN, or in the case of industrial actors, the heat is used directly in industrial processes or for space heating. LTES are therefore often located at the border of the city, close to a heat production unit. The alternative to LTES is to have large peak-load heat production units to make sure the heat demand is always supplied, and extra cooling capacities for dissipating excess heat. Another alternative to LTES is flexible heat demand, or the use of individual thermal storage. All alternatives are usually more expensive and technically more complex than LTES The market for large thermal energy storages is growing, with new plants built and planned in Denmark and Germany, mostly PTES with volumes in the range of 200’000 to 500’000 m³ (in Denmark). In order to facilitate and accelerate the market uptake of these large storages, better materials and knowledge is needed to improve the service lifetime of storages, better tools are needed for designing, planning and integrating the storages and more knowledge of the potential and integration possibilities of these storages is needed for decision makers.

Keywords: Energy storage, Renewable energy, IEA, Flexibility, Large thermal energy storages, District heating

As a PhD student at Vrije Universiteit van Brussel, Jonathan Hachez focusses on 5th generation district heating and cooling network modelling and simulation. His work features heating and cooling demand modelling and combined optimization of the design and operations of multi-energy systems.

Building load profile synthesis: a stochastic approach to model building energy consumption timeseries

Jonathan Hachez, Vrije Universiteit van Brussel; Stanislav CHICHERIN, Vrije Universiteit van Brussel; Afraz MEHMOOD CHAUDHRY, Vrije Universiteit van Brussel; Svend BRAM, Vrije Universiteit van Brussel

Jonathan Hachez (presenter) jonathan.hachez@vub.be

Collecting energetic performance data from buildings for energy community planning and modeling is a challenging and elaborate task, often left to the planner’s responsibility. Our tool aims to support and facilitate this undertaking.

The modeling and composition of synthetic timeseries of heating and cooling demands of buildings, is typically approached in a deterministic way. Good examples of such approaches are the degree-day method or the regression of measured data via neural networks. As a consequence of their deterministic nature, these approaches only provide deterministic results that are solely based solely on the considered inputs without stochastic variations and are thus not capable of capturing the randomness of the data. Other methods aim to represent it as an ARMA process with noise, but no tool was found so far for such approach.

The method on which our tool is based is presented here. It represents the energy consumption timeseries as a temporal succession of normal distributions with means and standard deviations that are context dependent (related to contextual timeseries such as temperature). These parameters are estimated with historical data of both the load and its environment. Such an approach allows us to represent not only central values such as mean or median but also variations with unchanged input.

Another advantage of the method is the possibility to generate various profiles for the same a context. Indeed, as the intermediary result of our computation is a probability distribution: the generated samples are always different, allowing the computation of different possible scenarios given the same conditions, which in turn, allows to assess the robustness of a given system.

The tool allows to apply this method in a user-friendly way: it consists in a gray-box for generating representative timeseries based on a mix of sample data (measured consumption) and contextual timeseries (outdoor temperature). This tool allows the generation of load profiles for different kinds of buildings in similar contexts, therefore enabling the simulation of various consumption scenarios. The presence of peaks and gaps in the so-generated timeseries allows a proper estimation of the required assets' power.

Keywords: Load, modelling, energy consumption, stochastic, gray-box

Martin Hartvig, M.Sc. Ph.D., is a Senior Engineer at Energinet. Works on integrated renewable energy system development. Key working areas: Hydrogen/Electricity coupling, PtX, North Sea Wind Power Hub, Energy Islands, Wind/Solar synergies, Technology data, R&D with academia and industry.

Pathway 2.0: Sector coupling is a driver for offshore shore hubs and spokes

Martin Hartvig, Energinet and North Sea Wind Power Hub Consortium (Tennet DE, Tennet NL, Gasunie and Energinet)

Martin Hartvig (presenter) mhr@energinet.dk

We examine how the geographic and temporal build-out of the European on- and offshore infrastructure (electricity and hydrogen) along with offshore wind and hydrogen generation can be realized in the most cost optimal manner in the TYNDP Distributed Energy scenario; and disturbed with a series of sensitivity disturbances of the future development (e.g. of onshore PV and wind). The model is sectorcoupled and have high resolution both in offshore EEZ and on the onshore (NUTS 1&2) European system for both electricity and hydrogen.

Across all sensitivities the model invests in an offshore hub-to-hub network where the connecting spokes have a higher average utilization rate (53-74%) than offshore wind (42-54%). Compared to radial landing the hub based approach have 24% less onshore electricity landing; offshore electrolysis drives roughly 2/3 of the cable reductions needs, and the last 1/3 is due to the network utilization of spatiotemporal differences in wind across the North Sea. The landing zones play a vital role in maximizing utilization of both the onshore and offshore electricity system; the hydrogen system is a key enabler for integration of renewables. Electricity consumption by electrolysis is the largest balancing asset in the European system. The hub network resembles more transport corridors than a highly meshed network.

We find that hubs and spokes is needed to enable utilization off farshore offshore wind; and that flexible consumption is needed to allow for high utilization rate of the spoke network. Without spokes the model invests in 32GW less offshore wind and replaces it with biomass-based generation. While the hubs and spokes enable more OSW it also enables high capacity trading corridors that surpasses the capacity of interconnectors in sensitivities where the model cannot invest in spokes. More OSW supports more electrolysis and reduces the need for import; thus hubs and spokes can aid self-sufficiency of European hydrogen needs.

The most cost optimal configuration has 350GW OSW compared to ~500GW in the TYNDP DE scenario. When restrictions of onshore buildout of PV is allowed to deviate from TYNDP DE the PV capacity increase with 50% while the OSW capacity decreases to 200GW.

Keywords: Energy system model, European model, sector coupling, offshore wind power, hydrogen, renewables, electrolysis, hubs, spokes, energy islands

Kristina Haaskjold is a research scientist at IFE, Norway. She is an experienced energy system and TIMES modeler, with interests in modelling methodology and interdisciplinary collaboration. One of her research focuses is on the role of flexible energy solutions in the low carbon transition.

Value of energy storages in ancillary and energy markets in the Norwegian low-carbon energy transition towards 2050

Pernille Seljom, Institute for Energy Technology (IFE), Norway
Kristina Haaskjold, Institute for Energy Technology (IFE), Norway

Kristina Haaskjold (presenter) Kristina.Haaskjold@ife.no

This paper applies a novel methodology to analyze the value of energy storage in ancillary and energy markets with a TIMES model of the Norwegian energy system. This is relevant given the increasing needs for flexible solutions, including energy storage solutions, to facilitate integration of more variable electricity generation and increased electrification. In long-term energy system models, with endogenous investments over several decades, it is traditionally assumed that the electricity generation and energy demand are always balanced by the energy market. This is often called “perfect foresight”. Our paper demonstrates an explicit modelling approach of ancillary markets in a long-term energy system model and shows how the “perfect foresight” underestimates the need for flexible investments in energy system models. Ancillary services have a major impact on new investments in energy storages, increasing e.g., the battery capacity in commercial buildings with 292%.

The analysis builds on the ancillary service market functionality of the TIMES code to the TIMES model of the Norwegian energy system model, IFE-TIMES-Norway. The ancillary service market ensures that the electricity demand is always met after the energy market is settled, accounting for the uncertainty in production, demand, and other operational issues. A first novelty is the demonstration of an explicit modelling approach of ancillary markets in a TIMES energy system model. (Panos et al., 2019) has used the TIMES code on ancillary markets, but this paper does not present the isolated effect of including ancillary markets. A second novelty is the analysis of including ancillary markets in analyzing storage needs towards 2050 in the Norwegian energy system. The modelling builds on data from the Norwegian TSO, Statnett, on the three types of capacity reserves: primary (FCR-N and FCR-D), secondary (aFRR) and tertiary reserves (mFRR). Today, it is primarily hydropower and larger industries that contribute to these markets. In line with the anticipation of Statnett, our results show that the profitability for energy storages to provide flexible solutions to the ancillary markets increases in the future with more uncertainty in the energy system.

Keywords: TIMES model, ancillary markets, flexible resources, district heat, batteries, energy system, variable renewables, sector coupling

Richard is professor Sustainable Energy Systems at Saxion UAS and focusses his research on system integration for local, sustainable energy systems. Applied research is done in the lab, and in fieldlab experiments, concerning modelling and system validations.

Development and implementation of a Smart Energy System for local energy communities to improve sustainability and decrease electricity grid loads

Richard P. van Leeuwen, B. Homan, V. Nikolayev, R. Garcia Peran, E.W. Schaefer, F. Vercammen, J.F. Gonzalez (Saxion University of Applied Sciences); G. Hoogsteen, F.H.J.M. Coenen, J.L. Hurink (University of Twente); F. Hummelink (vereniging Aardehuizen); F. Taken (Loqio)

Richard van Leeuwen (presenter) r.p.vanleeuwen@saxion.nl

Within the H2020 project SERENE (http://h2020serene.eu), Dutch partners work together to develop an integrated multi-energy carrier smart energy system. The demonstrator consists of 23 individual homes with solar PV and solar thermal installations, as well as a solar PV carport. The aim of the neighbourhood is to achieve as much sustainability and self-sufficiency as possible, including building material, water consumption, waste-water treatment and energy. Thereby the inhabitants are motivated to minimize energy exchange with the connected electricity grid, as the Dutch electricity system is partly powered by fossil fuels. More generally, grid congestion and instances of overloading are on the rise in the Netherlands and increasing self-sufficiency helps to prevent such congestion.

The following measures and flexibility assets have been implemented within the SERENE project: (a) neighbourhood battery, (b) EV charging stations, (c) controllable e-boilers for household hot water, (d) electricity monitoring systems, (e) Energy Management System (EMS) software to control the flexible options, (f) dashboard and human interface app for the inhabitants and researchers.
The EMS is developed in collaboration by University of Twente (algorithms), Saxion (e-boiler and data platform) and Loqio (edge distributed computer platform and communication interfaces). The EMS monitors the electricity consumption and production, as well as performing control over the flexibility assets at both household and neighbourhood level, e.g. pre-heating water in e-boilers or charging the battery system during peak production. Furthermore, an app is developed as a result of a co-creation process with inhabitants that provides valuable insights into the current and forecasted energy balance of the local grid, with which the inhabitants can make informed decisions to more closely match energy consumption and production, i.e., Demand Response (DR) by the user. For example, inhabitants can decide to shift when they start their white goods or cook.

The presentation will explain the context and scale of the demonstration project, the approach and main details of the solutions, and the approach to support the grid.

Keywords: Smart Grid, Energy Management System, Multi-energy systems, Battery integration, sector coupling, smart energy systems, energy community, sustainable energy

Simon Nießen is an engineer for energy efficiency and environmental engineering and has been working at Münster UAS since 2017. He has headed the research group “Integrated Energy” and has been leading the research project HY-Core, which deals with the commercial ramp-up of AEM electrolysis.

Hydrogen as a key technology in modern energy systems

Simon Nießen, Münster University of Applied Sciences (Germany)

Simon Nießen (presenter) simon.niessen@fh-muenster.de

The use of hydrogen as an energy carrier is considered a key technology in the energy transition—not only in Germany, but worldwide. The many possible applications of hydrogen (for energy and material use) make it a promising technology in future energy systems based on renewable energies.
As part of the research project "HY-Core—Up-scaling AEM electrolysis", Münster University of Applied Sciences is not only working with electrolyser manufacturer Enapter to investigate how hydrogen can be produced cost-effectively using AEM electrolysis, but also how it can be produced, temporarily stored and reused in line with demand.
To this end, Münster University of Applied Sciences has built an electrolyser with a rated electrical output of 1 MW, a hydrogen storage facility with a storage volume of around 1,300 standard cubic meters and a hydrogen Combined heat and power plant at its research site in the Saerbeck bioenergy park.
Built on the site of a former ammunition depot, the Saerbeck bioenergy park is a role model for a successful energy transition and a diverse mix of renewable energies. In addition to photovoltaic systems with a total rated output of 6 MW and wind turbines (total rated output 21 MW), the bioenergy park also has a biogas plant with biogas storage and a biowaste fermentation plant, making the park the ideal location for large-scale testing of hydrogen production, storage, and reconversion into electricity.
The presentation describes the transition of the local energy system from the supply of conventional energy sources via the expansion of renewable energies to an energy system that produces and reconverts hydrogen to serve the grid in such a way that electricity purchases (from conventional sources) can be avoided.

Keywords: Hydrogen, Smart Energy Systems, Integrated Energy, Sustainability, CHP, Energy Storage

Henning Rahlf is a research assistant at the Department of Energy Systems Engineering at Paderborn University. He previously worked on big data platforms and industrial DC grids. His current research focus is on the investigation of climate-friendly neighbourhoods based on RES and sector coupling.

Analysis of bidirectional EV charging infrastructures within industrial DC grids

Henning Rahlf, Department of Energy System Technologies, Paderborn University
Lukas Knorr, Department of Energy System Technologies, Paderborn University
Simon Althoff, Technology Development, Weidmüller Interface GmbH & Co. KG
Henning Meschede, Department of Energy System Technologies, Paderborn University

Henning Rahlf (presenter)

Industrial processes are being electrified to reduce dependence on fossil fuels. In addition, the amount of volatile renewable energies in the electricity mix is increasing. Securing the supply of electrical energy is of great importance for industrial companies. As a result, the original grid topology with centralised generators is changing. Grids are being decentralised and feed-in is taking place at all grid levels. In an industrial context, DC microgrids are becoming increasingly popular. By using DC grids, CO2 emissions can be reduced, and security of supply can be increased. This is possible because the braking energy of electrical systems can be recuperated, and components and cables can be reduced. In addition, storage systems and local generators can be used to bridge supply interruptions or reduce peak power.

As electric vehicles also have storage systems, synergies arise. By using EVs as mobile temporary energy storage units, an oversupply of locally generated renewable energy can be stored and then made available at different times and locations. In addition, the typically large capacity of EVs makes it possible to bridge grid outages to reduce costs and store renewable energy. At the same time, these are utilised more efficiently and the need for grid expansion is reduced.

Grid operators, companies and EV users have different needs. While the company has a need for security of supply and stability of the DC grid, EV users are interested in their own mobility. On the other hand, the energy supplier has a need to keep the supply grid stable, simplify dispatch and reduce grid expansion.

The novelty in this paper lies in EV charging processes in combination with droop-controlled DC grids. The question arises how supply grid can be relieved by the load shifting potential of the EV storages. It also needs to be clarified how supply interruptions can be bridged. For this purpose, a droop control DC grid has been modelled in this paper. In addition, an EV charging park has been implemented based on probability functions. Scalable scenarios enable the investigation of different conditions. Since charging strategies for EVs are well studied, this paper focuses on an energy management system based on fuzzy systems and sequential MILP optimisation.

Keywords: DC-Grid, bidirectional charging, EV, energy management system, fuzzy system, sequential MILP optimisation

Mechanical Engineer focuses on energy system modeling and simulation. HVAC Project Consulting of the Engineering Department at Van Marcke NV. Scientific collaborator of the Building Physics Group, of the Department of Architecture and Urban Planning in Ghent University, Belgium.

Operational assessment of Large-Scale Ground Source Heat Pump and Borehole Thermal Energy Storage System

1) Julio Vaillant Rebollar, Van Marcke NV., Belgium ; 2) Tom Prinzie, Van Marcke NV., Belgium ; 3) Arnold Janssens, Ghent University, Belgium

Julio Vaillant Rebollar (presenter)

Borehole Thermal Energy Storage (BTES) coupled with Ground Source Heat Pump (GSHP) are key elements to increase the share of sustainable solutions on the energy sector. Nevertheless, post implementation evaluations of largescale industrial BTES are scarce. The present work focuses on the performance assessment of GSHP system based on the monitoring data from a BTES array consisting of 512 boreholes of 63 m deep. The facility with 77000 m² of area is formed by a logistics and an office building. The space heating demand is cover by means of five Heat Pumps (850 kW secondary side) which utilize for its operation a 1.2 million m³ borehole heat exchange with 770 kW of peak capacity. The system has been continuously monitored since the start of operations. In the current study, the analysis 12-month period starting from June 2021 of the operational data is presented. Several indicators to assess the system performance such as the seasonal performance factor, imbalance ratio, the percentage of heat loss among others are analyzed. In order to provide a set of benchmarks for comparisons of such GSHP systems, attention have been paid to the normalization of the indicators. In addition on-site measurements of subsurface gradient temperature in two sample boreholes performed from February to March of 2020 have also been analyzed. Ground heat exchange was found to be slightly dominated by extraction of heat over the monitoring period and modest seasonal variation in temperatures. With a total extraction of 616 MWh heat and 567 MWh cold (heat injection) per year. The annual peak during heating season reach value up to 495 kW meanwhile 739 kW was the peck value during cooling season. The BTES technology proved its enormous potential to significantly reduce CO_2 emissions meanwhile the comfort requirement are guaranteed. A suboptimal BTES pumping operation is detected both in winter and summer mode, due to an unnecessary continues recirculation flow, which decreases the efficiency of the system. A proposal of an adequate circulation pump controlling system to overcomes the underperformance issues among other action to optimize system operation are provided. In addition, recommendations are given for the follow-up and monitoring of each subsystem energy performance.

Keywords: Heat Pumps; Borehole Thermal Energy Storage; Energy Performance Assessment

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.

Techno-economic analysis of utilization of waste heat from a data center combined with a borehole thermal energy storage.

Dmitry Romanov, Stefan Holler
HAWK Hildesheim/Holzminden/Göttingen University of Applied Sciences and Arts, Faculty of Resource Management, Rudolf-Diesel-Straße 12, 37075, Göttingen, Germany

Dmitry Romanov (presenter) dmitry.romanov2@hawk.de

Seasonal heat storages are being often applied for enhancing waste heat utilization solutions and to tackle the mismatch between the heat demand and waste heat generation. Although data centers generate waste heat nearly uniformly during the year, the application of borehole thermal energy storages should also be considered. In such case, the ground-coupled systems can additionally offer cooling capacities for data centers in summer.
This work concerns the research question of how to utilize excess heat from a data center and store it in summer in a borehole thermal energy storage in the most efficient way exemplified by the case study of the Göttingen University campus.
Simulations were conducted with the help of a python model based on pygfunction package allowing for the evaluation of thermal response factors (g-functions) of geothermal borehole fields. The cooling demand of the data center and the heating demand of the neighboring research facilities were considered synergetically, whereby comparison of several scenarios was carried out: business as usual, utilization of waste heat, utilization of waste heat complemented by the seasonal heat storage. Moreover, different district heating network temperatures were taken into account.
The results of the simulations and the sensitivity analysis show under which conditions the introduction of borehole thermal energy storage into the system is feasible. The results of the work may guide other researchers, engineers and system developers during the decision-making process and can be transferred to similar case studies.

Keywords: Excess heat, feasibility study, ground source heat pump, levelized cost of heat (LCOH), pygfunction, seasonal heat storage, synergy.

Dietrich Schmidt is affiliated with the Fraunhofer Institute for Energy Economics and Energy System Technology (IEE) in Kassel/Germany. He works as Deputy Head of Department Energy Informatics - Digitalization of Heat Infrastructures and as Research Coordinator Operational Heat Applications.

Digitalization of District Heating Systems – Transforming heat networks for a sustainable future

Dietrich Schmidt, Fraunhofer Institute for Energy Economics and Energy System Technology IEE, Germany

Dietrich Schmidt (presenter) dietrich.schmidt@iee.fraunhofer.de

The district heating and cooling sector is experiencing new challenges with the current transformation of energy systems. The required decarbonisation will result in a more complex heat energy system, as a few large plants which utilise fossil fuels will likely be replaced mostly by smaller production plants distributed around the system, that use renewable or waste energy sources. Many of these sources are volatile; their output is affected by weather and other factors. Furthermore, district heating and cooling systems must be operated more efficiently and flexibly to ensure a consistent and cost-effective thermal energy supply, as well as effective participation in the power system balancing market. Because of the necessary changes in the energy system, district heating becomes increasingly beneficial to both end users as well as other energy sectors, and the number of connections is increasing in many countries in conjunction with the phase-out of fossil fuels such as oil and gas for space heating and hot water supply. In this changed environment, increased adoption of digital technology in the district heating and cooling sector provides a chance to make systems smarter, more flexible, efficient, and reliable, hence accelerating the necessary integration of additional renewable and waste energy sources into thermal supply systems. This change affects the entire district heating energy chain, from generation to end user usage, and supports the transformation of the overall energy system.

However, many existing systems still lack a high level of digitalization. With more complexity, flexibility, more powerful tools, and approaches (and hence increased digitalization) will be required. Aside from technology, the integration of new digital business processes will make deployment easier. On the other side, new concerns, such as data security and privacy, as well as questions concerning data ownership, must be addressed.

The presentation, as well as the paper, show and discuss results from research conducted as part of the IEA DHC Annex TS4 on “Digitalisation of District Heating Systems – Optimised Operation and Maintenance of District Heating and Cooling Systems via Digital Process Management”.

https://www.iea-dhc.org/the-research/annexes/2018-2024-annex-ts4

Keywords: digitalization of district heating, operation and maintenance, business processes and models

Aksana Krasatsenka serves as the Director of Knowledge Transfer at Euroheat & Power. Aksana has been involved in an important number of EU funded projects. She oversees the flagship education & training activities of DHC+ and steers the broader agenda focused on skills within the DHC sector.

Innovations in District Heating and Cooling: ground-breaking projects reshaping the DHC landscape

Aksana Krasatsenka and Martin Stroleny, Euroheat & Power

Martin Stroleny (presenter)

District heating and cooling (DHC) systems offer significant potential for innovation, particularly in reducing greenhouse gas emissions and tackling climate change. Technological advancements in the last two decades have made heat networks more complex, creating opportunities for enhancing efficiency and sustainability.

The DHC+ Platform, led by Euroheat & Power, serves as Europe's hub for DHC research and innovation, with over 60 stakeholders from academia and industry committed to a sustainable energy system. Since 2010, DHC+ has spearheaded various projects reshaping the DHC landscape. Our projects span a wide range of crucial topics, from renewable heating and cooling to low-temperature networks, integrated energy systems, and innovative education and training activities.

In my keynote, I will highlight ground-breaking projects such as USES4HEAT, focusing on seasonal Thermal Energy Storage (TES) for industrial waste heat recovery; THUNDER, addressing Data Centre waste heat recovery barriers with innovative Seasonal Thermal Storage; TREASURE, enhancing pit thermal energy storage (PTES) technology; and '2LIPP - 2nd Life for Power Plants,' facilitating the transition of combined heat and power (CHP) plants to renewable grid contributors.

Keywords: District heating and cooling, innovation, EU projects, seasonal thermal energy storage, waste heat recovery, pit thermal energy storage, hybrid storage, decarbonisation

Sreenath is working as a postdoctoral researcher in Tallinn University of Technology. His research interests are focused on solar energy, district heating & cooling, sustainability assessments, spatial energy planning and energy system modelling.

Enhancing the Sustainability of District Cooling Networks Through Integration of Snow Storage Systems: A Case Study of Tallinn, Estonia

Sreenath Sukumaran, Tallinn University of Technology
Anna Volkova, Tallinn University of Technology
Igor Krupenski, Tallinn University of Technology & HeatConsult (Fimpec Group)
Andrei Dedov, Tallinn University of Technology
Dmitri Nešumajev, Tallinn University of Technology
Aleksandr Ledvanov, HeatConsult (Fimpec Group)

Sreenath Sukumaran (presenter)

District cooling (DC) has already gained the attention of many cities and urban regions. It facilitates the utilization of geographic advantages for tapping of low-temperature cold sources (such as seawater). Urban snow is one of the rarely exploited and naturally available cold source. In colder climates, winter snow can be stored in thermally insulating pits and utilized for the spacing cooling during summers. Integration of snow storage into DC systems presents multiple opportunities: to reduce its energy consumption (thereby carbon footprint) and to repurpose the snow cleared from roads and streets, giving greater value to snow removal efforts, to reduce emissions from snow handling vehicles. Further, this snow utilization-and-disposal concept is a promising solution to various socio-economic issues related to snow disposal in cities. Though handful of snow cooling facilities are implemented in snowy regions, the potential of utilizing this cold source for DC applications is not fully explored. There are little to no studies that investigate the effectiveness of integrating snow storage into DC networks. The economic and climatic benefits from different configurations of snow storage cannot be overlooked. The aim of the study is to assess the holistic performance of snow storage-assisted district cooling (SSDC) systems. The proposed methodology is carried out as a case study of Tallinn city (Estonia) which is characterized by the high snowfall, expanding DC networks, rising cooling demand. At first, the cooling demand and snow availability for the selected site is theoretically calculated based on historical data. Then, the energy performance and thermal aspects of different types of snow storage systems are estimated in terms of energy output, heat loss, snow melting rate etc. Finally, sustainability assessment is carried out for each configuration using a multicriteria framework consisting of technical, economical, socio-environmental parameters. Also, the effectiveness of SSDC technology is compared with emerging renewable cold sources and waste heat sources. This

study is expected to enhance the significance for utilizing urban snow waste, thereby improving the energy sustainability of the cooling sector.

Keywords: Snow cooling, sustainable cooling, district cooling, environmental impact, green technology, urban sustainability, Snow storage

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

Ruihong has a background in Mechanical Engineering with a focus on energy science and technology. His research utilizes geospatial methods for resource assessments of renewable energy technologies such as solar PV and onshore wind turbines to address social factors beyond techno-economic analysis.

GIS-based landscape scenicness estimation using machine learning for visual impact assessment of wind projects deployment in Europe

Ruihong Chen, Chair of Energy Systems Analysis, Institute of Energy and Process Engineering, ETH Zürich, Switzerland.
Alena Lohrmann, Chair of Energy Systems Analysis, Institute of Energy and Process Engineering, ETH Zürich, Switzerland.
Russell McKenna, Chair of Energy Systems Analysis, Institute of Energy and Process Engineering, ETH Zürich; Laboratory for Energy Systems Analysis, Paul Scherrer Institute, Villigen PSI, Switzerland.

Ruihong Chen (presenter) ruchen@ethz.ch

Wind energy is an important renewable energy source for the energy transition, but the implementation of wind projects faces many challenges. One of the major concerns is the landscape impact resulting from the high visibility of wind turbines. To determine a suitable location for a future wind farm, the landscape impact of the proposed project needs to be assessed based on the landscape quality and visibility to nearby populations.
This study presents the first step of the landscape impact assessment, determining the landscape scenic quality using a Geographic Information System (GIS) approach. Firstly, various landscape metrics, including naturalness, human impact, remoteness, and ruggedness, are calculated for Great Britain, Switzerland, and Germany using open data sources. In contrast to previous studies, the calculation of the landscape metrics considers the entire viewshed (in other words, all surrounding points in the line of sight) instead of taking a single value at the specified location. Secondly, the existing crowd-sourced landscape scenic value dataset for Great Britain (ScenicOrNot) is used to identify the relationships between the perceived landscape aesthetic value and the above-mentioned landscape metrics using machine learning algorithms. Subsequently, the found relationships/patterns are validated using the available scenicness data for Germany, which comes from an empirically-based modelling approach. Finally, the validated method is propagated to the case of Switzerland to show the first estimation of landscape scenic value in high spatial resolution.
The results are expected to reveal the major drivers of human perception of landscape aesthetic value and to provide a transferable method for quantitative estimation of landscape scenic value in Europe using open data. This would serve as a useful input for minimizing the landscape impact of future wind farms and other utility-scale power plants beyond pure visibility analysis and expedite the energy transition in Europe.

Keywords: wind, energy, landscape, visual impact, machine learning, GIS

Stanislav Chicherin is a PhD researcher at Vrije Universiteit Brussel, specializing in research and project management. With 6 years of experience as an engineer in a district heating company and extensive background as a researcher, he continues his research on energy systems and renewables.

Improving design of the 5th generation district heating and cooling systems (5GDHC) systems: a robust GIS-driven approach

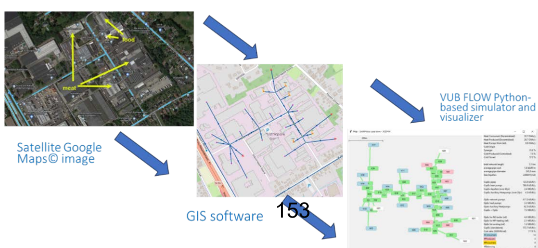
Stanislav Chicherin, Jonathan Hachez, Afraz Mehmood Chaudhry, Svend Bram

All at: Thermo and Fluid Dynamics (FLOW), Faculty of Engineering, Vrije Universiteit Brussel (VUB), Brussels, Belgium; Brussels Institute for Thermal-Fluid Systems and Clean Energy (BRITE), Vrije Universiteit Brussel (VUB) and Université Libre de Bruxelles (ULB), Brussels, Belgium

Stanislav Chicherin (presenter) stanislav.chicherin@vub.be

Europe aims for renewable energy integration, driving the need for sustainable district heating solutions. This study focuses on optimizing 5GDHC systems for enhanced efficiency and performance through waste heat utilization and advanced design methodologies. This study introduces a methodology for assessing waste heat potential and optimizing 5GDHC system design. By leveraging prosumer buildings and Geographic Information Systems (GIS), the research predicts chiller energy consumption with high precision. Integration of Chaikin's algorithm refines thermal images, aiding system design. The absence of an asset design method in 5GDHC is noted, with the study recommending energy-efficient strategies based on annual energy calculations and building types. Significant waste heat potential, particularly from data centers, is identified, and targeted system design using satellite imagery and operational data is proposed. Key findings underscore the importance of considering building characteristics and geographical location for optimal system performance, with potential CO2 emissions reductions of up to 100%. GIS technology and waste heat assessment are integrated with building energy analysis. Algorithms accurately predict chiller locations and energy consumption. The study recommends energy-efficient strategies based on building types and annual energy calculations. Results include: i) identification of significant waste heat potential, notably from data centers, ii) utilization of satellite imagery and operational data for targeted system design, iii) consideration of building characteristics and geographical location for optimal performance. The research offers practical insights into optimizing 5GDHC systems for improved efficiency and performance. By leveraging real data and advanced design methodologies, stakeholders can enhance district heating and cooling practices.

Keywords: Waste Heat, Geographic Information Systems (GIS), Chiller, Building, Energy, Satellite Imagery, CO2 Emissions, Greenhouse Gas



At the time of abstract submission Britta Kleinertz is undergoing job interviews for a postion in the energy system transformation field. Prior she led the team heat transformation at FfE, while working on her doctorate on integrated communal heat planning focussing on district heat transformation.

Spatial prioritization of heat supply systems – experience from literature and practise combined in a practical guideline

Britta Kleinertz, FfE

Britta Kleinertz (presenter) bkleinertz@gmx.de

In order to limit climate change emissions must be reduced as fast as possible, taking into consideration technical, economic and acceptance wise limitations. Emissions for heat supply of building make up 30 % of overall emissions, with no significant decrease over the past years. Hence, the development of communal heat supply strategies has become mandatory in Germany.
Hereby, after status quo analysis of heat demand as well as infrastructure and heat system potential analysis, this information must be connected intelligently in order to set up a realistic heat transformation strategy. In the research several internationally existing approaches for spatial prioritization of heat supply systems, consisting of a combination of heat generation unit and refurbishment, are holistically compared and key success factors derived. Furthermore, real project experience from communal heat planning in several German cities is reflected. From these two sides an overall approach on how to understandably and holistically derive a spatial prioritization strategy for heat supply systems (see figure 1). After a description of every step, the resulting advantages and key success factors are derived as well as possibilities for a simplified approach.

Keywords: Heat transformation, communal heat planning, renewable energies, district heating

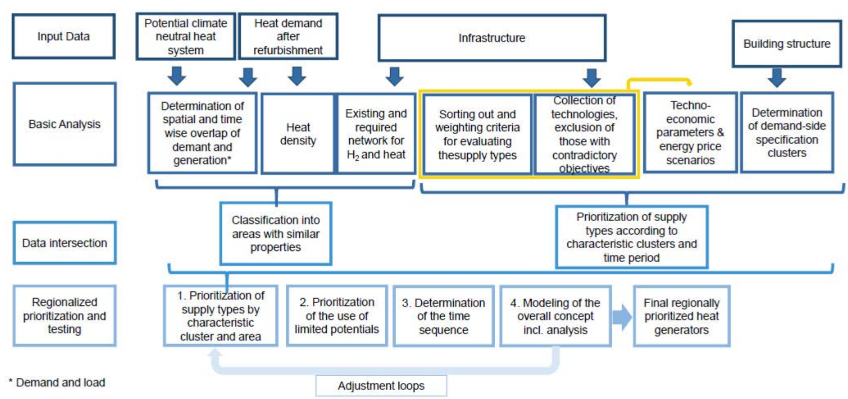


Figure 1: Stepwise approach for spatial prioritization of heat supply units

Franz Mauthner, a Senior Researcher at AEE - Institute for Sustainable Technologies (AEE INTEC) in Austria, specializes in urban and regional energy system analysis and planning, with a focus on spatial heat and energy planning.

Agent-based simulation of energy transition pathways in urban environments

Franz Mauthner: AEE-Institut für Nachhaltige Technologien, Gleisdorf, Austria
Andreas Stöger: AEE-Institut für Nachhaltige Technologien, Gleisdorf, Austria
Johannes Scholz: University of Salzburg, Department of Geoinformatics, Austria
Georg Weinberger: University of Salzburg, Department of Geoinformatics, Austria
Maria Anna Hecher: EPFL, Laboratory on Human-Environment Relations in Urban Systems, Switzerland
Simón Ladino Cano: EPFL, Laboratory on Human-Environment Relations in Urban Systems, Switzerland
Jürgen Hahn: MovingLayers GmbH, Vienna, Austria
Florian Korn: MovingLayers GmbH, Vienna, Austria

Franz Mauthner (presenter) f.mauthner@aee.at

This contribution presents the outcomes of the Austrian research project titled Agent-based simulation of energy transition pathways in urban environments (ABM4EnergyTransition).
ABM4EnergyTransition aims to develop and demonstrate an innovative simulation approach based on Agent-based Modeling (ABM) for spatially analyzing and assessing pathways toward municipal heat and energy transition. The ABM methodology incorporates spatial information describing the energy system of a study area (including buildings, grid-based energy infrastructure such as natural gas or district heating networks, renewable potentials, and population structure) and parameters describing the behavior of actors (agents), such as homeowners, investors, or policymakers. Additionally, the simulation system considers demographic and sociotechnical parameters such as income and education level.
The ABMS approach extends existing energy planning methods, enhancing the understanding of public policy impacts on climate and energy goals. The project's methodology is interdisciplinary, involving Spatial Analysis, Spatial ABM, Simulation, Energy Planning, Software Engineering, and a Social-technical empirical approach. Leveraging a comprehensive survey distributed to households in the Province of Styria (Austria), ABM technology now accurately models the behavior of individuals with different socio-economic backgrounds in diverse geographical contexts.
The tangible outcomes of the project include a prototype map-centered web application with a dashboard showcasing ABM results. Through the ABM, variable input parameters and a dashboard empower "expert" users from public administration and city or energy planning to examine and analyze the effects of various energy policy and technical interventions, displaying results such as Energy and Life Cycle Assessments, technology insights, and energy

carrier mixes with flexible spatial and temporal granularity. Furthermore, the web application enables interested citizens to engage in simplified simulation scenarios, providing a playful exploration of the heat transition and energy system change (see Fig. 1).

This research is funded by the Austrian Research Promotion Agency (FFG) through the "AI for Green 2021" program, under grant agreement FO999892237.

Keywords: Spatial Energy Planning, Geoinformatics (GIS), Agent-based Modeling and Simulation (ABMS), Actor Decisions, Energy Policy Intervention, Heat Planning, Scenario Development

Johannes Pelda is a researcher specializing in energy systems, focusing on the adaptation of district heating systems to the fourth generation. He researches the development of methods for the localization and optimal use of low-calorific heat sources using innovative solution algorithms.

MEMHIS 2.0 - Spatial identification and evaluation of the temporal availability and economic assessment of waste heat sources

Johannes Pelda, HAWK University of Applied Sciences and Arts Hildesheim/Holzminden/Göttingen; Abdulraheem Salaymeh, HAWK University of Applied Sciences and Arts Hildesheim/Holzminden/Göttingen; Stefan Holler, HAWK University of Applied Sciences and Arts Hildesheim/Holzminden/Göttingen; Stefan Reuter, AIT Austrian Institute of Technology GmbH; Gebetsroither-Geringer Ernst, AIT Austrian Institute of Technology GmbH; Marco Cozzini, EURAC Research; Rosanna Paradiso, EURAC Research;

Johannes Pelda (presenter) johannes.pelda@hawk.de

Sustainable energy systems necessitate the transition to renewable energy sources and improved energy efficiency. The use of waste heat sources promises to reduce carbon emissions in heat generation.
This study explores the use of low-grade waste heat from commercial or industrial processes and sewers that is associated with several challenges: Uncertainty regarding the location of the heat source, the amount of energy and the temperature level, imbalance between heat demand and availability, and long payback periods due to high investment costs and low heat sales revenues, especially in summer.
In the project a model was developed that finds optimal locations for waste heat recovery from sewer systems within city limits, specifying the energy content and temperature level. The model shows numerous points in the sewer network of the cities studied. The total waste heat potential within the urban areas is around 20 % higher than the use of waste heat at the outlet of the sewage treatment plant. The temperatures are above 16 °C all year round.
The economic viability of waste heat recovery is assessed through sensitivity and profitability analyses. Changes in the operating hours of a heat pump show the greatest impact on the levelized heating costs, followed by investment costs. With an electricity price of 122 EUR/MWh and a heat price above 152 EUR/MWh a minimum profitability of 10 % can be expected.
The data set for industrial waste heat was expanded to include information on availability over time and temperatures. A method was developed to estimate the cost of designing a waste heat recovery system, including the cost of laying piping by using terrain features. The data were validated by real information on commercial and industrial waste heat sources in three cities. In addition, it was found that the electrification of earlier combustion processes and the use of high-temperature heat pumps will reduce the externally available waste heat. Systems

like data centres or electrolysers can achieve an efficiency of up to 90 % by utilizing their waste heat.

The findings were implemented into the Waste Heat Explorer http://cities.ait.ac.at/uilab/udb/home/memphis/.

MEMPHIS 2.0 was funded by the IEA DHC within ANNEX XIII and bases on MEMPHIS performed in ANNEX XII.

Keywords: Waste heat, industrial processes, sewers, levelized cost of heat, heat pump, investment costs, localization

Urban Persson is a Swedish researcher in the academic field of energy and environmental technology with a special focus on district heating and cooling systems in a European perspective. He is Professor in Renewable Energy Systems at Halmstad University since 2020.

Data categories and selection criteria for an evaluation of the potential for solar district heating with pit thermal energy storage in Sweden

Urban Persson, Halmstad University (Corresponding author); Puneet Saini, Dalarna University; Luis Sánchez-García, Halmstad University; Fredric Ottermo, Halmstad University; Chris Bales, Dalarna University

Urban Persson (presenter) urban.persson@hh.se

This paper is the second of three accounts which describes a Swedish study aiming to derive a first order assessment of the national potential for large-scale solar thermal heat production with pit thermal energy storage's (PTES) connected to existing district heating systems (DHS). Whereas the first paper presented project objectives, outset parameters, and an updated Swedish district heating database – and the third is planned to report on the final project results and conclusions – this paper focuses on the assembled study data and the associated selection criteria applied to these data categories under the objective to distinguish suitable (and non-suitable) land areas within cost-efficient heat transmission distances from the existing DHS. The approach centres around a principal spatial analysis with superposition of study data and elimination of non-suitable land areas according to the used selections criteria but also entails a wide periphery of related activities, such as literature reviews, gathering of technology preferences, meetings with sector experts, data management etc. Apart from technical specifications for solar heat production and seasonal storage, key data categories for the spatial analysis consist of geological data (e.g. soil types, soil depth, bedrock etc.), hydrological data (lakes, rivers, wells, soil moisture, ground water levels etc.), geographical data (elevation, built-up areas, administrative units etc.), and thematic data (energy statistics, building heat demands, district heat deliveries etc.). Selection criteria for the relevant data categories have been defined iteratively during e.g. expert consultancy, for example minimum soil depth, preferred soil types, maximum feasible transmission distance to existing DHS etc. By application of the selection criteria, raw input data are converted to processed data extracts to be used in the final analysis. Study data categories are illustrated and summarised (raw and processed) together with a listing and discussion of the used selection criteria.

Keywords: District heating systems, Solar thermal, Pit thermal energy storage, Data management, Selection criteria, Geographical information systems

He is a senior expert for spatial energy planning, leading the subsequent team at the Energy Agency of the federal province of Salzburg.

Spatial Energy Planning for Heat Transition - Steering Transition by Information

Alexander Rehbogen, SIR - Salzburg Institute of spatial planning and housing

Alexander Rehbogen (presenter) alexander.rehbogen@salzburg.gv.at

Available data is a key lever for the heating transition. New, efficient heating technologies are available today. To achieve the energy targets, these must be brought to market quickly and in a targeted manner. Surveys in the context of the "municipal heating transition" in Germany show that the lack of data is one of the biggest obstacles to the rapid implementation of heating plans. With high subsidies, good technologies are therefore often used in the wrong place (heat pump in the district heating area) or are not even considered as an option due to the excessive effort involved in planning (groundwater heat pump).

In 2017, three federal states in Austria began to develop a joint approach to sovereign energy planning. In the project series „spatial energy planning for energy transition I + II“, all the foundations were developed from 2018 onwards in order to effectively establish spatial energy planning in the administration. The project ends in August 2024 and aims to present its results to a broad public. In Austria, a joint approach has been successfully developed that uses a standardised data model and standardised methods to generate a heat atlas (operated in the public GIS systems of the federal states) as the basis for sovereign heat planning.

This contains a four-digit number of building-specific information (attributes) in the areas of heat demand, heat supply infrastructure and renewable energy potential. Based on this, automated reports were developed for defined use cases. They provide the decision-making basis for legally established new planning processes in the area of heating and can be called up by planning stakeholders at the touch of a button. In the meantime, other interesting applications such as the heating app for citizens (property-specific information on heat supply options) or a planning dashboard for neighbourhoods have also been developed and scientific project use the data base for further developments.

And it's not just functions and quality that are constantly being scaled up. In the meantime, two more federal states have joined the approach and a national platform for heat planning is currently being set up to manage and network all activities relating to information bases for heat planning on a national level.

Keywords: Austrian national approach for heat planning, GIS based public heat atlas, automized reports, renewable energy potentials for heat, heat infrastructure, heat demands, joint datamodel and methods

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.

Assessing the Thermal Potential and Sustainable Water Withdrawal Rates from German Waterbodies for District Heating

Abdulraheem Salaymeh 1,2), Johannes Eck 1), Irene Peters 2), Stefan Holler1)
1)HAWK University of Applied Sciences and Arts
2)HafenCity University Hamburg

Abdulraheem Salaymeh (presenter) abdulraheem.salaymeh@hawk.de

The transformation to a climate-neutral energy system demands the utilisation of a broad spectrum of sustainable energy sources. The thermal utilisation of surface waters is a viable renewable source, given their local availability, perpetual replenishment through the natural water cycle, and substantial heat storage capacity. However, ecological and legal considerations necessitate a balanced approach. This study aims to assess the thermal potential of German waterbodies while ensuring compliance with ecological requirements set by the European Water Framework Directive (WFD) and the German Surface Waters Ordinance (OGewV).

Differing from previous studies primarily focused on certain water bodies or lacked ecological considerations, our methodology integrates nationally defined temperature limits for thermal discharge into rivers and employs flow rate data provided by a hydrological model covering the most relevant rivers in Germany. This enables assessing the thermal potential for different river types. These river types are grouped according to their fish communities and their specific temperature requirements. We conduct an analysis of eight scenarios to assess the thermal potential of German waterbodies, considering seasonal variability, fish sensitivity to thermal discharges, and flow rate changes.

The analysis reveals a maximum potential heating capacity of up to 15.4 GW, contingent upon fluctuations in flow rates. However, this maximum capacity decreases by approx. 18% to 12.6 GW when considering the temperature sensitivity of local fish communities. Further accounting for seasonal differences results in an additional 25% reduction (to 9.5 GW). The estimated potential varies primarily due to changes in flow rates. Notably, strict temperature requirements for sensitive fish species significantly impact the potential of small and medium-sized rivers. The highest potential is observed in the lower reaches of the Rhine River, followed by the Danube shortly after its confluence with the Inn at the national border, and subsequently the lower reaches of the Elbe, the Oder, and the Weser. Regarding the

temperature sensitivity of fish communities, coastal rivers exhibit lesser influence, with some Alpine rivers showing no impact at all.

Keywords: Thermal potential, German waterbodies, District heating, GIS analysis, Ecological considerations

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.

The potential role of island heating networks in decarbonizing heating supply of districts. A case study for the district of Freiburg Waldsee

Annette Steingrube, Fraunhofer Institute for Solar Energy Systems

Annette Steingrube (presenter) annette.steingrube@ise.fraunhofer.de

Heating networks can be an efficient way of decarbonizing heat generation in urban areas, as the replacement of heating systems does not have to take place at individual building level. In Germany, the Heat Planning Act has now created the legal basis for all cities to develop a strategy for how heat will be supplied in the future. To this end, priority areas for heating networks and decentralized supply solutions are being developed. Areas that are not located in a priority area for heating networks will therefore not be connected to a heating network by the local energy supplier. Nevertheless, it may be interesting for these areas to connect individual districts to smaller stand-alone grids. In the PED urban project, a tool chain was further developed that links heating network planning with an energy system optimization model. This tool chain allows spatially resolved determination of where heating networks should be expanded, while the most economically favourable overall energy system is determined with the energy system model. In the project, this tool chain is applied to the case study district of Freiburg Waldsee and its neighbouring districts and the expansion of various island grids is tested. A particular focus is placed on the decarbonization of the overall energy system, increasing the proportion of self-supply (also for electricity) and the system-oriented operation of the energy system. In order to assess these factors, an evaluation method for positive energy districts developed in the PED urban project will be applied and directly tested for its practicability. From a district perspective, the results allow an assessment of where smaller island grids in a defined area could be a sensible option for decarbonizing the heating sector. From a researcher's perspective, the study provides information on whether the new PED assessment method is suitable for assessing decarbonization, increased proportion of self-supply and system-oriented operation of an energy system.

Keywords: energy system modeling, heat network planning, positive energy districts, island heating networks

Eva Wiechers works for PlanEnergi as a consultant and undertakes energy system related GIS analyses mainly with focus on heat planning. She is involved in projects in Denmark, Germany and on European level.

German and Danish Case Studies undertaken on the Citiwatts platform replacing the Hotmaps platform

Eva Wiechers, Max Gunnar Ansas Guddat, both PlanEnergi, Denmark

Eva Wiechers (presenter)

During the research project OpenGIS4ET, the Hotmaps open-source toolbox for heat and cooling planning is being further developed and rebranded with the name "Citiwatts". The platform's usability was improved as well as the tools for the dispatch and the economic assessment of district heating networks were revised. Besides, a tool for district cooling networks was added. With the possibility of scenario analyses modelling the geographical and temporal distribution of electricity demands of electrical vehicles the platform helps to consider the impact of mobility on the energy system. Moreover, the platform allows to study flexibility options in the energy system.
The toolbox is developed and improved in agile development. New improvements and development are in this progress tested and demonstrated in case studies in Denmark, Germany, Austria, and Switzerland. In the undertaken case studies, the platform tools have been applied with the platform's default data as well as with adjusted data and parameters on sub-national level. In this way, datasets with hectare resolution have been created and evaluated. The results have been compared with the findings of existing studies available for the case studies' region. Doing so, the comparative studies serve both an analysis of the default data and of the results from more advanced analyses with bottom-up data.
For the Danish municipality of Sønderborg, several analyses have been carried out over the years. On the (district) heating side, potential heat supply areas have been analyzed in a strategic municipal heat plan as well as in the LIFE project "COHEAT", co-funded by the European Union. Both projects involved the use of external consultants. The comparison of the results from these two analyses with the model outcomes obtained in OpenGIS4ET demonstrates how far municipal energy planners can come themselves, using the free and easy to use Citiwatts online tools.

Keywords: Heat planning, Electric vehicles, Comparative study, Hotmaps, Online GIS tool

Integrated energy systems and smart grids

Faraedoon Ahmed has B.Sc in EE (Hons), an M.Sc in EEE (hons), and is currently a PhD student at the University of Manchester and Queen's University Belfast

The complementary role of interconnector and demand side unit in facilititating grid transition towards achieving 80% RES in the I-SEM system by 2030

Faraedoon Ahmed, The University of Manchester and Queen's University Belfast, Aoife Foley, The University of Manchester, Sean McLoone, Queen's University Belfast, Robert Best, Queen's University Belfast, Dlzar Al Kez, The University of Manchester

Faraedoon Ahmed (presenter)

The Integrated Single Electricity Market (I-SEM), facilitating wholesale electricity trade across the two synchronously connected small power systems in the island of Ireland, is undergoing significant transformation. Both system operators SONI (in NI) and EirGrid (in ROI) have jointly committed to reach an 80% instantaneous renewable electricity generation within the All-Island I-SEM by 2030. This synchonosly isolated island grid has established its sole connections to other major power systems through HVDC interconnectors, predominantly Great Britain (GB), with further plans for additional HVDC interconnections GB and France before 2030. Considering its extensive capacity in the region, wind power play a pivotal role in meeting the 2030 renewable ambitious target in the all-island. However, its seasonal and intermittent nature necessitates flexible resources to address inherent variability and uncertainty of wind power. This study pioneers a complete electricity power model for NI and ROI, utilizing PLEXOS software to integrate existing AC transmission line between both countris and their interconnection with GB, and estimated HVDC interconnectors with GB and France. The model is first validated against actual published data in 2022, the model is then extended to meet the 2030's ambitious targets, evaluating enhanced flexibility options (i.e.,demand response, battery storage, and HVDC interconnectors) in facilitating the transition towards achieving an 80% renewable electricity generation at different levels of system non-synchronous penetration (SNSP). Analysis encompasses wind power curtailment, CO2 emissions reduction, generation cost, net revenue, and optimal interconnection capacities. Findings offer crucial insights for global decision-makers, delineating the efficacy of technologies for grid security and flexibility. Furthermore, the study delves into addressing practical challenges, such as prolonged a week low wind generation, utilizing real data to assess technology impacts in 2030. The research aims to provide valuable insights for decision-makers, aiding in the development of technological strategies and policies for system operators like EirGrid and SONI, facilitating a smooth transition towards a renewable-rich grid while meeting 2030 targets.

Keywords: Variable renewable generation, HVDC interconnector, Battery storage, Demand side management, Grid security, and flexibility

The presenter is a dedicated researcher in the field of energy systems, focusing on the development and testing of advanced control strategies for decentralized district energy systems.

Development and Evaluation of a model predictive control strategy for an operational analysis in district energy systems

Abdul Azzam, University of Stuttgart

Abdul Azzam (presenter) abdulrahmman.azzam@ier.uni-stuttgart.de

Building upon a foundational software architecture for dynamic simulation of energy districts, this research introduces the development and testing of various control approaches. These include Model Predictive Control (MPC) and Rule-Based Control, which are applied in decentralized district energy systems. Further refinement of the simulation framework has been achieved to incorporate these advanced control strategies.

Implementation of these advanced control strategies has enabled the intelligent operational management system for urban districts to unlock flexibility potentials. Moreover, it facilitates the integration of renewable energies.

Enhancements to the simulation framework have been made to test and validate these control strategies. This has led to the ability to analyze and evaluate different target functions for the operation of the district energy system. Defined by various stakeholders, the simulation allows for a comprehensive energy system analysis. Furthermore, it studies the interactions and dependencies between buildings, urban districts, and the energy system on a scenario basis.

Ongoing work is focusing on the development of the control strategies and their integration into the digital twin. Designed to optimize the operation of the energy system, these control strategies take into account various factors. These include energy demand, supply conditions, and stakeholder preferences. Evaluation of the effectiveness of these control strategies is conducted through model experiments using the dynamic simulation.

Continuing to serve as a valuable tool, the simulation framework, with its enhanced capabilities, integrates municipal stakeholder groups. It creates a virtual experience of the decarbonization measures and simulates relevant impacts. Development and testing of the control strategies represent a significant step forward in the research. Consequently, they contribute to the sustainable transition of local energy systems.

Keywords: Decentralized Energy Systems,
Digital Twin,
Dynamic Simulation,

Model Predictive Control,
Stakeholder-Orientation,
Urban Districts

Christian Møller Jensen is an industrial PhD student with Grundfos Holding A/S and Aalborg University. His primary research interests are modelling and control of district heating systems, model-predictive control of time-delay systems, and distributed optimization.

Delay compensated peak shaving in district heating zones by automatic setpoint scheduling

Christian Møller Jensen, Grundfos Holding A/S and Aalborg University
Mathias Clement Frederiksen, Grundfos Holding A/S
Carsten Skovmose Kallesøe, Grundfos Holding A/S and Aalborg University
Jan Dimon Bendtsen, Aalborg University
Brian Kongsgaard Nielsen, Grundfos Holding A/S

Christian Møller Jensen (presenter)

District energy systems play a part in the green transition of the energy sector. For the district heating system to fulfil its role as a sustainable energy system, some main challenges that shall be solved are:

1. The supply temperatures shall be lowered to efficiently integrate more excess heat and renewable electricity via large scale heat pumps [1].
2. The performance of consumer heating systems shall be improved to operate at lower temperatures.

When lowering the supply temperature cf. 1, supply conditions at the consumer must still be fulfilled and different consumer types have different temperature needs. This is mitigated by dividing the grid into temperature zones where the consumers have similar temperature requirements.

Outdoor temperature is common as an input for the supply temperature adjustment. Additionally, grid operators may wish to compensate for periodic consumption peaks to avoid elevated return temperatures and large flow gradients. This is complicated by the transport delay, which requires the compensation to happen ahead of time.

In this work we strive to reduce the complexity for the grid operator by presenting a data-driven method that can adaptively calculate the appropriate setpoint for a zone while compensating for the transport delay. Existing methods for time delay estimation in DHS are often purely data-driven, but this makes incorporating model structure in the estimator design difficult, while heat load calculations usually do not correct for the delay between the supply and return line.

We address:

- Calculation of the transport delay and loss between the zone inlet and a grid measurement point inside the zone using a physics-informed approach.
- Prediction of the temperature setpoint for a zone.

- Minimum supply temperature at a selected grid measurement point.

The delay estimation is tested in a district energy grid, and the entire method is simulated on a model of a district energy zone.

[1] H. Lund et al., “4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems,” Energy, vol. 68, pp. 1–11, Apr. 2014.

[2] M. Dahl et al., “Using ensemble weather predictions in district heating operation and load forecasting,” Applied Energy, vol. 193, pp. 455–465, May 2017.

Keywords: District Heating, Delay estimation, Predictive control

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.

A Distributed Demand Response Approach for Heating Networks

Valentin Kaisermayer & Daniel Muschick & Markus Gölles, BEST - Bioenergy and Sustainable Technologies GmbH
Lukas Richter, DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH
Peter Nageler, EQUA Solutions AG
Hermann Edtmayr & Andreas Heinz & Thomas Mach, Institute of Thermal Engineering, Graz University of Technology
Martin Koren & Günther Beck & Wolfgang Rosegger, Schneid Gesellschaft m.b.H.
Karl Pfiel, Ing. Karl Pfiel GmbH
Harald Kaufmann, n.nahwaerme.at Energiecontracting GmbH
Werner Lerch-Riedler, ENAS Energietechnik und Anlagenbau GmbH

Valentin Kaisermayer (presenter) valentin.kaisermayer@best-research.eu

Smart, supervisory controllers for integrated energy systems can benefit from added flexibility in the energy system, provided either directly by storage or indirectly by demand response measures. Both types of flexibility allow reducing peak loads and increasing self-consumption, e.g., of electricity from PV or heat from solar collectors. In the case of CHPs, they can operate at times of higher electricity prices. However, implementing demand response can be more challenging than other forms of energy management because it requires coordinating the actions of multiple consumers, such as those in a heating network. Apart from legal and economic issues to motivate the consumers' participation, there are technical difficulties. These involve estimating the demand shifting potential and utilizing it in the supervisory controller, distributing the desired demand shift among the consumers, estimating their current state. They also involve distinguishing between the effects of the demand response measures and natural fluctuations of the demand.

We will present a solution for heating networks that is based on a representation of the demand shifting potential as a thermal storage with time-varying charging and discharging limits. This is combined with a distributed demand response algorithm employing mathematical models of the consumers to estimate individual demand and demand shift curves that are aggregated by a centralized coordinator. Compared to a market-based algorithm involving hourly prices, the proposed approach is better able to handle typical rebound effects, where reducing the demand at one time results in increased demand at a later time.

The approach is evaluated in simulation studies for the Austrian network of Reidling. The simulation models are based on IDA ICE and involve detailed models of both the networks and the individual substations. A model-predictive controller based on mixed-integer linear programming handles the heat and power production involving biogas CHPs and optimizes its operation by using the demand response measures.

Acknowledgment: The research leading to these results has received funding from the COMET Programme under Grant No. 869341 and the Austrian Climate and Energy Fund under Grant No. FO999888458.

Keywords: integrated energy systems, demand response, distributed, simulation, district heating network, optimization

Dr. Long is a Senior Engineer at the National Renewable Energy Laboratory's Controls and Analytics Group. He has 20 years of experience in modeling, district energy analysis, and software development. He has a PhD and master's in Architectural Engineering and a bachelor's in Electrical Engineering.

Ambient loop network and capacity expansion modeling case study in the USA and Austria

Nicholas Long, National Renewable Energy Laboratory; Sebastian Zwickl-Bernhard, TU Wien; Felix Bauer, TU Wien; Whitney Trainor-Guitton, National Renewable Energy Laboratory

Nicholas Long (presenter) nicholas.long@nrel.gov

Smart energy systems are critical for addressing contemporary energy challenges, such as sustainability, efficiency, resilience, and reliability. This abstract presents an analysis of capacity expansion planning in two prototypical locations: Vienna, Austria and Washington, DC, USA. While the USA case study examines a potential ambient loop district thermal connection in a disadvantaged neighborhood which is undergoing upgrades, the Austrian case study deals with an already well-developed district heating and cooling network transitioning toward carbon neutrality.

Our study integrates disparate modeling tools through end-use building load data exchange and assess the impacts of various energy strategies on thermal and electrical grids, including the integration of distributed energy resources (DERs) and district energy systems with wastewater heat capture and thermal energy storage. Through detailed evaluations using URBANopt's urban analysis, REopt's DER models (always price-taker approach) for distributed energy resources, and a two-stage stochastic optimization model for determining the optimal generation portfolio and dispatch of the district thermal supply, we provide robust insights into cost-effective generation investments aimed at reducing future energy use and carbon emissions. This includes integrating high shares of geothermal sources and thermal energy storage in order to decarbonize not only the fueling energy mix but also to improve the energy generation and demand matching in the systems.

Preliminary findings show improvements in grid efficiency and resilience, underscoring the importance of these strategies in advancing sustainable urban energy systems. By examining real-world case studies and utilizing advanced modeling techniques, our research offers practical solutions for optimizing energy systems in urban environments. From assessing the potential of district energy systems to leveraging distributed energy resources, our findings contribute to the enhancement of sustainability and resilience in smart energy. This work is funded by Geothermica FLXenabler, a project seeking to quantify how sector coupling and flexible energy supply can accelerate cost reduction when transitioning to a fully decarbonized energy system in Europe and the USA.

Keywords: district energy, distributed energy resources, ambient loops, capacity expansion modeling, case study

Nils Namockel is a Research Associate and a doctoral candidate at the University of Cologne. His research focus lies in the fields of energy system modeling with a focus on flexibility. He studied Industrial Engineering with a major in Electrical Energy Technology at the RWTH Aachen University.

Wholesale electricity market modeling with distribution grid constraints

Arne Lilienkamp, Nils Namockel, Oliver Ruhnau, University of Cologne.

Nils Namockel (presenter) nils.namockel@uni-koeln.de

The transition toward net-zero energy systems implies a rise of distributed generators, batteries, and new consumers, including electric vehicles (EVs) and heat pumps. The additional generation, consumption, and flexibility of these assets may substantially impact wholesale electricity markets. This is, however, subject to distribution gird constraints, which have been neglected in existing wholesale market models. Here, we propose to use the “equivalent electricity storage” approach to aggregate individual consumers’ net load and flexibility at distribution grid level, taking underlying grid constraints into account. The local constraints are approximated based on the installed capacity of low-voltage substations in exemplary distribution grids and scaled to the federal level proportionately to the prevalence of settlement structures. We illustratively apply the approach to flexible electric vehicle charging in Germany for a 2035 scenario. We find that considering distribution grid constraints reduces both the volatility and flexibility of electric vehicle charging, affecting wholesale markets. We analyze further implications for the wholesale market equilibrium as well as the value of relaxing distribution grid constraints.

Keywords: Wholesale Electricity Market, Distribution Grid Constraints, E-Mobility, Flexibility, Virtual Storage

He graduated in Energy Engineering from the Politecnico di Milano in May 2021. He is currently a research fellow and his area of analysis concerns the simplified modelling of complex building-plant systems integrated with district heating networks in decarbonisation scenarios.

District cooling system: energy, economic and environmental analysis of a case study in Tunisia

Nicola Cesare Di Nunzio, Alice Denarie, Mario Motta, Michela Romagnosi, Politecnico di Milano

Nicola Cesare Di Nunzio (presenter) nicolacesare.dinunzio@polimi.it

District cooling systems (DCS) have a higher efficiency and lower energy consumption compared to conventional cooling technologies; this makes them a strategic technology to cover cooling demand which is expected to have a tenfold expansion by 2050 . Considering the predominantly hot climate of the Middle East and North Africa (MENA) region, the adoption of DC systems would be very beneficial.
In this work, a case study of a district cooling network in Tunis is analysed. A feasibility analysis was conducted to assess the viability of the network from a design, economic and environmental point of view. The analysed area is a health district with hospitals, universities, clinics and specialised centres and is densely built-up and characterised by an irregular land elevation. Two different approaches were used and compared to determine the cooling demand of the area, and to establish which and how many buildings could be connected to the district cooling network. Taking the entire area and all project buildings into account, the simulations show that it has a low line heat density (<2.5 MWh/m) which decrease the economy performances of the district cooling network. For this reason, only two areas within the entire district were considered for the feasibility study. Then, different types of generation plants were evaluated from the point of view of environmental and economic design: solutions involving compression chillers with and without the installation of thermal storage, solutions involving photovoltaic panels, and solutions with a co-generator supplying the chillers with electricity and an absorption chiller with heat. In addition, sensitivity analyses were carried out to assess the economic and environmental feasibility of the district heating system under different technologies, costs, business model used and demand density. This sensitivity analysis is aimed at determining the best conditions for project feasibility. The results obtained show that the district cooling solution in a country like Tunisia can reduce greenhouse gas emissions and significantly decrease electricity consumption while also remaining economically competitive.

Keywords: District cooling, economic analysis, chiller, buisness model, heat density, Tunisia cooling demand

Dr. Tijs Van Oevelen is senior researcher at VITO, where he works in the Thermal Energy Systems team. His research aims at technologies for improving the sustainability of heating and cooling systems. Recently, most of his attention is devoted to management of energy flexibility in thermal networks.

Peak load reduction in a district heating network by means of demand response and supply temperature control: Evaluation of test results

Tijs Van Oevelen, Thomas Neven, Faran Ahmed Qureshi, Jan Diriken, Chris Hermans, Dirk Vanhoudt, VITO/EnergyVille

Tijs Van Oevelen (presenter) tijs.vanoevelen@vito.be

District heating networks are essential components of current and future smart energy systems. They have a high potential for decarbonization of building heat demands by distributing heat from sustainable and recovered heat sources. Furthermore, their high intrinsic thermal energy flexibility is a valuable resource for coordinating the supply and demand of energy, within and beyond the thermal energy sector.

In this work, a supervisory control system for optimizing the operational performance of district heating systems has been developed. It is aimed towards real-time high-level prediction and coordination of the flexibility assets across the thermal distribution chain based on thermal-hydraulic modeling. Recently, an improved version of this supervisory control system has been tested in an isolated branch of the district heating network of Brescia, Italy. In this test, the objective was to reduce heat load peaks by a combination of building demand response and network supply temperature control. In this conference contribution, the control methodology, testing approach and evaluated test results will be presented.

Keywords: District heating, Peak load reduction, Supervisory control, Energy flexibility, Demand response, Supply temperature control

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.

Demand side management (DSM) key performance indicators as a value driver for large scale DSM implementation in district heating networks

1) Dabrel Prits, TalTech 2) Eduard Latõšov, TalTech 3) Anna Volkova, TalTech

Dabrel Prits (presenter) dabrel.prits@taltech.ee

District heating demand side management (DSM) research and trend toward digitalisation have taken off in the past decade. Despite DSM systems being researched, tested, and developed, only several DH larger-scale DSM implementation projects, like in Copenhagen and Espoo, have been identified. In some cases, there is an expectations and priorities mismatch in DSM implementation between the consumers and the DH. Furthermore, it is possible that existing DSM key performance indicators (KPIs) do not convey or articulate the value of DSM implementation clearly enough. It is especially important from the DH company perspective.

Overview of existing DSM implementation KPI has been done. Several KPI have been selected and further developed in the frame of this research. In addition, value proposition for the customer and the DHC are considered. Well-known KPIs for the DSM are for example customer side energy savings, peak demand and emission reduction. These KPIs can be a bit abstract to articulate a DSM implementation value for a DH company, that is why additional KPIs should be identified and developed.

Selected KPI are used for impact evaluation of potential DSM implementation in existing Tallinn DH network. A commercially available system was used for DSM testing by load shifting during two heating seasons. Collected data have been used for network data aggregation and a bottom-up approach is used for evaluating and calculating the effects on Tallinn district heating network. The DH network uses a one component heat tariff, based on consumed heat without an installed capacity component. Thus, technical DSM KPI-s are especially important.

Keywords: District heating,digitalization,demand side management,demand side response, DSM KPI,Energy savings,peak demand reduction,emission reduction,EU district heating,smart systems,sector coupling

Dr. Faran Ahmed Qureshi is a researcher at VITO, where he works in the Thermal Energy Systems team. His research aims at developing technologies for improving the energy efficiency and sustainability of energy systems, and energy management of flexible loads.

Comparing and evaluating different predictive control configurations in a district heating network – Simulation study

Faran Ahmed Qureshi, Tijs Van Oevelen, Dirk Vanhoudt, VITO/EnergyVille

Faran Ahmed Qureshi (presenter) faranahmed.qureshi@vito.be

We have developed a model predictive control (MPC) based solution for reducing the peak load in district heating networks. MPC is based on a dynamic model of the system and uses that model to formulate a non-linear optimization problem. The MPC acts as a controller and is applied in a receding horizon fashion to achieve closed-loop control. MPC provides an ideal control framework for district heating networks because of its ability to formulate complicated control objectives effectively, handle nonlinear systems, and system constraints. All of this allows MPC to exploit system flexibilities and achieve optimal performance.

In this simulation study we compare the performance of various optimal control configurations designed to achieve demand response and supply temperature control, separately, and together. Open-loop simulations are carried out that vary in terms of the cost function, control variables, and tuning parameter settings. Various performance criteria are defined, which are used to benchmark the behavior of controller configurations among each other and compared to a base case without an MPC controller. This talk will share the results of our comprehensive simulations and the insights we learned about the different control configurations and settings on the operational performance of the district heating network.

Keywords: Model predictive control, District heating, Peak load reduction, Energy flexibility, Demand response

Costanza Saletti is a researcher at the Department of Engineering and Architecture of the University of Parma, Italy. Her research interests are related to the simulation, optimization and control of integrated energy systems and district heating and cooling networks.

Coordination of multi-energy prosumers with demand side management

Costanza Saletti, University of Parma;
Mirko Morini, University of Parma;
Agostino Gambarotta, University of Parma

Costanza Saletti (presenter) costanza.saletti@unipr.it

Due to the sharp transition from centralized to decentralized energy systems, energy networks with prosumers are expected to become more widespread in future years. In detail, prosumers are defined as consumers that also produce energy through local conversion plants, typically based on renewables.

An additional potentiality of prosumers in energy networks is Demand Side Management (DSM). This is a category of management strategies in which the energy demand of the prosumer is varied in coordination with the production, leading to a better use of resources, e.g. peak shaving, lower cost, better use of renewables.

Nevertheless, due to the deriving system complexity, the optimal operation of an individual prosumer may be in competition with that of another prosumer or of the global system. Thus, it is essential to provide reliable management tools, especially with a large number of interacting subsystems. New available tools applied to prosumers may lead to optimal solutions that are in competition with others, if they are not efficiently coordinated by an orchestrator.

This work presents a set of optimization strategies for optimal management of networks of generic prosumers encompassing multiple energy vectors and plants. All prosumers are linked to a district heating network and are able to carry out DSM actions, meaning that they accept variations in heat demand without significantly affecting thermal comfort. In the work, different optimization strategies are developed and compared, in order to identify the most suitable for future implementation in real-time control. One of the methods relies on centralized optimization, which considers the system in its entirety but is computationally challenging, while other tools implement hierarchical distributed optimization methods. These are structured into a set of Local Optimizers, which manage the set of prosumers, and a Global Optimizer, which operates the central plants and network. The optimal set of DSM options for the prosumers are obtained through different heuristic procedures, which lead to a more profitable solution for the whole network. The methods are tested on a University Campus, and the solution that guarantees low computational effort and feasible performance is selected for future implementation.

Keywords: prosumers, integrated energy systems, multi-energy systems, district heating, demand side management, optimization, energy management

Nicolas is a researcher specialized modeling for simulation and optimization of large-scale energy networks. His interests range from the optimal (and sober) design and operation of district heating or gas networks, to the integration of renewable energy sources in energy production systems.

Optimal control for gas distribution networks with flexibility and biomethane injection targets

Nicolas Vasset, CEA-LITEN (France); Yacine Gaoua, CEA-LITEN (France)

Nicolas Vasset (presenter) nicolas.vasset@cea.fr

The current situation in Europe requires to find robust, sustainable and operational alternatives to the use of natural gas. At the same time, production of decentralized, non-fossil biomethane by new actors is swiftly increasing in several European countries. Many of those actors seek valorization of this renewable resource through injection in natural gas networks, typically at the distribution level. The operational management of these distribution networks requires the implementation of piloting schemes guaranteeing security constraints, time stability and demand satisfaction. While network operators today use full scale hydraulic simulation tools in order to secure operation planning, finding the right piloting for a network becomes extremely challenging; especially when operation has to guarantee a prioritized injection for multiple, decentralized production points for biomethane. Complexity arises also with the need to operate at the same time reverse flow stations, allowing to handle demand intermittency through injection in the transportation network.
We have proposed, implemented and tested a methodology to compute the best piloting strategy for gas distribution networks of large scale (10000+ nodes) with an arbitrary number of biomethane injection points. The approach is based on mathematical optimization of large-scale networks, with refined hydraulic description of its operation on a yearly basis. The optimization method is based on mixed integer non-linear programming techniques, and mobilizes a hierarchical approach for resolution. Multiple objectives are seeked, including biomethane injection, minimization of the linepack over multiple scenarios and mimimal variability for piloting strategy settings with respect to demand evolution. Results show the capacity of this approach to guarantee biomethane injection while minimizing the linepack much more aggressively than previous, state-of-the-art settings, through CPU-limited computations for some of the largest French distribution networks. We describe also here the network capacity to compute the maximal network flexibility for temporarily hosting injected gas without compromising its operation, using it as a de facto storage facility for possible power-to-gas processes.

Keywords: Biomethane, Large-scale networks, network flexibility, non-linear optimization, large-scale numerical modeling, power-to-gas

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

Naomi Adam is an enthusiastic first-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.

Co-design of Thermal Systems in a Collective Low-Carbon District

Naomi Adam, KU Leuven / Lieve Helsen, KU Leuven & EnergyVille / Louis Hermans, KU Leuven

Naomi Adam (presenter) naomi.adam@kuleuven.be

Collective low-carbon districts are promising to decarbonize the building sector in a cost-effective and energy efficient way. These low-carbon districts aim to increase the share of renewable and residual energy sources (R2ES). Thanks to thermal storage, flexibility can be exploited to shave peaks and increase the R2ES share in final energy use. However, an efficient system integrator and an appropriate sizing method are needed to minimize both operational expenditures (OPEX) and capital expenditures (CAPEX). An integrated optimal control and sizing approach, known as co-design, ensures that the eventual (optimal) control of the district is already considered during the (optimal) sizing phase, which is important as sizing and control are mutually dependent.

This research, therefore, develops co-design algorithms that use a nested optimization. These algorithms combine inner-layer control strategies, including rule-based control and non-linear white-box Model Predictive Control (MPC), with outer-layer sizing methodologies. These sizing methodologies encompass both brute force sizing and meta-heuristic sizing algorithms, aiming to reduce computational effort. The considered meta-heuristic sizing algorithms are genetic algorithm, simulated annealing, particle swarm optimization and ant colony optimization.

The effectiveness of the developed co-design methodologies is evaluated through a case study involving a small district heating network comprising three buildings with a centralized ground-source heat pump and buffer tank, taking the heat pump capacity and buffer tank volume as sizing variables.

First, the performance of the outer-layer sizing methodologies is assessed. Compared to brute force sizing, the genetic algorithm and simulated annealing approach emerge as meta-heuristic algorithm frontrunners in overall performance, including optimal solution quality and speed of convergence.

Second, the comparison between co-design and conventional rule-based approaches demonstrates significant cost reductions and improvements in energy efficiency. The adoption

of the co-design method, particularly when coupled with MPC, showcases a 36,1% decrease in OPEX and a 14,7% decrease in CAPEX, along with CO_2 emissions reduction.

Keywords: Co-design, integrated optimal control and sizing, model predictive control, meta-heuristics, collective low-carbon districts

After finishing his master degree in Mechatronics - Systems Engineering, Philipp Althaus is currently a research associate at Forschungszentrum Jülich.
His research interest is in intelligent control solutions, focussing the application field of building heating.

Intelligent control using flexible controller architecture for improved energy efficiency of room heating: Design and evaluation in a living lab

Philipp Althaus, Institute of Energy and Climate Research, Energy Systems Engineering (IEK-10), Forschungszentrum Jülich GmbH;
André Xhonneux, Institute of Energy and Climate Research, Energy Systems Engineering (IEK-10), Forschungszentrum Jülich GmbH;
Dirk Müller, Institute of Energy and Climate Research, Energy Systems Engineering (IEK-10), Forschungszentrum Jülich GmbH and E.ON Energy Research Center, Institute for Energy Efficient Buildings and Indoor Climate, RWTH Aachen

Philipp Althaus (presenter) p.althaus@fz-juelich.de

Transforming the heat supply of buildings to the efficient use of renewable energies is a complex task which can comprise different layers of decisions and supply elements. Arguably, the energy demand at room level is a key factor as it influences the necessary supply system at all higher levels (ranging from building-wide distribution, building supply to district heating) regarding absolute energy demand as well as flexibility.
The heat demand curve for room heating can be influenced by physical refurbishment, adaption of a user's demand and the control action to supply such demand. In this work, we focus on the control aspect for influencing the demand curve. The research is executed in a living lab environment. The real-world testbed comprises several office buildings in regular use, underlining the applicability of the tested solutions to the field.

In previous works, the hardware allowing to close the control loop has been set up as well as a web-based user interface JuControl which enables users to supply their temperature wishes.
The cloud-based control application put into action covers multiple tasks. First, it collects all relevant data from databases and APIs. Second, it determines the desired temperature wish by combining information from different input sources (user interface or physical devices). Third, it calculates the next control action output. Lastly, it packages the control action for the implementation by the heating actuator.

Considering user-specific schedules (or assuming fallbacks if unknown) and short-term interactions allows the extraction of desired behaviour over time. Different control algorithms have been integrated in the application ranging from relatively simple setpoint extraction over rule-based predictive control to model predictive control algorithms. A comparison of selected configurations and aspects is shown.

On top of the room level, also the influence on the supply at building level is studied: The trajectories of the building-wide heatflux demand show significantly changed characteristics compared to operation with purely manually operated thermostats. For some buildings, previously configured configurations for the building-wide rule-based, supply automation needed to be adapted for further improved operation.

Keywords: controller architecture, model predictive control, living lab, end energy use, energy efficiency, energy flexibility, room heating

Cameron Downing is a PhD candidate and researcher at the University of Chester. He has co-developed the IDEAS+ methodology for the assessment of heating solutions for use in both domestic and commercial properties. Aswell as this, he's developed the OPTIC methodology, integrating optimisation within the inverse dynamics of a system.

Comparison of the Thermal Experience & Controllability of Gas Boilers and Air Source Heat Pumps

Professor John M Counsell, Cameron Downing, University of Chester

Cameron Downing (presenter)

This presentation/paper introduces a study that applied the IDEAS+ modelling approach (NB: presented at SES 2023) to gas boilers and air-source heat pumps (ASHP). This required the derivation of nonlinear inverse dynamics based control algorithms and optimum start algorithms to ensure that both the modelled systems were perfectly controlled to meet the specified thermal experience of the occupants. These control algorithms were integrated with the IDEAS+ model which models the building physics and occupant thermal experience. Results are presented to demonstrate the controllability, achieved thermal experience and energy performance of both heating systems. The results also explore the sensitivity of each of the heating system's performance to different occupancy patterns and home insulation standards.

Keywords: Building Physics Modelling, Controllability of Heating Systems, Gas Boilers, Air Source Heat Pumps, ASHP, advanced temperature control, Matlab, Inverse Dynamics, IDEAS, IDEAS+

Dr. Wen Liu is an assistant professor at Copernicus Institute of Utrecht University. Her research domain is technology assessment on seasonal thermal energy storage and occupant behaviors' impacts on heat demand in the built environment.

The impacts of behavioral variables on heat demand in the built environment and on the economic consequences of energy efficiency measures investment

Wen Liu, Utrecht University; Robert Harmsen, Utrecht University; Tianrun Yang, Utrecht University; Gert Jan Kamer, Utrecht University

Wen Liu (presenter) w.liu@uu.nl

Energy efficiency improvement and decarbonizing the energy mix of residential buildings are essential to achieving the climate targets. Heat demand reduction for space heating is regarded as a crucial step. Despite the maturity of technologies and available subsidies, energy efficiency improvement in existing dwellings goes slow in many regions. Existing studies investigated the barriers to private homeowners investing in energy efficiency measures.
This research aimed to contribute to the existing literature by explicitly quantifying how occupants' behavior impacts the heat demand of a dwelling and how this affects the economic feasibility of energy-saving measures. Considering this objective, an existing well-insulated apartment and a poorly insulated apartment (artificial one) are selected as the cases. Scenarios are developed to represent the upper and lower bands of behavior parameters. The TRNSYS model is applied to simulate the heat demand of the case apartments and, for the first time, examine the impacts of occupants' behavior on heat demand. The payback period for investing in energy efficiency measures is calculated for each scenario.
The results indicate that the model can accurately simulate the heat demand of the real case. Heat demand in the upper bond behavior scenario is 4.8 times that in the lower bond behavior scenario. The level of partial heating and Indoor temperature are the behavior parameters causing the major variations. Lowering the indoor temperature during the holiday and working times has limited impacts on heat demand variation in a well-insulated apartment. It has a larger impact on the heat demand variation in a poorly insulated case. Unconscious and conservative heating behavior leads to a PBP variation between 12 and 56 years for promoting the energy label from B to A. Improving energy saving to a larger extent leads to a short PBP. In a poorly insulated apartment, the PBP variation is between 6 and 29 years to upgrade the energy label from F to B and between 11 and 56 years for F to D. The dynamic of energy efficiency measures costs, level of subsidies, and heating price are tested in the Monte Carlo analysis, the calculated PBP in conservative scenarios has a higher level of uncertainty.

Keywords: heat in the built environment, occupant behavior, Trnsys, energy efficiency, Payback Period

Mazarine Roquet is a PhD student at the University of Liège. She works on decarbonisation of urban building stocks through low-temperature thermal networks.

Decarbonation of an Existing Building Asset Energy Supply: A Case Study on Low Temperature Thermal Network

Mazarine Roquet, University of Liège
Natalia Kozlowska, University of Liège
Pierre Dewallef, University of Liège
Geoffroy Magnan, Liège Airport

Mazarine Roquet (presenter) mazarine.roquet@uliege.be

In a context of growing pressure to reduce the building stock carbon footprint, newly designed buildings tend towards zero-emission standards. Yet improving existing ones often requires additional insulation and deep revamping which, most of the time, present payback times above 30 years. On the other hand, switching from liquid or gaseous fossil fuels (typically natural gas or fuel oil) to electrified sources (e.g., heat pumps) is also very costly and partly resolves the issue by displacing the fossil fuel use from heating/cooling towards electricity production. Thermal networks are more and more fostered by new policies as they offer the economy of scales and peak demand shaving in order to decrease the costs and enable a profitable decarbonised energy supply.
This work aims to provide a tool that assesses the impact of energy saving measures at the building level (such as insulation or temperature set point adjustment) coupled with the operation and design of thermal networks (e.g., high or low-temperature networks, advanced control strategies, thermal storage…). Most of the existing tools consider separately the network operation and the building comfort conditions transforming the decision-making process into a lengthy trial and error process.
To accelerate the decision process, a physical dynamic-modelling of the thermal network is coupled to the building structures which predicts the perceived indoor temperature based on the operation of the thermal network, ambient conditions and building use. The detailed dynamic building models enable a precise estimation of load demand curves, thus providing a direct link between indoor temperatures and energy consumption.
To underline the effectiveness of the approach, the models, developed on the Dymola modelling platform, are applied to the case study of Liège Airport who is committed to decarbonize their activities linked to the building stock operation (offices, fret halls, passenger halls,…) yet face the aforementioned challenges. This research is focused on showing the capability of a low-temperature thermal network to best meet the heating demands while minimizing the environmental impact. Several decarbonisation strategies are proposed showing how thermal networks can help this purpose.

Keywords: Low Temperature Thermal Network, Building Simulation

Dr. Stavrakas is Co-founder of the Institute for European Energy and Climate Policy (IEECP), based in the Netherlands, where he serves as Financial Director and Senior Researcher. He has major experience in EC-funded projects and several publications in high impact scientific journals.

Advancing integrated and smart renovation packages for efficient, sustainable, and inclusive energy use: Modelling of real-life residential buildings

1) Vassilis Stavrakas, Institute for European Energy and Climate Policy (IEECP), Kingsfordweg 151, Amsterdam, 1043GR, Netherlands.
2) Dimitris Papantonis, Institute for European Energy and Climate Policy (IEECP), Kingsfordweg 151, Amsterdam, 1043GR, Netherlands/ Technoeconomics of Energy Systems laboratory (TEESlab), Department of Industrial Management and Technology, University of Piraeus, Karaoli & Dimitriou 80, Piraeus 18534, Greece.
3) Vlasios Oikonomou, Institute for European Energy and Climate Policy (IEECP), Kingsfordweg 151, Amsterdam, 1043GR, Netherlands.
4) Alexandros Flamos, Technoeconomics of Energy Systems laboratory (TEESlab), Department of Industrial Management and Technology, University of Piraeus, Karaoli & Dimitriou 80, Piraeus 18534, Greece.

Vassilis Stavrakas (presenter) vasilis@ieecp.org

Accelerating the Renovation Wave in Europe demands innovative approaches for designing, demonstrating, validating, and replicating integrated renovation packages that promote efficient, sustainable, and inclusive energy use. However, uptake at the European Union's level lags behind the ambitious decarbonisation goals set by 2050, due to various barriers, including financial constraints, fragmented decision-making processes, split incentives, and uncertainty regarding the long-term benefits of renovation investments. In this work, we address these challenges by providing robust data-driven insights and quantifications to facilitate well-informed policymaking. This proactive approach enables relevant stakeholders, financing bodies, and end-users, to assess the economic viability, energy saving potential, and environmental impact of different renovation strategies. Our study contributes to this imperative by analysing the cost-effectiveness of diverse portfolios of measures, emphasising economic viability, energy savings, and sustainability, to develop integrated renovation packages. To do so, we implement the DREEM model, a fully integrated energy demand and demand-side management simulation model in the building sector. Focusing on real-life residential pilots across different Member States (including Greece, France, Portugal, Spain, etc.), as part of the European Commission-funded Horizon Europe project "FORTESIE" and the LIFE project "RENOVERTY", the application of the DREEM model evaluates the performance and replicability of conventional and smart energy efficiency measures towards the smart-grid paradigm and the development of innovative policy and financing frameworks, like Smart

Performance-Based guarantees. In addition, our analysis considers energy poverty implications and assesses the economic benefits of each measure at a disaggregated (i.e., household) level. Overall, modelling outcomes yield integrated renovation packages comprising various targeted measures and financing options tailored for each case and different building typology under study. This comprehensive approach ensures that the identified solutions are adaptable to diverse contexts, facilitating their replication across different regions in the European Union.

Keywords: Electrification, Building sector, Energy efficiency, Energy modelling, Renovation packages

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

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

Assessing the suitability of existing buildings to operate at lower temperatures via in field temperature lowering testing

Simran Chaggar, FairHeat; James Gallimore, CEng MCIBSE, FairHeat

Simran Chaggar (presenter) simran.chaggar@fairheat.com

The UK government has identified that one of the most cost-effective routes to decarbonising heat are low-temperature heat networks. The introduction of Heat Network Zoning areas in 2025 will make it mandatory for most existing buildings within those areas to connect to new low-temperature heat networks.

One of the greatest challenges is that most buildings were designed with operating temperatures greater than 82°C and small temperature differentials in the region of 10°C, whereas the district heat network (DHN) operators will likely have strict requirements when it comes to flow and return temperatures to maximise the heat network efficiency. This will incentivise both flow and return temperature lowering to increase heat pump efficiency and reduce heat losses and pump electricity consumption. This will lead to lower heating tariffs for consumers making the technology more attractive and economically viable.

FairHeat have carried out a temperature lowering test in a large commercial building over the peak heating period in the winter. The aim of the test was to reduce operating temperatures by 10°C – 15°C to identify if a low temperature heat network or heat pump solution could be a viable heat source without costly fabric and services upgrade work.

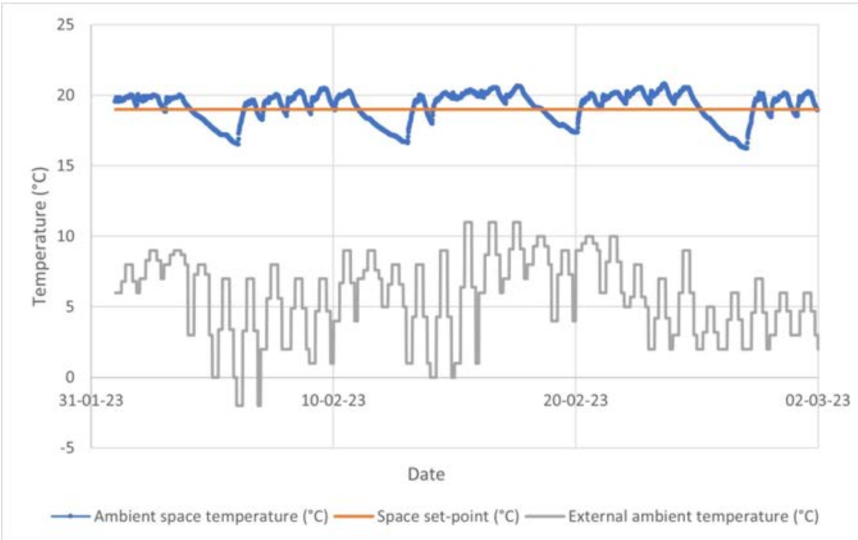
The building is heated via radiators operating at c.70°C. Boiler flow temperatures was reduced from c.75°C – 80°C to 65°C with the weather compensated space heating circuit set to a maximum of 60°C to simulate operating at flow temperatures similar to low temperature heat networks.

Live data was remotely monitored over three months of the test to identify if ambient temperatures within heated spaces were achieving the required set points.

In February 2023, the external temperature dropped below 0°C, however the occupied areas comfortably maintained 19°C – 20°C during occupied hours. The system operated well at a space heating temperature of 60°C throughout February and March.

This exercise demonstrated that reducing temperatures in existing buildings may be possible without fabric or services improvements, which would greatly reduce the cost of decarbonisation and enable the speed-up of low-carbon heating deployment.

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



Maya Neyhousser's work focuses on optimizing complex energy supply concepts using machine learning for district heating. She has contributed to multiple national and international cooperative projects related to sustainable thermal energy systems and the promotion of energy-conscious behavior.

Adaptive Control for Decentralized Feed-in of Solar Heat into District Heating Networks Based on Reinforcement Learning

1) Thilo Walser and Maya Neyhousser 2) Solites - Steinbeis Research Institute for Solar and Sustainable Thermal Energy Systems

Maya Neyhousser (presenter) Neyhousser@solites.de

Controlling decentralized feed-in stations for renewable energies in district heating (DH) networks is challenging due to heat production fluctuations especially by solar heat, varying network conditions as well as feed-in temperature requirements. Experimental testing in the solar heat feed-in station in Düsseldorf, Germany highlighted the significant impact of PID control parameter tuning on feed-in duration and temperature deviation. As part of the research project saM_soL ("Self-learning PID controller for self-optimizing feed-in substations e.g. for solar thermal systems") a machine learning (ML)-based optimization of PID control parameters will be developed in a digital twin of the feed-in substation in Düsseldorf and later tested in the experimental plant.

The digital twin includes a TRNSYS simulation model coupled with a real duplicate of the specific plant controller system. After each simulation time step, the controller system uses simulated temperatures and volume flows to determine the resulting control signals for both hydraulic circuits' pumps, which are then transmitted as input to the simulation model. Simulation results match measured data for a characteristic week. This new approach accelerates the development and pre-training of a ML algorithm for adaptive PID control by approximately 340 times.

A state-of-the-art review of ML identified reinforcement learning (RL) as the most suitable method for real-time adaptive control in dynamic scenarios. RL includes value-based and policy-based algorithms. Value-based algorithms offer simplicity, while policy-based algorithms are adapted to continuous action spaces. Actor-critic (AC), combining aspects of both, appears as a suitable choice for adaptive PID control in feed-in substations. Various AC algorithms such as soft actor-critic (SAC), deep deterministic policy gradient (DDPG) have shown promising results in the literature for adaptive PID control. The selected algorithms will be implemented and customized for this project's requirements.

The presentation will explain the method of validation of the digital twin as well as the procedure of the selection of the algorithm based on the literature review of RL.

Keywords: District heating, Artificial Intelligence, Machine Learning, Adaptive control, Parameter optimization, Solar thermal, Decentralized feed-in, Digital twin, Renewable energy

In an ever-evolving energy landscape, we remain dedicated to pioneering advancements that utilize optimization techniques, power system flexibilities, and sector coupling to enhance resilience towards a carbon-free sector in our modern, interconnected world.

AI based heat pump controller for power grid resilience enhancement

Sadia Ferdous Snigdha, Fraunhofer IEG. Tanja Manuela Kneiske,Fraunhofer IEG

Sadia Ferdous Snigdha (presenter) sadia.snigdha@ieg.fraunhofer.de

In a future CO2 free energy system heat pump controller will manage energy supply for households with multi-energy systems (MES), offering efficiency and cost savings by leveraging MES flexibility. The heatpump controller can also be used as a heating and power grid couling point.These controllers, operated by a server-based system, require effective communication for optimal performance.

But what happens if the communications infrastructure is interrupted by an attack or other natural disaster? Are there more costs, is the network overloaded or does the HP system fail completely? How to accommodate that?

A possible solution involves modifying the HP control system to ensure continuous operation even during ICT failures. An AI-based approach to HP control could be crucial in this scenario, guaranteeing uninterrupted operations and sustained heat provision amidst ICT disruptions, thus preventing possible disruptions to the energy system.

In this research, genetic algorithm has been employed to train a neural network model for optimizing heat pump control to implement this solution. During the training process, the model's performance was compared to that of a server-based mixed-integer linear programming (MILP) optimized heat pump controller, serving as a reference benchmark. By employing a well-trained neural network model, the controller can efficiently achieve key performance indicators (KPIs) for uninterrupted heat supply to consumers and enhances computational speed. In summary, this research explores how AI-based heat pump controllers effectively sustain power grid resilience during ICT failures, ensuring uninterrupted heat supply. Initial findings suggest efficient heat pump management, showcasing AI's potential to boost power grid reliability and resilience.

Keywords: resilience, heat pumps, smart energy control, artificial intelligence based control, optimization, power system flexibility, sector coupling point, energy efficiency, robust, smart electricity grid

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Anna Volkova is is professor of thermal engineering in TalTech. She is the head of the 'Smart District Heating Systems and Integrated Assessment Analysis of Greenhouse Gas Emissions' research group and is one of the main proponents of sustainable district heating in Estonia.

Decarbonisation options of district heating peak loads

Anna Volkova, Tallinn University of Technology, Simon Moser, c Energieinstitut an der Johannes Kepler Universitat Linz, Gabriela Jauschnik, c Energieinstitut an der Johannes Kepler Universitat Linz, Aleksandr Hlebnikov, Tallinn University of Technology, Hesham Ali, Tallinn University of Technology, Chiara Cecchin, Euroheat&Power

Anna Volkova (presenter) anna.volkova@taltech.ee

Decarbonizing district heating presents a significant challenge for existing district heating networks. While numerous decarbonization strategies have been implemented to target base and semi-base heat loads, such as the deployment of large-scale heat pumps, utilization of waste heat, using geothermal resources, and leveraging solar thermal energy, addressing the peak heat load remains a critical obstacle. Currently, fossil fuel-fired boilers meet district heating peak loads in most cases.

To address this challenge comprehensively, this study introduces a systematic taxonomy for characterizing peak heat load dynamics within district heating systems, based on an extensive literature review. This taxonomy delineates peak heat loads based on their respective size, duration, and profile form, thereby identifying various types of peak heat load variability.
Essential criteria for implementing carbon-neutral solutions to cover district heating peak loads, including operational switch-on speed and resilience of supply, are identified.

In subsequent stages of the research, efforts were made to ascertain feasible ranges for each criterion across different types of peak heat load variability. This stage was crucial for establishing a robust framework for evaluating carbon-neutral technical solutions within the context of varying peak heat load characteristics. Through this evaluative process, the most preferable solution was identified for each distinct category of peak heat load.

Besides it a comprehensive techno-economic analysis was conducted for the selected technical solution corresponding to each type of district heating peak heat load. This analysis aimed to provide insights into the viability and cost-effectiveness of implementing carbon-neutral solutions across different peak heat load scenarios, thereby informing decision-making processes within the district heating sector.

Keywords: peak heat load, district heating, decarbonisation, green electricity, base load, cold climate, energy systems, boilers, thermal energy storage

Johannes Nicolás Wildfeuer is a PhD student at the Technical University of Denmark in data-enabled heating optimization in apartment buildings. He currently works on digital twins for various applications in apartment buildings. He is interested in cyber-physical modeling and data processing.

Continuous commissioning of hot water installations using a digital twin

Johannes Nicolás Wildfeuer, Technical University of Denmark;
Co-Authors:
Kevin Michael Smith, Technical University of Denmark;
Christian Anker Hviid, Technical University of Denmark;
Michele Tunzi, Technical University of Denmark

Johannes Nicolás Wildfeuer (presenter)

This study investigates the use of digital twins for continuous commissioning of hot water systems. The aim is to increase efficiency and reduce energy consumption in district heating systems. A residential building in Lundtoftevej, Lyngby (Denmark) was selected to optimize the return temperatures of the hot water system, a critical factor in improving the performance of district heating systems. The identification and implementation of these operational improvements was enabled by a specially developed digital twin that mirrors the behavior of the real hot water system. The methodology includes data collection from the building's hot water system, development of a baseline model, and subsequent iterations to refine the accuracy and predictive capabilities of the digital twin. The system's control logic was mapped using custom classes and controllers based on the Modelica framework.
The results of using the digital twin show significant potential for reducing return temperatures and improving energy utilization. The mass flow weighted average return temperature of the studied DHW system has the potential to be reduced from 32.2°C to less than 20°C. This can be achieved by adjusting flow rates or improving heat exchanger performance. In addition, optimization can better account for usage patterns and external influences. The results highlight the value of digital twins in achieving energy efficiency goals by providing a replicable model for similar installations. Future work will focus on extending the application of digital twin technology to a wider range of systems within district heating networks, further reducing carbon emissions and improving the resilience of heating networks.

Keywords: Digital Twins, Continious Comissioning, Modelica, District Heating, Hot Water Installation, Domestic Hot Water, DHW, Energy Efficiency, Return Temperatures Optimization

Poul Alberg Østergaard is a professor in energy planning at Aalborg University working with energy system simulations and energy system transition scenarios

District heating in Denmark – Dynamically reshaping the composition of heat supply

Poul Alberg Østergaard, Marina Georgati and Iva Ridjan Skov, Aalborg University.

Poul Alberg Østergaard (presenter) poul@plan.aau.dk

The district heating sector is often perceived as a conservative and somewhat un-dynamic sector, operating systems with long time horizons and thus also system configurations evolving slowly. In this work we investigate the literature on the perception of the district heating sector in different countries, and with a base in the Danish district heating system probe deeper into how this system has evolved over time. In the paper, we approach the theme from three different aggregation levels. Through analyses of national data on technology stock and usage; through analyses on municipality level using geographical information system analyses and lastly from a single-plant case where the development and drivers of a district heating system established in 1990 is exemplified. Furthermore, insights on emerging technologies entering the Danish district heating sector, such as utilisation of waste heat from PtX plants are provided. In conclusion we see a Danish district heating sector which is adapting well to changing environments and thus organically transforming for the benefit of consumers and overall energy system transition.

Keywords: District heating, evolution, technology stock, technology use, drivers, case study.

Electrification of transport, heating and industry

Wellington Alves is an Assistant Professor at the Polytechnic Institute of Porto. Is a researcher at the Center for Innovation and Research in Business Sciences and Information Systems and also at ALGORITMI Research Centre.

A Data-Driven Exploration of End-of-Life Scenarios for Lithium-ion Batteries in Electric Vehicles

1) Anna Santosa, 2) Wellington Alvesb and 3) Paula Ferreirac
1,2 CIICESI, Escola Superior de Tecnologia e Gestão, Instituto Politécnico do Porto, Rua do Curral, 4610-156 Felgueiras, Portugal
2,3 ALGORITMI Research Centre, University of Minho, Portugal

Wellington Alves (presenter) wal@estg.ipp.pt

Electric vehicles (EVs) have been considered one important strategy for the decarbonization process, while Lithium-Ion Batteries (LIBs) have been the favorite option as a power source due to their exceptional performance. Despite the importance of EVs, the End of Life (EoL) of LIBs remains a challenging task. Due to the increased number of vehicles, a large number of batteries will reach the end of their useful lives soon, which is why actions need to be taken by both governments and companies to anticipate and be prepared for the event. As an alternative to develop strategies to support the EoL of LIBs, over the last few years different studies have used different forecasting techniques to estimate batteries and their components that are approaching their EoL. In this context, this research aims to analyze the EoL of LIB based on data derived from the predictive models available in the existing literature, aiming to understand each available model to draw a picture of the most suitable and friendly model to be considered when developing scenarios for EoL of LIB. From the research conducted, Product Flow Analysis (PFA) was pointed out as the most suitable method to be considered in this research to predict the volume of LIB available for recycling across the Iberian Peninsula. This result put in evidence the possibility of PFA considering aspects such as variations in lifespan and disposal rates, and the influence of the total volume of LIB that reaches the end of its useful life. Additionally in the modeling process, a set of variables such as sales, geography location of battery uses, lifespan, and discard probabilities can be also considered to forecast the future scenarios of LIBs.The results from the application can add value to the current literature by enabling the prediction of waste by district. This, in turn, facilitates the analysis of sensitive areas and the creation of strategies from the perspective of the circular economy such as establishing collection points and dismantling centers.

Keywords: Electric Vehicles Batteries; End-of-Life, Product Flow Analyses

Christopher Graf is a PhD fellow in the Department Thermal Energy Systems Technology at Fraunhofer IEE in Kassel, Germany. His research focuses on energy-efficient domestic hot water systems, which face challenges balancing energy efficiency, hygiene, and comfort.

Domestic Hot Water Systems in existing residential buildings: A Comparative Simulation Study on Efficiency and Hygiene Challenges

Christopher Graf, Fraunhofer Institute for Energy Economics and Energy System Technology IEE; Anna Cadenbach, Fraunhofer Institute for Energy Economics and Energy System Technology IEE; Peter Pärisch, Institute for Solar Energy Research Hamelin GmbH (ISFH).

Christopher Graf (presenter) christopher.graf@iee.fraunhofer.de

Domestic hot water (DHW) is vital for comfort and well-being of residents in daily life. However, the production and circulation of hot water often require considerable energy consumption.

According to the 2023 climate protection programme in Germany, the building sector must reduce its GHG emissions by 42% between 2021 and 2030. To improve efficiency and reduce GHG emissions, advances in building envelope insulation are expected to reduce the overall heat demand of buildings, while the demand for hot water will remain relatively constant or even increase due to increased comfort requirements and higher per capita consumption. This reduces space heating demand and allows for the use of low temperature heating systems, thereby providing a great opportunity for renewable heat sources.

In contrast, the demand for hot water has remained relatively constant or even increased due to increased comfort requirements and per capita consumption. Additionally, DHW systems in existing buildings typically employ centralised architecture, requiring high supply temperatures, yielding high return temperatures, and resulting in low system efficiency due to large plumbing systems and DHW circulation. This, especially the need for high temperatures, results in limitations for the efficient operation of renewable heat sources and district heating networks.

The conflict in DHW systems between energy efficiency, hygiene and comfort is amplified, as high temperatures are mostly required for hygienic purposes and a higher share of renewable heat is demanded. Thus, developing DHW systems efficiently utilizing renewable heat without excessive temperature requirements and ensuring impeccable hygienic conditions is essential.

This study evaluates measures to address current challenges, with a specific emphasis on transforming existing DHW systems within different existing buildings. The primary objectives

In 2012, Oddgeir joined Danfoss as a global district energy expert. His role covers a wide spectrum within the district energy sector, including detailed component analysis, examination of complex interactions, and assessing district energy systems within the broader energy context.

Economic comparison of hydronic based heating and multi-split A2A heat pumps – using a case study

Oddgeir Gudmundsson, Danfoss Climate Solutions, Denmark

Oddgeir Gudmundsson (presenter) og@danfoss.com

As the impact of climate change is becoming more and more obvious the decarbonization of the energy system is continuously rising in the political arena. In the building sector the phase out of fossil fuels for heating is a priority. For building thermal demands heat pumps offer attractive benefits, such as avoidance of local emissions, reduced demand of high quality energy sources, and moving the decarbonization responsibility from the end-users to the electricity suppliers. In that respect heat pumps are recognized as an important piece of the decarbonization puzzle. However, heat pumps enclose range of different technological alternative, such as air-to-air, air-to-water and water-to-water, where each alternative has its benefits and limitations. The choice of the heat pump alternative, and where it is applied, district or building level, can have profound impact on the complexities of decarbonizing the electricity supply as well as the cost of the decarbonization, where the cost both includes the cost of decarbonized electricity generation as well as the total cost to the end users. Ideally the future decarbonized energy systems should be optimized based on energy consumption, energy flexibility and system cost. The purpose of this study is to compare end-user economics for different heating demand electrification alternatives, and reflect on the benefits, and implications, that these alternatives have on the upstream energy system.

Keywords: hydronic installations, heat pumps, air-to-air heat pumps, air-to-water heat pumps economics

She is currently pursuing her Ph.D. at the research Center for Combined Smart Energy Systems (CoSES) at Technical University of Munich, Germany. Her research interests include power system, energy storage system, electrical vehicles and game theory.

Equilibrium Analysis of Coupled Energy Sharing Community and Transportation Network: A Game-theoretic Approach

Peiyao Guo, Univeristy of Munich

Peiyao Guo (presenter)

With the increasing deployment of distributed energy resources (DERs) such as photovoltaic (PV) panels, wind turbines and microturbines, the traditional consumers are transformed into prosumers in power systems, which incentivizes the shift from centralized power generation systems to the energy sharing communities based on prosumers. Furthermore, the ongoing proliferation of electrical vehicles (EVs) is coupling the power and transportation sectors, which necessitates the new business model for interdependent energy sharing community and transportation network. This paper proposes the game-theoretical models for coupled energy sharing community and transportation network, and the equilibrium between two systems is analyzed and proved.

In this paper, a user equilibrium model for the transportation system is proposed, where rational drivers select charging opportunities and routes to minimize travel cost. It can be proved that the user equilibrium in the transportation network is reached when travel cost cannot be reduced by users unilaterally changing routes. Furthermore, a non-cooperative game model is formulated to represent the interactions among prosumers in an energy sharing community. In the coupled power-traffic system, the traffic flow is influenced by charging prices, and has the potential to redistribute the electricity demand in the energy sharing system. The existence of socially optimal equilibrium between the coupled energy sharing and transportation systems is proved. Case studies illustrate the mutual impact between energy-sharing and transportation systems.

Keywords: Electric vehicle, Transportation network, Energy sharing, Non-cooperative game, Equilibrium

Julian Hermann is a doctoral student at the Chair of Energy Systems Analysis at ETH Zurich. His research focuses on the decarbonisation of existing residential buildings, particularly integrating the synergies between heat pumps and building renovation measures into energy system optimisation.

A surrogate model for residential heat pump COP estimation in the context of energy system optimisations

Julian Hermann, ETH Zurich.
Marco Willi, ETH Zurich.
Dennis Roskosch, ETH Zurich.
Russell McKenna, ETH Zurich, Paul Scherrer Institute.

Julian Hermann (presenter) jhermann@ethz.ch

Space heating and domestic hot water account for around 30% of European final energy consumption and greenhouse gas emissions. Heat pumps (HP) are an essential technology to leverage renewable electricity for low-carbon heating. The coefficient of performance (COP) is a crucial metric for HP efficiency. Therefore, the COP is frequently used in energy system models, which are valuable tools for energy planning and identifying optimal energy system design . The COP depends on multiple aspects, such as heat source and sink temperatures, compressor efficiencies , or the HP integration into the building's hydronic system. A mismatch between HP capacity and heat demand occurs at higher ambient temperatures, resulting in the HP switching on and off frequently and deteriorating the COP. Energy system models neglect these operational aspects and use simplified COP estimation methods based on constant values, the Carnot/Lorenz cycle or fits based on manufacturer data. These simplifications result in overestimating COPs and underestimating operational costs, impacting the optimal energy system design. This work attempts to bridge the gap between real-world HP operation in residential applications and HP representation in energy system models by developing a thermodynamically based surrogate model for COP estimation.

We develop a Python-based framework that models a standard vapour compression cycle combined with a compressor model. Additionally, we consider how the HP's integration into the hydronic system affects the on and off switching. A first validation of our model with field study data shows a good agreement in seasonal performance factors. Moreover, estimating annual electricity costs shows that the choice of the COP estimation method can significantly impact the results. As the thermodynamic model is computationally intensive and therefore unsuitable for energy system modelling, we use the results to develop a data-driven surrogate model for fast COP computations. Our surrogate model improves the representation of HPs in energy system models, as it provides a more realistic COP estimation and, thus, more accurate operational cost.

Keywords: Heat pumps, COP, residential heating, surrogate model, energy system modelling

Noémie Jeannin is a PhD candidate in the laboratory of photovoltaics and thin-film electronics (PV-lab) of the EPFL, Switzerland. She is studying the impact of electric vehicle charging and photovoltaic electricity production on energy systems.

Using electric vehicle as flexibility asset for photovoltaic electricity production: A geographical approach

Noémie Jeannin, EPFL PVlab

Noémie Jeannin (presenter) noemie.jeannin@epfl.ch

Transportation and electricity production are the two largest contributors to greenhouse gas emissions in Europe. Decarbonizing mobility and integrating more renewable sources in electricity production are necessary levers to meet the climate targets. Those transformations require precise energy planning to cope with the additional demand resulting from the electrification of vehicles and the fluctuation of renewable energy sources. Coupling electric vehicle (EV) charging with photovoltaic (PV) electricity generation could help to provide clean electricity for charging EVs and provide flexibility storage to the overproduction of PV power plants. The batteries of the vehicles can then be discharged into the grid to support the electricity supply during periods of high demand. This study uses a GIS-based methodology to analyse the mobility needs of the European population and deduce the charging needs of an electrifying vehicle fleet. Scenarios of charging behaviour are then applied to distribute the charging needs between home, work, and point of interest to quantify the charging demand in space by hectare and hourly in time. The load curves of the charging demand are then compared to the PV potential to estimate the amount of PV electricity that can be stored locally in the batteries. Reduction in electricity costs and CO2 emissions are used as metrics to evaluate the benefits of the EV-PV coupling for an area. The methodology was applied to three cities with different solar radiance Aalborg (Denmark), Bern (Switzerland) and Palermo (Italy), looking at three different charging scenarios to compare the potential of EV-PV coupling in different contexts. Results show that load curves of EV charging are highly dependent on the charging behaviours. Despite a lower solar radiance in Denmark, PV electricity production can cover most of the charging demand during the day. There is a high potential to store PV production in EV batteries. Still, in summer, the battery capacity of only the private EV fleet is not enough to absorb all the PV overproduction. The methodology is implemented in Citiwatts, an online open-source tool for energy transition planning.

Keywords: electric vehicle, photovoltaic, flexibility, vehicle to grid, electrification of the mobility, GIS, geographic

Antoine Laterre is performing a joint thesis at the Catholic University of Louvain and the University of Liège in Belgium. His research activities focus on the techno-economic potential of Carnot batteries as effective sector coupling systems and flexibility options in renewable energy systems.

Comparing Carnot batteries and chemical batteries for residential heat and electricity management: a prospective life-cycle assessment

Antoine Laterre, Catholic University of Louvain and University of Liège;
Diederik Coppitters, Catholic University of Louvain;
Vincent Lemort, University of Liège;
Francesco Contino, Catholic University of Louvain;

Antoine Laterre (presenter) antoine.laterre@uclouvain.be

Carnot batteries convert electricity into heat for storage, and later transform this stored heat back into electricity as required. Because of their nature and the conversion technologies used for charging and discharging (heat pumps and an organic Rankine cycle, respectively), they are generally seen as an effective sector coupling tool to bring flexibility to renewable energy systems (reuse of waste heat, supply of heat and electricity, etc.). In addition to their strategic independence from rare materials, Carnot batteries are frequently highlighted for their lower environmental impact compared to chemical batteries. However, this has not been demonstrated yet in a comparative study considering the overall environmental footprint, i.e., not restricted to Global Warming Potential (GWP). To fill this gap, we performed a prospective and comparative life-cycle analysis of four different energy system topologies for a residential application (heat and electricity demand), distinguished by the storage systems used: chemical battery, chemical battery + thermal storage, thermal storage + organic Rankine cycle to discharge electricity (i.e. the proper Carnot battery), and, finally, a reversible heat pump/organic Rankine cycle configuration. In each case, a photovoltaic array is used as a source of renewable electricity and a heat pump is used to meet the thermal demand. First, a multi-criteria optimisation is carried out to size the system components, aiming to minimise the GWP while providing an equivalent level of energy self-sufficiency. Secondly, at the predefined level of energy self-sufficiency, the different topologies are compared through a full life cycle analysis, including the 18 midpoint indicators defined by the ReCiPe method. The results illustrate the environmental impact of the different topologies, and for which indicators the Carnot battery outperforms the chemical battery.

Keywords: Life-Cycle Assessment (LCA), Carnot Batteries, Sector Coupling, Thermal Integration, Micro-Combined Heat and Power (micro-CHP), Organic Rankine Cycle, Decentralised Energy System

Mirko Morini is associate professor at University of Parma since 2016. He coordinated internation 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.

Trends in smart energy in airports

Mirko Morini, University of Parma
Costanza Saletti, University of Parma
Agostino Gambarotta, University of Parma

Mirko Morini (presenter) mirko.morini@unipr.it

The aviation industry is actively pursuing decarbonization, and airports can lead the charge by adopting three key trends: electrification, smart energy management and hydrogen integration.
The work explores the potential of electrifying facilities and vehicles using renewable energy, primarily solar photovoltaic technologies and wind turbines. It acknowledges the challenges of implementing these technologies, such as air navigation safety, glare interference, and radar signal distortion. It also highlights the potential of heat pumps for building heating and cooling, the future role of battery-powered aircraft, and the need for ultra-fast charging stations. It further discusses the transition to low or zero-emission ground support equipment and the potential of electric vehicle management in airport parking lots.
It is also discussed how airports can manage energy production to incorporate renewable energy sources and enhance the flexibility and reliability of local energy networks by means of energy storage systems, demand side management strategies, and microgrids. The work further discusses the impact of electric vehicles on the power grid, the potential of vehicle-to-grid technology, and the use of battery energy storage systems. The work then discusses the concept of energy communities as a means to optimize energy management and promote a decentralized energy ecosystem.
Finally, it presents the concept of using liquid hydrogen as a sustainable fuel for aircraft and suggests that airports could serve as hydrogen hubs to lower supply costs. It discusses the processes of hydrogen production and liquefaction, both of which require significant electrical energy and release heat that can be repurposed through heat pumps.
This study has been performed within the framework of the ALIGHT project, funded by the European Union's Horizon 2020 research and innovation programme under grant agreeement No 957824, and it aims to contribute to the reduction of carbon emissions, the improvement of local air quality, and the overall sustainability of airport operations.

Keywords: renewable energy, energy management, heat pump, hydrogen, smart management

Lucas Verleyen is a PhD student in the Thermal Systems Simulation research group led by prof. Lieve Helsen at KU Leuven. His main focus is on the design and operation of district energy systems,

The battery – A blessing or a curse for Positive Energy Districts?

Lucas Verleyen, KU Leuven / Lieve Helsen, KU Leuven & EnergyVille

Lucas Verleyen (presenter) lucas.verleyen@kuleuven.be

Positive Energy Districts (PEDs) are a possible solution for decarbonising the urban environment. PEDs integrate Renewable Energy Sources (RES) and accelerate the integration of RES in the broader energy system thanks to the PED's annual energy surplus and cost-effective collective investments. Previous work, which has been partially presented at last year's conference, shows that a full energy community, in which thermal and electrical energy are shared, performs best in the case of a tiny residential cluster. The energy system consists of a collective air-to-water heat pump and a collective solar PV installation and reduces CO2 emissions the most at the lowest cost of 96 euros per ton of CO2 compared to a reference scenario with individual gas boilers.

As residential thermal energy services are electrified when a heat pump is used, batteries seem to be an attractive component. Short-term electrical storage can offer more flexibility in district energy systems by storing excess PV electricity, leading to a further decrease in CO2 emissions and CO2 emissions reduction cost. However, batteries require many materials and have a significant embedded life cycle impact. Moreover, if both thermal and electrical energy are shared, the building's thermal mass also offers flexibility to the electrical energy vector via the heat pump.

Therefore, this work aims to investigate and quantify the benefits of a battery in district energy systems, especially envisaging the cost of CO2 emissions reduction as key performance indicator. The collective energy system mentioned above is considered the main layout and will be compared with a reference scenario consisting of individual gas boilers and an individual electrified scenario consisting of individual heat pumps and individual batteries in the absence of an energy community.

All layouts are modelled in Modelica using a white-box (physics-based) approach to fully exploit the inherent system flexibility and the synergies between multiple energy carriers. Detailed building models, proper hydraulic and electrical connections between all components, and optimal control as a system integrator are considered to have workable solutions and perform dynamic simulations.

Keywords: Positive energy districts, thermal and electrical district energy systems, key performance indicators, model predictive control, system integration, battery

Special Session: IEA Annex 84

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

Novel Concepts and Technologies for Demand Side Management in Thermal Networks – A review of selected Case Studies

Anna Cadenbach, Fraunhofer Institute for Energy Economics and Energy System Technology IEE; Christopher Graf, Fraunhofer Institute for Energy Economics and Energy System Technology IEE; Anna Marszal-Pomianowska, Aalborg University

Anna Cadenbach (presenter) anna.cadenbach@iee.fraunhofer.de

District heating is recognised as a key technology for the efficient integration of renewable energy and waste heat sources into our energy systems. For district heating management, demand-side management is seen as a promising technical solution. Various research activities show that the application of this technical solution leads to significant cost and emission reductions, thus contributing to the decarbonisation of the heat supply in buildings.

To demonstrate novel concepts and technologies for demand side management in thermal networks, case studies are compiled and analysed. The cases reflect different levels of technology readiness for both new and existing buildings, as well as laboratory systems. For the evaluation, different key parameters are collected. These parameters include, for example, building characteristics, energy storage options, thermal network specification and type of demand side management approaches. Other detailed technical and non-technical information (e.g. energy supply scheme, business model) is also recorded. The publication presents the main findings of the evaluation of the different case studies, the lessons learnt and the recommendations for action.

The lessons learnt from the case studies on technologies, buildings or districts will help to facilitate and improve demand side management in district heating systems in the future. The resulting recommendations for action will support the implementation and transferability of the recommendations to research and industry stakeholders.

The work carried out presents the results of the collaborative research work within the IEA EBC Annex 84 on Demand Management of Buildings in Thermal Networks.

Keywords: district heating, demand side management, case studies, innovative heat supply, thermal load management

Anna Marszal-Pomianowska is an Associate Professor at the Department of the Built Environment, Aalborg University. Her focus is on the integration of building sector in the green transition of smart energy system

Demand Response application – A survey with district heating professionals

Anna Marszal-Pomianowska, Aalborg University
Markus Schaffer, Aalborg University
Hicham Johra, Aalborg University
Elisa Guelpa, Politecnico di Torino
Benedetto Nastasi, Tor Vergata University of Rome

Anna Marszal-Pomianowska (presenter) ajm@build.aau.dk

The transition to smart and decarbonized energy systems calls for active involvement from all energy sectors. To meet the conditions of the 2015 Paris Agreement, the entire energy supply chain, encompassing production, distribution, and consumption, must contribute and collaborate. In the recent energy crisis, resilience and Demand Response (DR) in the District Heating (DH) systems have gained international interest.
Although numerous simulation studies and a few demonstrations, conducted in controlled real-life environments, have documented the potential benefits of DR, there is still limited understanding of the approach DH professionals take toward DR.
This work presents the results of a 17-question survey conducted with DH professionals in seven European countries (Austria, Denmark, Germany, France, Italy, and Switzerland) to gain insights into the existing practices, rationalities, barriers, legal framework and needed developments for the large-scale roll-out of DR in the DH sector.
In total 30 responses were collected. The results show, that DH professionals lack clear evidence of the advantage of distributed storage over centralized solutions. Control, ownership, responsibilities, and security are the topics that hinder the use of DR in everyday operation of DH systems. Moreover, there is a lack of business models for how to price the customers for delivered flexibility. The lack of a well-formulated and clear legal framework is also an additional obstacle.
The study presented here is the result of a collaborative research work within the International Energy Agency (IEA) Energy Buildings & Communities (EBC) Annex 84 on Demand Management of Buildings in Thermal Networks.

Keywords: district heating, demand response, district heating professionals, survey, thermal load management

He is a PhD student from KTH Royal Institute of Technology. His research interest is on data-driven sector coupling strategy leveraging thermal energy storage solutions.

Flexibility potential analysis with quantifiable KPI assessment for energy sector coupling leveraging advanced thermal storage solutions

Yangzhe Chen, KTH Royal Institute of Technology. Ilaria Marotta, CNR ITAE. Valeria Palomba, CNR ITAE. Thomas Ohlson Timoudas, RISE Research Institute of Sweden. Qian Wang, KTH Royal Institute of Technology, Uponor.

Yangzhe Chen (presenter) yangzhec@kth.se

The decentralized energy techniques like heat pumps and storages are increasingly applied to ensure the balance between supply and demand. However, rather than barely meeting the demand, the need for zero energy buildings in the EU landscape aims to respond to the fluctuations and stabilize the grid by developing sector coupling between thermal and electricity systems. Accordingly, demand side thermal energy flexibility plays a key role in enhancing the stability of the power grid. Moreover, as the district heating transition towards fifth generation, the supply temperature can be reduced to 40°C, which faces challenge when peak load occurs. Hence, the coupling also contributes to the peak shaving in district heating networks. Due to efficient coupling of the thermal and electricity sectors, power-to-heat (P2H) assets such as heat pumps as well as electric boilers play an increasingly important role in unlocking flexibility, both as boosters of the district heating network or stand-alone devices. However, there is a research gap in comprehensively analyzing the flexibility potential in such sector coupling networks. This study aims to develop a data-driven demand response strategy for such power-heat coupling systems, and the flexibility potential will be analyzed thoroughly through simulation from a district heating connected energy community in Großschönau, Austria. Furthermore, novel midterm storage solutions, such as phase change materials (PCM), will be considered to incorporate with district heating and P2H assets.

Keywords: Energy flexibility, demand response, PCM storage, sector coupling.

Zeng is working on AI for smart building, fusing advanced AI technologies like deep learning, large language models with modern building systems. His recent endeavors encompass a variety of fields, including Building Semantics, FDD/Anomaly Detection, Knowledge Graph and Federated Learning.

Critical Review of Digital Infrastructures on the Interoperability between Buildings and 4th Generation District Heating System

1)Zeng Peng, KTH Royal Institute of Technology. 2)Thomas Ohlson Timoudas, RISE Research Institutes of Sweden. 3) Qian Wang, KTH Royal Institute of Technology

Zeng Peng (presenter) zengp@kth.se

The digital infrastructures of both buildings and the 4th Generation District Heating (4GDH) system are critical for enabling a variety of improved energy management and services across the network. Implementing a digitalization solution requires setting up a comprehensive infrastructure, which includes deploying a large number of sensors throughout the system and establishing their connections in a machine-readable format. This setup is crucial for facilitating automated data management, enabling advanced data analyses, and supporting the development of smart services. Furthermore, digital infrastructures pave the way for new business models and the introduction of innovative services and products into the market.

Interoperability between buildings and 4GDH is a central theme of this critical review. Interoperability refers to the ability of different systems and organizations to communicate and operate seamlessly together, which is foundational for optimizing energy efficiency and advancing decarbonization efforts. In the context of digitalized energy systems, interoperability works on the harmonization of digital infrastructures across buildings and 4GDH. This enables not only the real-time exchange of data but also the synchronized management of energy flows to meet dynamic demands efficiently. For instance, through interoperable systems, buildings can adjust their energy consumption based on real-time data from 4GDH, leading to significant enhancements in energy conservation and reductions in carbon emissions.

This paper reviews the current state of interoperability between buildings and 4GDH, focusing on how digitalization serves as the backbone for these interactions. It examines various methodologies and technologies that have been developed to enhance interoperability, assesses their effectiveness, and identifies gaps and challenges in current practices. Through this analysis, the review aims to highlight how improved interoperability can lead to better energy management solutions that are crucial for achieving greater energy efficiency and meeting global decarbonization targets.

Keywords: Digitalisation, Interoperability, Building Semantics, 4th Generation District Heating

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

Anders is an energy professional working more than 12 years in energy trading. With his background in software, combined with his thorough understanding of the energy market and energy technologies, he is now heading the Power2X solutions at Norlys Energy Trading.

Depending on your neighbor - Sector coupling challenges of the future

Anders Borup

Anders Borup (presenter) abo@norlysenergytrading.com

Power-to-X (PtX) offers vast opportunities for various energy sectors. The shipping industry depends on methanol for its green transition, while aviation focuses on sustainable aviation fuels. Clean water is essential for hydrogen production, and ammonia is crucial as both a fuel and a means of transporting hydrogen. District heating is also changing, with power becoming the new source.

In PtX-integrated systems, low round-trip efficiency is a common concern, emphasizing power's key role in the green transition. Power markets will significantly impact the viability and profitability of PtX technology in the future. However, these markets are complex and uncertain, raising concerns about managing power consumption and the return on investment for PtX technologies.

Industrial experience shows that being a first mover can lead to high early profits, but mature technologies eventually bring lower investment costs. Thus, the timing of investments is crucial.

Sector coupling might provide an answer. This concept involves co-locating wind and solar power generation with industries needing green power, utilizing resources that would otherwise be wasted. For example, combining CO_2 from biogas with hydrogen from electrolyzers and clean water from industrial processes can produce e-methanol, while providing residual heat to nearby residential customers through district heating. Integrating batteries and heat storage ensures flexibility and supply security within the coupled system.

With high levels of sector coupling, two main challenges arise. The first is developing and operating optimization algorithms for complex, integrated energy systems involving multiple key commodities. The second challenge is establishing a framework for commercial agreements among various asset owners involved in sector coupling. This talk will address these main challenges and opportunities, aiming to bring sector coupling closer to being a viable option for a green future.

Keywords: Sector coupling, Green transition, Sustainable aviation fuels, Methanol, Clean water supply, Hydrogen production, Ammonia, District heating, Power markets

Christine Brandstätt is an Assistant Professor at the Copenhagen School of Energy Infrastructure at Copenhagen Business School.

Incentives for pipeline decomissioning and repurposing in regulated grids

Christine Brandstätt, Copenhagen Business School

Christine Brandstätt (presenter)

This paper analyses a gas network operator's incentives to decommission or repurpose. The paper is motivated by the expectation of decreasing demand for natural gas due to decarbonization efforts. Interestingly, gas pipelines can potentially be repurposed for the emerging supply of hydrogen, which in turn might accelerate the demand reduction due to substitution effects. In Europe, it is anticipated that short of 20% of the existing natural gas grid could be repurposed and would make for 60% of a future hydrogen grid (European Hydrogen Backbone 2023).
In this paper, repurposing is formalized as a decision to scrap part of the existing assets in the expectation of decreasing demand.The analysis shows that network operators are more likely to let their assets strand with rate-of-return regulation and if the course of demand decrease (or its translation into the regulatory framework) is uncertain. The paper explores options for tuning regulatory parameters to the requirements of repurposing and decommissioning. Tuning parameters include, (1) the sharing factors between shareholders and network users for operational and (2) accepted capital expenditure, (3) a mark-down for the expected demand decline, (4) the timing of the regulatory review and (5) the depreciation model. Decisive characteristics of the scrapping options are (1) cost of decommissioning resp. revenue from repurposing, (2) residual life time, and (3) substitutability between natural gas and hydrogen.

Measures such as advances of depreciation might serve to support struggling incumbent operators and to support emerging hydrogen operators but at the expense of network users and overall system efficiency. Instead, adjustments in network regulation that reflect the expectation of declining demand for network operators may be more suitable. Both options, however, suffer from the significant uncertainty regarding key aspects of the gas transition.

Keywords: natural gas, hydrogen, decomissioning, repurposing, network regulation

Dr. Flamos is (Full) Professor at the University of Piraeus (UNIPI) and Director of the "Technoeconomics of Energy Systems Laboratory (TEESlab)". He has major experience in EC-funded projects and projects funded by international donors, and several publications in high impact scientific journals.

Bidirectional soft-linking of open-source energy models to evaluate the feasibility of transition pathways to carbon neutrality in the power sector

1) Nikos Kleanthis, Technoeconomics of Energy Systems laboratory (TEESlab), Department of Industrial Management and Technology, University of Piraeus, Karaoli & Dimitriou 80, Piraeus 18534, Greece.
2) Vassilis Stavrakas, Technoeconomics of Energy Systems laboratory (TEESlab), Department of Industrial Management and Technology, University of Piraeus, Karaoli & Dimitriou 80, Piraeus 18534, Greece.
3) Alexandros Flamos, Technoeconomics of Energy Systems laboratory (TEESlab), Department of Industrial Management and Technology, University of Piraeus, Karaoli & Dimitriou 80, Piraeus 18534, Greece.

Alexandros Flamos (presenter) aflamos@unipi.gr

Energy system models have supported well-informed decision-making processes in Europe over the past few decades. However, the vision of climate neutrality requires an additional level of detail that comes with designing an energy system based on intermittent renewables; many models that have already been applied to explore decarbonisation pathways, though, lack the necessary time resolution to capture the integration of variable renewable energy, or are not open source, raising concerns of transparency and scientific reproducibility. In this work, we address this gap by introducing a bidirectional soft-linking approach between two open-source tools- the Capacity Expansion Model, OSeMOSYS, and the Production Cost Model, FlexTool- to generate long-term scenarios and evaluate their short-term feasibility. More specifically, our approach allows the optimisation of power sector investments over a 30-year period and its hourly operation at different snapshots, thus evaluating the integration of variable renewable energy more accurately. To test our approach, we apply it to the power sector in Greece, as part of the EC-funded projects "ENCLUDE" and "IAM COMPACT", to study the capacity and flexibility requirements of the transition to carbon neutrality by 2040 and the economic impacts of reducing reliance on gas. We aim at improving current power sector planning by providing alternative decarbonisation pathways that differ in the timing of gas phaseout, including the integration of variable renewable energy with electricity storage and power to hydrogen technologies, or the use of carbon capture and storage for gas and biomass power plants. Our results provide insight into the conditions under which emission and electricity capacity and generation targets can be attained. Modelling outcomes demonstrate that there is a path dependency on natural gas in Greece at least until 2033, while there is potential to achieve carbon neutrality much earlier than 2040 if significant investments in renewable energy materialise. Finally, cost comparisons reveal that switching to hydrogen could be, not only an effective solution for new gas plants to avoid becoming stranded assets, but also the most economically efficient alternative for a green transition in the power sector.

Keywords: Carbon neutrality, Capacity Expansion Models, Energy system modelling, Flexibility assessment, OSeMOSYS, Production Cost Models

She is a Marie Skłodowska-Curie Postdoctoral Fellow at DTU, using energy systems modeling to analyze the emissions impacts of renewable hydrogen regulation and carbon accounting rules.

Conditions on electricity purchasing: More (emission reduction) bang for your buck?

Lissy Langer, Technical University of Denmark
Anders Bjørn, Technical University of Denmark
Benjamin F. Hobbs, Johns Hopkins University (USA)
Matthew Brander, University of Edinburgh (United Kingdom)
Rasmus Bramstoft, Technical University of Denmark

Lissy Langer (presenter) lilang@dtu.dk

This paper analyzes the impact of different electricity purchase conditions on the carbon emissions of hydrogen production. These conditions are also discussed in the context of the revision of the Greenhouse Gas Protocol's carbon accounting rules for the purchase of voluntary renewable energy certificates to report companies' scope 2 carbon emissions. The techno-economic analysis presents a case study of hydrogen production in several European countries with different characteristics, such as varying initial RES shares, grid carbon intensity, and RES potentials, comparing the cost-optimal energy system for 2030 with a counterfactual scenario with no electricity purchase conditions. The study analyzes the impact of annual and hourly matching through power purchase agreements (PPAs) with local RES versus purchasing renewable energy certificates (RECs) through virtual PPAs on carbon emissions, system costs, and carbon reduction costs. Our initial results suggest that the purchase conditions significantly affect the distribution of RES between countries, the additionality of RES, and the total system emissions.

Keywords: Hydrogen regulation, GHG Protocol, Carbon accounting, Renewable energy certificates

Marie Münster is Professor in Energy System Analysis at the Technical University of Denmark. She holds a PhD in Energy System Modeling and focuses on integrated energy systems analyzing technologies producing power, heat as well as renewable gases and fuels (including PtX).

Why do we see differences in results when modeling hydrogen in integrated energy systems?

Marie Münster, Technical University of Denmark

Marie Münster (presenter) maem@dtu.dk

Recently, a number of energy system analyses have emerged, which highlight the potential roles of hydrogen in future energy systems. The results however differ substantially in terms of the outcomes. This is partly due to hydrogen being an expensive energy carrier, which requires a number of conditions to become feasible in large scale some of which include e.g. high carbon taxes, the availability of low-cost renewable electricity and low availability of biomass. To investigate in more detail where the differences stem from, a number of studies of the role of hydrogen in Denmark has been compared and a modeling and reporting framework is proposed.

Results of similar scenario runs have been compared for a range of models. The models have been run for similar overall scenarios include Balmorel, EnergyPLAN, SIFRE, TIMES and PyPSA. Based on a comparison of results, important assumptions and modeling choices have been identified.

The goal of the framework is to ensure transparency and understanding of results, highlighting important input parameters and conditions. The 7 main features identified can be summarized as:

1. Model type
2. Modeling of time (aggregation, pathways and foresight etc.)
3. Modeling of space (aggregation, scope, grids etc.)
4. Scenario boundary conditions (e.g. CO2 tax/cap, import/export possibility etc.)
5. Resource assumptions (potentials, prices, variance etc.)
6. Technology assumptions (conversion, storages etc.)
7. Demands (energy carriers, sectors included, amounts & timing & flexibility etc.)

In order to be able to compare and understand differences between different studies it is recommended to document and reflect upon each of these model characteristics as well as the main assumptions and modeling choices.

Keywords: Hydrogen, PtX, integrated energy systems, drivers, assumptions, modeling choices

He works as Assistant Professor at the Department of Green Technology, University of Southern Denmark. His research area is the intersection of multiple fields, including process simulation and system modeling of energy systems, sector coupling and E-fuel production.

Optimizing Regional Electrolysis Capacity

Hossein Nami and Henrik Wenzel, University of Southern Denmark

Hossein Nami (presenter) hon@igt.sdu.dk

Lolland-Falster region has proven attractive for installing wind and solar power plants due to its geographical location, with proximity to the Baltic Sea and open landscapes, lower land prices, political will, etc. Considering both confirmed and unconfirmed capacities, the installation of 957 MW of solar power, 1186 MW of offshore wind, and 127 MW of onshore wind is projected. These installations will lead to a maximum electricity production of 2157 MW when aggregating these capacities. At the same time, the electricity transmission capacity to Zealand is currently limited to 625 MW and is assumed to be expanded to 1000 MW by 2026-7. The local electricity demand for future large-scale heat pumps and smart charging of vehicles is estimated to be a maximum of 150 MW. As the capacity for renewable electricity production on the islands grows, it becomes imperative to implement power-to-x technologies within this region. However, determining the optimal capacity of power-to-x technology in the existing framework is crucial for evaluating its economic viability, particularly considering the potential expansion in transmission capacity soon, given that some of the projected capacities of wind and solar energy remain unproven. An hourly analysis is conducted, utilizing the reported LCOE for DK2 in 2030 by Energinet as the electricity price per hour in the islands. It is assumed that the surplus renewable electricity can be transported to Zealand or utilized by power-to-x facilities located in the islands. Importing electricity during low-price hours is also assumed to enhance the economic viability of power-to-x facilities. With a hydrogen sales price of 3.5 €/kg, the optimal electrolyzer capacity for alkaline type is determined to be 1400 MW with a transmission capacity of 625 MW and around 5700 annual operation hours. For a transmission capacity of 1000 MW, the optimal electrolyzer capacity increases to 1800 MW with approximately 5000 annual operation hours.

Keywords: Power-to-X, Green hydrogen, Techno-economic, Electro-fuel

Prof. Dr. 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) and MIT-CEEPR Affiliate.

Regulatory framework for hydrogen hubs: Taking stock and looking ahead

Anne Neumann, NTNU.
Lissy Langer, DTU.

Anne Neumann (presenter) anne.neumann@ntnu.no

The development of hydrogen valleys or hubs hinges on the regulatory framework surrounding it. Against the enthusiasm around the future of renewable and low-carbon gases and derivatives thereof one must consider the institutional framework they are embedded in.
Hydrogen valleys are essentially projects (usually funded by local, national, and international funds) that cluster industrial and research initiatives to carry out pilots along the complete hydrogen value chain (production, transport, distribution, and end use with storage).
The hydrogen value chain itself is not that complex by itself but becomes complex when considering interactions with other sectors such as electricity, natural gas, industry, or transportation. Whereas some see a bright future for hydrogen for achieving ambitious net-zero targets, realistic assessments of today's status find that it may remain a niche application for some industries.
The aim of this paper is to categorize and summarize existing legislation and to outline open issues related to the development of on- or offshore hubs.
Whereas in a first step the focus of attention was on the production of hydrogen it now becomes clear that the integration of renewable hydrogen into the existing energy system requires specific elements of economic regulation.

The Renewables Energy Directive and the hydrogen and gas package have specific elements related to hydrogen, such as unbundling of network operators or the establishment of an entity (ENNOH) like ENTSO-E or ENTSO-G. If a hydrogen hub is to develop offshore it will also be subject to regulations set out by the International Maritime Organization.

Keywords: hydrogen, hydrogen hub, renwable gas, regulation

The research is centered on establishing the DAC value chain to decrease capture costs and enhance technology adoption. The initial phase involves integrating DAC with traditional industrial processes requiring CO2 as feedstock and utilizing available waste heat, introducing innovative designs.

Direct Air capture cost reduction and market development via process intensification. Establishing the DAC insetting concept.

Albert Pujol, COWI A/S Green Fuels and Energy and Aalborg University
Mads Heuckendorff, COWI A/S Green Fuels and Energy

Thomas H. Pedersen (presenter), Aalborg University

Albert Pujol, apdu@cowi.com

Direct Air Capture (DAC) is part of the Carbon Removal technologies portfolio that captures already emitted CO_2 from the atmosphere. DAC technologies are anticipated to have a crucial role in fulfilling the climate objectives outlined in the Paris Agreement, aiming for megaton-scale achievement by 2030 and gigaton-scale by 2050. However, current capture costs and pace of development arise skepticism from part of the scientific community regarding DAC's readiness to contribute to environmental goals in the 2030s. This study introduces an innovative framework to reduce capture costs and facilitate the widespread deployment of DAC technology. It leverages from process intensification potential inherent in DAC-to-industry processes.
The methodology involves modelling in Aspen Plus software the integration of absorption-based DAC systems with industrial processes. The focus is directed to processes that employ CO_2 as feedstock and generate waste heat to reduce DAC energy requirements. Process intensification yields two First-of-a-kind (FOAK) DAC plant designs in conjunction with the urea fertilizer process (DAC-to-urea). A techno-economic analysis demonstrates technical viability of FOAK proposed designs. Furthermore, FOAK costs are projected into the future using learning rates to assess the impact of DAC technology deployment rate on capture costs. Our findings indicate that low renewable electricity prices and ambitious learning rates lead to competitive DAC-based fertilizer costs. Renewable ammonia generation acts as the primary bottleneck for sustainable urea production employing air-captured CO_2. DAC-CO_2 position as a chemical feedstock for high-demand commodities is reinforced through our study. The work concludes that DAC-to-industry is a viable mechanism that can foster the creation of the DAC market to fulfil climate goals of the Paris Agreement. We encourage stakeholders to promptly act now, as industries can strategically position themselves to capitalize on emerging carbon removal initiatives in future economies.

Keywords: Carbon removal, Direct Air Capture, Urea process, techno-economic analysis, DAC market, DAC value chain, learning rates, green ammonia.

Kirill Resnikow is a mechanical engineer and current PhD student at Münster UAS. Here, he has worked in the field of "Integrated Energy Systems" since 2021 and has been leading the research project BOOST, which deals with modelling different electrolyser systems, since 2024.

Modelling Electrolyser Systems – The research project BOOST

Kirill Resnikow, Münster University of Applied Sciences (Germany)

Kirill Resnikow (presenter) kirill.resnikow@fh-muenster.de

The successful transformation to a sustainable energy supply requires the use of green hydrogen. In addition to importing the gas, however, large production capacities must also be built up nationally. To make the integration of electrolysers for the production of the versatile energy carrier hydrogen more efficient, the aim of the INTERREG funded research project "BOOST" is to design and build an innovative software-based toolbox for electrolysers. This enables companies along the green hydrogen production chain to digitally analyse, evaluate, and optimise use cases in advance of real implementation. The toolbox is freely configurable so that components can be easily exchanged or adapted to simulate and compare different situations, plant designs or electrolysis processes (AEL, PEM, AEM). In addition to its use in the context of project planning and in the business environment, concepts for the application of such simulation tools in the education and training of specialists for the hydrogen economy will be considered. The consortium consists of companies with different competences in the field of hydrogen-based technologies and the integration of electrolysers, three universities with a focus on industrial research and experimental development as well as educational institutions for the training and further education of specialists.

The software toolbox developed as part of the project forms the basis for digital twins. These virtual copies of real plants make it possible to improve electrolysis applications in a variety of ways so that companies along the hydrogen production chain can benefit from them. Manufacturers can optimize and further develop electrolysers, plant planners can make integration more efficient, and operators can simulate realistic behaviour under different conditions, for example, to identify the causes of errors during operation. In this way, both the investment and operating costs of electrolysers can be lowered, and the costs of hydrogen production reduced. By developing this solution, the project partners are making an important contribution to an innovative and efficient hydrogen economy.

The progress and initial findings of the project, which was launched in March 2024, will be presented at SESAAU2024.

Keywords: Hydrogen Production, Electrolysis, Modelling, Simulation, Optimisation

Leon Schumm is a research assistant at OTH Regensburg and PhD candidate at TU Berlin. His research focus is on modelling net-zero energy systems, energy policies and open-source models, enriched by his international work experience in India, Denmark, Scotland and New Zealand.

Offtaker regulation: Impacts on New Zealand hydrogen export ambitions

Leon Schumm, OTH Regensburg University of Applied Sciences, TU Berlin
Jannik Haas, University of Canterbury

Leon Schumm (presenter)

New Zealand's abundant resources and high share of renewable energy in the existing electricity system provide an exciting opportunity for the production and export of green hydrogen and derivatives. However, the regulation of green hydrogen in different import markets varies considerably. While the European Union imposes strict rules on additionality, temporal and geographical correlation, hydrogen regulation in countries such as Japan is less stringent. This has profound implications for New Zealand's hydrogen export potentials and prices.

To investigate these potentials and prices under different hydrogen regulations on the import side, we developed a fully sector-coupled capacity expansion and dispatch model of New Zealand across 15 regions, including integrated gas and electricity network planning based on PyPSA-Earth. The open-source model is used to simulate and optimise New Zealand's energy system in various scenarios, sweeping through different hydrogen export volumes and hydrogen regulatory regimes.

The model results show that the prices and potentials of hydrogen exports are highly dependent on the applied hydrogen regulation. Stricter regulation, as imposed by the European Commission's Delegated Act on Union Methodology for RFNBOs, reduces grid emissions and increases the price of exported hydrogen through additional solar PV and onshore wind installations. Conversely, less stringent regulations result in lower prices for exported hydrogen in countries such as Japan. The choice of import markets and their green hydrogen regulations play a critical role in New Zealand's hydrogen export infrastructure and electricity supply. Accompanying policies can prevent carbon leakage while unlocking New Zealand's extraordinary potential and prerequisites.

Keywords: Energy Transition, Hydrogen regulation, Hydrogen export, Climate-neutral, Domestic prices, Hydrogen prices, Power-to-X

Lars Schwarzer is a consultant with the Renewable Energy Systems department at Danish Technological Institute. He works mainly in research and development projects within carbon capture and emission reductions. Lars has a background in energy engineering, combustion sciences, and thermal processes.

Carbon management in a volatile energy system – DTI's research in flexible carbon capture, utilization, and storage

Lars Schwarzer, Gunnar Rohde, Anne Mette Frey; Danish Technological Institute

Lars Schwarzer (presenter) lars@teknologisk.dk

Reducing greenhouse gas emissions to net zero is one of today's most urgent technological, economic, and political challenges. Where decarbonization is not (yet) possible or economically feasible, carbon capture, utilization, and sequestration (CCUS) can bridge the gap. Common to all CCUS technologies is their high energy demand. Integrating CCUS into the energy system thus comes with its own challenges with respect to dynamics and flexibility, but also presents opportunities in energy buffering and storage.

CCUS will likely be applied at combined heat and power plants burning biomass or waste. Currently, these plants follow heat demand and/or need for waste disposal, with electricity as a by-product. While heat demand follows seasonal variations, electricity market fluctuations have a much higher frequency. Several plants already participate in load balancing of the electric grid. With the installation of carbon capture, CO2 removal becomes an additional service. This will have a profound impact on the operation of these plants: As CO2 is directly proportional to the amount of fuel consumed, the balance between production of heat, production of electricity, and own consumption will shift. The captured CO2 can either be compressed or liquified and ultimately sequestered, utilized (with hydrogen) as an energy carrier, or used in synthesis of materials. The above processes are energy intensive, and important questions remain unanswered: What parameters determine the optimal use (including storage) of the captured CO2? What is the optimal technology for a given process? Where in the process chain should buffers be located, and of what type and size? How do process units react to frequent load changes, and how does this affect their lifetime and operating costs?

To answer these questions, Danish Technological Institute (DTI) has established a pilot scale setup replicating a bioenergy plant with carbon capture. The setup with a thermal power of 100 kW is based on results from a case-study of an existing biomass combined heat and power plant. DTI's Carbon Capture Lab is currently used to investigate flexible operation and control strategies for CO2 capture. In a further step, the lab will be expanded to also investigate novel, flexible carbon utilization processes.

Keywords: CCUS, flexibility, heat and power, sector coupling, smart energy management

Jens is an Asst. Prof. with the Copenhagen School of Energy Infrastructure (CSEI) at CBS. His research mainly focuses on flexibility options, sector integration, decentralization, and planning and market design in energy systems using – amongst other methods – open-source energy system models.

Fueling the Future: Optimizing Power-to-X Production in Renewable Energy Hubs through Flexible Operating Units

Johannes Giehl, Dana Josephine Hentschel, and Jens Weibezahn, Copenhagen School of Energy Infrastructure (CSEI), Copenhagen Business School

Jens Weibezahn (presenter) jew.eco@cbs.dk

The European ambitions for a hydrogen economy require the rapid development and scaling of technology and business models. As frontrunners, the Nordics have the potential to contribute to and benefit from the establishment of hydrogen valleys with the development of energy hubs. Analyzing specific locations is essential to gain insight into the characteristics of optimal production, cost structures, and investments of hydrogen and its derivatives, like methanol. The application of an energy hub model for a case study of producing e-methanol in Southern Jutland helps to obtain specifics on the operation and structure of these business models. The model uses the Spine environment using Mixed Integer Linear Programming to investigate cost-optimal production and investments. Thus, the model helps to obtain specifics of the hub by a detailed representation with variable efficiency rates to improve the representation of flexibility by electrolysis and by-products such as the use of excess heat. An integrated sensitivity analysis enables the evaluation of the impact of regulatory measures and costs on the feasibility and viability of energy hubs. Results show the optimal costs alongside the energy flow of each technology. The evaluation of the energy hub focuses on the levelized cost of the depicted energy carriers. Further development will concentrate on refining investment implementation and integrating technological, and socio-economic aspects identified by the Nord_H2ub project.

Keywords: energy hubs, hydrogen valleys, e-methanol, flexibility, investment modeling, business models

Henrik Wenzel is a Professor at the Department of Green Technology, University of Southern Denmark. His research area covers Environmental Engineering, Energy System Analysis & Design, Waste & Resource Management, Life Cycle Assessment, Carbon Management & Bioresources.

Local Energy Parks in Northern Fun

Hossein Nami, Mads Emil Dalhoff Greisen and Henrik Wenzel,
University of Southern Denmark

Henrik Wenzel (presenter) henrik.wenzel@igt.sdu.dk

Local energy parks are centralized around modern biogas facilities and dimensioned accordingly. The synergies obtained from sector integration through power-to-X (PtX) in the energy park with biogas production facility and local district heating network represent a focal point from both business and socio-economic perspectives. The techno-economic feasibility of sector integration through PtX at a proposed energy park located in Give is assessed to determine the most cost-effective design configuration. The energy park was conceived in three configurations: one consisting solely of the biogas plant and installed wind and solar supplying biomethane and electricity to grids; the second incorporating PtX to convert biogenic CO2 to E-methane, all processes located within the energy park in Give; and the third distributing some PtX capacities to Billund to disperse excess process heat to more locations for improved utilization. Each system configuration was analyzed across six scenarios representing varying biogas production and installed renewable capacities, to evaluate their impact on the techno-economic performance of the system. All assessed scenarios exhibited a positive net present value. Implementation of PtX resulted in an average net increase in cash flow of 26% from a business economic perspective and 6.8% from a socio-economic perspective. The scenario yielding the highest return was consistently the one with the largest capacities of both biogas and installed renewable energy in every system configuration. When comparing the economic impact of decentralized PtX to central PtX, the results were less pronounced. However, there was a preference for decentralization from a business economic perspective, though not from a socio-economic standpoint. The findings demonstrate a significant improvement in the economic feasibility of methanation at a methane price of approximately 5 DKK/m3. Maximum capacities were reached at prices of 8 DKK/m3 and higher when considering projected 2050 electricity prices. These results underscore the influence of electricity costs in the E-methane value chain, with costs shown to increase methanation rates by up to 40 percentage points when comparing 2030 and 2050 prices.

Keywords: Power-to-X, Sector coupling, E-methane, Techno-economic

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, district heating and energy planning in general.

Beyond Borders: Alternative Renewable Energy Export Strategies

Meng Yuan, Jakob Zinck Thellufsen, Henrik Lund
Department of Sustainability and Planning, Aalborg University, Denmark

Meng Yuan (presenter) mengy@plan.aau.dk

The global energy landscape is undergoing a transformative shift – transitioning away from fossil fuel dependence, spanning the growing expansion of renewable electricity, and shifting towards emerging power-to-X technologies to pave the way for the green fuel era. Such changes raise questions about the type of commodity to be traded in the international markets, which in turn calls for the re-evaluation of cross-border energy trading.
Previous studies mainly examined electricity and hydrogen for export purposes, yet the investigations on other types of electrofuels are still limited. This study aims to answer the key research question – what are the techno-economic consequences of the energy export strategies for the future renewable energy hubs in terms of the choice of alternative options of energy carriers from a system perspective? A total of four competing energy carriers are explored in this study, including electricity, hydrogen, methane and methanol.
We develop four energy export scenarios for Denmark by using the advanced energy system simulation tool EnergyPLAN, which are all under the context of a 100% renewable energy smart energy system in the year 2045 when the country achieves its national climate neutrality goal. The optimal export configurations of the export scenarios are investigated by implementing the best available potential of renewable energy resources in Denmark to produce and export surplus energy while supplying the domestic energy needs in a cost-effective and energy-efficient way. The maximum export potential and levelized cost of energy of the alternative export options as well as the techno-economic impacts on the overall energy system are analysed.
Results reveal that renewable electricity generators and electrolysers pose the primary restraints on export costs of green fuels, whereas the infrastructure for cross-border energy transportation accounts for a relatively minor share from a system perspective. A sensitivity analysis highlights that uncertainties in technology development and cost projections of key technologies bring significant uncertainties when evaluating the export market. This study offers a reference for Denmark and other countries with shared interests in renewable energy exports.

Keywords: Energy export, Power-to-X, Hydrogen, Electrofuels, 100% renewable energy systems, Denmark

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

Anna Billerbeck has been a research associate at Fraunhofer ISI since 2019. She works on national and international research and consulting projects in the field of renewable energy. Her research activities focus on transformation pathways and policy measures for climate-neutral district heating.

Increasing the spatial resolution of climate-neutral district heating supply in European energy system models

Anna Billerbeck, Fraunhofer ISI and University of Freiburg.
Alexander Burkhardt, Fraunhofer ISI.
Christiane Bernath, Fraunhofer ISI.
Pia Manz, Fraunhofer ISI.
Gerda Deac, Fraunhofer ISI.
Anne Held, Fraunhofer ISI.

Anna Billerbeck (presenter) anna.billerbeck@isi.fraunhofer.de

District heating (DH) networks will play a key role in achieving a climate-neutral energy system. Especially in densely populated areas, DH can be an efficient and economically viable solution as it can integrate large heat sources that are not suitable for individual heating, such as deep geothermal or industrial excess heat. At the same time, DH can provide valuable flexibility to an electricity system that has to cope with an increasing share of fluctuating renewable energy. DH networks are very heterogeneous, partly because renewable and excess heat potentials are unevenly distributed. Due to the difficulty of representing the high heterogeneity, DH is usually modelled in a spatially simplified way in integrated energy system models covering Europe. Existing approaches aggregate DH into network types based on different temperature levels, network sizes or technologies. Our research aims to contribute to existing aggregation methods with a new approach focusing on high spatial resolution renewable and excess heat potentials for DH supply.

We distinguish four DH network types based on the available renewable and excess heat potentials. These DH types are based on a clustering analysis where 5815 DH areas in Europe in 2050 are clustered according to the available potentials. Thereby, we cover the following potentials: geothermal energy, biomass, waste incineration, industrial excess heat, river and lakes as well as wastewater that can be utilised as heat sources for large-scale heat pumps. The resulting types represent networks, where certain heat sources are dominantly available, giving the type its name: DH type 1: River and lake; DH type 2: Geothermal; DH type 3: Biomass; DH type 4: Mixed.

The DH types are integrated into the existing model Enertile, which is a detailed techno-economic linear optimisation model for the European energy system that covers the supply of electricity, DH, and hydrogen. Subsequently, a scenario-based modelling analysis for the EU and the year 2050 is carried out. The results show that the new modelling approach

captures the heterogeneous resource availability in DH, as the results show multivalent DH networks based on a wide range of renewable and excess heat sources used directly or in combination with large-scale heat pumps.

Keywords: district heating, integrated energy system modelling, renewable and excess heat potentials

Sina Dibos received the B.Sc. and M.Sc. degrees in energy engineering from RWTH Aachen. She is currently pursuing the Ph.D. degree with Forschungszentrum Jülich in Energy Systems Engineering (IEK-10). Her field of research is the modeling and simulation of district heating and cooling networks.

Impact Analysis of Electrolyzer Waste Heat on Low Temperature District Heating and Cooling Networks

Sina Dibos, Forschungszentrum Jülich

Sina Dibos (presenter) s.dibos@fz-juelich.de

The heating sector accounts for 50 % of the total EU energy consumption, while 60 % of which is used for space heating and hot water demand of buildings. Currently, the heat generation is still mainly based on fossil fuels. To shift the dependency from fossil to renewable energy sources, the LTDHC technology is under rapid development. The lower supply temperature enables an increased electrification via heat pumps and furthermore the integration of environmental and commercial waste heat sources is enhanced. Amongst these waste heat sources, electrolyzers will play an increasingly important role in the future. Electrolyzers consume electricity in times of a high renewable power production and can therefore balance the temporary fluctuations within the electricity market. As a product, hydrogen is generated which can, in comparison to electricity, efficiently be stored in large-scale storages. However, the influence of the electricity driven electrolyzers on the heating sector needs to be investigated, taking the overall potential and the temporally availability of the waste heat into account.

A simulation of the investigated energy system is used to analyze the impact of the electrolyzer operating strategy on the heating sector. The energy system includes an electrolyzer model with interfaces to the electricity, the gas and the heating sector. The heating sector is represented by a thermal grid supplying the demands of the connected buildings, based on a real German district. Therefore, we use our inhouse-developed open-source tool HeatNetSim, which is a simulation tool for bidirectional networks such as district heating and cooling networks.

The operation strategy of the electrolyzer aims to fully utilize the local renewable energy generation. To achieve this, we assume several scenarios with different installed PV and wind capacities. We analyze the influence of the electrolyzer by comparing the overall energy input of the thermal network with and without the waste heat integration. Furthermore, we take temperature levels of the waste heat and efficiencies of the electrolyzer into account.

Keywords: Electrolyzer Model, Waste Heat Integration, Energy System Simulation, District Heating and Cooling Network, Electricity from Renewables

Hanne Kauko is a senior research scientist at SINTEF Energy Research. Her main fields of expertise lie within district heating and thermal energy storage, as well as modelling and optimization of integrated energy systems for neighbourhoods an industry.

Electrolysis waste heat utilization towards district heating – a case study for Norway

Hanne Kauko, SINTEF Energy Research;
Davide Tommasini, SINTEF Energy Research;
Nicolas Marx, Austrian Institute of Technology (AIT);
Yannick Wimmer, AIT;
Stefan Reuter, AIT;
Stefan Puschnigg, Energieinstitut an der JKU Linz;
Simon Moser, Energieinstitut an der JKU Linz;
Anna Volkova, Tallinn University of Technology (TalTech);
Hesham Ali, Taltech

Hanne Kauko (presenter) hanne.kauko@sintef.no

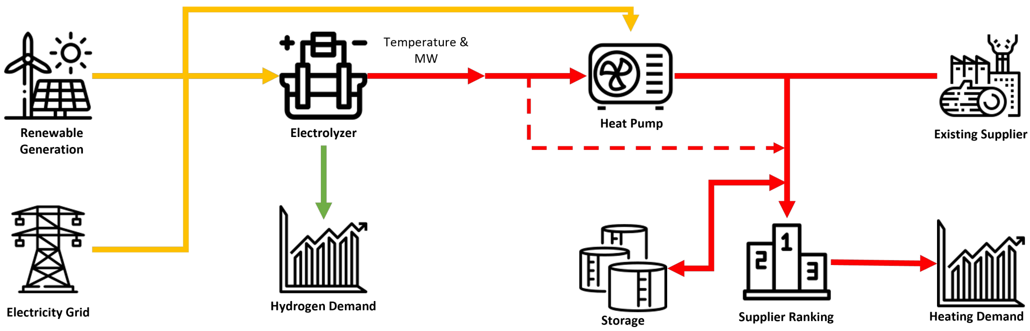
Hydrogen will play a central role in a future climate-neutral energy system. It will primarily be produced by water electrolysis, and significant production capacities are planned on a global scale. Approximately one third of the electricity used to generate the hydrogen will be wasted as heat. Assuming that at least a part of hydrogen production will take place nearby existing or planned DH networks, there is a high potential for utilizing electrolyser waste heat for DH supply. Such coupling between the two sectors would benefit both the hydrogen producers, through possible incomes from selling the excess heat, and the DH suppliers, by providing an emission free heat source.

The most established electrolyser technologies are alkaline and proton exchange membrane electrolysers, with operation temperatures at 60-90 °C and 50-80 °C, respectively. Due to practical concerns, the temperature of the waste heat is typically limited to 50-60 °C. Utilizing the waste heat in existing, high-temperature generation DH networks is thus not possible without a heat pump. However, low-temperature DH systems may allow direct utilization.

This study focuses on a planned alkaline electrolyser facility in Bodø, Northern Norway, with a future waste heat capacity of 5 MW. The electrolyser is situated close to an existing, high-temperature DH network. Waste heat supply to the existing DH network will require investment in a heat pump but can potentially cover a substantial part of the base load, currently supplied with a 12 MW biomass boiler. The city is also planning to build a new neighbourhood nearby, compatible with low-temperature DH supply. Supply to the future low-temperature network would be possible without a heat pump, however, the timeline and hence the business case is uncertain.

The study will apply techno-economic modelling with the AIT TESCA framework to assess the feasibility of the high- and low-temperature supply cases. In addition, dynamic modelling will be applied for detailed evaluation of the integration of the waste heat supply to the DH network, with different heat pump configurations. The study is a part of the HY2HEAT project, funded through the IEA technology collaboration programme on district heating and cooling (Annex XIV).

Keywords: Electrolysis waste heat recovery, District heating, Techno-economic modelling, Dynamic modelling, Sector coupling



Leander Kimmer is researcher at Fraunhofer IFAM. His research projects focus on sector coupling between district heating, hydrogen and electricity. He uses heat distribution optimization to compare business-wise and economic perspective and future tax incentives for a decarbonized energy system.

Decarbonising district heating with hydrogen: A comparison of business and economic optimums

Leander Kimmer, Fraunhofer IFAM
Max Fette, Fraunhofer IFAM
Roland Meyer, Fraunhofer IFAM

Leander Kimmer (presenter) leander.kimmer@ifam.fraunhofer.de

In Germany and most of Europe, district heating and electricity generation are linked via fossil-fired CHP plants. An electricity system built with solar and wind energy has periods of positive and negative residual load. Hydrogen can provide a balance through its storability. The conversion of electricity to hydrogen and back is subject to thermal losses, which can be utilised by sectoral coupling in district heating. This also helps the defossilisation of district heating. In contrast to the all-electric route, the electricity system is relieved. Synergy effects can be used, and the overall efficiency of the system is increased.

The extent of this benefit and the effects that play a role are being investigated in the project "Roadmap Gas-Transition", the results of which will be subject of this presentation. In our work, the European energy system is mapped in its current state in the REMix model and economically optimised in five-year steps up to 2045 with decreasing CO2 limits. The focus is on the conversion of the gas infrastructure to green hydrogen. Based on this economic optimum, the district heating systems are analysed from a business perspective.

The presentation will discuss the following research questions:

- What are the benefits of sector coupling, using hydrogen and electricity in district heating systems?
- What is the impact of the price of imported hydrogen on integrated energy systems in Germany?
- What are the differences between the windy north and the sunny south of Germany for the optimal operation of sector coupling plants?
- Does Germany need to be divided into two electricity price zones, in order to incentivise H2 CHP capacities and deployment times?
- What is the path from fossil district heating systems today to green integrated systems in 2045?

- What are the implications for energy utilities and policy makers regarding the integration of hydrogen into district heating systems?

Keywords: Sector coupling, hydrogen, waste heat utilization, electrolysis, PtG, incentives, district heating system, Integrated energy systems, CHP, energy infrastructure, smart operation

Dan is an Associate at FairHeat and acts as Head of Technical for the business. He is an expert in heat network design, controls and commissioning having worked on >300 heat networks either as designer or client side engineer. He is an industry expert in building level heating and hot water systems.

How large-scale ASHP deployed on DH networks can decarbonise challenging urban environments

Dan Staunton and Mike Ridge, FairHeat

Dan Staunton (presenter)

At a regional level, many public sector buildings have been set net-zero mandates but have no viable building level solutions for moving away from gas-fired heating systems.
At a national level, DH is a key pillar of UK decarbonisation, with government funding promoting the development of new networks within city centre environments.
Many of these cities do not have viable heat sources to leverage a new heat network. Not all areas have accessible water sources (river, sea, lakes etc.) for Water Source Heat Pumps (WSHP) and there remain commercial and regulatory challenges with accessing waste heat sources. A principal challenge of waste heat is the risk presented by being reliant on third parties in agreeing to provide the network with waste heat, which presents significant uncertainty during the development phase. Further, the economics of these strategies are proving challenging due to the remote location of waste heat sources, increasing CAPEX to levels which start to negate the benefit of their higher efficiencies.
Whilst in many areas, water source and waste heat sources facilitate attractive DH projects, there are many scenarios in which ASHP is either the only, or the more optimal, solution. However, they are not without their own unique challenges.
Using case studies and technical research, the presentation will provide a summary of how ASHP technology can be de-risked at design stage, and a model of how it can be a powerful "first phase" technology for new heat networks. Substantial weather compensation has been utilised to optimise SCOP whilst minimising upgrade works required within buildings. We will discuss return temperature reductions through weather compensated flow temperature and use of innovative procurement and contracting approach (e.g. volume weighted tariffs). The risk of localised cold plumage through extensive modelling and suitable boiler back up will be presented, as well as how the system can be future proofed for further decarbonisation and expansion by balancing pipe size CAPEX with future flexibility options.

Keywords: ASHP, heat networks, decarbonisation, public sector, operating temperatures, built environment

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

Søren Djørup is an economist with a PhD in Sustainable Energy Planning. The primary focus of his research concerns economic and regulatory questions within renewable energy, energy efficiency, and energy system integration

A Framework for Heating Technology Characterisation and its Relevance to Energy Policy Design

Søren Djørup, NORCE

Søren Djørup (presenter) sodj@norceresearch.no

Heating and cooling consume around half of Europe's energy demand, making it a critical policy area for improving the economy, sustainability, and energy security. The heating sector is characterized by a range of very different technological solutions for meeting building heating demands. The technologies vary in terms of basic techno-economic characteristics such as cost structure, building requirements, locality of energy source and more. This variety in technological characteristics makes discussions about policy design and regulatory frameworks pertinent when transitioning between heating technologies. To contribute to this discussion, this paper proposes a categorization of heating technologies that focuses on properties significant to policy design and regulation. Based on this categorization, key questions for assessing - or designing - the regulatory environment for specific heating technologies are identified.

Keywords: Heating policy, heating regulation

Lisa Hjerrild is an assistant professor of energy law and public administrative law at the University of Southern Denmark. She is also appointed chairman of the Valuation Authorities in Denmark in relation with the Danish renewable energy act.

Experiences with economic compensation to neighbors of large-scale renewable energy farms

Lisa Hjerrild, University of Southern Denmark

Lisa Hjerrild (presenter) lch@sam.sdu.dk

This abstract explores the legal experiences and challenges associated with the value loss compensation scheme for neighbors of large wind farms and solar installations in Denmark. As renewable energy projects continue to expand globally, concerns regarding their potential economic impacts on neighboring communities have become increasingly prominent. The value loss compensation scheme aims to address such concerns by providing financial compensation to neighbors affected by decreased property values resulting from the proximity of renewable energy developments.
Drawing on case studies and experiences as a chairman of the Valuation Authorities in Denmark in relation with the Danish Renewable Energy Act, this presentation focus on the fieldwork experiences of value loss compensation schemes and sales options scheme. Additionally, it analyzes the challenges and limitations encountered in implementing these schemes, including issues related to valuation methodologies, eligibility criteria, and the perception of fairness among stakeholders. The abstract concludes by highlighting the importance of stakeholder engagement, transparent communication, and adaptive policy frameworks in achieving equitable outcomes for both renewable energy developers and the affected communities and neighbors.

Keywords: renewable energy farms, neighbors, economic compensation, valuation authority

Kristina Lygnerud works as a researcher at the Swedish Environmental Institute (IVL) and as Adjunct Professor at the Department of Energy Sciences at Lund University of Technology (LTH). She has been active in the district heating sector since 2004. Main research topic is business model innovation.

Increased district energy competitiveness through social sustainability

Kristina Lygnerud University of Lund, Sweden, Kerstin Sernhed, University of Lund, Sweden, Somil Miglani VITO, Belgium, Johanna Aurault, Paris Mines, France and Hanne Kortegaard_Stochel, DBDH, Denmark

Kristina Lygnerud (presenter) kristina.lygnerud@energy.lth.se

District heating built around the conventional principle of centralized production and distribution at lowest, possible marginal cost, is based on the logic of economy of scale and an important number is the marginal cost of heat. The more efficient the assets, the lower the cost.

Soon, when fossil fuels are no longer an option and the classification of fuels that are currently seen as renewable (like biomass and waste) shifts making them obsolete, the heat supplies available will be solar, geothermal, and waste heat. In such a future, the economy of scope will be increasingly important and to generate added customer values compared to competing heat suppliers will be key.

In the conventional district energy setup, both economic and environmental values can be very strong. However, studies have shown that the aspect of social sustainability is not yet explored. To understand how the inclusion of social sustainability features into a district energy business model can increase competitiveness a case is studied. It is a startup company foreseen to operate entirely on waste heat recovery. The case is located in Canada, in the Vancouver area in Burnaby. The work encompasses an analysis of how value chains in mature markets (Sweden and Denmark) and new markets (Belgium and Canada), identification of social sustainability factors of relevance to the district energy sector and interviews with stakeholders of the case study leading up to an analysis of how the conventional business model differs from a non-combustion-based district heating business model with strong social sustainability features. At the time of the conference we will be glad to share our insights of the value chain analyses and the identified social sustainability factors.

Keywords: Social sustainability, district energy, Canada, case study

Bernhard Mayr, Research Engineer at AIT Austrian Institute of Technology, specializes in renewable gases and heat. With a Master's in Physical Energy Engineering from TU Vienna, he excels in gas demand modeling.

Introducing the concept of an integrated decision-making framework for sustainable heating (and cooling) technologies

Bernhard Mayr, AIT Austrian Institute of Technology GmbH

Bernhard Mayr (presenter) bernhard.mayr@ait.ac.at

Decarbonization of the heating sector is pivotal for achieving net-zero emissions across Europe. Traditional energy planning approaches primarily focus on analyzing heat demand densities to identify priority areas for deploying sustainable heating technologies. However, the complexity of transitioning to sustainable energy systems demands a more integrated approach that aligns energy infrastructure with the building sector and spatial energy planning.
This contribution introduces the concept of the project “CleanHeatSelector”, a comprehensive decision-making framework that addresses the multifaceted challenges of the heating (and cooling) sector. The framework is designed to guide the prioritization and implementation of sustainable heating (and cooling) technologies by considering not only technical aspects such as heat demand density reduction, renewable energy diversification, and storage implementation, but also the shift towards decentralized and small-scale systems, i.e. low temperature heating and cooling networks. It integrates these technical challenges with ecological and socio-demographic considerations, offering a robust solution to the current fragmented planning landscape.
The existing procedures in spatial energy planning are often marred by complexity and lack an evidence-based approach for assessing the environmental and social impacts of heating systems. To address these gaps, the CleanHeatSelector framework incorporates relevant EU and national legislation and introduces a novel set of quantifiable criteria. These criteria span techno-economic, environmental, social, and regulatory dimensions, providing a comprehensive assessment tool that facilitates informed decision-making.
The framework enhances the selection process for optimal regions to implement sustainable heating (and cooling) solutions. This not only improves the efficiency and sustainability of heating systems but also aligns with broader decarbonization objectives through a regulated, evidence-based approach to energy planning.

Keywords: Spatial energy planning, decision framework, resilience, district heating, individual heating, decarbonization strategies, waste heat, RES potential, uncertainties, risk-assessment, energy poverty

Lucy, over the last 18 months, has been developing Technical Specifications for the UK's Heat Network Technical Assurance Scheme. Her role has also involved undertaking quality assurance for heat network design and construction, as well as feasibility design for district heating energy centres.

Establishing Key Performance Indicators for heat networks for use within the UK's Heat Network Technical Assurance Scheme

Lucy Sherburn, Senior Engineer, FairHeat
Gareth Jones, Managing Director, FairHeat

Lucy Sherburn (presenter) lucy.sherburn@fairheat.com

Heat networks are a key part of the UK Government's strategy to reach net zero emissions by 2050. The heat network market is set to grow rapidly, and the Government is encouraging its growth with financial support and a new regulatory regime, which puts heat networks on a trajectory to become a regulated utility, like gas and electricity.

Underpinning this, a regulatory Heat Networks Technical Assurance Scheme (HNTAS) is to be put in place to ensure a minimum level of performance and reliability for all heat networks, resulting in good consumer outcomes.

One of the core principles of HNTAS is for the scheme to be outcomes oriented. This requires a methodology for assessing performance outcomes of heat networks, via Key Performance Indicators (KPIs).

Research has been carried out to determine an appropriate set of KPIs for use within HNTAS. As HNTAS covers all elements of a heat network (energy centres, substations distribution networks, consumer connections) and all temperatures of heat networks (4th generation, 5th generation, cooling), the KPIs determined can be applied to all types of heat networks.

To determine the KPIs for HNTAS, a review of existing literature, industry O&M contracts and existing heat network performance has been undertaken. Additionally, a review of the industry's key failures was also undertaken and used to identify KPIs which would prevent these key failures from occurring. These KPIs were then discussed within working groups, containing industry specialists, to come to an agreed position.

The outcome of this process is that 28 KPIs have been established, across 6 different categories of KPIs. These categories are the following:

1. Reliability

2. Heat losses
3. Performance
4. Domestic consumer
5. Water quality
6. Data monitoring and capture

This work discusses the methodology and considerations behind selecting the KPIs, the KPI measurement methodology and the KPI target levels. These KPIs, assessed against a target level, will form the basis of measuring performance outcomes and determining compliance with HNTAS.

Keywords: Heat networks, district heating, certification, assurance scheme, regulation, industry standards, key performance indicators, performance outcomes

Former analyst in IEA, Green Energy and PlanEnergi. PhD from DTU Management. Affiliated researcher at Lund University + project leader at Energy Modelling Lab. Focus is on economic and financial aspects of district heating.

Making district heating bankable: District heating as an asset class

Daniel Møller Sneum, Department of Energy Sciences, Lund University. Tobias Popovic, Center for Sustainable Economics & Management (CSEM), Hochschule für Technik Stuttgart. Kristina Lygnerud, Swedish Environment Research Institute (IVL)

Daniel Møller Sneum (presenter) daniel.moller_sneum@energy.lth.se

The potential for district heating (DH) as a pillar of the energy transition in Europe and beyond is well-established. Less well-understood is how and wherefrom the money should flow to enable such widespread deployment of DH. In some cases, against the backdrop of already high public debt levels it is questionable, whether public funding of DH may be sufficient. Therefore, especially for expansion, other sources of private sector finance will be needed.

As part of the IEA DHC-funded project Financial frameworks' impact on district heating, we systematically structure DH finance, focusing on investors' strategies as well as innovative financing approaches (e.g., blended finance, European Long-Term Investment Funds (ELTIFs)). Further, we reflect this financing against the recent European regulatory initiatives, such as the EU Action Plan on Financing Sustainable Growth, the EU Taxonomy, the EU Green Deal, the Sustainable Finance Disclosure Regulation (SFDR) and the Corporate Sustainability Reporting Directive (CSRD), aiming at redirecting capital flows towards sustainable activities, utilizing financial markets as a lever for decarbonizing the economy.At the time of presenting this abstract, the project will be ongoing, mainly focused on the collection of qualitative data to structure the financial frameworks. Subsequently, quantitative data is collected for energy system modelling of the financial framework impact on DH and DH as an asset class. Data is thus a critical resource for all involved stakeholder as well as for acquiring funding for DH investments. Preliminary results will be presented during the conference, while final results will be available in 2025.

The expected result of the initial qualitative data collection – a fundamental classification of DH finance under the current regulatory environment – is novel and a useful "toolbox" for stakeholders such as investors. With this increased level of knowledge on the financial side of DH investments, money may flow more freely towards the large investments necessary to transition to increased shares of sustainable DH.

Keywords: District heating, sustainable finance, EU taxonomy, sustainable infrastructures, decarbonization

Sino-Danish special session:
Harvesting waste heat sources and better understanding heat demand patterns for 4th generation district heating in China and in Denmark

Chang Shiyan is an associate professor in the Institute of Energy, Environment and Economy, Tsinghua University. Main research areas: the green and low-carbon economy transformation pathways and policies, negative emission technologies and regional transition pathways towards carbon neutrality.

Waste heat recovery for urban heating in northern China

Hu Hao, Institute of Energy, Environment and Economy, Tsinghua University
Ma Sining, Institute of Energy, Environment and Economy, Tsinghua University
Chang Shiyan, Institute of Energy, Environment and Economy, Tsinghua University
Guo Siyue, Institute of Energy, Environment and Economy, Tsinghua University

Guo Siyue (presenter)

Data centers, as crucial infrastructure, play a pivotal role in driving the digital transformation and intelligent upgrading of our economy and society. In China, the number of data centers and racks has witnessed a significant surge. However, this growth has also brought to the forefront the issue of energy consumption and carbon emissions. The data centers consumed about 1% of global electricity consumption in 2018. It's predicted that the total energy consumption of data centers in China will exceed 380 TWh by 2030, accounting for about 3.7% of the total electricity consumption in the same period. This alarming trend underscores the urgent need for more stringent energy efficiency requirements for data centers in China.

Electricity consumption in data centers generates a significant amount of waste heat. Numerous studies have been conducted on the waste heat recovery technologies and applications. Among these, waste heat recovery for district heating is a promising solution. This technology holds immense potential to replace China's coal-based fossil fuel heat source, significantly reducing carbon dioxide emissions and mitigating air pollution.

Most existing research focuses on the technical feasibility of data centers' waste heat recovery for district heating, with few evaluations on the economic potential of large-scale utilizationat the regional level. In our study, we aimed to fill this gap by analyzing the potential contribution of data centers for district heating in northern China considering the economic heating radius. We built an integrated assessment model framework that included a heating source-load spatial matching model with high-resolution data of data centers and buildings, a newly built data center distribution simulation model, and a China regional energy system model. The results show that waste heat from data centers is a critical measure to promote the decarbonization transformation of northern urban heating. In 2020, the waste heat of data centers that could be recovered in winter in northern China was about 0.08 PJ, 90% of which could be matched within the heat transfer distance of 100 km. The potential in the medium- and long-term, considering the size and distribution of newly built data centers, is also projected.

Keywords: Waste heat recovery, Data center, Urban heating

He specialize in district heating and industrial waste heat utilization, presenting research to enhance energy efficiency and sustainability in industries.

Intermittent and Fluctuating Waste Heat Characteristics in Steel Plants: Recovery Optimization Study

Zanyu Yang, Tsinghua University

Zanyu Yang (presenter) yang-zy23@mails.tsinghua.edu.cn

As urbanization accelerates and energy-intensive industries rapidly expand in China, energy challenges are increasingly prominent. The steel industry, as one of China's most important energy-intensive industries, accounts for approximately 16% of the country's total energy consumption, yet its waste heat utilization rate remains below 30%. While existing research mainly focuses on steady-state waste heat recovery, there is an obvious gap in understanding the intermittent and fluctuating characteristics of waste heat itself. This gap leads to operational waste heat utilization systems being unstable, unable to reach their maximum potential, and hampering the sustainable development of the industry, thus necessitating comprehensive research.

In this study, a steel plant with an annual production of 10Mt in Hebei Province, China, was selected as the research object. We systematically examined the waste heat sources of the main processes in the steel plant, obtaining basic parameters such as temperature and flow rate. Additionally, we analyzed the intermittent and fluctuating characteristics of waste heat sources. Meanwhile, the waste heat was classified and integrated in this study, and waste heat utilization schemes matching its intermittent and fluctuating characteristics is proposed.

It was found that waste heat with periodic fluctuating characteristics accounts for approximately 26%, mainly concentrated in the ironmaking and steelmaking processes, including slag flushing water waste heat and converter oxygen lance cooling water. The intermittent and fluctuating characteristics of the waste heat are primarily correlated with the actual production patterns of the steel plant. To harness the waste heat effectively, utilization schemes were designed that incorporate features such as heat storage and adjustable flow rate. Notably, our scheme can provide heating for an area spanning 18 million ㎡, at an investment cost of approximately 9.25 RMB/GJ—considerably more economical than gas heating at 84 RMB/GJ. The findings provide a data basis for subsequent waste heat utilization in steel plants and contribute to improving future waste heat utilization technologies, enhancing both the waste heat recovery ratio and the utilization efficiency in steel plants.

Keywords: steel plant; intermittency; fluctuation; waste heat recovery

John Tang Jensen is an experienced district heating expert regarding regulation and the Danish District Heating model. He has been involved in most aspects of the Danish energy transition since the 90'ties including regulation, tax/subsidy, energy conversation, environment and technologies.

Heat source pricing - District Heating Networks

John Tang Jensen, Energistyrelsen (GR)

John Tang Jensen (presenter) jhntj@ens.dk

The purpose of this paper is to establish an understanding of which elements, procedures and methodologies are needed from identifying a potential waste heat source to have negotiated and agreed a price model in a contract benefitting heat source owner and district heating network company. The methodology regarding finding and agreeing payment can additionally be used by regulator when contracts are appealed or if heat sources are required to connect and the decision is appealed.

Future district heating networks should be established with the purpose to replace individual fossil heating solutions and should primarily be based on ambient and surplus waste heat sources. When district heating networks collect and use waste energy from other sectors a corporation between the heat source owner and district heating company needs to be established and delivery contracts signed to ensure investments are financed, costs are covered, and feasibility are achieved for both partners. This paper explores how this cooperation can be established between the partners with the purpose to make contracts fitting both.

If a heat source exploration is a part of a new heat network zone identification the possible heat delivery from heat source to expected heat network can be based on estimated heat delivery extracted from energy consumption in industrial plants able to deliver high-grade heat. The identified heat sources then can be investigated further in zone refinement phase which should include cooperation between heat source owner and district heating network company for finding the best contract suiting both partners. When it comes to making contracts for CHP plants, waste incineration plants and combined cooling and heat production lines there is special conditions that the partners must be aware of, and this is discussed in separate sectors in paper.

Keywords: District heating, Heat sources, Heat pricing, Waste heat, Surplus heat, Substitution price, Contrafractual prise, Marginal heat price, Cost based heat price

Lipeng Zhang holds a Ph.D. in District Heating (DH) from DTU and has nearly two decades of experience in the district heating sector. Her work primarily focuses on leveraging Danish DH expertise to enhance China’s urban heating systems from technical, economic, and environmental perspectives.

Insights from Danish Heating Metering and Billing: Implications for China's Clean Heating Development

Lipeneg Zhang, Noémi Schneiderb, Allan Bertelsen, John Tang

Lipeng Zhang (presenter) lipengzhang_dh@outlook.com

This article explores the lessons China can learn from Denmark's efficient heat billing and metering systems to advance its carbon neutrality goals. Denmark's effective approach is marked by individual heat meters and consumption-based billing, fostering energy conservation and efficiency across its district heating networks. Currently, China's traditional method of heat metering based on floor area could lead to challenges with energy overuse and lacks incentives for conservation. By examining Denmark's regulatory framework, technological adoption, and consumer engagement, this article recommends strategies for China, including the implementation of advanced metering infrastructure, supportive policies for energy-efficient technologies, and increased consumer awareness. These recommendations aim to align with China's broader energy policies and its commitment to achieving carbon neutrality by 2060.

Keywords: Heat metering, Heat billing, district heating, Denmark, China

The presenter is a researcher specializing in renewable energy and zero-carbon heating, focuing on district heating, waste heat recovery, and sustainable energy systems, aiming to develop environmentally friendly solutions for heating in China.

Aligning Heat Demand with Sources Based on Heat Intensity: A Heat Roadmap for China

Zhaoyang Liu,Tsinghua University

Zhaoyang Liu (presenter) liuchaoy19@mails.tsinghua.edu.cn

China's ambitious plan to transition to a zero-carbon energy paradigm includes shifting from fossil fuels and establishing a low-carbon heat system. However, the complex nature of China's heat demand, with its large scale and varied needs, poses significant challenges. Unlike Europe's well-established heat roadmap program, China lacks a comprehensive, systematic plan for zero-carbon heating. This paper aims to address this gap by exploring China's heat demand and sources to build a strategic zero-carbon heat roadmap.

The study analyzes urban heat demand across several sectors, including domestic hot water, district heating in northern cities, heating in mixed climate regions, steam for public buildings, and industrial heat. It assesses current and projected heat demand, temperature, and heat intensity across these sectors. Additionally, the paper examines natural heat source limitations and the potential of low-grade waste heat from human activities.

Findings reveal a staggering urban heat demand in China, currently estimated at approximately 16 billion GJ. Heat intensity exhibits considerable variance across sectors, thereby constraining the viability of heat pump heat sources. Notably, district heating in northern urban areas and light industry heat demand exhibit pronounced heat intensity characteristics, surpassing 10 TJ/㎡, with light industry heat demand exceeding 50 TJ/㎡. The heat intensity of ground-source and air-source heat pumps is subject to environmental constraints and should not exceed 10TJ/㎡. Additionally, the paper evaluates the current and future potential of waste heat from various human activities, estimated at approximately 47.5 billion GJ and 19 billion GJ, respectively, providing ample resources to address high heat demand intensity.

This paper proposes a zero-carbon heating strategy for China, highlighting heat intensity as a key factor in matching renewable heat sources with demand. Natural heat sources face extraction intensity limitations, posing challenges for air-source and ground-source heat pumps in high-intensity applications. Waste heat from human activities presents significant potential; efficient recovery and utilization can address high-intensity heating requirements.

Keywords: heat roadmap,heat intensity,natural heat source,waste heat

Special session: IEA DHC Annex TS5 - Integration of Renewable Energy Sources into existing district heating systems

Ingo Leusbrock is head of "Cities and Networks" department at AEE INTEC in Gleisdorf, Austria. His research interests include urban energy systems and infrastructure with a focus on district heating and cooling and innovative energy supply concepts.

TRANSFORMATION OF LARGE DISTRICT HEATING AND COOLING SYSTEMS TO HIGHER SHARES OF RENEWABLE ENERGY SOURCES

Ingo Leusbrock, AEE INTEC

Ingo Leusbrock (presenter) i.leusbrock@aee.at

DHC systems based on renewable energy and waste heat sources are considered as major solution for climate change mitigation in the heating and cooling sector. The IEA DHC Annex TS5 (“Integration of Renewable Energy Sources into existing District Heating and Cooling Systems”) has been working in recent years to facilitate the transformation of existing DHC systems and to support their operators and other branch stakeholders with the necessary knowledge and methodologies.
The transformation of especially large-scale DHC must be seen as a holistic and long-term process with technical and organizational / non-technical challenges. These challenges must be addressed jointly at the same time to actually enable necessary steps and align expectations between DHC operators, cities and public authorities as well as clients.
The transformation of district heating networks presents stakeholders with a host of challenges that can impede progress and innovation. These range from personnel shortages to technical aspects like a general trend towards electrification ignoring district heating ddvantages to cultural and economic barriers.Stakeholders are thus faced with multifaceted challenges, which needs a comprehensive approach and even includes workforce development, partnerships, policy incentives, and cultural adaptation strategies.
Distinguishing between real problems and perceived obstacles is essential for effectively addressing challenges in the transformation of district heating networks. By adopting a nuanced understanding of the underlying dynamics and engaging stakeholders in collaborative problem-solving, the district heating sector can overcome barriers and realize its full potential in the transition to sustainable heating systems.
The IEA DHC TS 5 addresses this long-term process and analyses it on base of case studies – successful and not successful –, which bottlenecks, challenges and key enablers exist in such a process and which steps are necessary to be taken. Methods and tools for planning and simulation as well as for support for the overall progress will be highlighted. A transformation guideline will be developed and presented.

Keywords: Transformation processes, district heating, guidelines

Researcher at the Energy department of Politecnico di Milano focusing on the modelling of renewable based district heating networks. Deeply involved in national and international projects on the decarbonization of these systems and in their diffusion. She is subtask leader in IEA DCH TCP TS5.

Decentral integration of renewables in existing district heating networks - results and lessons learned from IEA DHC Annex TS5

Alice Dénarié, Politecnico di Milano. Giulia Spirito, Politecnico di Milano. Michela Romagnosi, Politecnico di Milano. Paola Caputo, Politecnico di Milano. Giulio Ferla Politecnico di Milano. Thomas Schmidt, Solites. Axel Oliva, Fraunhofer ISE. Christian Wolff, Fraunhofer ISE. Vera Boss, TU Dresden. Karin Rühling, TU Dresden. Frederik Feike, TU Darmstadt. Frank Dammel, TU Darmtsadt. Markus Gölles, BEST Research. Klaus Lichtenegger, BEST Research. Daniel Heiler, AGFW. Thomas Pauschinger, AGFW. Gunnar Lennermo, Energianalys AB.

Alice Dénarié (presenter) alice.denarie@polimi.it

The distributed integration of renewables and waste heat in DH, although more complex and challenging than the centralized feed-in, offers several interesting opportunities of local decarbonization projects. There is in fact a significant untapped potential of integration of small-scale renewables distributed along networks. The research here presented starts from the work developed in the framework of the IEA Annex TS5, "Integration of Renewable Energy Sources into existing District Heating and Cooling Systems" expanding it to a comprehensive analysis of the distributed integration in DH. Here the participants have collected and deeply analyzed more than 10 case located in Sweden, Germany, Denmark, Italy and Austria, with the goal of extracting main lessons learnt and providing recommendations and guidelines, both technical and non-technical, for designers, planners and researchers to unlock this untapped diffuse potential in a more optimized and faster way.

The analysis shows that, even if challenging, decentral integration is definitely feasible from a technical point of view and can have good performances. On the other hand, it is more expensive and more complex with respect to the centralized concepts, because of the lack of non-standardized integrational schemes. One of the most influential aspects for a proper design of decentral feed-in is the knowledge of the operating conditions (temperature and pressure) of the DH network in the connection point. The common lack of monitoring is the main cause of poor sizing or wrong operational logic. Nevertheless, the main barriers to the successful implementation of decentral integration turns out lying in non-technical aspects, i.e. different ownership, multiple stakeholders' involvement, authorization procedures, fundings scheme, supply contract, difficult tariff's definition and lack of skilled installers.

The innovative intent of this work is to critically systematize all the gathered information into an overall guideline for decentral integration starting from practical experiences. The oral presentation at the conference will start with a general overview of the analyzed case studies and will present the consequent main knowledge derived from their analysis.

Keywords: District heating, decentral feed-in, renewable energy sources, waste heat, case studies

Mohammad Saeid Atabaki, a PhD in Industrial Engineering, is currently a postdoctoral researcher at Halmstad University, Sweden, researching sector coupling and decarbonization of district heating. His research interests extend to analytical frameworks to address sustainability in energy systems.

A systematic approach to analyze methodologies for renewables-based district heating potential assessments – A categorization and literature review

Mohammad Saeid Atabaki, Halmstad University; Giulia Spirito, Politecnico di Milano; Luis Sánchez-García, Halmstad University; Alireza Etemad, University College Dublin; Urban Persson, Halmstad University

Mohammad Saeid Atabaki (presenter) saeid.atabaki@hh.se

The transition from fossil to low-carbon heat supplies represents a necessary change as well as a major challenge for existing district heating and cooling (DHC) systems worldwide. This work aims to gather and present knowledge and facts about current, past, and upcoming methodologies used for assessing the potential for integrating renewable energy sources (RES) in existing DHC systems. Also, the aim is to identify typical/overarching problems and obstacles to attain this integration. A systematic literature review was conducted over more than 250 scientific publications, national comprehensive assessments for district heating, and project reports. The Web of Science (WoS) databases were used for document retrieval, given it is the world’s most extensively employed repository of research publications and citations. The collected projects were analyzed and organized according to a matrix structure, making the derivation of the results easier and smarter. The first main distinction concerns whether a study presents a geographical or non-geographical approach. In parallel, eight dimensions were introduced based on the scope of the analysis and on the considered aspects, such as technical, temporal, and economic aspects. At the end, results can be derived not only based on the dimensions defined but also according to the integrated type of renewable sources and according to the approach used for heat demand and source matching. The analysis shows, among others, that the transition to renewables in DHC systems has received dramatically increased interest over the last two decades, and that the sources gaining more and more interest are surplus heat, geothermal heat, power-to-heat, and low-grade heat sources for heat pumps. Findings also suggest that, even if challenging, the decarbonization of DHC systems is possible and that suitable and effective methodologies to tackle this topic exist and can be used. The work is a part of the IEA DHC Annex TS5 and aims to contribute to defining common guidelines and strategies towards effective transition roadmaps.

Keywords: District heating, Potential assessment, Renewables, Surplus heat, Bibliometric analysis

Giulia is a Ph.D. student at Politecnico di Milano. Her research focuses on district heating, intending to merge local and national scales of analysis. She manages tools to design and optimize DH networks holistically based on geo-referenced data.

A GIS-based tool to optimally plan and operate renewables-based DH systems.

Giulia Spirito, Politecnico di Milano; Alice Dénarié, Politecnico di Milano; Giuseppe Muliere, Politecnico di Milano; Fabrizio Fattori, Università degli Studi dell'Insubria; Mario Motta, Politecnico di Milano

Giulia Spirito (presenter) giulia.spirito@polimi.it

This research presents an open-source tool to perform a combined investment and dispatch optimization of renewables- and waste heat-based district heating (DH) systems. It includes technical, economic and environmental considerations. Starting from a georeferenced graph connecting energy sources and heat demand points, the model returns the configuration of a decarbonized DH system optimized both on investments and operational energy performances. The aim is to minimize the total costs of delivered heat while ensuring the energy balance of the overall system and the full coverage of heat demand with the limited availability of resources over the entire considered timeframe. The tool is based on the python package called oemof-solph which uses a linear programming (LP) approach. The model strength is that it performs DH planning with both a high spatial and temporal resolution. Indeed, the dispatch optimization is based on the temporal characterization of the system's elements. With the energy production curve and the load profiles in input, the decisions that are taken by the solver at any time instant comprise how much each energy unit is supplying and how much energy is flowing on each branch of the distribution network. Regarding the investment optimization, the solver defines whether to invest for the installation of a supply unit or not, with the possibility to limit the amount of installable capacity. At any timestep, the energy flowing in each branch and the capacity to be installed for each source are defined so that the overall cost of the system is minimized. Eventually, constraints on embedded CO2 emissions can be introduced in the model in order to evaluate how the evolving decarbonization strategies may impact on the potential of DH systems and their planning. In this specific work the case study is a province located in northern Italy, but the modular structure of the tool makes it at applicable at both small-scale and large-scale contexts.

Keywords: District heating, Renewables, Waste heat, Energy planning, Dispatch and investment optimization, Linear programming, GIS

Frederik Feike works in the field of transforming existing fossil district heating and cooling systems into decarbonized systems of the 4th generation. For this purpose, he uses simulation models in MATLAB Simulink to analyze the integration of renewable heat sources.

Modeling heat loads and return temperatures of buildings connected to a district heating network using a neural network

Frederik Feike, Frank Dammel, Peter Stephan, Technical University of Darmstadt

Frederik Feike (presenter) feike@ttd.tu-darmstadt.de

Simulations are a very useful tool to compare different options for developing existing district heating systems towards sustainability as part of decarbonization targets. An important question to consider when using simulations is how to model the heat demand of the connected buildings. In existing district heating systems, the district heating operator usually has large amounts of historical demand data available from billing meters.
However, this heat demand data is dependent on weather conditions and can vary significantly from year to year. Therefore, this data should not be used directly as input for simulating a future scenario with different weather conditions than at the time of measurement. Instead, data should be used that corresponds to typical weather conditions at the site.
To calculate this typical heat demand, a neural network is developed that uses historical heat demand and weather data as training data. This is done using the Matlab Machine Learning Toolbox. The procedure described in this work does not require any additional data on the building parameters. The preprocessing of the data is discussed, including the generation of useful features and standardization.
The trained model is then used to predict the heat demand for typical weather conditions from the "Test Reference Year" data set provided by the German Weather Service DWD. This approach is applied to each building on TU Darmstadt's Lichtwiese campus.
The same approach is used to model the return temperatures of the buildings. In this case, the network's supply temperature is also used to train the model and make predictions. In addition to modeling building behavior for typical weather conditions, this approach can also be used to estimate how the return temperatures would change if the supply temperature in the network were lowered, with the goal of generally lowering network temperatures to increase overall efficiency and reduce heat losses. It can also be used to estimate the effect of a change in ambient temperature on the heat demand of the buildings.

Keywords: Heat demand regression, return temperature regression, machine learning

He is trained as macro economist and is mainly interested in structural and macroeconomic aspects of the green transition. He holds a PhD in Economic Integration focusing on the working of the Single Market in Denmark. Doing research in the green transition is some of his latest research

The involvement of stakeholders when decarbonizing larger existing DHC plants. A guide for politicians, planners, and operators of DHC plants

Poul Thøis Madsen

Poul Thøis Madsen (presenter) pmadsen@plan.aau.dk

To ensure a green transition already existing district heating need to decarbonize. The best way to achieve this goal is to develop and integrate more renewable energy into district heating. This would require the fulfillment of several preconditions. In this presentation it is the role of the stakeholders that is emphasized and analyzed. It is discussed who the main stakeholders might be and what their respective role would be during the green transition of district heating plants. But there might also be some drawbacks in involving stakeholders more, and this overlooked aspect is also analyzed. Finally, it is discussed how involvement of stakeholders could take place and how it is possible to stimulate the participation of more stakeholders than commonplace.

Keywords: District heating, stakeholder involvement, green transition, renewable energy

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

He has 3 years of experience carrying out design and overseeing the install and commissioning of new build heat networks. He is an assistant author to the Heat Network Technical Assurance Scheme, forming part of heat network regulations in the UK launching in 2025.

Optimising thermal storage volume to reduce the electric peaking plant capacity

Jake Adamson, FairHeat

Jake Adamson (presenter) jake.adamson@fairheat.com

Energy centres with a combination of heat pumps and electric boilers are a standard approach to deliver all electric and low carbon heat to communal heating systems. Heat pumps are used to deliver an acceptable cost of heat, and electric boilers used as peaking plant to optimise the required heat pump size and reduce the capital expenditure of equipment.
Specifying large electric boilers to meet the peak heating demand increases the associated electrical grid reinforcement size and cost. Given the a) significant associated cost grid infrastructure upgrades, and b) the surge in grid upgrade applications causing long lead times in the UK, there is an increased driver to optimise the i) total thermal storage volume, ii) the heat network control strategy and iii) the peaking plant capacity sizes in future projects
An assessment of operational data during UK peak heating seasons, between November to March, from ten residential heat networks has been undertaken to determine the impact of varying the thermal storage volume has on the required boiler capacity and therefore the size of the electrical grid infrastructure upgrades necessary to accommodate the generation equipment. The operational data acquired was at 5-minutes intervals, giving a unique insight into the heat demand profile and resident behaviour on heat networks at varying sizes.
A model was developed to utilise the 5-minute readings to simulate how the Energy Centre would have operated with varying thermal storage volumes to assess the impact on the required electrical capacity and to gain insight into the ability to charge the thermal store during cheaper periods whilst providing heat during peaks.
The findings show there is potential to reduce the total peaking plant capacity by 20-30% by optimising the thermal storage volume, thus reducing the required grid connection size and associated cost. The risk associated with reducing the boiler capacity can be mitigated by optimising the control strategy to fully charge and discharge the thermal storage during the night in the coldest periods. The increased thermal storage volume allows for optimisation on generation equipment enabling times to enhance the benefits of variable tariffs by charging during times where electricity is cheaper.

Keywords: Heat Network, Thermal Storage, Optimisation, Heat Pumps, Operational Data, Electric Heat Generation, Variable Tariff, Peaking Plant Capacity

He has 20 years of experience in the power plant industry and as consulting engineer developing district heating systems and working with energy savings in industry. 3 years ago he joint academia.

Comparison of direct and indirect district heating systems in Denmark

Jens Møller Andersen

Jens Møller Andersen (presenter) ja@pe.au.dk

The direct type of house installations in district heating systems has a lower return temperature and resulting in higher capacity of the grid than the indirect systems. Here, the differences are quantified. There appears to be considerable potential in focusing on direct systems, as the direct systems in Denmark on average have an 8.6°C lower return temperature and an 8.5°C more cooling of the DH water.

There seems not to be any publicly available analyses or data to compare direct vs. indirect district heating systems. Since most data is confidential, the analysis is based on data from the Danish District Heating Association (Dansk Fjernvarme) from the last year where data was publicly available (2016). Access to the confidential 2018 data showed the same trends (Hornstrup et al., 2023). The investigations and analysis included collecting data from the technical provisions of the 261 district heating companies that are included in the annual statistics, to determine operation parameters of direct and indirect systems. The detailed analysis was limited to district heating companies that supply more than 90,000 MWh of district heating annually.

The analysis shows:

Return temperature:
Direct yearly 40,11°C
Indirect yearly 48,73°C
Direct Winter 38,32°C
Indirect Winter 48,59°C

Cooling of DH water
Direct yearly 36,01°C
Indirect yearly 27,53°C
Direct Winter 41,1°C
Indirect Winter 31,66°C

This shows a clear advantage of the direct district heating systems, which can be quantified into the following for Denmark:

- 26% less heat loss from pipes.
- Simpler and cheaper house units.
- Less risk for malfunctions.
- 23% higher capacity of pipes.

However, there are disadvantages with direct district heating systems. If district heating water is leaking in the house, there is much more water that can leak into the house. This may be handled with leak detection systems, which add additional cost to the direct systems. But overall, there seem to be clear advantages for the direct systems.

(Hornstrup et al., 2023): Kasper Pedersen Hornstrup, Mohamad Hossni Mohamad, Kristian Myrup Høg: Konceptudvikling af Prisbillig Lækagesikring til Direkte Fjernvarmeforsyning i Danske Boliger.

Keywords: District heating, direct, indirect, temperature, return temperature, cooling, economy, savings, efficiency

Orestis is an Industrial PhD Student with a focus on energy systems design and optimization. He specializes in district energy and holistic system design, drawing on his expertise in techno-economic modeling, hydraulic & thermodynamic analysis, gained during his role as a senior engineer at Ramboll.

A Scottish Case Study: Can 5th Generation District Heating and Cooling Facilitate Holistic Decarbonisation in Clyde Gateway?

Orestis Angelidis, University of Glasgow;
Anastasia Ioannou, Technical University of Denmark;
Daniel Friedrich, University of Edinburgh;
Alan Thomson, Ramboll;
Gioia Falcone, University of Glasgow.

Orestis Angelidis (presenter) 2072680a@student.gla.ac.uk

Achieving a decarbonised thermal grid that balances cost, environmental impact, and security of supply requires a holistic approach that integrates sector coupling and energy storage. A system that allows for energy sharing between heating and cooling and an interaction with the electricity grid through heat pumps is 5th Generation District Heating and Cooling (5GDHC). An ambient network is connecting decentralised water source heat pumps, allowing energy sharing and low temperature waste heat utilisation.

However, the economic viability of such schemes relies heavily on demand co-occurrence and energy trading to offset the increased capital and operational costs. Current efforts to quantify energy trading potential in these networks primarily rely on energy flow analysis, without considering the hydraulic effects of the system, which can be complex due to bidirectional mass flow and hydraulic sub-cycles. This is due to a lack of a coherent hydraulic design and control philosophy that allows bidirectional flow without hindering hydraulic stability. Understanding the boundaries of beneficial operation of the system against energy supply alternatives requires a complete technoeconomic assessment.

This work presents a complete analysis of a 5GDHC system, integrating heating, cooling, and energy storage, for a real-world application in Clyde Gateway, Scotland. The analysis, using experimentally validated open-access tools, quantifies the economic and environmental benefits of 5GDHC compared to counterfactual supply options. A detailed data analysis identifies the key 5GDHC design opportunities and pitfalls as well as key sensitivity variables for the proposed design and operational methodology. It sheds light on the potential impact to the electricity grid, the space constraints and interactions with other utilities, phasing of construction and operational challenges.

The results of this work can inform decision-makers, energy planners, and stakeholders in the development and operation of ambient district heating and cooling systems, supporting the transition towards decarbonised and sustainable thermal grids.

Keywords: 5th Generation District Heating and Cooling, 4th Generation District Heating and Cooling, Energy Trading, Sector coupling, Smart energy systems

Carolin is a PhD student at the Energy Information Networks and Systems Lab of Technical University of Darmstadt. Her current research comprises the development of optimization models of multi-energy systems with a focus on municipal heat planning in Germany.

Heating System Optimization considering Technology, Temperature, and Retrofit Flexibility Model-endogenously

Carolin Ayasse, Technical University of Darmstadt. Florian Steinke, Technical University of Darmstadt.

Carolin Ayasse (presenter) carolin.ayasse@eins.tu-darmstadt.de

Optimization approaches for determining decarbonization pathways for multi-energy systems should consider as many flexibilities as possible model-endogenously, in order to correctly represent the various interdependencies between the different options during the optimization process. Existing models for the heat sector that incorporate building retrofits and heat grid expansions often use binary variables for each individual building. The resulting MILP problems are then computationally expensive to solve, practically restricting their use to districts with a very limited number of buildings.

This work proposes a novel multi-energy system model with special focus on the heat sector that aggregates buildings into several clusters and optimizes the shares thereof. The resulting optimization problem is a LP problem which significantly reduces computation times compared to the MILP formulation and allows to address larger districts. At the same time, the model still accounts for possible building retrofits, different temperature levels, and heat grid extensions, as well as the interdependencies between all these decisions.

The aggregation is performed on the heat demand side as the retrofit costs, as well as the resulting reduction in heat demand, are averaged over all buildings in each cluster. On the supply side, the model comprises four different options per cluster, including district heating at a low and a high temperature level as well as decentral heating at a low and a high temperature level. Each supply option itself consists of different heat generation technologies. The model considers three different clusters with respect to the space heating demand, each corresponding to a different retrofit standard. The domestic hot water demand is considered separately. The space heating demand of buildings with a low retrofit standard, as well as the domestic hot water demand, can only be supplied by heat at the higher temperature level, or with heat at the lower temperature level if an additional auxiliary heater is used.

The new energy system model is demonstrated for a district of a municipality in southern Hesse, Germany.

operational efficiency but also foster a more sustainable and resilient district heating ecosystem. The green transition hinges on our ability to engage customers and optimize heating systems effectively.

Keywords: Low-temperature district heating, end-user engagement, demand side management, cost reduction gradients, motivation tariffs. optimization

Prof.Dagnija Blumberga is the author of more than 500 scientific publications and has experience in more than 20 international projects as a researcher, expert, and project leader in wide range of environmental engineering topics.

Multi-energy Hub Forwards to Decarbonisation

Dagnija Blumberga, Ieva Pakere, Riga Technical University

Dagnija Blumberga (presenter) dagnija.blumberga@rtu.lv

Decarbonization of the smart energy system is a complex opportunity depending on the numerous interrelated factors and multiple pathways. Transitioning from fossil resources to sustainable renewable energy involvement is impossible without reflecting on the complex relations between the different energy supply and sources from one side and the energy end-user from the other side.
The pathway to decarbonization is directed to a sector-coupled and collaborative effort among stakeholders for the development of adaptive strategies. The objective is to optimize resource utilization by interaction and sharing of energy resources between the sectors.
The development of flexible and adaptive market mechanisms is important for encouraging and driving sector coupling. Therefore, the concept of multi-energy hubs as a holistic approach for the sector-coupled planning and operation of the energy system have been developed.
Within this study, energy producer, consumer, or prosumer and aggregator nodes are modelled as multi-energy hubs that may involve multiple energy vectors i.e., electricity, heat, gas, e-fuels, or biofuels.
The paper is based on the concept of multi-energy hubs in municipality which allows for sectioning the complex energy system into manageable nodes where the energy efficiency, energy accumulation and renewable energy mixture will be optimized by energy community partners and energy aggregator activities. Three multi-energy hub scenarios are modelled by the HOMER software for energy supply systems in middle size municipality in Latvia to optimise the overall energy costs and reduce total emissions.

Keywords: Energy hubs, smart energy systems, decarbonisation

Gerrid Brockmann is a research associate at the Technische Universität 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 thirteen years' experience in numerical methods.

Economic and ecological investigation of a heating network in the suburban area Leeste in Germany

Gerrid Brockmann, Technische Universität Berlin, Shixin Ni, Technische Universität Berlin, Jonas Bergmann, Institut für ökologische Wirtschaftsforschung, Tidian Baerens, Institut für ökologische Wirtschaftsforschung, Steven Salecki, Institut für ökologische Wirtschaftsforschung, Karim Shawky, Technische Universität Berlin, Amin Darbandi, Technische Universität Berlin, Ingrid Kreiser-Saunders, Umweltzentrum Stuhr Weyhe, Bernd Olma, Umweltzentrum Stuhr Weyhe, Martin Möhring, Umweltzentrum Stuhr Weyhe, Martin Kriegel, Technische Universität Berlin

Gerrid Brockmann (presenter) brockmann@tu-berlin.de

In the SubWW2 project, the goal is to plan a decarbonized local heating network for a typical suburban area without access to industrial waste heat. Various scenarios based on mainly local energy potentials are being examined numerically for this purpose. All scenarios are subject to the current federal funding criteria for efficient heating networks and reduce CO2 emissions by at least 52 % compared to the status quo. Depending on the boundary conditions, the dominant technologies in terms of the quantities of heat generated are air source heat pump and biomass. Condensing boilers should only be used where necessary due to their unavoidable CO2 emissions and the currently high prices for natural gas and biomethane, which are likely to rise further in the future. Fossil-based generation technologies only produce a small proportion of the heat and therefore only operate in the peak load range. By dispensing with natural gas-fired condensing boilers, further CO2 emissions can be avoided. The costs increase only moderately and peak loads are covered by P2H systems. As the emissions assessment is based on the current German electricity mix, the scenarios in which large proportions of the heat are used by biomass in particular lead to a sharp drop in CO2 emissions. Additionally, costs of the heat grid scenarios are compared to climate-neutral decentralized supply solutions and a scenario with no changes (status quo) in the heat supply. No matter, in this study the grid scenarios have an increased economic efficiency assuming that all households will connect to a heating network.

Keywords: heat grid scenarios, oemof, MILP, decarbonization,

Tom is a CIBSE Chartered Engineer and Principal Engineer at FairHeat with over 5 years of experience in heat network design and quality assurance, specialising in the optimisation of existing systems.

Heat Network Optimisation Guidance: Standardising the approach to improving the performance of legacy systems

Tom Burton, FairHeat

Tom Burton (presenter) tom.burton@fairheat.com

Decarbonisation of the built environment over the next generation faces unique complexities given that the majority of buildings already exist. Many of these rely on heat networks to deliver hot water and space heating to consumers, which will be key for reducing carbon emissions by facilitating the centralised production and distribution of heat. However, analysis of the performance of existing heat networks in the UK has identified a number of issues which consistently compromise heat network performance and severely affect both the cost of heat and consumer experience. This is due to a range of factors, including system design, installation methods, and maintenance practices.

Addressing these issues whilst maintaining heat supply for consumers and minimising disruption poses a significant challenge that New Build heat networks do not have to consider. As heat networks are still a relatively new approach in the UK, there is a lack of general industry knowledge and experience with regards to how to approach the optimisation of existing systems, particularly within the operator community. To address this, FairHeat (in collaboration with Anthesis) were commissioned by the UK Government Department for Energy Security and Net Zero to produce a Heat Network Optimisation Guide and series of explanatory videos for operators and M&E engineers detailing how to improve the performance of legacy systems.

This guide provides a standardised heat network optimisation philosophy by defining key principles, processes and minimum technical expertise for those undertaking optimisation assessments. The philosophy is centred on a KPI based approach, ensuring that consumer wellbeing and cost of heat are fully quantified and assessed. The techniques outlined will also help to ensure that solutions enable future connection to district heat networks or decarbonisation at a building level.

https://www.gov.uk/government/publications/heat-networks-optimisation-guidance-to-help-operators-improve-performance

Keywords: optimisation, decarbonisation, heat networks, knowledge sharing

Martina Capone is a postdoctoral research fellow at the Energy Department of Politecnico di Torino. Her research focuses on the simulation and optimization of large-scale energy systems. Her area of expertise includes district heating networks and their transition to next generation.

Enhancing District Heating Transition through the Integration of Groundwater Heat Pumps

Martina Capone, Elisa Guelpa, and Vittorio Verda, Politecnico di Torino.

Martina Capone (presenter) martina.capone@polito.it

The challenge of decarbonizing District Heating represents a crucial step towards establishing a sustainable energy system reliant on non-fossil resources. In the chasing of this goal, District Heating technology is undergoing a transition phase, leading to the development of a new generation of systems characterized by lower operating temperatures, extensive integration of renewable energy sources, and integrated connections with other energy networks within a multi-energy system framework. In this context, groundwater heat pumps have an important role to play, offering the possibility of incorporating an efficient and sustainable source of production, but requiring appropriate conditions to be integrated into an existing system. The challenges could be many, considering both the requirements of the installed district heating system and the underground interactions with groundwater systems already installed in the surrounding areas of the city. From the point of view of the heating network, one of the problems can be the possible mismatch between the required temperature levels and the temperature level achievable by groundwater heat pumps. For this reason, the installation of the groundwater heat pump must be carefully analyzed and adapted to the requirements of the network in different outdoor conditions. On the other hand, the underground situation must also be properly analysed by taking into account all the groundwater systems installed in the surrounding area. In fact, the thermal plume generated by each groundwater system has a strong influence on the coefficient of performance of the heat pumps located downstream of the temperature perturbation. The choice of the location of the newly installed well must then be based on an accurate analysis of the overall groundwater flows, avoiding performance degradation and instead pursuing possible performance improvements. For these motivations, the aim of this work is to discuss the criticalities and opportunities arising from the possible installation of groundwater heat pumps in existing district heating networks to promote the transition to renewable next-generation systems, to provide useful guidelines to be considered in the technical decision process, and to quantify the potential benefits achievable.

Keywords: District heating, renewable energy, groundwater heat pumps, thermal plume, heat network.

Luca is a PhD candidate at TU Wien since November 2019. Luca's work analyses specifically the building stock, its thermal efficiency and district heating. The aim is to increase energy efficiency in buildings while being technically and economically viable to allow low-temperature heating.

Comparative study of LTDH distribution systems in urban heating: a cost-effectiveness and sustanaibility analysis

Luca Casamassima, TU Wien; Lukas Kranzl, TU Wien

Luca Casamassima (presenter) casamassima@eeg.tuwien.ac.at

This study investigates the economic and environmental impacts of three distinct low-temperature district heating (LTDH) strategies to identify sustainable and cost-effective solutions for urban heating systems. Central to this investigation is the question: How do different LTDH strategies impact the economic and energy efficiency of district heating companies and customers? This analysis measures overall system efficiency and explores financial implications for the key stakeholders.

The research analyses three distinct LTDH configurations: 1) LTDH with low-temperature production and distribution using building-level booster heat pumps (HP), 2) LTDH with building renovations for direct compatibility, where heat is generated, distributed and used at low-temperature, and 3) use of a low-temperature heat source, where a central high-temperature HP boosts the temperature to approximately 100°C before entering the distribution network.

Scenario 1) assesses avoiding renovations by using building-level boosters, increasing DH operator costs and complexity while leaving demand unchanged. Scenario 2) explores the benefits and challenges of renovations that enable low-temperature heating, potentially reducing heat sales and consumer costs. Scenario 3) utilises central high-temperature boosters to simplify the infrastructure at the expense of higher heat distribution losses, balancing initial lower capital investment against maintenance savings.

The findings are expected to provide valuable insights into how different configurations can balance costs with ecological benefits. Utilising indicators such as Internal Rate of Return (IRR), Net Present Value (NPV), and Levelized Cost of Heat (LCOH), this study will offer a comparison that informs stakeholders—including municipal planners, policymakers, and energy providers—about LTDH systems implementation. The goal is to guide the development of heating infrastructure that reduces environmental impact while offering economic advantages to providers and consumers, facilitating a smoother transition to sustainable urban energy solutions. By evaluating these economic metrics, stakeholders can better assess the long-term financial benefits and sustainability potential of each LTDH configuration.

Keywords: Low-temperature district heating, Energy Efficiency, Sustainable heating, Heat pump, Renovations, Techno-economic analysis, Booster, Building Renovations

He received the B.E. degree in Electronics Engineering and the M.S. degree in Computer Engineering in 2006 and 2012, respectively. Since Feb 2020, he is working as a PhD Fellow at VUB on robust design and operational optimization of thermal grids.

A framework for optimizing prosumer-based thermal networks in urban communities: robust design approach with uncertain energy markets

1)Afraz Mehmood Chaudhry, a)Thermo and Fluid Dynamics (FLOW), Faculty of Engineering, Vrije Universiteit Brussel (VUB), Brussels, Belgium; b)Brussels Institute for Thermal-Fluid Systems and Clean Energy (BRITE), Vrije Universiteit Brussel (VUB) and Université Libre de Bruxelles (ULB), Brussels, Belgium, 2) Kevin Verleysena, a)Thermo and Fluid Dynamics (FLOW), Faculty of Engineering, Vrije Universiteit Brussel (VUB), Brussels, Belgium; b)Brussels Institute for Thermal-Fluid Systems and Clean Energy (BRITE), Vrije Universiteit Brussel (VUB) and Université Libre de Bruxelles (ULB), Brussels, Belgium, 3) Stanislav Chicherin, a)Thermo and Fluid Dynamics (FLOW), Faculty of Engineering, Vrije Universiteit Brussel (VUB), Brussels, Belgium; b)Brussels Institute for Thermal-Fluid Systems and Clean Energy (BRITE), Vrije Universiteit Brussel (VUB) and Université Libre de Bruxelles (ULB), Brussels, Belgium, 4) Jonathan Hachez, a)Thermo and Fluid Dynamics (FLOW), Faculty of Engineering, Vrije Universiteit Brussel (VUB), Brussels, Belgium; b)Brussels Institute for Thermal-Fluid Systems and Clean Energy (BRITE), Vrije Universiteit Brussel (VUB) and Université Libre de Bruxelles (ULB), Brussels, Belgium, 5) Julien Blondeau, a)Thermo and Fluid Dynamics (FLOW), Faculty of Engineering, Vrije Universiteit Brussel (VUB), Brussels, Belgium; b)Brussels Institute for Thermal-Fluid Systems and Clean Energy (BRITE), Vrije Universiteit Brussel (VUB) and Université Libre de Bruxelles (ULB), Brussels, Belgium, 6) Svend Bram, a)Thermo and Fluid Dynamics (FLOW), Faculty of Engineering, Vrije Universiteit Brussel (VUB), Brussels, Belgium; b)Brussels Institute for Thermal-Fluid Systems and Clean Energy (BRITE), Vrije Universiteit Brussel (VUB) and Université Libre de Bruxelles (ULB), Brussels, Belgium,

Afraz Mehmood Chaudhry (presenter) afraz.mehmood@gmail.com

Next generation district heating and cooling systems lower carbon emissions by utilizing waste energy sources and relying on smart mutual energy exchange among prosumers. However, finding suitable locations for such systems poses a challenge due to uncertain energy prices, demands and investment costs. For a robust design, these uncertainties are considered during the design phase, allowing us to select the design that is least sensitive to the uncertainties, i.e. the most robust one. For this study, we employed a three-step methodology for selecting a suitable location. To determine the main uncertain input parameters, we first performed a sensitivity analysis via Sobol's indices on each district heating network's key performance indicators, i.e. the upfront cost of the network infrastructure, associated emissions and network savings by adopting heat pumps and centralized thermal storage. Secondly, an economic and risk analysis is conducted, considering uncertain but bounded variations of inputs, reducing the number of potential locations. Finally, we applied a robust design optimization to the selected locations, which adapts the network temperatures and pipe connections between the prosumers and heat sources to optimize the mean and standard deviation of the chosen key performance indicators. The optimization offers a Pareto front of optimized designs, where we can opt for a robust design in terms of savings and emissions, a robust design based on the annualized cost's standard deviation or a design with the lowest mean annualized cost. The developed optimization provides investors with distinct design options, allowing them to choose between a more resilient or cost-effective solution.

Keywords: Global sensitivity analysis, Energy market analysis, Techno-economic analysis, Robust design optimization, CO2 Emissions, Investment return, Net present value, Risk analysis

Johan Dalgren has worked at Stockholm Exergi since 2007 as a development Engineer with the design and control of Stockholm's thermal networks. Since 2018 he is a part time industrial PhD student at KTH focusing on the design of future thermal networks.

Circulation flows in District Heating Systems – A comparison between necessary, demanded and real flows.

Johan Dalgren, KTH Royal Institute of Technology

Johan Dalgren (presenter) johdal76@kth.se

To succeed with the energy transition and mitigate climate change, the next generation of district heating and cooling is an important part. This is established in several research projects, e.g. Heat Roadmap Europe. One of the key features is to make new and existing thermal networks more efficient. Apart from lowering the heat losses, one of the main tasks identified is to minimize the Circulation flows in the networks.

The total flow in a network can be divided into a Delivery flow, which is the flow that goes to all the consumers, and a Circulation flow. This Circulation flow occurs through both intentional and unintentional connections between supply and return pipes (bypasses). There are mainly two reasons for the intentional bypasses. First, is for freezing protection during winter. Second, is to assure the agreed supply temperature to all consumers. In times of low demands and/or oversized distribution pipes, the Delivery flows get so small that the heat losses reduce the supply temperature lower than what is promised to the consumer. Although the domestic hot water (DHW) circulation at the consumer asserts the necessary flow to reach the set value of the DHW, the promised supply temperature is often higher and therefore demands an additional circulation flow. The unintentional bypasses often come from when the pipes are pre-warmed during installation, forgotten and left when they are buried. Since no documentation of them exist, they are very difficult to identify and to be located afterwards.

Little information is available in literature about real Circulation flows in existing thermal networks. Therefore, this paper has examined the circulation flows that are present in the district heating network of Stockholm, Sweden. Both at overall system level and in sub networks. Two different methods of assessing the Circulation flows are used and discussed.

A hydraulic model of one of the sub networks has been made with the software Termis, to compare the reel Circulation flows with what is demanded in theory. Both to meet the agreed supply temperature to all customers, but also to assess what minimum Circulation flow that in theory could be enough for the minimum practical supply temperature needed for all customers.

Keywords: Circulation flows, 4GDH, District heating, Thermal networks

PhD Fellow at the Department of Energy System Technologies at Paderborn University

Optimising heat planning: Cost effective refurbishment for enabling low carbon district heating

Denis Divkovic, Paderborn University

Denis Divkovic (presenter) denis.divkovic@uni-paderborn.de

The heating sector is responsible for around 15 % of national carbon dioxide emissions in Germany. In order to reduce emissions, the government has taken the first step towards transferring the heating sector. Local authorities are obliged by law to draw up a heating plan for their communities. District heating plays a key role in this, and not just because of its ability to utilise waste heat. Looking at the current situation in most German cities, suitable district heating locations have a very high heat demand density, for which 3rd generation district heating systems are well suited under current conditions.
Various measures are possible with regard to enabling a low-carbon district heating supply. On the one hand, investments in heat generation with renewable energies and, on the other hand, measures on the demand side to reduce the heat requirement are practicable. With regard to modern 4th generation district heating systems, these systems enable the integration of low-temperature heat sources such as low temperature waste heat and are therefore a possible enabler for low-carbon district heating. However, both the flow temperatures and the heat demand density must be reduced compared to 3rd generation district heating systems. Renovation measures are therefore required for existing buildings.
The aim of this study is therefore to show the costs of refurbishment measures that are necessary to enable low-carbon district heating. For this reason, the German city of Paderborn is first analysed for suitable district heating areas. Different district heating concepts are designed, and necessary refurbishment measures are considered in order to reduce the heat demand of the analysed buildings in the district heating areas and to implement renewable heat generation. As a result, the total investment costs required for the various concepts and the associated operating costs are compared. This economic comparison shows how much economic effort is required to convert the district heating areas from the third to the fourth generation of district heating.

Keywords: district heating, refurbishment, heat planning, 4GDH

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 their heat networks

Impact of technical assurance on reducing heat network capital cost by addressing oversizing in design

Nina Dungworth, FairHeat

Nina Dungworth (presenter) nina.dungworth@fairheat.com

Heat networks are a key part of the UK Government's strategy to reach net zero emissions by 2050 and the heat network market is set to grow rapidly. To aid this transition a regulatory Heat Networks Technical Assurance Scheme (HNTAS) is to be put in place to ensure high standards of design are met.

One of the core principles for HNTAS is that it should be proportionate, with the effectiveness of the assurance process balanced against the cost of compliance.

Heat networks in the UK have historically been subject to significant peak load and network pipework oversizing. Research has been undertaken to determine the cost saving opportunity to developers as result of correctly sizing schemes, through having a technical quality assurance (TQA) scheme in place. This research contributes towards ensuring the scheme is cost effective.

To facilitate this, data was taken from existing networks that have been audited as well as new build schemes that have been through a design review. The opportunity to improve the design of those schemes provides an initial proxy for the gains that would be expected from a TQA process.

The direct cost saving opportunities of assurance have been identified through calculating the potential reductions in CAPEX & equipment servicing costs related to correctly sizing heat network pipework and heat generation equipment. For heat generation equipment, various energy strategies have been assessed throughout the research. These schemes are 100% gas boiler, 95% heat fraction ASHP & gas boiler top up and 100% ASHP only.

In conclusion the following cost saving opportunities have been identified:
•Correctly sizing network pipework has expected CAPEX savings of c.£380/dwelling

•Correctly sizing heat generation equipment has expected CAPEX savings of c.£530/dwelling for a gas boiler only scheme, c.£1,300/dwelling for a 95% heat fraction ASHP & gas boiler top up scheme and c.£2,500/dwelling for an ASHP scheme.
•The expected equipment servicing cost saving NPV was calculated to be c.£120/dwelling over a typical 25 year equipment life span.

Keywords: technical quality assurance, high standards of design, correctly sizing heat networks, cost saving opportunities

Dr Mieczysław Dzierzgowski is a specialist in district heating systems. His activities included DH diagnostics and regulation, auditing and building thermomodernisation as well as modernisation of DH systems and boiler houses.

Sustainable district heating in Łomża - on the road to decarbonisation

Mieczysław Dzierzgowski; Institute of Fluid-Flow Machinery, PASci Gdansk and Warsaw University of Technology.
Adam Cenian; Institute of Fluid-Flow Machinery PASci Gdansk.

Mieczysław Dzierzgowski (presenter) mieczyslaw.dzierzgowski@pw.edu.pl

The aim of this paper is to present the methodology to decarbonize district heating systems (DHS) taking example from implementation in DH Łomża, a city in north-east Poland with 63,000 inhabitants. The municipal District Heating System (DHS) in Łomża, like most of the systems in Poland, was designed in the 1970-ties and was designed taking into account the expected rapid growth of the city. This unrealised plan as well as performed during last 30 years thermo-modernization of most buildings resulted in large oversizing of the whole system. In 2017, the grid 160 km in length, with 860 substations provided heat from boiler house fuelled 100% by coal. The nominal heat demand was estimated as 98.52 MWt but after verification it was downsized to 73.71 MWt. The nominal supply and return temperatures: Ts/Tr = 121/65^{O}C, which led to heat losses of DH grid 12.5%.
Presently, the most important task in the field of district heating in Poland is the gradual transformation of existing DH systems into decarbonized, 3G grids with supply temperature below 100°C. This is possible and needs taking into account oversized radiators, heat exchangers and DH grid as well as considering huge work being done during thermal modernization of buildings. Such work has been undertaken in the 2017/2018 heating season in a DH system in Łomża as part of a project aiming at increased energy efficiency.

Keywords: District heating, decarbonization, LTDH, energy efficiency

Enric Gonzalez Gonzalo holds a MSc in Sustinable Cities and a BSc in Energy Engineering from Universitat Politècnica de Catalunya. He currently conduct research focusing on European energy systems and energy efficiency in a Smart Energy Systems context as a research assistent at Aalborg University.

Heat Roadmap Europe: Key findings across five EU countries comparing district heating options compared to EU27

Enric Gonzalez Gonzalo, Brian Vad Mathiesen, Jelena Nikolic. Alisson Aparecido Vitoriano Julio, Jakob Zinck Thellufsen

Aalborg University

Enric Gonzalez Gonzalo (presenter) egg@plan.aau.dk

Modern heating management, incorporating low-temperature district heat sources, renewable energy sources, and heat conservation, could offer compelling alternatives to individual heating solutions when integrated into future energy systems. This study examines the decarbonization of the building sector at two analytical levels: the EU27 and a selection of five specific EU countries. The aim is to understand the differences between the overall level and the local country level when considering: (1) the available untapped heat sources, and (2) the feasible levels of district heating and district heat sources. By such approach it is hoped to find results that enables exploring the impacts of implementing different heating scenarios considering different levels of district heating, costs, energy efficiency and biomass consumption. Therefore, this investigation provides valuable insights into the benefits for increasing the market share of district heating from 13 percent to about 50 percent, by utilizing low-temperature waste heat sources more effectively, within the EU27 building sector.

Keywords: District heating, renewable energy systems, smart energy systems, waste heat, 4DGH, heat pumps, geothermal, solar thermal, energy storage, thermal storage, energy efficiency, buildings

Aya Heggy is a doctoral researcher at London South Bank University, focusing on UK heat network decarbonisation. She also serves as Technical Manager at the LSBU Energy Advice Centre, where she enhances energy efficiency for London residents.

Decarbonising the UK's Heat Networks: A Framework for Archetype-Based Strategies and Case Study Analysis

Aya Heggy(a), Henrique Lagoeiro(a), Catarina Marques(a) and Graeme Maidment(a). (a) London South Bank University*

Aya Heggy (presenter) Heggya2@Lsbu.ac.uk

The UK's heat network market, predominantly made up of small communal systems, currently fulfils only 3% of the nation's heat demand. This sector is hindered by a lack of robust, organised market data, which significantly constrains the development of effective policies and strategic innovations. In response, our study introduces a novel framework that uses market archetypes, identified through the k-mode clustering algorithm, to streamline and enhance decarbonisation strategies. This paper presents a detailed case study on the decarbonisation of a selected archetype, illustrating how advanced technologies and systemic solutions can be integrated to facilitate the transition towards a low-carbon model. The study thoroughly examines the archetype’s heat load requirements and the implementation of targeted sustainable energy solutions. Preliminary results from the case study demonstrate significant carbon emission reductions, accompanied by increases in energy efficiency and substantial operational cost savings. These outcomes provide a scalable model that can be applied to enhance the efficiency and sustainability of the broader UK heat network system. This model aligns with the nation's ambitions to achieve net-zero emissions by 2050, offering a structured approach to overcoming the current limitations in the heat network market.

Keywords: Decarbonisation, heat networks ,UK heat demand ,market archetypes, k-mode clustering ,low-carbon model

Mu Huang is a researcher of Department Energy Efficient Buildings at the Fraunhofer ISE in Freiburg, Germany. Her focus is on the evaluation and optimization of heat pump systems in existing buildings.

Energy performance assessment of heat pump systems in three existing multi-family buildings in Europe based on field measurement

Mu Huang, Fraunhofer Institute for Solar Energy Systems.
Jeannette Wapler, Fraunhofer Institute for Solar Energy Systems.
Sebastian Helmling, Fraunhofer Institute for Solar Energy Systems.
Jon Iturralde, Fundación Tecnalia Research & Innovation.
Lorenzo Civalleri, Tecnozenith s.r.l.
Franz Hengel, AEE - Institute for Sustainable Technologies.
Danny Günther, Fraunhofer Institute for Solar Energy Systems.

Mu Huang (presenter) mu.huang@ise.fraunhofer.de

Heat pumps, powered by low-emissions electricity, are a proven solution for the decarbonization of the heat supply, both for space heating and domestic hot water, in buildings. However, the implementation of heat pump systems in existing multi-family buildings remains marginal. One of the main technology challenges is the high temperature requirements in this type of building, which significantly affect the heat pump performance and the necessity to install a backup heater.

The EU-funded research project HAPPENING aims to address this challenge by developing an easy-to-plan and easy-to-install solution based on decentralized heat pumps. The HAPPENING solution can be customized to accommodate the different constraints and requirements in existing multi-family buildings. One common feature of HAPPENING systems is that they are all driven by a low-grade renewable heat source. The heat source can be different, such as a geothermal field, an air source heat pump or a low-temperature district heating network. The existing hot water distribution pipes is utilized as low temperature distribution loop, and each dwelling is equipped with a decentralized heat pump to provide the required heating supply temperature. The electricity use of the heat pumps can be supported by PV panels, which can be installed in the roof or façade of the buildings.

This study evaluates the energy performance of the HAPPENING systems in three existing multi-family buildings based on field measurement data. The demonstration buildings are located in Spain, Italy and Austria, each operating under different climatic conditions and with different control strategies. The study compares them to standard solutions in existing multi-family buildings in terms of primary energy use and green house gas emissions. The temperature levels and energy flows provided by the heat pumps are examined and evaluated as part of this study. The findings demonstrate the technical feasibility of retrofitting

HAPPENING systems to existing multi-family buildings and provides insights on addressing challenges related to high temperature requirements.

Keywords: Decentralized heat pumps, Low-temperature distribution loop, Existing multi-family buildings, Photovoltaic, Monitoring, HAPPENING

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 energy systems. The focus of her work is on the optimization of both the design and the operational strategies to reduce the costs.

Integrated Design and Operational Optimisation for District Heating Networks: Seasonal Subsurface Storage and Heat pumps

Femke Janssen, Kobus van Rooyen, Jim Rojer, TNO

Femke Janssen (presenter) femke.janssen@tno.nl

The Netherlands, with over 90% of homes heated by natural gas, will use District Heating Systems (DHS) for up to 40% of future heating systems in the built environment, according to ambitions of the Ministry of Economics and Climate. Trade-offs taking into account the interaction between assets, but also trade-offs between design and operational strategy are key in reducing the overall system cost.
The application of the MESIDO workflow on a use-case in Rijswijk has indicated a significant reduction in costs when HT-ATES is utilised. This research extends the physical modelling approach of MESIDO with a method to integrally consider varying network temperatures. It is utilized to more accurately model high temperature seasonal storage (HT-ATES) with a heat pump (HP).
The MESIDO approach will be applied to the Rijswijk use-case again, which gives more representative results of the seasonal storage, a more realistic discharge period and temperature, and a better estimation of the electricity cost with varying COP for the HP.
MESIDO utilizes an Mixed Integer Linear Problem approach for minimisation of Total Cost of Ownership (TCO) over the lifetime to enable optimal trade-offs between CAPEX, incorporating sizing and placement decisions, and OPEX, incorporating operational decisions, for each asset, over the time horizon.
The HT-ATES has significant heat losses over time, resulting in reduced thermal power and temperature drop when discharging. Configurations with a HP or another asset to upgrade the heat is gaining attention. Without upgrading the temperature, the seasonal storage cannot be used to its full potential as the cut-off temperature will be relatively high. The seasonal storage gets an additional variable representing the temperature, which is linked to the heat losses.
The COP of the HP is a linearised with the supply temperature on the primary side. As the COP during discharging of the HT-ATES will go down, more electricity and a larger sized HP is required. This both influences the CAPEX and OPEX and results in a more accurate sizing of the corresponding assets.
The approach has been validated with the high fidelity 3D subsurface simulator ROSIM (TNO). Results show that MESIDO is conservative when configured correctly for the local subsurface.

Keywords: MILP, techno-economic optimisation, seasonal thermal energy storage, district heating network, heat pump

Lars Skytte Jørgensen has over 30 years of experience in the business sector. He has optimized energy systems in China and Germany and returned to Denmark in 2012. In 2023, he became the Head of Distric Heating, Cooling, and City Gas at Aalborg Forsyning.

Advancing Sustainable Energy Solutions: Aalborg Forsyning's Strategic Green Transition Initiatives

Lars Skytte Jørgensen, Aalborg Forsyning A/S

Lars Skytte Jørgensen (presenter) lars.joergensen@aalborgforsyning.dk

This presentation delineates the strategic initiatives of Aalborg Forsyning aimed at enhancing sustainable and secure energy solutions in Aalborg, Denmark. The discourse encompasses the production and distribution of electricity, district heating, city gas, district cooling, potable water, and wastewater management. A central focus is the green transition, specifically the gradual elimination of coal in favor of surplus heat and electrification. The presentation elucidates the capabilities and contributions of Nordjyllandsværket, recognized as the world's most efficient and flexible power plant, and provides a detailed timeline and key activities for achieving fossil-free heat production.
Furthermore, the presentation addresses the development of Norbis Park as a testing and demonstration site for innovative green technologies, with an emphasis on fostering circular resource flows and synergistic partnerships. The FjordPtX project is highlighted, demonstrating its potential to repurpose CO2 from waste incineration, produce sustainable aviation fuel, and supply surplus heat to district heating systems. Additionally, the Kyoto HeatCube project is discussed, showcasing an innovative heat storage solution that utilizes excess electricity to sustain efficient district heating.
Through these initiatives, Aalborg Forsyning aspires to establish a resilient and sustainable energy infrastructure, thereby contributing to the city's comprehensive green transition and ensuring energy security for future generations.

Keywords: Sustainable energy,District heating,Green transition,Fossil-free heat production,Norbis Park,FjordPtX,CO2 reutilization,Sustainable aviation fuel,Kyoto HeatCube,Heatstorage,Energy infrastructure

As Senior Product Manager, David Kodz is responsible for the growing product portfolio of Mega Heat Pump Systems designed and engineered by MAN Energy Solutions in Switzerland.

Grid Stabilization with Mega Heat Pumps

David Kodz, Emmanuel Jacquemoud, Emin Cemberlitas
MAN Energy Solutions Schweiz AG, Hardstrasse 319, 8005 Zürich, Switzerland
david.kodz@man-es.com

David Kodz (presenter) david.kodz@man-es.com

The global imperative to mitigate climate change and transition to sustainable energy sources is driving the end of conventional heat generation, typically based on large-scale fossil-powered infrastructure, as the backbone of domestic (in particular district heating) as well as industrial heat & cold supply. However, with the inevitable progression of climate change, humanity is faced with the urgent need to close this chapter and usher in a new era - the era of renewable energy and its effective use.The use of renewable energy sources to generate electricity and thus heat is not only a response to the growing environmental crisis, but also a symbol of technological progress and innovation. Efficient technologies such as large-scale industrial or even Mega Heat Pumps offer a clean, inexhaustible and increasingly cost-effective alternative to fossil-powered infrastructure and play a significant role in decarbonisation as well as the energy and heat transition.However, the transition to decarbonization and renewables poses a number of challenges, particularly in managing the inherently volatile and less predictable availability of renewable energy supplies, as well as the stability and reliability of the electricity grid. Mega Heat Pumps can be seen as both a blessing and a curse in this respect - on the one hand, they are among the ultimate large electricity consumers of the future, and on the other hand, they can be used intelligently to overcome the volatility of electricity supply.This paper aims to explain how Mega Heat Pumps can help stabilize the electricity grid by providing balancing power in addition to heat production. With the increasing share of volatile renewable energy sources, grid operators are facing new challenges. Mega heat pumps offer technical solutions here and open up new markets for balancing energy. The analysis covers technical aspects, markets for balancing power and the economic benefits resulting from the use of heat pumps. The paper discusses the future potential of this technology in the context of the energy transition and emphasises its central role in a more sustainable energy future.MAN defines Mega Heat Pumps as a system size of industrial large-scale heat pumps with a thermal output of >20MW up to 50+ MW per system unit.

Keywords: Mega Heat Pump, Grid Stabilization, Grid Balancing, Decarbonization of Heat & Cold Supply

Aadit is a research associate and PhD candidate at the Energy Economics Group (EEG), TU Wien. His research focus at EEG is on strategic heating and cooling planning aimed at energy efficiency and sectoral decarbonization.

Assessing the Economic Viability of Thermal Source Networks: The Role of Temperature Sensitivities

1) Aadit Malla, TU Wien 2) Mostafa Fallahnejad, TU Wien 3) Lukas Kranzl, TU Wien

Aadit Malla (presenter) malla@eeg.tuwien.ac.at

Thermal source networks (TSN) utilize ambient temperatures to provide combined heating and cooling, thereby enhancing the efficiency of the overall system and facilitating the integration of local renewable energy sources. Our research aims to identify priority zones where the development of TSNs is economically viable and can significantly improve sustainability in the supply of heating and cooling. For the implementation of a TSN, a change to existing technology would be the need to switch to lower grid temperatures. This could either mean a reduction in supply or operating temperatures. This change in temperature has a direct impact on the costs of either the initial investment or the operation.

With this research, we analyze the effect of variations in the temperature, either supply or operational, on the overall economics of the network for heating, as well as observe the extent to which it can fit the cooling cycle. In doing so, we identify fitting scenarios where the temperature ranges and system sizes permit the possibility of combined heating and cooling use of the same grid. We perform a techno-economic assessment to analyze the feasibility of the network under different temperature sensitivities. The model is unrestricted by geography; however, for this work, we will perform an analysis of a few test cities. For this, we start with the identification of areas, based on demand, where district heating networks under conventional supply and operating temperatures are feasible, modeling a 3rd generation supply model. Thereon, we test different sensitivities on how this feasibility for the heating network changes with the change in the temperature of the grid. We further assess the extent of the improvement in technological feasibility, including cooling demand into the assessment and model TSNs, and identify the impact on the overall costs of such systems.

The results of the study provide identified locations where TSNs are feasible under different temperature sensitivities, including the demand coverage, pipe sizing of the network, and the tentative costs associated with the network development.

Keywords: Thermal Source Networks, Ambient Temperature, Heating, Cooling,
Techno-economic feasibility

Giulia Mancò is a PhD student at the Energy Department of the Politecnico di Torino. Her research area is the optimisation of multi-energy systems. Her current work focuses on simulation and optimisation for the integration of thermal prosumers in district heating networks.

Design optimization for solar thermal prosumers in district heating networks

Giulia Mancò, Elisa Guelpa, Vittorio Verda. Politecnico di Torino

Giulia Manco' (presenter) giulia.manco@polito.it

The European Directive has set an overall binding target for the Union: to increase the share of renewable energy in the district heating and cooling sector to nearly 48% by 2030. Achieving this target requires significant changes to existing district heating networks, which have historically relied on large centralized heat production units fuelled by fossil fuels. A transition from centralized to distributed generation is imperative, mainly due to the lower energy density of renewable sources. Because of this, interest in thermal prosuming (i.e. an entity that is both a producer and a consumer) has significantly grown in recent years. While the concept of prosuming is well established in the electricity sector, its adoption in the district heating sector is still evolving. Thermal prosumers offer great opportunities both for both the users and the district heating operators. For the former because of the integration of renewable energy sources in the heat production, for the latter because of the possibility to sell the production surplus to the network at any time when there is no thermal demand. On the other hand, these opportunities are counterbalanced by challenges and additional constraints needed to optimally integrate these entities into the thermal network, especially in the system design phase and in the decision-making process. For example, an additional variable is the temperature at which the hot water should be produced, based on various factors such as the operating parameters of the network and the temperature level required by the downstream users. In this context, solar energy technologies are often the subject of such analyses, as they are more likely to be installed in urban areas. This study presents a synthesis and design optimization for solar thermal prosumers in district heating networks. The optimization procedure determines the size of the components, taking into account the temperature of the produced water and, consequently, the operation of the bi-directional substation. Different configurations composed of renewable technologies such as solar thermal, photovoltaic panels, heat pumps and thermal storage on the prosumer side are studied and compared with the aim of improving the decarbonization of the district heating sector.

Keywords: Prosumer, District Heating, Optimization, Renewables

Catarina is a Senior Research Fellow at London South Bank University with 17 years' experience working on research projects in the areas of district heating/cooling and refrigeration.

A district heating network with heat recovery from waste water treatment plant

Ana Catarina Marques, London South Bank University, Philip Jones, Building Low Carbon Solutions, Chris Dunham, Carbon Descent Projects, Henrique Lagoeiro, London South Bank University, Graeme Maidment, London South Bank University

Ana Catarina Marques (presenter) catarina.marques@lsbu.ac.uk

This paper presents the results of a feasibility study for a district heating network in an urban area in West Yorkshire, UK. The network design included heat recovery from a waste water treatment plant with 101 GWh/yr of heat available. The network would be built in five phases connecting 4,421 new homes, an enterprise zone and existing homes in the city centre. The CAPEX for the scheme is estimated at £72m (€89m) with the main heat network piping and heat interface units accounting for 52% of the total network costs. The techno-economic model shows an internal rate of return (IRR) of -0.1% over a 40-year period indicating that additional connections are required to obtain a positive IIR, however there are significant carbon savings of up to 1,271 tonnes of CO_2 per year over a counterfactual of gas boilers in existing buildings and individual air source heat pumps in new buildings.

Keywords: district heating, waste water treatment, recoverable heat

Nicolas Oliver Marx, a research engineer at the Austrian Institute of Technology since 2021, works on promoting district heating and sector coupling in Austria and the EU. He develops risk assessment tools for renewable energy integration in heating and advises on industrial decarbonization.

Techno-Economic Feasibility of District and Individual Heating & Cooling Solutions – A Preliminary Assessment of Selected Case Studies

Nicolas Marx, AIT - Austrian Institute of Technology GmbH

Nicolas Oliver Marx (presenter) nicolas.marx@ait.ac.at

Current energy system design practices lack standardisation and transferability. Platform-based design (PBD) approaches, successfully applied in other industries, offer multiple benefits in that regard. By separating functions and design architectures, PBD facilitates the design of Geothermal Optimised Energy Systems (GOES) at the different spatial aggregation levels of urban energy planning. The concept enables the exploration of cost- and emission- optimized design alternatives at different scales and will be applied and validated at various sites and spatial scales, including Vienna. The current implementation of the concept in Vienna includes a city-scale analysis of heating and cooling (H&C) demands, factoring in climate change and building retrofit rates. Additionally, the potential for low carbon heat sources, like geothermal energy, is geo-spatially is modelled. A novel approach combines the developed demand and supply models to pinpoint suitable areas for geothermal utilization, and considers the requirements introduced by relevant stakeholders. The concept further employs techno-economic optimisation of the energy supply, including district heating technologies, and the integration of low-temperature heat sources and prosumers. This contribution describes a rapid assessment methodology to evaluate the techno-economic feasibility of connecting buildings to existing district heating (DH) networks, 5th generation district H&C (5GDHC) solutions or the installation of individual H&C solutions within district scale case studies. Using only a few relevant parameters (H&C demand, heat supply from geothermal, storage potential, average energy price etc.), the selected district will be modelled on a seasonal level. Together with the energy planning department of Vienna, a concrete case study will be selected at district level. The selection criteria will reflect the immediate planning needs of the city, and the local conditions for heat supply solutions and technology potentials. This contribution will compare first case studies for DH, 5GDHC and individual H&C solutions on the basis of economic parameters (e.g. net present value (NPV)) to provide a better initial indication for promising technologies in the early planning stages when little data is available.

Keywords: District heating and cooling, techno-economic evaluation, Urban energy planning, 4th generation (4GDH), 5th generation (5GDHC), low-temperature networks, Geothermal energy

Brian Vad Mathiesen is Professor in Energy Planning and holds a PhD in fuel cells and electrolysers in future energy systems. His research focuses on technological and socioeconomic transitions to renewables, energy storage, the design of 100% renewable energy systems and energy planning.

Heat Roadmap Europe: Electrification versus low temperature district heating for heating buildings

Brian Vad Mathiesen, Jelena Nikolic, Alisson Aparecido Vitoriano Julio, Enric Gonzalez Gonzalo, Jakob Zinck Thellufsen

Aalborg University

Brian Vad Mathiesen (presenter) bvm@plan.aau.dk

The challenges for the decarbonisation of European building sector are vast. While the amount of waste heat sources is significant, the implementation of infrastructure requires local planning, regulatory changes, and financial mechanism suitable for critical infrastructure. To ensure that the electrification of heating is not narrowly focused on individual heat pumps, it is crucial to adopt a comprehensive approach towards heating and heat planning. This study presents two potential scenarios for the EU27 region, each with a different focus. One scenario centers around further electrification, while other highlight district heating coverage for approximately half of the buildings using different untapped heat sources. Both scenarios include ambitious heat savings in buildings. In the scenario of electrification, an increase in demand for renewable energy sources is expected, particularly wind energy, which is more prevalent during the winter season. It also requires however rather large increases in the amount of power plants due to the distribution of the heat demands over the year, although the vast heat savings help to decrease the needed power plant capacities. On the other hand, an increase in the market share of district heating from the current 13 percent to about 50 percent can increase the use of waste heat sources. With energy efficient buildings, more low-temperature heat sources can be used than in today's buildings. This requires an expansion of district heating in urban areas. The district heating scenarios show a better overall economy due to lower need for wind power, lower demand for bioenergy as well as lower costs of the heating systems compared to the scenarios with expansion of electric grids and individual heat pumps.

Keywords: District heating, renewable energy systems, smart energy systems, waste heat, 4DGH, heat pumps, geothermal, solar thermal, energy storage, thermal storage, energy efficiency, buildings

Daniel Muschick is 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

Implementation results from an optimization-based, predictive supervisory controller for a district heating network in Austria

Daniel Muschick & Valentin Kaisermayer & Markus Gölles, BEST - Bioenergy and Sustainable Technologies GmbH
Martin Koren & Wolfgang Rosegger, Schneid Gesellschaft m.b.H.
Karl Pfiel, Ing. Karl Pfiel GmbH
Harald Kaufmann, n.nahwaerme.at Energiecontracting GmbH

Daniel Muschick (presenter) daniel.muschick@best-research.eu

The increasing complexity of integrated energy systems considering heating, cooling and electricity at the same time and integrating renewable energy sources requires intelligent supervisory control strategies. These strategies must be able to handle forecasts of renewable energy production, energy demand and electricity prices and must coordinate production, storage and demand to optimally utilize all available flexibilities.

We will present a smart predictive control algorithm based on mixed-integer linear programming that was extended and implemented for the heating network of Reidling, Austria. Despite being small in size, the network presents several challenges for a supervisory controller, including the use of waste heat from biogas CHPs, unit commitment, dispatching and the management of two separate feed-in stations with storage. To consider heat transport and different temperature levels from different heat sources while still relying on linear models, the controller uses a multi-temperature method representing variable temperatures as a mixed mass flow of water at discrete, fixed temperatures. This also allows a more precise representation of the state of charge of the two sensible heat buffers. Stochastic optimization based on probabilistic forecasts is employed to provide robustness, and fall-back solutions were implemented as a safety measure in case of internet problems or issues with the optimization.

The controller implemented has been operational since mid-December 2023. We will present our experiences from the operation and will highlight practical issues that are often overlooked in simulation studies. We will compare the achieved results with results from the previous year where the standard control method was used, and showcase how the supervisory controller could also be used to support the CHP operator in day-ahead market participation by suggesting optimal schedules.

Acknowledgment: The research leading to these results has received funding from the COMET Programme under Grant No. 869341 and the Austrian Climate and Energy Fund under Grant No. FO999888458 as well as the “Zukunftsfonds Steiermark” under Grant No. 1406.

Keywords: integrated energy systems, smart control, district heating, implementation, predictive, MILP

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.

MODERN BENCHMARK OF ADAPTIVE THERMAL SOURCE NETWORK AT AN INDUSTRIAL SITE – THE INCAMPUS

Simon Müller, University of Applied Sciences Ingolstadt (Germany), Christoph Bott, Martin Luther University Halle-Wittenberg (Germany), David Schmitt, University of Applied Sciences Ingolstadt (Germany), Markus Faigl, AUDI AG (Germany), Klaus Göttl, AUDI AG (Germany), Rainer Strobel, Planungsgruppe M+M AG (Germany), Peter Bayer, Martin Luther University Halle-Wittenberg (Germany), Tobias Schrag, University of Applied Sciences Ingolstadt (Germany).

Simon Müller (presenter) simon.mueller@thi.de

This contribution presents an in-depth technical analysis and evaluation of a thermal source network (TSN) with distributed heat pumps implemented at an industrial site in Ingolstadt, Germany. It addresses the shift towards renewable and smart energy systems, analyzing both opportunities and challenges in adopting TSN technology in an industrial setting. Utilizing a mixed-method approach, including data analysis, and simulation, we assess in particular the system's design, implementation, and operational dynamics.
A central part of this study is the presentation of the incampus's chosen design as a shared thermal energy network, sprawling over a 75-hectare industrial domain. The evolving TSN infrastructure enables a sophisticated integration of energy flows, servicing up to 70 buildings in the projected final state of expansion. The design accommodates a substantial annual heating demand of approximately 17 GWh and a cooling demand of around 35 GWh. The network's reach is underscored by its 9,100 meters of piping, featuring diameters of up to 800 mm, illustrating the system's capacity and scale.
A key characteristic of this system are its diverse thermal energy sources, including 1.8 MW of waste heat from a data center, supplemented by the potential harnessing of up to 10 MW from the Danube River. Complementing these sources, the system's storage capacities play a pivotal role in energy demand balancing. The network itself acts as a primary thermal buffer with approximately 2,200 m^3 of water. Thermal storage is also achieved with the integration of firefighting water tanks providing an additional 3,150 m^3 (about 130 MWh). Finally, the inclusion of seasonal thermal energy storages, repurposed from existing infrastructure, with a capacity of roughly 30,000 m^3 or up to 428 MWh of thermal energy, enhances the network's long-term flexibility and efficiency.
While thermal source networks enable enhanced energy efficiency, operational flexibility, and reduced carbon emissions, they also face significant hurdles, including their novel technology,

limited operational data, and concerns about scalability. This paper positions the Ingolstadt IN-Campus project as a forward-looking example that navigates these challenges effectively.

Keywords: Thermal source network, 4GDHC, CO2-neutral industry, renewable energy, energy efficiency, Ingolstadt case study

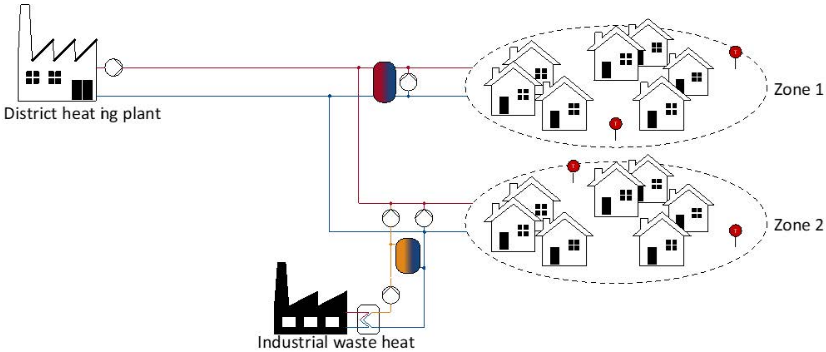
Lars Krusborg Jakobsen has worked within the district heating sector for over 25 years, always with a focus on optimizing and developing solutions to ensure the best possible performance E2E from both an energy efficiency and environmental perspective.

Intelligent heat management and distribution are crucial in a district heating network

Lars Krusborg Jakobsen and Anders Nielsen (presenter), Grundfos A/S

Intelligent heat management and distribution are crucial in a district heating network.
Integrating low-temperature renewable energy sources into a district heating network requires an optimized and controlled energy distribution, achieved through flexible and decentralized system integration.
Locally lowering temperatures in specific areas or zones to match demand is straightforward with the use of mixing loops for temperature control. However, temperature reduction must be accompanied by local pressure control to optimize the entire network and incorporate energy sources from various locations where they are available.
The key to success lies in digitalization and the use of real-time data, integrated with pump controls for distribution in a zoned network, which is the essence of Grundfos' iGRID concept.
Real-time network monitoring, along with the ability to adjust flow and pressure according to varying demands over time, enables the optimization of pump operations. The results include significantly reduced heat losses, CO_2 savings, optimized energy production, energy savings in pump operations, increased capacity, reduced pressure in the existing network, and the potential to expand the network by integrating new consumers—all while maintaining comfort for the end-users.
A true end-to-end approach, considering both supply and return temperatures and pressures, is essential for a fully optimized network that enhances overall performance, efficiency, and capacity.
Distribution in a zoned network with integration of decentralized renewable energy sources implemented by use of digitalization, AI, and insights into consumers' heat installations and performance will play a vital role in delivering the energy ecosystem of tomorrow.

Keywords: Integrating low-temperature renewable energy, distribution in a zoned network, digitalization, iGRID, heat loss reduction, DH network optimization, decentralized system integration


District heat ing plant
Zone 1
Zone 2
Industrial waste heat

Her scientific capability is proven with more than 50 articles published in scientific journals. She has wide experience in energy system-related research due to participation in several international and national projects and contract works.

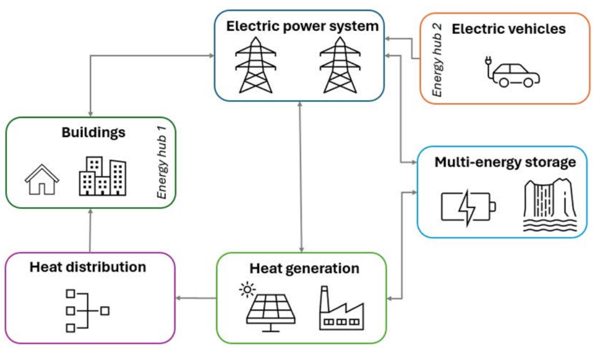
District heating resilience under high energy price shocks

Authors: Ieva Pakere, Vivita Priedniece, Guntars Krīgers, Dagnija Blumberga;
Affiliation: Institute of Energy Systems and Environment, Riga Technical University

Ieva Pakere (presenter) ieva.pakere@rtu.lv

Maintaining sustainable heating price levels is a crucial aspect of the future development of district heating systems to provide a carbon-neutral and affordable heat supply. The recent extreme resource price increase during the energy crisis in 2022/2023 has raised an important question on how to increase the overall resilience of energy systems. This research particularly focuses on the ability of district heating systems to maintain affordable heat price levels under significantly increased resource prices. The simple definition of resilience has been attributed to the ability of a system to recover from adversity.
The research analyses 10 different district heating systems in Latvia with various heat production technologies and fuel mixes used and their heat price changes from 2020 to 2023. The research identifies the resilience curves of each district heating system and compares their ability to recover after the disruption. A novel resilience capacity quantification methodology has been applied. Assessment allows us to identify and quantify which heat production technologies reduce the recovery time and increase the overall economic performance of district heating under extreme price fluctuation. Additionally, qualitative assessments have been performed through interviews with district heating operators to evaluate the measures which have been performed to maintain the normal operation of heat supply after extreme price shocks.

Keywords: District heating resilience, energy securtiy, renewable energy, energy prices



Nirav is a research associate and PhD candidate at the Energy Economics Group (EEG) TU Wien. He holds a master's degree in Renewable Energy Engineering and Management from the University of Freiburg (Germany).

Optimizing District Heating Supply for Positive Energy Districts

1) Nirav Patel, TU Wien. 2) Ali Kök, TU Wie. 3) Lukas Kranzl, TU Wien. 4) Sebastian Zwickl-Bernhard, TU Wien

Nirav Patel (presenter) patel@eeg.tuwien.ac.at

Positive Energy Districts (PEDs) aim to generate more energy than they consume by leveraging renewable energy sources (RES) and innovative energy systems. These districts represent a transformative urban development approach that prioritizes sustainability, resilience, and carbon neutrality. A key component in achieving PED objectives can be district heating. However, existing district heating networks often rely on fossil fuels, thus not contributing to PED targets. The research aims to understand how cost-minimal investment portfolios in district heating supply change when considering PED constraints.

The study addresses a main research objective: identifying the cost-optimal portfolios for decarbonized district heating generation in PEDs, considering locally available renewable energy and excess heat potential.

The methodology involves modeling the district heating supply mix by optimizing supply investment and dispatch, integrating renewable energy sources and excess heat, and incorporating PED constraints into the optimization procedure. The model is designed to run on synthesized cases, which vary in terms of local energy resources. The Hotmaps district heating supply investment and dispatch models are expanded for this purpose, ensuring a net positive balance on an annual level while minimizing the total cost of the district heating supply.

The expected results include the identification of a cost-minimal technology portfolio, such as the use of heat pumps and thermal storage, to minimize carbon emissions while meeting heating demands in PEDs. The study will provide insights into the technology shift when integrating constraints specific to PEDs into the district heating supply investment and dispatch model. In conclusion, the study is expected to offer important perspectives on the planning and enhancing district heating systems in Positive Energy Districts.

Keywords: Positive Energy Districts (PEDs), District Heating (DH), Optimization, Renewable Energy (RE)

Els van der Roest is a researcher turned into a policy maker with a background in energy system modelling and integrated energy systems, now using her knowlegde to work on the municipal heat transition.

Collective or individual heating solutions - the case of Utrecht (NL)

Els van der Roest

Els van der Roest (presenter) els.van.der.roest@utrecht.nl

The municipality of Utrecht, Netherlands, is striving to establish a 100% sustainable heating system. Presently, approximately 30% of the city is served by a district heating network (90˚C), while the other buildings rely on natural gas. A strategy has been devised to decarbonize heat sources across the city-wide district heating system, integrating high-temperature sources such as geothermal energy and biomass, alongside low-temperature sources like thermal energy from waste water and power-to-heat, while considering their implications on the electricity grid.
However, as the district heating network does not encompass all neighborhoods, the development of a sustainable heating system for the entire city is necessary. This investigation evaluates the viability of collective heating systems versus individual heating solutions. An analysis is conducted, employing the societal costs model of the Netherlands Environmental Assessment Agency (Vesta MAIS), and considers for four heating scenarios: 1) city-wide district heating with central sources (70˚C), 2) neighborhood-scale district heating with local sources and heat storage at 70˚C, 3) neighborhood-scale district heating with central heat pumps at 20˚C delivery temperature, and 4) individual air-sourced or ground-sourced heat pumps. The analysis is done for 2050, and includs building insulation and climate change effects on heating demand for the entire city, comprising 165,000 households and 8 million m2 of utility.

Findings indicate that buildings in close proximity to the existing district heating network incur the lowest costs by connecting to the established system. Conversely, for other buildings, societal costs across heating strategies exhibit marginal differences (not exceeding 20%). Thus, additional selection criteria are necessary, of which space requirements emerge as a crucial factor. The study presents an analysis of the space requirements for the four scenarios on the level of the household/building, neighborhood, city, and renewable electricity production. Overall, the study underscores the feasibility of both individual and collective heating systems, emphasizing the growing importance of spatial considerations in determining the most suitable solution.

Keywords: low temperature district heating, thermal energy from waste water, district heating, renewable heat sources, spatial analysis, modelling

She graduated in 2023 at Politecnico di Milano with a master's degree in energy engineering. Now she works at the energy department of Politecnico di Milano, within the research group “Relab”, dealing with district heating and cooling.

A modelling tool for dynamic simulations of a 5th generation district heating and cooling system applied to Italian case studies

Michela Romagnosi, Politecnico di Milano; Alice Dénarié, Politecnico di Milano; Marcello Aprile, Politecnico di Milano; Jacopo Famiglietti, Politecnico di Milano; Giorgio Villa, Politecnico di Milano; Mario Motta, Politecnico di Milano.

Michela Romagnosi (presenter) michela.romagnosi@polimi.it

The work describes a new model for dynamic simulations of 5th generation district heating and cooling networks and its first applications to some Italian districts as case studies. The model is conceived to simulate the performances of an entire district, including the buildings with internal terminal units, with the aim of reducing its environmental impact. The model receives as first inputs the geometry of buildings inside the district directly through a GIS map processing, and the building envelope properties. Then, by considering hourly schedules and specific values of ventilation, occupancy, domestic hot water demand and appliances, it calculates the theoretical demand for each building unit following the standard EN ISO 52016:2017. By including efficiencies of internal terminal units and distribution system, the buildings energy loads are evaluated. Substations are consequently designed with a heat pump for the space heating demand and a reversible heat pump for the space cooling and the heating of the domestic hot water tanks. The low temperature of the 5th generation bidirectional network is maintained thanks to a main energy centre with a balancing task: a heat pump heats up the network in cold periods and a groundwater heat exchanger discharges the heat directly into the ground when dissipation is required. The operation of generation systems is optimized to reduce energy consumption. The optimization is performed using MILP in Gurobi. Finally, the LCA approach is used to show environmental impact in terms of CO2eq emissions.

The model is applied to different case studies in Italy, evaluating the overall thermal and electrical consumption of the district and the possibility of self-consumption of electricity produced on site by photovoltaics. In this type of bidirectional networks, exploiting the synergy and the self-balancing between cold and heat loads, the ratio between heating and cooling needs and the shape of their profiles is of particular interest.

Project funded under the National Recovery and Resilience Plan (NRRP); Project title “Network 4 Energy Sustainable Transition – NEST”.

Keywords: 5th generation district heating and cooling, MILP, dynamic simulation model, low-temperature district heating and cooling, Positive Energy Districts

Dr. Kobus van Rooyen is currently a Medior 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.

Integral Heating and Cooling Optimization; Design and Operation

Femke Janssen, Jim Rojer, Kobus van Rooyen, TNO.

Kobus van Rooyen (presenter) kobus.vanrooyen@tno.nl

The need for cooling will increase towards 2050 as the global temperature is predicted to rise. At the same time the number of district heating networks (DHN) is increasing as we are transferring to more sustainable sources for heating. Future designs of DHNs should account for these developments and thus include options for combined heating and cooling in the decision making.

An open-source Mixed Integer Linear Problem framework is developed for design and operational optimization of energy systems; Multi Energy Systems Integral Design and Operation (MESIDO). MESIDO enables an integral optimization which includes sizing of assets, determining source and storage allocation and sizing of transport pipes. This is achieved by minimizing the Total Cost of Ownership of the system while ensuring the technical feasibility. This work focuses on the inclusion of cooling demand and cooling asset, to allow for the design and operational optimization of 5th Generation District Heating and Cooling Networks (5GDHC).

5GDHC networks operate at lower temperatures and have the ability to use sustainable energy sources like aquathermal energy or residual heat from datacentres. Combining such sources with Low Temperature Aquifer Thermal Energy Storage (LT-ATES), at temperatures up to 25°C for cold and heat storage, can improve the business case significantly. The reason being, when the heat pump is used in the winter, both hot and cold water is produced simultaneously. The warm water from the aquathermal source or LT-ATES, is upgraded for heating purposes. However, during summer the LT-ATES can be charged with heat originating from the aquathermal source when there is an imbalance between the seasonal cooling and heating demand. Furthermore the operation of the heat pumps is also considered as a result of fluctuating price profiles or limiting electricity grid capacities.

A combined heating and cooling network could be economically beneficial over a separate DHN and individual cooling solutions depending on several factors. These include factors like the heating and cooling demands of a specific area and the availability of low temperature energy sources in lieu of high temperature renewable heat sources.

Keywords: 5GDHC, 5th Generation District Heating and Cooling Networks, MILP, asset sizing, operational optimization, aquathermal energy, Low Temperature Aquifer Thermal Energy Storage, TCO, DHN.

Christina Rosan, MCP, Ph.D., is an Associate Professor in Geography, Environment, and Urban Studies Department at Temple University. She is particularly interested in how we make cities more sustainable and just.

How Can District-Wide Heat Pumps be used to meet Climate and Equity Goals in U.S. Cities? Translating Lessons from Europe

Christina Rosan, Temple University

Christina Rosan (presenter) christina.rosan@temple.edu

European cities have innovated the use of District Wide Heat Pumps. U.S. cities are interested in learning from the European experience, but we have different policy and governance challenges that may make it difficult to translate European ideas to U.S. cities. This research examines the current energy and climate justice challenges in U.S. cities with the goal of identifying ways that lessons from the European experience can be adapted to the U.S. context. The presentation reports on initial findings from the National Science Foundation PIRE Project: Building Decarbonization via AI-empowered District Heat Pump Systems.

Keywords: This research examines the current energy and justice challenges in U.S. cities with the goal of identifying ways that the European experience can be adapted to the U.S. context.

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

Aftercooling concept for 4th generation district heating substations

Jan Eric Thorsen Danfoss, Denmark
Oddgeir Gudmundsson, Danfoss, Denmark
Michele Tunzi, Technical University of Denmark

Jan Eric Thorsen (presenter) jet@danfoss.com

In light of the continuous requirements for increased energy efficiency and renewable-source utilization, the district heating (DH) supply temperature will inevitably be reduced where possible. A low district heating return temperature is necessary to realize this future trend.
A common bottleneck in lowering DH return temperatures are multi-apartment buildings operating with domestic hot water (DHW) circulation loops.
To address this challenge, an innovative design was studied for DHW substations for large multi-apartment buildings. For the new design, the DHW and DHW circulation loop are decoupled, each utilizing a dedicated heat exchanger for its specific purpose. This design enables aftercooling the high DH return temperature from the DHW circulation by channeling of the return water through the space heating heat exchanger.
A number of building case examples are presented in this study, as well as various yearly heat demand profiles.
The DH return temperature reduction potentials are significant and in the range of 4-8°C for the 4G temperature profiles.

Keywords: Low-temperature district heating, 4th Generation district heating, Space heating; Domestic hot water systems, Domestic hot water circulation, District heating return temperature

Ulrich Trabert is a PhD candidate at the Institute of Thermal Engineering at the University of Kassel, Germany. His current research comprises data analysis and modelling of district heating systems with a focus on optimised control for large district heating substations.

Optimised Operation of Industrial Prosumers in District Heating Systems

Ulrich Trabert; University of Kassel, Felix Pag, University of Kassel; Janybek Orozaliev, University of Kassel; Ulrike Jordan, University of Kassel; Klaus Vajen, University of Kassel

Ulrich Trabert (presenter) trabert@uni-kassel.de

The decarbonisation of urban district heating (DH) systems requires increased heating grid efficiency combined with the development of new heat sources such as renewables and waste heat. Industrial sites have the potential to provide waste heat, but also flexibility through their own heat supply systems and storage. However, the impact on the overall DH system due to their size is a challenge for developing sustainable business cases for DH utilities.
Therefore, this work investigates the integration of a heat pump combined with a cold and a hot water thermal energy storage in an existing DH substation to utilise the low temperature waste heat of an industrial site in a German city. The substation is already equipped with a feed-in pumping station, so that the recovered waste heat can either be used by the industrial site or fed back into the supply line of the DH grid, turning the site into a prosumer of the DH system. The available waste heat is estimated to exceed the heat demand of the industrial site in summer, while additional heat from the DH grid is required in winter.
A thermal model of the prosumer is created using the TRNSYS simulation software. The model for the substation heat exchangers is validated with measured data and extended to include the heat pump and thermal storage as new components.
The simulation model is used to develop optimised operating strategies for the prosumer substation. The thermal storages enable flexible operation, allowing optimisation objectives for the individual substation that can be beneficial to the DH system. These include integration of the DH utility’s heat production facilities to minimise the use of heat-only boilers, but also electricity price-driven operation to minimise electricity costs and maximise the use of renewable electricity. It is analysed how increased flexibility through larger components helps to achieve the optimisation objectives.
Finally, the impact of the prosumer substation on the DH system is evaluated based on measured operational data (heat loads, flows, temperatures) at several locations in the grid. The evaluation criteria include the supply and return temperature and heat loss in the relevant section of the DH grid, as well as the efficiency of the central heat production facilities.

Keywords: District Heating Prosumer, Waste Heat, Industry, Heat Pump, Demand Side Management

Carles Ribas studied industrial engineering, specialization in thermal energy, at the Polytechnic University of Catalonia in Spain. He works since 2017 as a researcher at AEE INTEC in Austria. He specializes in analyzing and modeling thermal energy systems utilizing Modelica.

Enabling Return Temperature Reduction in Austrian District Heating System: Absorption Heat Exchanger Integration and Impact Analysis

Carles Ribas Tugores, AEE INTEC. Carina Seidnitzer-Gallien, AEE INTEC. Gerald Zotter, ecop Technologies GmbH

Carles Ribas Tugores (presenter) c.ribastugores@aee.at

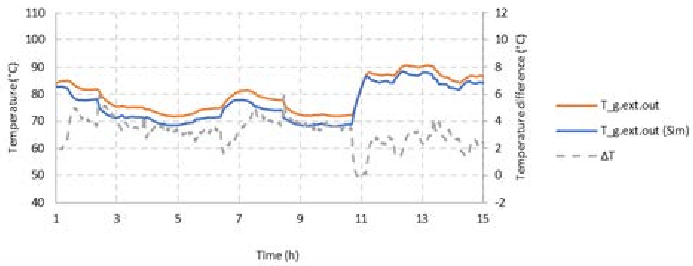
Austria's DH systems encounter difficulties in its decarbonization. Among these, the presence of high return temperatures that difficult the integration of renewable energy sources like solar thermal and waste heat. Furthermore, these high return temperatures limit the grid's heat transport capacity [2]. Return temperatures at the supply side strongly dependent on temperatures at the consumer side, being a challenge to intervene on. Research shows that the use of an absorption heat exchanger (AHE) has great potential to reduce the return line temperature [1].

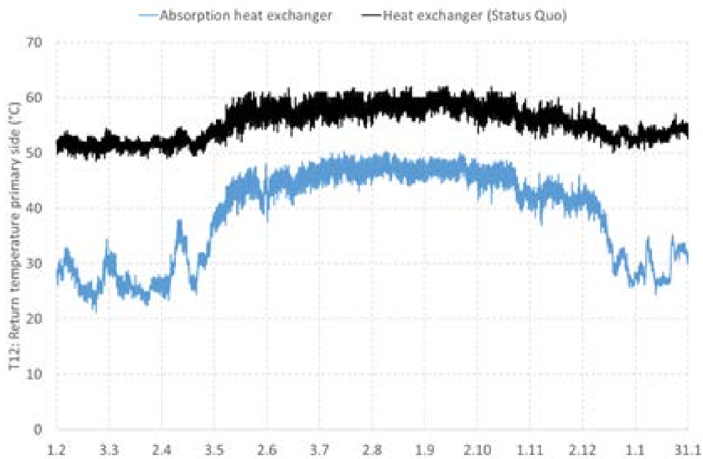
This study investigates the application of an AHE in an Austrian DH system and estimates its annual impact on the reduction of the return temperature by a dynamic simulation. Experiments have been carried out at AEE INTEC to investigate the operation of a 10 kW H2O/LiBr AHE [2]. As a follow up, an AHE model has been implemented in Modelica and validated on those experimental results. External temperatures of the AHE are used to evaluate the accuracy of the model. The highest deviations are observed at the generator outlet with a deviation between 0 to 6°C (3,2°C / 4% on average).

The model is scaled up to a 2.8 MW AHE to match the size of the substation under consideration. Reference values for the upscaling has been provided by the technology provider StepsAhead. The model presented in this work shows a slightly lower subcooling capacity in comparison to the reference values. The model is applied to analyze a substation between the primary and secondary grid, focusing on an older grid operating at high primary supply temperatures, based on previous measured data. A reduction of the temperature of the return line of the primary side can be achieved through the whole year and it is estimated to be in the range of 7 to 25 K. This means, a reduction of the mass flow rate at the primary side of a yearly average of about 22% could be achieved.

[1] C. Zhu, et al. A multi-section vertical absorption heat exchanger for district heating systems. Int. Journal of Refrigeration, 2016
[2] G. Zotter, et al. An energetical, exergetical and experimental analysis of an absorption heat exchanger used as transfer substation in an already existing district heating grid. 14th IEA Heat Pump Conference, 2023.

Keywords: Absorption heat exchanger, district heating, heat transfer station, simulation





Michele Tunzi is an Associate Professor at DTU actively working on innovation in 4GDHC systems. This includes investigating innovative solutions for integrating heating, cooling, and electricity networks and the role of digitalization as an enabler for the green transition of the energy sector.

Enhancing Temperature Optimization and Economy in a Danish District Heating Network through Domestic Hot Water Substation Renovation

Michele Tunzi, Qinjiang Yang, Lyse Clara Fournel, Department of Civil and Mechanical Engineering, Technical University of Denmark, Brovej, Building 118, 2800 Kongens Lyngby, Denmark;

Jesper Brink Olesen, EMD International A/S, Niels Jernes Vej 10, 9220, Aalborg Ø, Denmark;

Tom Diget, Viborg Varme, Håndværkervej 6, 8800 Viborg

Michele Tunzi (presenter) mictun@dtu.dk

Large apartment buildings with storage tanks (or heat exchangers) and domestic hot water (DHW) circulation systems are critical for minimizing district heating (DH) network operating temperatures. Investigating the potential for temperature optimization across the entire network, innovative DHW substations with circulation booster units were introduced in a critical mass of buildings within an urban area of Viborg. Results indicate a potential reduction in the supply temperature by 4.6°C and up to 0.43°C for the return temperature. This reduction in network temperatures yields significant financial benefits, including lower heating prices for end-users, alongside improved energy generation and reduced distribution losses for the local municipally-owned DH company. Furthermore, the study evaluates the conventional user-owned business model for the substation and proposes an alternative company-owned model, offering insights into their respective implications for stakeholders.

Keywords: 4GDH, low-temperatures, DHW, renovation

Jelena Ziemele is a senior expert at the Riga Energy Agency with broad experience in thermal engineering. Her professional interests are in energy systems and their transformation into smart energy systems.

Synergies between heat production, distribution, and consumption for decarbonizing strategy of urban district heating system

1) Jelena Ziemele, Riga Governmental City Agency "Riga Energy Agency"; Ilvars Pētersons, JSC "RĪGAS SILTUMS"; Uģis Osis, JSC "RĪGAS SILTUMS"; Ingars Baļčuns, JSC "SMART Consulting"; Ivars Bekmanis, JSC "BEK-KONSULT"; Jānis Ikaunieks, Riga Governmental City Agency "Riga Energy Agency"

Jelena Ziemele (presenter) jelena.ziemele@riga.lv

Achieving climate neutrality in cities is a goal closely related to the decarbonization strategy of urban district heating (DH) systems. This study aims to investigate urban decarbonization strategies and their impact on the share of high-efficiency cogeneration (CHP), RES technologies, and waste heat technologies, as well as to determine the energy efficiency and economic and environmental indicators of decarbonization scenarios. A dynamic model is used to analyse DH systems to characterize the existing and future DH behaviour in a medium-term perspective (2030), considering the interaction between heat production, distribution, and consumption, which are managed by an urban DH operator using a multi-energy platform.
The study examines the role of cogeneration in the future due to the city's decarbonization strategy and considers the need to reduce CO2 emissions and decrease the use of bioenergy resources. The Eisenhower matrix is used for analysing the interconnection between decarbonization measures and their prioritizing. The study examines such questions as the steps required for the development of the transformation strategy, their sequence, and measures, as well as the methodology of their comparison, which is based on scientific knowledge of optimal DH system design and is related to the practical experience of the relevant stakeholders involved in the transformation process.
The strategy includes broader measures to integrate renewable electricity into the DH system, the implementation of storage technologies, and inter-sectoral measures. The research conducted an analysis of energy, economic, environmental, and social indicators to determine indicators for various development scenarios. The elaborated strategy shows an opportunity to reduce CO2 emissions by approximately 50% compared to 2020 and ensure progress toward achieving the climate neutrality goals in the city of Riga.

Keywords: District heating, 4GDH, decarbonisation, energy transition, climate neutrality, techno-economic analysis, building energy efficiency, building renovation

Theda Zoschke has been with Fraunhofer ISE since 2015 in the field of thermal system simulation. In 2022 she started her PhD in the department “Thermohydraulics and District Heating” to investigate model predictive control in heating networks with decentralized producers.

Survey of optimal dispatch methods of decentralised production units in district heating networks: A technical review

Theda Zoschke, Fraunhofer ISE Germany; Christian Wolff, Fraunhofer ISE Germany; Armin Nurkanović, University Freiburg Germany; Axel Oliva, Fraunhofer ISE Germany; Lilli Frison, Fraunhofer ISE Germany; Moritz Diehl, University Freiburg Germany

Theda Zoschke (presenter) theda.zoschke@ise.fraunhofer.de

District heating networks play a major role in defossilization of the heating sector in Europe. They are about to be expanded by developing new areas and consolidating further clients at existing network structures. By that network topology is enlarging and additionally the integration of renewable energies increases complexity due to decentralised feed-in, lowering of the flow temperature and branched network structures. This change makes it more difficult to ensure optimal operation under hydraulic restrictions of the network. This requires complex control algorithms, as simple controls such as low-point control of the differential pressure, temperature control at the heat sources and mass flow control using valves at the consumers are no longer sufficient. Recent research offers a variety of different control approaches for this. These include model predictive control (MPC), multi-agent-based control and demand side management. With MPC in particular, there are various ways of modelling the optimisation problem. Frequently used approaches are linear programming (LP), non-linear programming (NLP), mixed-integer linear programming (MILP) and mixed-integer non-linear programming (MINLP). A relatively new approach is the modelling of the network with physically informed neural networks (PINN). In addition to the problem formulation, measurement data from the operation of the network is required, which flows into the control system as input or is used for load prediction. The approaches must be online-capable, must be able to deal with hydraulic bottlenecks in the network and map production unit behaviour. Due to the large number of different approaches with different advantages and disadvantages, this paper analyses the various control algorithms. Further research questions addressed in current federal R&D project WOpS (FkZ PtJ/BMWK: 03EN3054A-C) are then derived from this.

Keywords: Control, District heating, MILP, MILNP, MPC, PINN, MAS, Dispatch methods, decentralised

DHC+ Platform Special Session: Experiences and outlooks on digitalisation of district heating and cooling

Matteo Pozzi is Partner and CEO of Optit, an Italian company that develops Decision Support Systems for the DIstrict Energy industry. He is also Chair of the DHC+ Platform, Research & Innovation Hub of Euroheat & Power, where he coordinates the working group on digitalisation

Fostering Digitalisation to enhance DHC Systems: progresses and perspectives by the DHC+ platform

Matteo Pozzi - Optit Srl/Chair of DHC+ Platform

Matteo Pozzi (presenter) matteo.pozzi@optit.net

Decarbonisation of the District Heating & Cooling industry implies a significant evolution in the supply side mix, capacity to achieve higher levels of efficiency along all operations and a systemic value chain perspective that engages customers and buildings into a virtuous circle. Integration with the electric system becomes crucial, widening the range of competences required to achieve the desired objectives and the capacity to adapt decisions based on volatile prices and external conditions that cannot always be planned with accuracy.
The need to manage efficiently and effectively this growing complexity is introducing a growing need for digital innovation across the industry and the DHC+ Platform, the research and innovation hub of Euroheat & Power, has revamped in early 2022 a working group on digitalisation of DHC, that had released a position paper in 2019, producing a new report that outlines the current opportunities and challenges, as already reported at the previous SES conference.
While many utilities are actively progressing in a digitalisation pathway, it is undoubtful that this potential is still largely untapped. Our current objective is to really create the conditions to scale up, which requires a marked cultural shift, widening of competences together with increasing consolidation and maturity growth of the solutions that can be provided to DHC utilities. Tangible examples of applied digital innovation are meant to lower the resistance to engage into new ways of leveraging on data, engaging customers and integrating decision making across sectors to achieve tangible benefits, both at design and operations phase. At the same time, one cannot disregard the difficulty to engage in development paths that drag users out of their comfort zone.
We intend to provide an overview of this debate, that involves some of the major utilities, research institution, industrial players and digital solutions providers, and share the initiatives that the DHC+ Platform is proposing to its members and DHC industry stakeholders, aiming to provide DHC utilities and indeed all value chain actors with the competences and resources to really express their full potential in contributing to the decarbonisation of the energy sector.

Keywords: Decarbonization, Decision Support, Digitalisation, Competences, Artificial Intelligence

I'm driven by unlocking the enormous potential of using data-driven solutions. As Head of Business Development at Kamstrup, my focus is on developing data-driven solutions and services that enable utilities to optimise their business and day-to-day operations.

Leveraging End-User Engagement for Enhanced District Heating Systems

Steen Schelle Jensen, Head of Business Development, Kamstrup A/S

Steen Schelle Jensen (presenter)

As district heating systems strive to align with green energy goals, the imperative for end-user engagement emerges as pivotal.

Traditionally, district heating optimization and the journey towards 4th generation low-temperature district heating has focused on production and distribution, overlooking the untapped potential of end-user engagement and the demand side. Reports reveal significant inefficiencies within end-user installations, necessitating proactive measures for optimization. Four concrete tactics are outlined to address this challenge:

Motivation Tariff: Implementing financial incentives to encourage end-users to optimize their heating systems.

Customer Guidance: Leveraging data-driven insights to provide tailored guidance and support to end-users for system optimization.

Heat Installation as a Service: Offering rental units and service agreements to proactively monitor, maintain, and optimize end-user heating installations.

Demand side management: Strategies and measures aimed at efficiently controlling and modifying end-consumers' energy usage patterns within the district heating system

Several case studies from utilities such as DIN Forsyning and Næstved District Heating highlight the efficacy of these tactics in achieving tangible outcomes. Through tailored approaches and innovative digital solutions, utilities have achieved significant reductions in flow and return temperatures, heat loss, and operational costs, underscoring the potential of end-user engagement in district heating optimization.

The path forward entails embracing digital solutions that empower utilities to transcend traditional approaches and unlock the full potential of end-user engagement and demand side management. By leveraging data analytics and innovative tools, utilities can not only enhance

Keywords: Linear Programming, Energy System Modelling, Decarbonization, Building retrofit, District heating, Decentral Energy System

Ard de Reus is Product Market Lead at Gradyent and is epxert in what District Heating and Cooling companies need from digital to decarbonize. He has a background in control engineering with a focus on heating, and has discussed digitalization with 100+ heating companies across Europe.

Real-time dynamic pressure and temperature control of a District Cooling system

Ard de Reus, Product Market Lead, Gradyent (Netherlands)

Ard (presenter) ard@gradyent.ai

A real-time Digital Twin operates and controls a District Cooling network connected to a District Heating network, serving 35 customers with a total yearly consumption of 19 GWh. The cold is provided by absorption and compressor chillers and free cooling from a river close by. In addition to the cost of producing cold, operating network pumps can also be costly due to the high flow required to transport the necessary thermal energy. Balancing costs for both cold production and cold transport is therefore crucial for an efficiently operating district cooling network. To balance this, the Digital Twin is dynamically optimizing the differential pressure in the whole network, in real-time. The live control of a district cooling network is one of the first of real-time digital cloud-based cooling-control technologies available for cooling companies.

As is common, the differential pressure in the network is controlled by a feedback loop, where the differential pressure at the end of the network is used to control the network pumps. However, instead of relying on a single sensor location in the network, the Digital Twin estimates the pressure in the complete network and determines the lowest differential pressure. This value is provided as a setpoint to the integrated controller of the network pumps. Consequently, the Digital Twin can lower the differential pressure in the network by 0.6 bar on average in the analyzed period, reducing the load on the network pumps and saving on operational costs.

In the next steps, the Digital Twin will simultaneously optimize the asset merit order and maximize the use of the free cooling drawn from the river in co-optimization with the temperatures and differential pressures. Prior to the Digital Twin, the network was mainly operated at a constant 5 °C forward temperature. A dynamic control of the supply temperature based on the state of the network turned out to be beneficial in terms of energy efficiency and cost. In winter, this often results in increased supply temperature to increase the COP of the absorption chillers and to enable a more frequent use of free cooling. In summer, the supply temperature could be decreased to reduce the required flow in the network and the active cold production sources.

Keywords: Digital Twin, Real-time, District Cooling, Dynamic, District Heating, Pressure, Absorption, Electricity

Luca Scapino is currently working as a Solutions Lead at Gradyent, driving the integration of Gradyent Digital Twin at several district heating networks. He has been working in the district heating field for few years, and he holds a PhD on energy engineering with a focus on thermal energy storage.

A Real-Case Study on Dynamic Operational Optimization of Thermal Energy Storage with an end-to-end Live Digital Twin

Luca Scapino, Gradyent

Luca Scapino (presenter) luca@gradyent.ai

In modern district heating networks, system flexibility is crucial. To this extent, centralized and decentralized thermal storage play a vital role in district heating and cooling networks. It can decouple energy supply and demand, smooth demand peaks, increase the renewable energy production share, prevent hydraulic bottlenecks, and enhance the profitability of combined heat and power units while ensuring security of supply. From the district heating network operator perspective, controlling and optimizing day-to-day such complex systems continuously in real-time, including dynamics such as heat propagation, requires an accurate virtual representation of the full network.

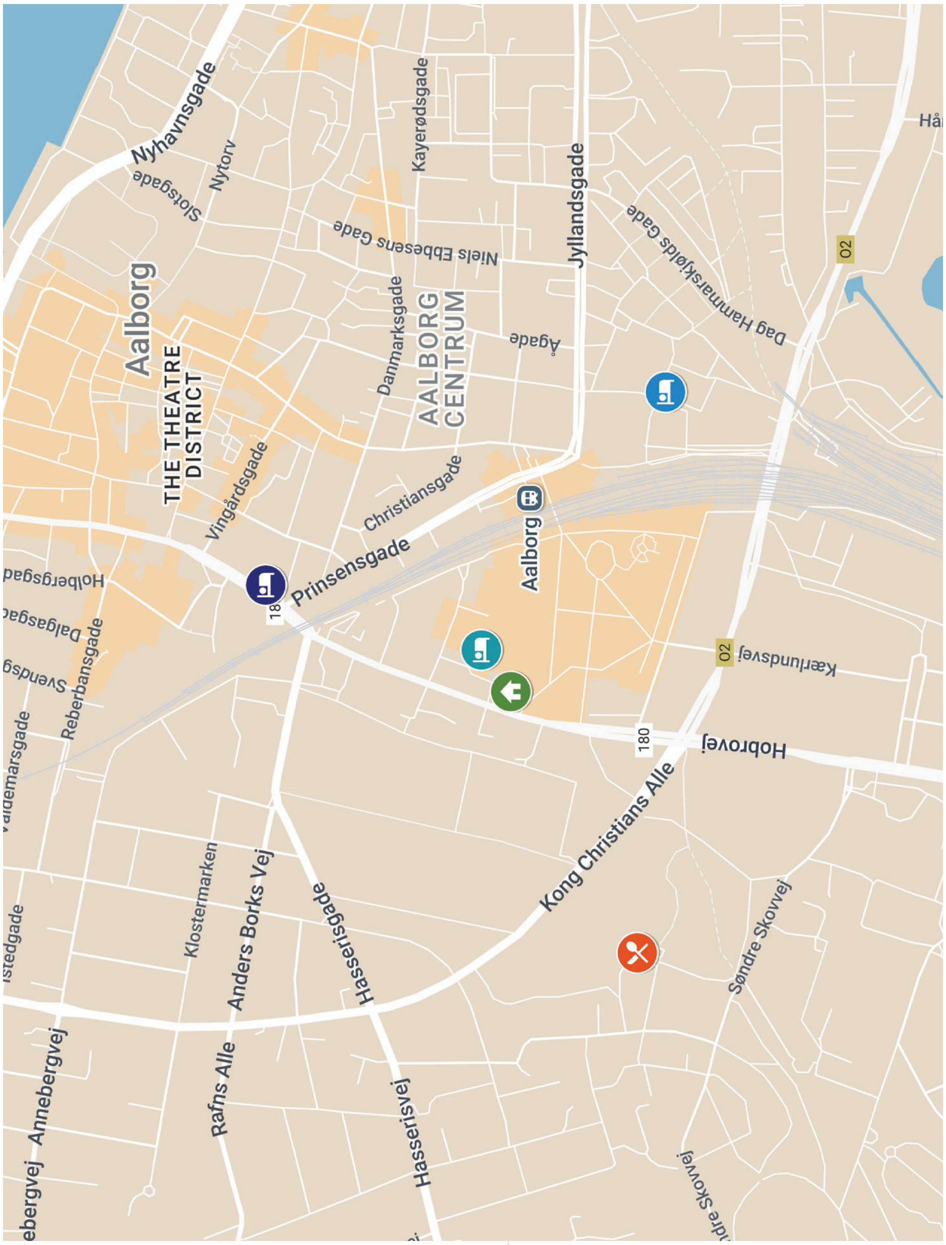
In this work, we present a unique real-case study focused on real-time operational optimization of a network with an existing decentralized thermal storage. The network is located in Southern Europe, and it serves approximately 1700 users. The average network supply temperature was also relatively high and it had potential for reduction with a dynamic optimization approach. Moreover, the main heat source had strict constraints to be respected in terms of ramp rates of power, flow, and supply temperature. An end-to-end Digital Twin of the whole network is built and used to dynamically optimize its operational behavior, considering also the presence of the decentralized thermal storage and the heat propagation dynamics through the network.

The Digital Twin dynamically optimizes, including day-ahead planning, the thermal storage and the network operation as a whole, considering also the network operational constraints and the operating ranges of the heat production units. The optimization objectives were production peaks shaving, minimizing the ramp rate of the main heat production units, and reducing the overall network thermal losses. The full network dynamic optimization led significant benefits: yearly network thermal losses reduction of 4 GWh, estimated cost savings of 120 – 180 k€/year, and up to 700 ton/year of CO_2 emissions avoided from backup gas boilers.

The dynamic nature of the Digital Twin optimization approach was paramount to respect the operational constraints of the heat production units, and to maximize the value of an optimized network operational behavior.

Keywords: district heating, thermal storage, real-time optimization, dynamic operational optimization, digital twin, real-case study, peak shaving, thermal losses reduction, cost savings, emissions reduction

Maps of Aalborg and conference venue



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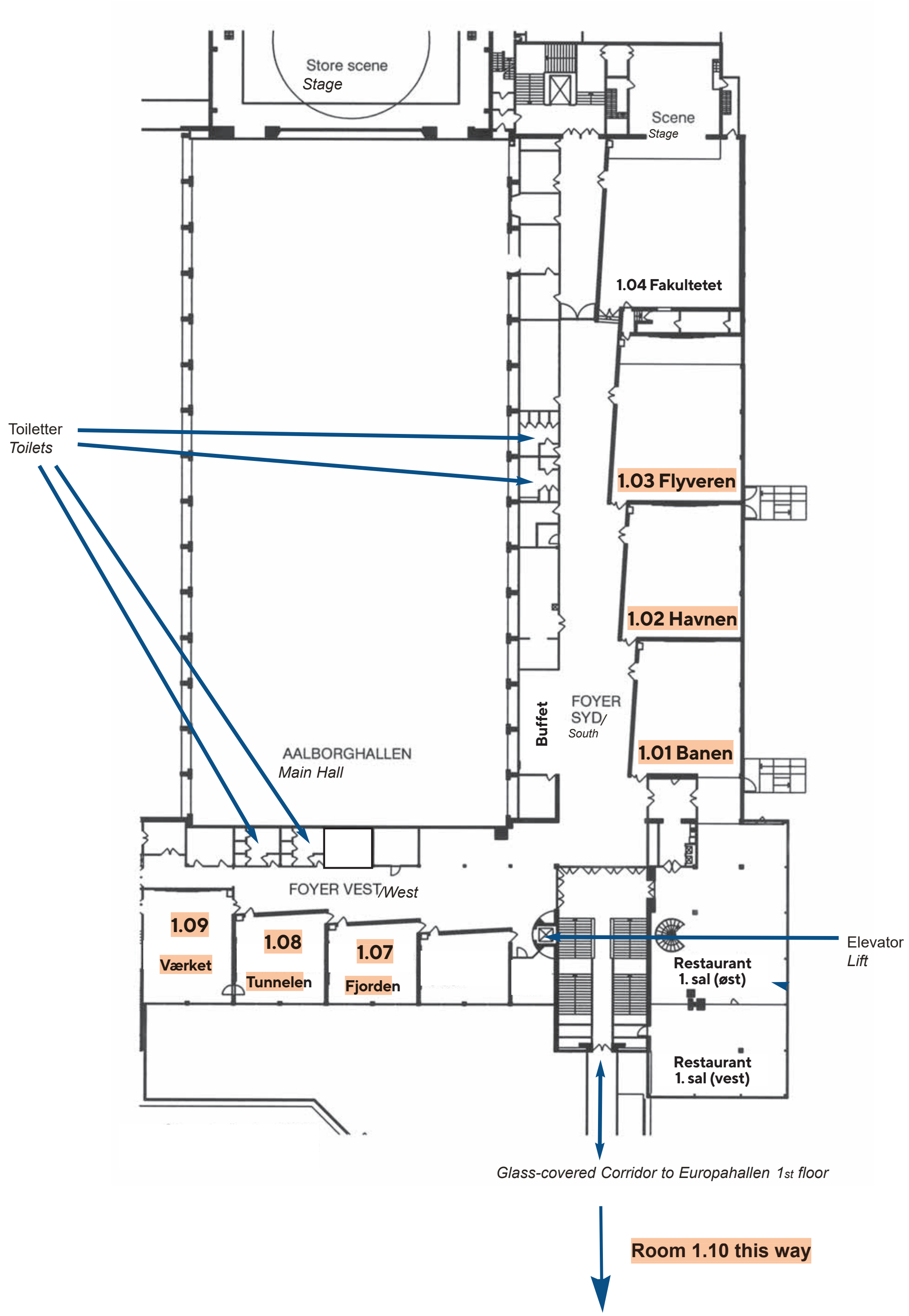

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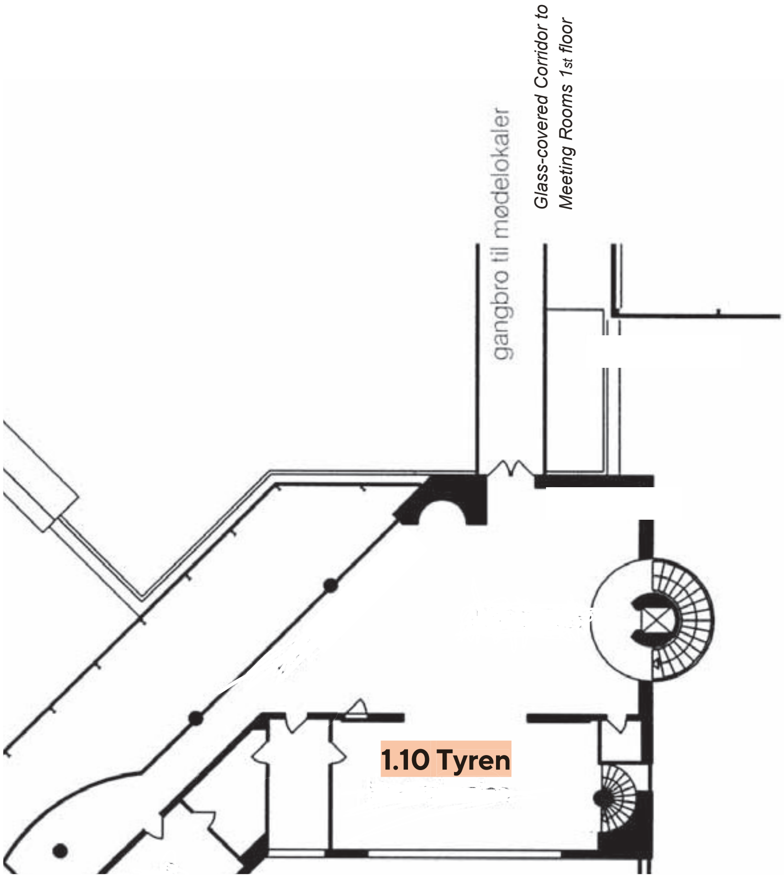

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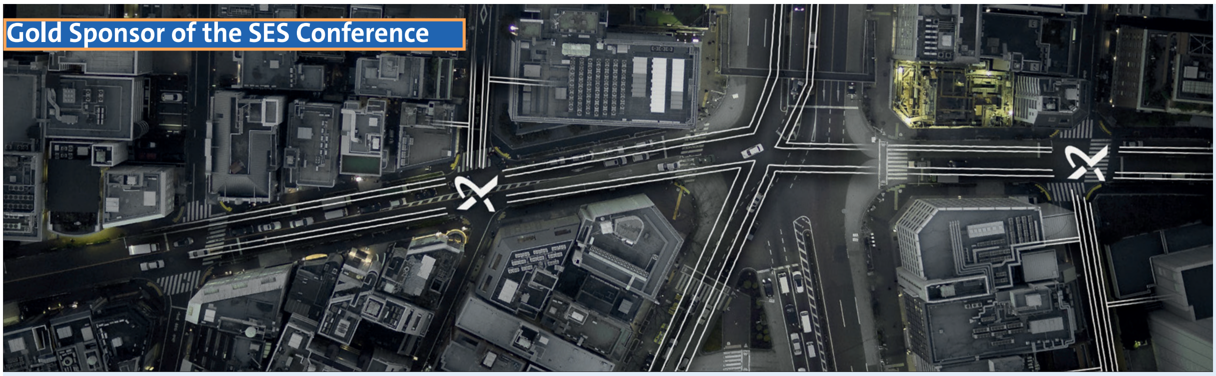

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The researchers making presentations at this year's International conference on Smart Energy Systems will be competing for the Best Presentation Award—one of which is sponsored by Kamstrup. Kamstrup will be donating the Best Presentation Award worth 1000 euro to a presenter with excellent communication skills.

Kamstrup is a leading industry player in district heating and is driven by unlocking the enormous potential of using data-driven solutions and services to connect the entire value chain from production to buildings and end-users … and vice versa. Digitalisation is key to enable integration of renewables and waste heat, to ensure security of supply in an energy efficiency context and not least to make district energy an attractive offering to the end-users.

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Best Presentation Award ceremony 2023. Photo: Peter Kristensen

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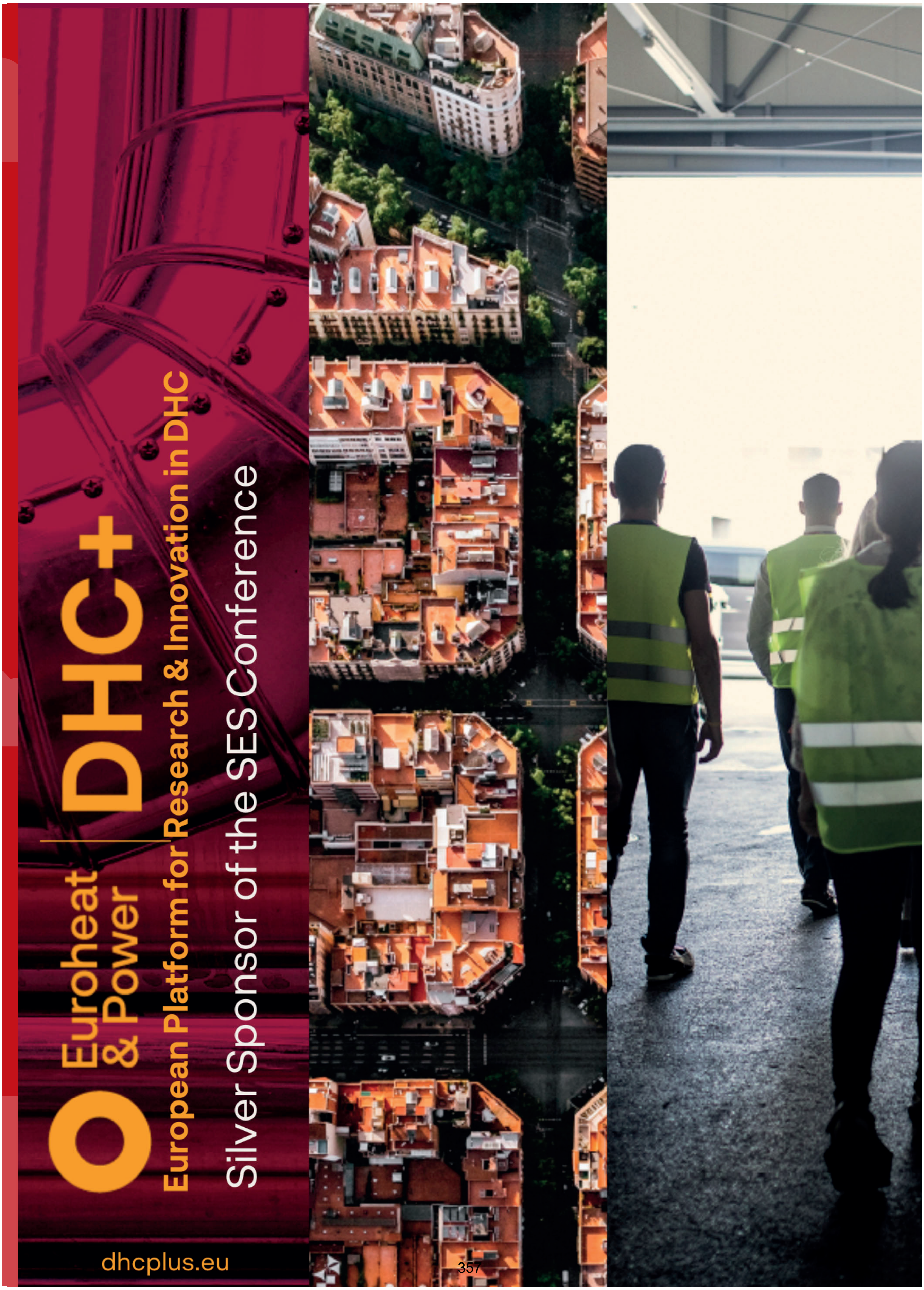
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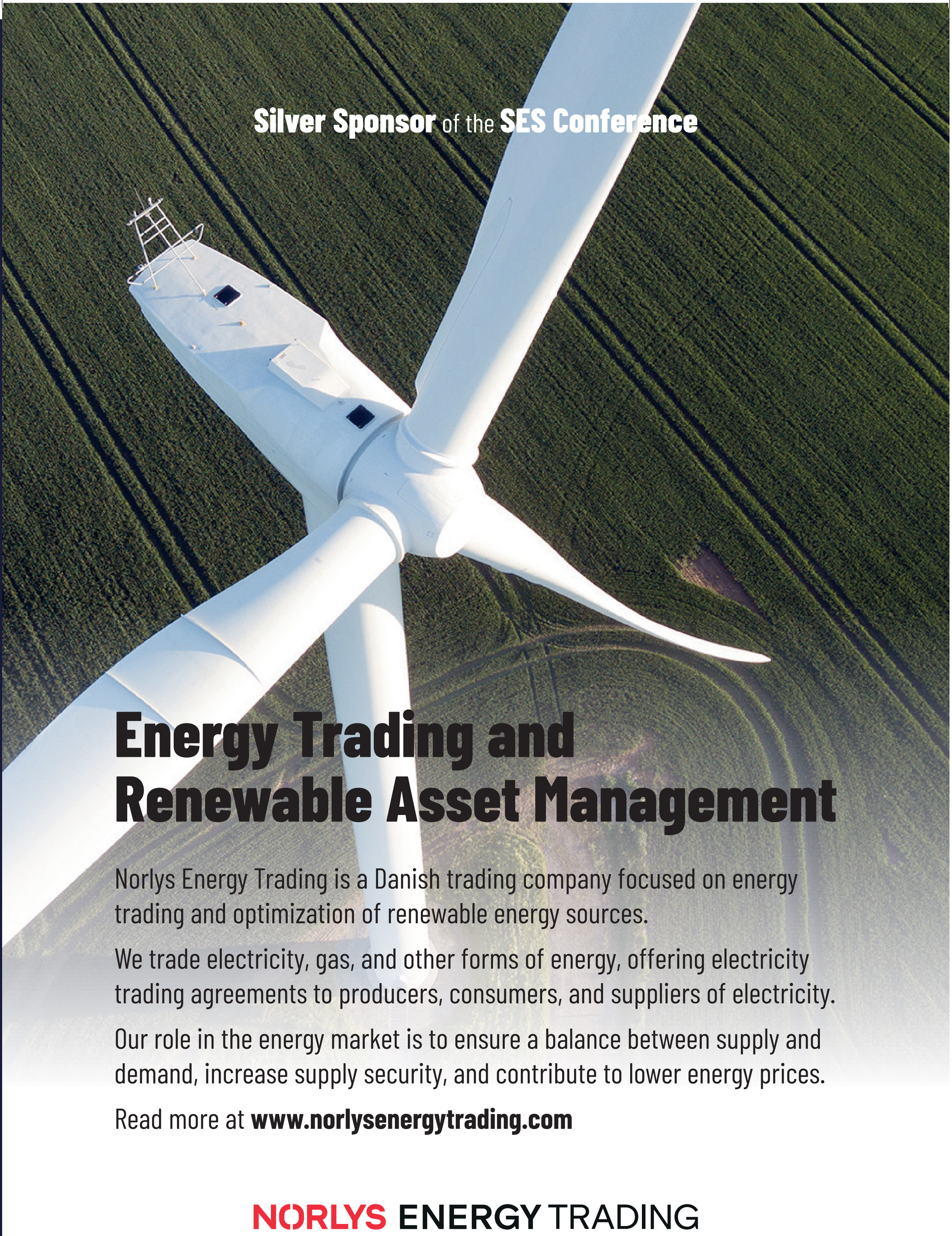
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List of special issue journal papers from previous SESAAU conferences

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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*

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International Journal of Sustainable Energy Planning and Management, Vol 34 (2022)

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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*

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Smart Energy (Last update 7 June 2023)
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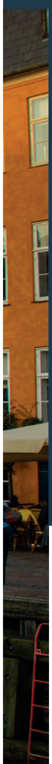

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