Aalborg Universitet

Book of Abstracts

9th International Conference on Smart Energy Systems

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9TH INTERNATIONAL CONFERENCE ON SMART ENERGY SYSTEMS

BOOK OF ABSTRACTS

AALBORG UNIVERSITY
DENMARK

energy CLUSTER DENMARK

Copenhagen, 12-13 September 2023

9th International Conference on Smart Energy Systems
12-13 September 2023

Book of Abstracts

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PREFACE AND WELCOME

It is a great pleasure to welcome you to the **9th International Conference on Smart Energy Systems** on 12-13 September and technical tours on 11 and 14 September 2023. The conference is organised by Aalborg University and Energy Cluster Denmark. We thank the sponsors for their contribution to this year's conference: Danfoss, HOFOR, Kamstrup, Kingspan, CIP, EMD International, Gradyent, Green Power Denmark, INNO-CCUS, Mission Green Fuels and Ørsted.

In 2023, we have changed the conference back to an in-person participation format, as many of you were used to before the COVID 19 pandemic. We are thus looking forward to meeting participants from academia and industry from around the world in person. The conference this year is in DGI Byen in Copenhagen, and the dinner is in central Copenhagen.

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 via the platform. Further, you should remember to nominate candidates for the Best Presentation Award via the platform. The platform will be accessible from 8 to 15 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 9th 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 six strong keynote profiles and more than 200 session presentations as well as technical tours. The keynotes will focus on the European and global deployment of renewable energy in the light of the continuing logistical challenges and the war in Ukraine on the first day. On the second day, the keynotes will focus on the vast opportunities of energy efficiency in Europe in buildings and focusing on district heating and coupling heat and electricity in the light of the REPowerEU initiatives.

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, Jakob Zinck Thellufsen and Hans Jørgen Brodersen, Conference organisers, Aalborg University and Energy Cluster Denmark

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9th International Conference on

Smart Energy Systems

4th Generation District Heating, Electrification, Electrofuels and Energy Efficiency

12-13 September 2023
Copenhagen

AALBORG UNIVERSITY
DENMARK

#SESAAU2023

energy CLUSTER DENMARK

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.

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, in buildings and transport as well as within industry

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

Electrification of transport, heating and industry

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

Planning and organisational challenges for smart energy systems and district heating

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

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

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

Important dates 2023

14 April	**Deadline for submission of abstracts**
	(Additional upgrade to paper is optional)
24 April	**Reply on acceptance of abstracts**
24 April - 31 May	**Early registration**
1 June - 10 August	**Normal registration**
12 - 13 September	**Conference**

Conference fees

Early registration (for presenters with accepted abstracts):

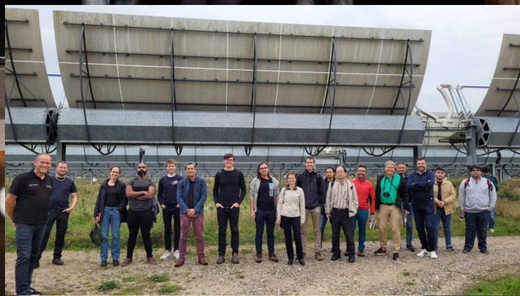
- **375 EUR** (attendance in Copenhagen)
- **275 EUR** (virtual attendance)

Normal fee:

- **475 EUR** (attendance in Copenhagen)
- **375 EUR** (virtual attendance)
- Conference dinner (CPH): **100 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 9th conference in the series 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 2023, we look forward to welcoming our participants to a hybrid conference with the possibility to attend either online or in person – this time at DGI Byen in central Copenhagen. In Copenhagen, 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 both before and after the conference in Copenhagen.

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

Submission Procedure

Both scientific and industrial contributions to the conference are most welcome.

To attend the conference as a presenter, you need to submit both an **abstract** and a **recorded presentation**. The abstract must be submitted by 14 April 2023. The recorded presentation must be prepared in the summer of 2023. 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** from **1 February to 14 April 2023.**

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. Anton Ianakiev, Nottingham Trent University, GB
Prof. Bent Ole G. Mortensen, University of Southern Denmark
Prof. Bernd Möller, University of Flensburg, DE
Prof. Christian Breyer, Lappeeranta University of Tech, FI
Prof. Dagnija Blumberga, Riga Technical University, LV
Prof. Erik Ahlgren, Chalmers University of Technology, SE
Prof. Ernst Worrell, Utrecht University, NL
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Prof. Martin Greiner, Aarhus University, DK
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Steen Schelle Jensen, Head of Business Dev. at Kamstrup, DK
Ulrik Stridbæk, Vice President at Ørsted , DK

9th International Conference on

Smart Energy Systems

4th Generation District Heating,
Electrification, Electrofuels and
Energy Efficiency

PROGRAMME COPENHAGEN

TUESDAY 12 SEPTEMBER 2023

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

Plenary room

09:00-10:30 **Smart Energy Systems in the light of the current security crisis** - 1st plenary session chaired by Professor Poul Alberg Østergaard

09:00-09:10 **Professor Henrik Lund and CEO Glenda Napier:** Opening speech

Plenary keynotes

09:15-09:30 **Kristian Jensen, CEO Green Power Denmark:** Energy security <-> secure energy

09:30-09:45 **Christina Grumstrup Sørensen, Senior partner Copenhagen Infrastructure Partners:** Supplier of green capital to large-scale renewable energy projects

09:45-10:00 **Philip Cole, Director WindEurope:** Accelerating Wind Energy Growth in Europe: A Call for Robust Industrial Policy

10:00-10:30 Questions and debate

10:30-10:45 **Short break**

PROGRAMME COPENHAGEN — TUESDAY 12 SEPTEMBER 2023

10:45-12:30 Parallel sessions 1-7

10:45-12:30

ROOM: Hovedbanegården

Session 1: Smart energy systems analyses, tools and methodologies

Chaired by Matteo Giacomo Prina

Session keynote Gorm Bruun Andresen: Exploring 2030 decarbonization scenarios of the European electricity sector using Modeling All Alternatives

Thibaut Wissocq: Strategies for decarbonisation of a heat district network using an optimization tool: Application to Grenoble city

Jan Stock: Automated separation of existing district heating networks for the utilisation of available heat sources

Nicolas Marx: Heat transmission network design optimization and robustness analysis for a case study in Tyrol

Sina Dibos: Development of the simulation tool HeatNetSim for thermal networks

Saltanat Kuntuarova: Design and simulation of district heating and cooling networks: A review of modelling approaches and tools

10:45-12:30

ROOM: Kødbyen

Session 2: Smart energy infrastructure and storage options

Chaired by Benedetto Nastasi

Session keynote Kristian Honoré: The age of Digitalization and Flexibility - from consumer to FLEXUMER in the district heating system

Matteo Pozzi: Digitalisation of the DHC industry: a review by DHC+ and Euroheat & Power

Maximilian Bernecker: The Value of Information – How Enhanced Load Profiles Save Costs for Local Congestion Management

Pascal Häbig: Quantifying the Standardization Gap in Smart Energy Systems: Standardizing Information and Communication Interfaces for Small-Scale Flexibility

Lukas Hofmann: How seasonal heat storage can benefit power system flexibility and power-to-heat integration? An optimisation on the scale of the French territory.

Anna Vannahme: Study of the optimization of an existing local district heating network with an increasing degree of digitalization

10:45-12:30

ROOM: Enghave Plads

Session 3: Integrated energy systems and smart grids

Chaired by Paula Ferreira

Session keynote Silvia Ricciuti: Modelling the optimal transition of an urban neighborhood towards an energy community and a Positive Energy District

Miguel Chang: Energy transition scenarios on Norwegian islands: The case of Utsira

Kushagra Gupta: Integrated Assessments of City Energy Systems: City Planning Vs National Targets

Dana Kirchem: Power sector effects of different roll-outs of flexible versus inflexible heat pumps

Rasul Satymov: From Winter Wind to Summer Sun: Unlocking the Arctic Region's Renewable Energy Potential

Abdulrahmman Azzam: Intelligent Operation Management System for Urban Districts – Conceptualization of a Dynamic Simulation as a Foundation for a Digital Twin

10:45-12:30

ROOM: Tivoli

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

Chaired by Iida Tetsunari

Session keynote Bent Ole Gram Mortensen: Consumer empowerment in a time of change in the energy sector

Hironao Matsubara: Design of smart energy system for decarbonization leading areas in Japan

Zhe Zhang: Challenges of setting up energy communities involving the Danish public sector: lessons learned

Daniel Møller Sneum: End-users' up-front payments in district heating: Striking the balance between competitive price and long-term risk

Nina Kicherer: District heating organizational models for a cost-effective energy transition

Kristina Lygnerud/Nathalie Fransson: Business models for low temperature district heating - 10 case studies

10:45-12:30

ROOM: Vesterbros Torv

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

Chaired by Ulrike Jordan

Session keynote Pernille Seljom: The value and impact of building mass upgrade on the Norwegian energy system transition

Enrico Ghidoni: Analysis of the impact of energy savings interventions on key performance indicators of a university campus

Christopher Graf: Domestic Hot Water Preparation in Residential Buildings: Comparison of Current Challenges and Future Solutions

Peter Lierhammer: Proposal of a Modular Management System to Quantify Suitable Smart Heating Approaches in Existing Buildings

Valentin Kaisermayer: Intelligent Building Control with User Feedback in the Loop

Lucas Verleyen: Positive energy districts – Performance assessment of different collective energy systems in a tiny residential cluster of buildings

10:45-12:30

ROOM: Kastrup Lufthavn

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

Chaired by Graeme Maidment

Session keynote Lei Wang: Case study of a local district heating expansion scenario n scenario within the framework of EMB3Rs

Els van der Roest: Flexibility of a low temperature District Heating system with Power-to-Heat and ATES

Henrik Pieper: Heat pump configurations for aquifer thermal energy storage

Jakub Garbacik: Heat pumps with thermal energy storage for district heating – standalone or integrated with fossil fuel heat plant

Thomas Schmidt: Emission-free heat supply for a large new residential area with a smart combination of natural heat sources

10:45-12:30

ROOM: Spisehuset

Session 7: Renewable energy sources and waste heat sources including PtX for district heating

Chaired by Iva Ridjan Skov

Session keynote Ieva Pakere: Optimizing Energy Independence for Achieving Climate Neutrality Goals

Hamza Abid: Existing and future potential hydrogen demands in Europe

Gabriele Humbert: Optimal sizing and operation of hydrogen generation sites with waste heat recovery for district heating network integration

Stefan Reuter: Optimizing the Domestic Production and Infrastructure for Green Hydrogen in Austria for 2030

Doris Beljan: Utilization of the available offshore wind potential - case study for the North Adriatic with the focus on HVDC, hydrogen and ammonia infrastructure

Maximilian Fey: A combined stochastic wind power forecasting and operational optimisation approach for off-grid offshore green hydrogen

12:30-13:45 Lunch and networking

PROGRAMME COPENHAGEN — TUESDAY 12 SEPTEMBER 2023

13:45-15:30 Parallel sessions 8-14

13:45-15:30

ROOM: Hovedbanegården

Session 8: Smart energy systems analyses, tools and methodologies

Chaired by Gorm Bruun Andresen

Session keynote John Counsell: Intelligently Controlled Solar Powered Energy Storage & Air-Source Heat Pump Home Heating System

Ari Laitala: A hybrid city – how the combined production curve of solar and wind electricity looks like in urban locations?

Kertu Lepiksaar: Integration of solar energy into district heating and cooling systems – Tallinn case study

Gerd Hofmann: Decarbonizing Municipal Utilities: A Strategy for Achieving CO2-Neutrality by 2035

Mominul Hasan: Techno-economic and geospatial opportunities for meeting Bangladesh's energy demand by solar PV systems

13:45-15:30

ROOM: Kødbyen

Session 9: CCUS and PtX technologies and the production and use of electrofuels in future energy systems

Chaired by Anders Bavnhøj Hansen

Session keynote Carina Jensen: Accelerating Green Transition: Scaling CCUS Technologies and Green Fuels towards Denmark's Climate Goals

Lazaara Ilieva: Toward holistic sustainability assessments of CCUS pathways

Nikola Mößner: Modelling the flexibility of process engineering PtX processes to achieve dynamic operation with volatile energy availability

Dirk Vries: Control strategies for flexible hydrogen production by a 2.5MW electrolyser stack supplying a filling station

Andreas Krogh: Economic and environmental feasibility of biofuel production facilities based on a Geographical Information System approach

13:45-15:30

ROOM: Enghave Plads

Session 10: Planning and organisational challenges for smart energy systems and district heating

Chaired by Bent Ole Gram Mortensen

Session keynote Steen Schelle Jensen: Consumers role in the transition to low temperature heat networks

Seán Harty: Starting a district heating network in locations with no experience of district heating

Alessandro Capretti: City-scale, multi-year and multi-stakeholder optimal district heating network developments planning

Andreas Möbius: Heat transformation tool to support communities with "municipal heating planning"

Hinnerk Willenbrink: The new housing area "Warendorf In de Brinke" - 5GDH: from project to principle?

Thomas Haupt: Cost-optimized decarbonization strategy for an existing residential area in Germany

13:45-15:30

ROOM: Tivoli

Session 11: GIS for energy systems, heat planning and district heating

Chaired by Lei Wang

Session keynote Robbe Salenbien: Using geographically informed non-linear district heating topology design to support higher level assessment methodologies for the potential of DHN

Hyunkyo Yu: Heat planning in a rural municipality

Marvin Schnabel: Interactive geodata analyses to support the multi-stakeholder process of thermal energy planning

Giovanni Dalle Nogare: GIS tool for the individuation of waste heat recovery opportunities

Shravan Kumar: Integrating excess heat in district energy systems based on a long-term spatiotemporal and dispatch optimisation

Juan Pedrero: Review of georeferrenced energy planning tools and methods for the assessment of decarbonization scenarios

13:45-15:30

ROOM: Vesterbros Torv

Session 12: Components and systems for district heating, energy efficiency, electrification and electrofuels

Chaired by Jacek Kalina

Session keynote Stefan Hay: Sustainable Asset Management District Heating - a Future Perspective

Jonas Ottosson: Accelerate your growth of DHC with Demand Side Flexibility

Myeongsik Kong: Risk of pipe fault analysis process for safety diagnosis of district heating network pipe

Martin Buitink: Effects of smart control of PVT heat pump systems on PV self-consumption

Gerald Zotter: Using of a special heat pump to lift the district heating supply temperature for an industrial facility

Ding Mao: Study on the identification of critical pipe segments and reliability design methods for district heating networks based on vulnerability

13:45-15:30

ROOM: Kastrup Lufthavn

Session 13: Renewable energy sources and waste heat sources including PtX for district heating

Chaired by Dagnija Blumberga

Session keynote Anna Volkova: Waste Heat-Based District Heating Network for Industrial Buildings With Low Energy Intensity

Max Fette: CHG: what are the potentials and barriers of using the waste heat of electrolysers and how can it be utilised?

Markus Fritz: What to do with the excess heat? - Assessing the techno-economic potential of different excess heat transport technologies in the European Union

Bjarne Jürgens: Covering district heating demand by waste heat usage from data centres – a feasibility study in Frankfurt, Germany

Henrique Lagoeiro: The Potential of Crematoria as Waste Heat Resources in the UK

Jelena Ziemele: Potential of treated wastewater as an energy source for district heating: a multi-factorial comparative assessment for the cities of London and Riga

13:45-15:30

ROOM: Spisehuset

Session 14: Integrated energy systems and smart grids

Chaired by Ralf-Roman Schmidt

Session keynote Jan Eric Thorsen: Sønderborg (DK) case example of district heating sector coupling and the related control solution

Sverre Stefanussen Foslie: Leveraging industrial flexibility, sector coupling and wind power production to mitigate power grid capacity limitations

Sigurd Bjarghov: Coordination mechanisms in local energy communities for connection of industry in congested grids

Costanza Saletti: Concurrent optimal management of communities of multi-energy prosumers

Thanh Huynh: Local energy market for thermal-electric energy systems with consideration of temperature flexibility in heating subnetworks

Christian Schützenhofer: Industrial energy demand and GHG emission scenarios under changing technologies

15:30-16:00 Coffee break

PROGRAMME COPENHAGEN TUESDAY 12 SEPTEMBER 2023

16:00-17:30 Parallel sessions 15-21

16:00-17:30

ROOM: Hovedbanegården

Session 15: Electrification of transport, heating and industry

Chaired by Peter Jorsal

Session keynote Oliver Ruhnau: Representing electric vehicles in energy system models: an accurate and scalable aggregation approach

Alaize Dall'Orsoletta: The systemic impacts of electric vehicles' uptake: A conceptual model

Benjamin Blat-Belmonte: Smart Energy Systems and Electrified Transport: Analyzing the Flexibility Potential of Bus Fleet Operators in Germany

Noémie Jeannin: From PV to EV: Mapping the Potential for Electric Vehicle Charging with Solar Energy in Europe

Judith Stute: How do dynamic electricity tariffs and dynamic grid charges interact?

16:00-17:30

ROOM: Kødbyen

Session 16: Smart energy systems analyses, tools and methodologies

Chaired by Erik Ahlgren

Session keynote Sara Månsson: Enhancing Efficiency and Reliability in 4th Generation District Heating: Insights from Automated Fault Detection Implementations

Maximilian Roth: SlothBrAIn: a holistic energy operating system

Pia Manz: Heating density as main factor for district heating: Empirical data analysis and outlook

Cameron Downing: A Simulink Based Dynamic Home Heating Model Calibrated with BREDEM 12

Alessandro Sartori: Optimizing the integration of renewable energy sources, energy efficiency, and flexibility solutions in a multi-network pharmaceutical industry

16:00-17:30

ROOM: Enghave Plads

Session 17: Smart energy systems analyses, tools and methodologies

Chaired by Richard van Leeuwen

Session keynote Matteo Giacomo Prina: Machine learning with EPLANopt to speed up the optimization process and explore uncertainty in energy system modelling

Pascal Friedrich: Effects of network model simplifications in local heat markets on district heating system operation

Rasmus Magni Johannsen: Developing energy system scenarios for municipalities - introducing MUSEPLAN

Goran Stunjek: Data-Based Correlation Analysis and Modelling of Water and Energy Systems on an Island Using Renewable Energy Sources for Desalination

Julia Eicke: Development of simplified models for future district heating networks

16:00-17:30

ROOM: Tivoli

Session 18: Planning and organisational challenges for smart energy systems and district heating

Chaired by Stefan Holler

Session keynote Ralf-Roman Schmidt: Risk minimization for decarbonizing heating networks via network temperature reductions and flexibility utilization – concepts and measures

Maarten Blommaert: Automated Design Strategies for Low-Temperature District Heating Networks with Multiple Producers

Mostafa Fallahnejad: Validation of calculated heat demand of the building stock using consumption data under GDPR

Peter Lorenzen: A new classification for district heating activities and the gap of a comprehensive methodology for the green transition

Lucy Sherburn: Development of a heat network typology for use within a heat network technical assurance scheme

16:00-17:30

ROOM: Vesterbros Torv

Session 19: Smart energy systems analyses, tools and methodologies

Chaired by Steen Schelle Jensen

Session keynote Paula Ferreira: Citizens' attitudes towards energy policy to foster the energy transition

Xavier Rixhon: Robust policy optimization for the pathway towards a sustainable energy system using a hierarchical multi-objective reinforcement learning approach

Arnau Aliana: Policy representation in Energy System Models in context of Sector Coupling: A review

Nicolas Ghuys: Integrating Energy System Optimization and Life Cycle Assessment for a Comprehensive Assessment of Sustainable Energy Transitions

Paolo Thiran: The role of renewable fuels in a fossil-free European whole-energy system

16:00-17:30

ROOM: Kastrup Lufthavn

Session 20: CCUS and PtX technologies and the production and use of electrofuels in future energy systems

Chaired by Urban Persson

Session keynote Diederik Coppitters: Evaluating the Environmental Impacts of Importing Electrofuels Using Planetary Boundaries: A Multi-Objective Optimisation Approach

Federico Parolin: The role of electrofuels in carbon-neutral scenarios of multi-sector integrated energy systems: An analysis for Italy

Aurélia Hernandez: Hydrogen in Power System Adequacy Studies

Eliana Lozano: Integrated e-methanol and drop-in fuels HTL platform –Techno-economic assessment for flexible operation

Shivaraj Chandrakant Patil: Current and Emerging Technologies for Waste-to-Energy Conversion: A Comparative Study with Multi-criteria Decision analysis approach

16:00-17:30

ROOM: Spisehuset

Special session: IEA DHC Annex TS7

Chaired by Christian Schützenhofer

Peter Sorknæs: Reviewing Methods for Identifying Waste Heat Potentials for District Heating

Gabriela Jauschnik: How can industrial waste heat be used in district heating networks? Insights on effective project initiation and business models

Thomas Kohne: Planning District Heating Connections of Multi-Modal Industrial Energy Systems: Optimization Approach from an Industrial Perspective

Lukas Theisinger: Living Lab DELTA: Development of an Interacting Energy-Optimized Industrial District

17:30	**Break**
19:30	**Conference dinner at Enghavevej 82B, 2450 Copenhagen**

PROGRAMME COPENHAGEN WEDNESDAY 12 SEPTEMBER 2023

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

09:00-10:45

ROOM: Hovedbanegården

Session 22: Smart energy systems analyses, tools and methodologies

Chaired by Ieva Pakere

Session keynote Ard de Reus: Real-time non-linear optimization of three district-heating connected heat pumps and a buffer with a Digital Twin

Jelger Jansen: Model predictive control of a 4th generation district heating network – comparison with rule-based control and impact of prediction uncertainties

Daniël Bakker: Advancing the use of datacenter waste heat, solar thermal, power-to-heat and heat storage with a digital twin for district heating supply in Groningen

Hermann Edtmayer: Virtual reality digital twin for immersive energy research and communication

Benedetto Nastasi: Digitalization and Smartness of Energy Systems from interactive models to Digital Twins

Kevin Michael Smith: Utilizing Digital Twins to Optimize District Heating Substations and Minimize Return temperatures

09:00-10:45

ROOM: Kødbyen

Session 23: Integrated energy systems and smart grids

Chaired by Costanza Saletti

Session keynote Andra Blumberga: When does Energy Island transfer to Energy Community?

Christine Nowak: Integrated energy system flexibility options when using heat pumps to save carbon emissions

Igor Krupenski: Geothermal energy implementation in Estonian District Heating Networks

Joseph Jebamalai: Optimization of thermal energy storage in district heating systems using Comsof Heat and GBOML

Jim Rojer: Dynamic GROW Model for Heat District Network feasibility by Techno -economic Planning and Design Optimization with a Mixed Integer Linear strategy

Lukas Peham: Implementation of a lifetime prediction model for crosslinked, foamed polyolefin insulation of pit thermal energy storages

09:00-10:45

ROOM: Enghave Plads

Session 24: Smart energy infrastructure and storage options

Chaired by Anders N. Andersen

Session keynote Miguel Herrador Moreno: Design of a renewable district heating and cooling plant for a university Campus in Cyprus

Alaa Farhat: A Novel Aggregator Algorithm for Coordinated Control of Multiple Battery Energy Storage Systems

Zhiyuan Xie: Interactions between energy storage and electricity prices in a highly renewable energy system for Europe

Sleiman Farah: Investment-based optimisation of energy storage parameters in a grid-connected hybrid renewable energy system

Mathieu Peeters: Optimal Extension Planning of District Heating Networks by Phased Investment

Ebbe Kyhl Gøtske: Cost and efficiency requirements for a successful electricity storage in a highly renewable European energy system

09:00-10:45

ROOM: Tivoli

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

Chaired by Jan Eric Thorsen

Session keynote Marek Brand: Economic comparison of 4GDH&C and 5GDH&C in Rome

Niklas Kracht: Feasibility study of an innovative drilling method for inclined medium-deep borehole heat exchangers in a 5th generation district heating concept

Seyed Shahabaldin Tohidi: Optimal price signal generation for local energy management using flexibility function

Lucien Genge: Evaluating Germany's Ammonia Economy: A Comprehensive Analysis of Application-Specific Demands and Well-to-Tank Supply Costs

Şirin Alibaş: Hybrid heat pump systems as bridging technology in the natural gas independence of Germany's residential buildings

Alessandro Maccarini: Techno-economic evaluation of 4th and 5th gen. DH networks and comparing to individual heat pumps: Idea and concept of a simple decision support tool

09:00-10:45

ROOM: Vesterbros Torv

Session 26: 4th generation district heating concepts, future district heating production and systems

Chaired by: John Counsell

Session keynote Graeme Maidment: Energy Superhubs - the use of supermarkets as local energy centres

Orestis Angelidis: Operational Designs for District Heating and Cooling Networks with Decentralized Energy Substations: Development and Validation

Daniel Zinsmeister: Flow direction in district heating and cooling grids with booster heat pumps: Does it make sense to have unidirectional flow?

Aleksandr Hlebnikov: Evaluation of a Technical Solution for Seawater District Heating and Cooling Systems

Rahul Mohandasan Karuvingal: Analyzing Complex Network Hydraulics and Control Strategies in Cold District Heating Networks via Dynamic Thermo-Hydraulic Simulations

Aadit Malla: Modelling the potential for district cooling

09:00-10:45

ROOM: Kastrup Lufthavn

Session 27: Renewable energy sources and waste heat sources including PtX for district heating

Chaired by Peter Sorknæs

Session keynote Thomas Pauschinger: IEA DHC Annex TS5 – Integration of Renewable Energy Sources into existing District Heating and Cooling Systems

Frederik Feike: Different scenarios for the decarbonization of a campus district heating system

Giulia Spirito: Has the global energy crisis enhanced the potential of district heating?

Luis Sánchez-García: Viability of district heating networks in temperate climates: Benefits and barriers of cold and warm temperature networks

Carina Seidnitzer-Gallien: Transition of district heating and cooling systems to a higher share of renewable energy sources - Outcomes from six European countries

Frederik Dahl Nielsen: Case study of local sector coupling strategies for e-methanol synthesis

09:00-10:45

ROOM: Plenary room

Session 28: Smart energy infrastructure and storage options

Chaired by Matteo Pozzi

Session keynote Daniel Trier: Simple real time monitoring of large thermal storages

Toke Kjær Christensen: The Role of Thermal Energy Storages in Smart Energy Systems

Torstein Balle: Inspection of added thermal storage to increase the match of consumption and renewable generation, analysed for domestic heating on the Faroe Islands

Karl Vilén: The role of Thermal Energy Storages in Future Heating system – A Long-term Study of an Evolving Heating System

August Brækken: Energy system modelling of a future zero-emission neighbourhood with seasonal thermal energy storage

Emanuela Marzi: Coordinating multiple Power-to-Gas plants for optimal management of e-fuel seasonal storage

10:45-11:15 Coffee break

PROGRAMME COPENHAGEN
WEDNESDAY 12 SEPTEMBER 2023

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

11:15-13:00

ROOM: Hovedbanegården

Session 29: 4th generation district heating concepts, future district heating production and systems

Chaired by Dirk Vanhoudt

Session keynote Elisa Guelpa: Solutions to reduce supply temperature in existing small-to-large scale DH networks

Alixe Degelin: Influence of supply temperature and booster technology on the energetic performance of a district heating network

Isabelle Best: System temperature reduction for new DH systems in low-energy residential areas: cost-effectiveness and eco-efficiency as a function of plot ratio

Martin Sollich: Unlocking the energy efficiency potential of heating networks through low-temperature design and optimal retrofit

Ali Kök: Achieving Carbon Neutrality in District Heating: The Impact of Temperature Levels on the Supply Mix of EU-27 in 2050

Tom Naughton: Practical experience of converting a 1970s UK social housing block into a 4GDH network with independent quality assurance support

11:15-13:00

ROOM: Kødbyen

Session 30: Renewable energy sources and waste heat sources including PtX for district heating

Chaired by Steffen Nielsen

Session keynote Jacek Kalina: Sizing large-scale industrial heat pump for heat recovery from treated municipal sewage in coal-fired district heating system

Michał Raczkiewicz: The use of heat pumps in a district heating in selected European countries

Dagnija Blumberga: How to integrate carbon farming in smart district heating energy systems?

Ana Catarina Marques: A Smart Local Energy System with heat recovery from power stations

Ulrike Jordan: Potential analysis for phasing out coal, oil and natural gas for heat supply in Kassel, a medium-sized city in Germany

Martin Colla: A comparative analysis of the energy return on energy invested (EROI) for different biomass district heating systems

11:15-13:00

ROOM: Enghave Plads

Session 31: Smart energy systems analyses, tools and methodologies

Chaired by Miguel Herrador Moreno

Session keynote Moritz Bitterling: Evaluating different artificial neural network approaches for forecasting heat demand in district heating networks

Andreas Bott: Efficient Training Data Generation for Learning-Based State Estimation in 4th Generation District Heating Grids

Klaas Mielck: Permutation-based Feature Importance Analysis for Medium-Term Heat Load Forecasting in District Heating Systems

Manuela Linke: Grid operation management with Convolutional Neural Networks

Lea Rehlich: Mixed-integer nonlinear optimization approach for district heating networks

Anna Cadenbach: IEA DHC Annex TS8: Experimental investigations of district heating systems

11:15-13:00

ROOM: Tivoli

Session 32: Smart energy systems analyses, tools and methodologies

Chaired by Kevin Michael Smith

Session keynote Dennis Lottis: Collaborative Laboratory Testing of District Heating Networks Using a Hardware-in-the-Loop Framework: A Proof-of-Concept Study

Felix Agner: Numerical Estimation of Improved Heat Transport Capacity using Load Control in a District Heating Grid

Dominik Stecher: Creating a labelled district heating data set: From anomaly detection towards fault detection

Jonne van Dreven: A Systematic Approach for Data Generation for Intelligent Fault Detection and Diagnosis in District Heating

Yannick Wack: The Role of Demand Variability and Intermittent Supply on the Optimal Routing and Design of District Heating Networks

Parisa Rahdan: Distributed photovoltaics provides key benefits in a highly renewable European energy system

11:15-13:00

ROOM: Vesterbros Torv

Session 33: Institutional and organisational change for smart energy systems and radical technological change

Chaired by Gareth Jones

Session keynote Anders N. Andersen: Major economic opportunities and challenges for Danish wind farms and district energy plants of German special regulation and netting

Anna Billerbeck: Is Germany on the right way for the market uptake of large-scale heat pumps in district heating? An analysis of the economic framework conditions

Elisabeth Andreae: The impact of offshore energy hub and hydrogen integration on the Faroe Island's energy system

Marianne Petersen: Vision of Offshore Energy Hub at Faroe Islands: The Market Equilibrium Impact

Freddie Valletta: Development of a new standardised testing regime to improve performance levels of residential heat interface units in the UK district heating market

Julia Barbosa: Game-theoretic Analysis of Suppliers' Market Power in Local Multi-Energy Markets

11:15-13:00

ROOM: Kastrup Lufthavn

Session 34: Integrated energy systems and smart grids

Chaired by Andra Blumberga

Session keynote Lykke Mulvad Jeppesen: Unleashing renewable energy potential through anticipatory grid investments and risk sharing models

Vladimir Z. Gjorgievski: Optimal management of community energy systems considering different energy sharing incentives

Kristina Haaskjold: Effect and value of end-use flexibility in the low-carbon transition of the Norwegian energy system

Kai Hoth: The Energy Aggregator Problem – A Holistic MILP Approach

Nicolas Lamaison: Operational long-term management of a salt cavern for green H2 production for industry

Jens Schmugge: Transformation of the heat and gas infrastructure for a cost-optimised climate-neutral European energy system

11:15-13:00

ROOM: Plenary room

Special session: IEA DHC Annex TS4

Chaired by Dietrich Schmidt

Session keynote Tijs Van Oevelen: Testing and evaluation of a smart controller for peak reduction in an Italian thermal network

Chris Hermans: Instance-based approach for fault detection in district heating substations

Mohammed Ali Jallal: Advancing Smart Heating and Cooling Networks: Deep Learning-Based Fault Detection for Substation Fouling in Heating and Cooling Networks

Dietrich Schmidt: Digitalization as the basis for efficient and flexible district heating systems

Ulrich Trabert: Flexible Use of Thermal Storage in a Large District Heating Substation using Incremental Deep Learning Heat Load Forecasts

Qinjiang Yang: Identifying Common Faults and Misuses in Large Multifamily Building Heating Systems Through Digitalization: A Survey

PROGRAMME COPENHAGEN

WEDNESDAY 13 SEPTEMBER 2023

13:00-14:00 **Lunch and networking**

Plenary room

14:00-16:00 **REPower EU and the focus on energy efficiency in Europe** - 2nd plenary session chaired by Professor Brian Vad Mathiesen

Plenary keynotes:

14:00-14:15	**Hans van Steen, Principal Adviser EU DG Energy:** Towards a Sustainable and Resilient European Energy System with Energy Efficiency
14:15-14:30	**Aurélie Beauvais, Managing Director Euroheat and Power:** Resource efficiency: a new moto for the heating & cooling transition
14:30-14:45	**Goran Krajačić, Associate Professor University of Zagreb:** Opportunities for increasing energy efficiency and decarbonisation of heating in the Eastern and Southeastern Europe
14:50-15:20	Questions and debate
15:20-15:35	DHC+ Student Award Ceremony
15:35-15:50	Best Presentation Award Ceremony by Professor Poul Alberg Østergaard
15:50-16:00	Closing

PROGRAMME COPENHAGEN - TECHNICAL TOURS

MONDAY 11 SEPTEMBER AND THURSDAY 14 SEPTEMBER 2023

Technical Tour: Public and Business Energy Communities
Avedøre Holme

Thursday 14 September 2023

The Energy Community Avedøre consists of a wide variety of stakeholders – both citizens, the municipality, a social housing organization, businesses, the local district heating company and the local high school. The aim is to share locally produced energy and to integrate both production and consumption of electricity and heating. The energy community is working with PVs, charging of EVs, batteries and windmills alongside a range of innovative district heating projects. At the site of Hvidovre High School the principal and chairman of the Energy Community Avedøre will bid you welcome and introduce you to the thoughts behind. A representative of a local company – the movie production company Zentropa – will also be sharing his thoughts on being part of the development of the Energy Community Avedøre.

The industrial energy community of Avedøre Holme will also be presented by one of the local stakeholders. He will share his thoughts on the common vision of the companies of the area and their ambitions. They wish to become self-sufficient with locally produced and shared energy.

More information at conference website

Technical Tour: Heat pit storage at Høje Taastrup District Heating

Monday 11 September 2023

Høje Taastrup District Heating and the district heating company VEKS have built and now own a heat pit storage together. Since its inauguration in late 2022 it has added value to the Greater Copenhagen district heating system and contributes to the green transition. The purpose of the storage is to store district heating when it is cheap to produce – and supply when it is expensive to produce. The storage contains 70,000 m3 (equivalent to 3,300 MWh), has a charging and discharging capacity of 30 MW and is expected to add an annual value of DKK 6-7 million to the Greater Copenhagen district heating system. Quoting CEO Astrid Birnbaum: "The project is a unique cooperation between many players in the district heating systems of the Copenhagen metropolitan area. Our common goal is less expensive and greener energy.

More information at conference website

ONLINE PROGRAMME - KEYNOTE PRESENTATIONS

ACCESSIBLE FROM 12 TO 15 SEPTEMBER 2023

energy CLUSTER DENMARK

AALBORG UNIVERSITY

Keynote presentations

Kristian Jensen, CEO Green Power Denmark: Energy security <-> secure energy

Christina Grumstrup Sørensen, Senior partner Copenhagen Infrastructure Partners: Supplier of green capital to large-scale renewable energy projects

Philip Cole, Director WindEurope: Accelerating Wind Energy Growth in Europe: A Call for Robust Industrial Policy

Hans van Steen, Principal Adviser EU DG Energy: Towards a Sustainable and Resilient European Energy System with Energy Efficiency

Aurélie Beauvais, Managing Director Euroheat and Power: Resource efficiency: a new moto for the heating & cooling transition

Goran Krajačić, Associate Professor University of Zagreb: Opportunities for increasing energy efficiency and decarbonisation of heating in the Eastern and Southeastern Europe

ONLINE PROGRAMME SESSION PRESENTATIONS - ACCESSIBLE FROM 8 TO 15 SEPTEMBER

Smart energy systems analyses, tools and methodologies

Felix Agner: Numerical Estimation of Improved Heat Transport Capacity using Load Control in a District Heating Grid

Arnau Aliana: Policy representation in Energy System Models in context of Sector Coupling: A review

Gorm Bruun Andresen: Exploring 2030 decarbonization scenarios of the European electricity sector using Modeling All Alternatives

Daniël Bakker: Advancing the use of datacenter waste heat, solar thermal, power-to-heat and heat storage with a digital twin for district heating supply in Groningen

Moritz Bitterling: Evaluating different artificial neural network approaches for forecasting heat demand in district heating networks

Andreas Bott: Efficient Training Data Generation for Learning-Based State Estimation in 4th Generation District Heating Grids

Anna Cadenbach: IEA DHC Annex TS8: Experimental investigations of district heating systems

John Counsell: Intelligently Controlled Solar Powered Energy Storage & Air-Source Heat Pump Home Heating System

Sina Dibos: Development of the simulation tool HeatNetSim for thermal networks

Cameron Downing: A Simulink Based Dynamic Home Heating Model Calibrated with BREDEM 12

Jonne van Dreven: A Systematic Approach for Data Generation for Intelligent Fault Detection and Diagnosis in District Heating

Hermann Edtmayer: Virtual reality digital twin for immersive energy research and communication

Julia Eicke: Development of simplified models for future district heating networks

Paula Ferreira: Citizens' attitudes towards energy policy to foster the energy transition

Pascal Friedrich: Effects of network model simplifications in local heat markets on district heating system operation

Nicolas Ghuys: Integrating Energy System Optimization and Life Cycle Assessment for a Comprehensive Assessment of Sustainable Energy Transitions

Jonas Gottschald: Lessons Learned: On the Potentials and Challenges of a Model Predictive Controlled DHN Heat Supply

Mominul Hasan: Techno-economic and geospatial opportunities for meeting Bangladesh's energy demand by solar PV systems

Gerd Hofmann: Decarbonizing Municipal Utilities: A Strategy for Achieving CO2-Neutrality by 2035

Jelger Jansen: Model predictive control of a 4th generation district heating network – comparison with rule-based control and impact of prediction uncertainties

Rasmus Magni Johannsen: Developing energy system scenarios for municipalities - introducing MUSEPLAN

Saltanat Kuntuarova: Design and simulation of district heating and cooling networks: A review of modelling approaches and tools

Ari Laitala: A hybrid city – how the combined production curve of solar and wind electricity looks like in urban locations?

Kertu Lepiksaar: Integration of solar energy into district heating and cooling systems – Tallinn case study

Manuela Linke: Grid operation management with Convolutional Neural Networks

Dennis Lottis: Collaborative Laboratory Testing of District Heating Networks Using a Hardware-in-the-Loop Framework: A Proof-of-Concept Study

Pia Manz: Heating density as main factor for district heating: Empirical data analysis and outlook

Nicolas Marx: Heat transmission network design optimization and robustness analysis for a case study in Tyrol

Klaas Mielck: Permutation-based Feature Importance Analysis for Medium-Term Heat Load Forecasting in District Heating Systems

Sara Månsson: Enhancing Efficiency and Reliability in 4th Generation District Heating: Insights from Automated Fault Detection Implementations

Benedetto Nastasi: Digitalization and Smartness of Energy Systems from interactive models to Digital Twins

Pavel Paulau: Building physics monitoring with open standards

Aljoscha Pollmann: Waste heat as a driver for greenfield heat networks? Planning trade-offs illustrated using a case study for Zelzate, Belgium

Matteo Giacomo Prina: Machine learning with EPLANopt to speed up the optimization process and explore uncertainty in energy system modelling

Parisa Rahdan: Distributed photovoltaics provides key benefits in a highly renewable European energy system

Lea Rehlich: Mixed-integer nonlinear optimization approach for district heating networks

Marius Reich: Prior-Approximation of Rule-Based Energy System Simulation for Fast Design Optimization

Patricia Reindl: Redensification potentials through building renovation in a test area in Salzburg considering the existing district heating network

Ard de Reus: Real-time non-linear optimization of three district-heating connected heat pumps and a buffer with a Digital Twin

Xavier Rixhon: Robust policy optimization for the pathway towards a sustainable energy system using a hierarchical multi-objective reinforcement learning approach

Maximilian Roth: SlothBrAIn: a holistic energy operating system

Alessandro Sartori: Optimizing the integration of renewable energy sources, energy efficiency, and flexibility solutions in a multi-network pharmaceutical industry

Kevin Michael Smith: Utilizing Digital Twins to Optimize District Heating Substations and Minimize Return Temperatures

Dominik Stecher: Creating a labelled district heating data set: From anomaly detection towards fault detection

Jan Stock: Automated separation of existing district heating networks for the utilisation of available heat sources

Goran Stunjek: Data-Based Correlation Analysis and Modelling of Water and Energy Systems on an Island Using Renewable Energy Sources for Desalination

Signe Swarttouw: Combining Diverse Datasets for Whole Systems Local Area Energy Planning

Paolo Thiran: The role of renewable fuels in a fossil-free European whole -energy system

Yannick Wack: The Role of Demand Variability and Intermittent Supply on the Optimal Routing and Design of District Heating Networks

Thibaut Wissocq: Strategies for decarbonisation of a heat district network using an optimization tool: Application to Grenoble city

ONLINE PROGRAMME SESSION PRESENTATIONS - ACCESSIBLE FROM 8 TO 15 SEPTEMBER

Planning and organisational challenges for smart energy systems and district heating

Maarten Blommaert: Automated Design Strategies for Low-Temperature District Heating Networks with Multiple Producers

Dhekra Bousnina: Optimal Multi-Energy Management in Smart Energy Systems: a Deep Reinforcement Learning approach and a case-study on a French eco-district

Alessandro Capretti: City-scale, multi-year and multi-stakeholder optimal district heating network developments planning

Mostafa Fallahnejad: Validation of calculated heat demand of the building stock using consumption data under GDPR

Seán Harty: Starting a district heating network in locations with no experience of district heating

Thomas Haupt: Cost-optimized decarbonization strategy for an existing residential area in Germany

Steen Schelle Jensen: Consumers role in the transition to low temperature heat networks

Peter Lorenzen: A new classification for district heating activities and the gap of a comprehensive methodology for the green transition

Andreas Möbius: Heat transformation tool to support communities with “municipal heating planning”

Ralf-Roman Schmidt: Risk minimization for decarbonizing heating networks via network temperature reductions and flexibility utilization – concepts and measures

Hinnerk Willenbrink: The new housing area "Warendorf In de Brinke" - 5GDH: from project to principle?

Smart energy infrastructure and storage options

Torstein Balle: Inspection of added thermal storage to increase the match of consumption and renewable generation, analysed for domestic heating on the Faroe Islands

Maximilian Bernecker: The Value of Information – How Enhanced Load Profiles Save Costs for Local Congestion Management

August Brækken: Energy system modelling of a future zero-emission neighbourhood with seasonal thermal energy storage

Toke Kjær Christensen: The Role of Thermal Energy Storages in Smart Energy Systems

Sleiman Farah: Investment-based optimisation of energy storage parameters in a grid-connected hybrid renewable energy system

Alaa Farhat: A Novel Aggregator Algorithm for Coordinated Control of Multiple Battery Energy Storage Systems

Ebbe Kyhl Gøtske: Cost and efficiency requirements for a successful electricity storage in a highly renewable European energy system

Lukas Hofmann: How seasonal heat storage can benefit power system flexibility and power-to-heat integration? An optimisation on the scale of the French territory.

Kristian Honoré: The age of Digitalization and Flexibility - from consumer to FLEXUMER in the district heating system

Pascal Häbig: Quantifying the Standardization Gap in Smart Energy Systems: Standardizing Information and Communication Interfaces for Small-Scale Flexibility

Emanuela Marzi: Coordinating multiple Power-to-Gas plants for optimal management of e-fuel seasonal storage

Miguel Herrador Moreno: Design of a renewable district heating and cooling plant for a university Campus in Cyprus

Mathieu Peeters: Optimal Extension Planning of District Heating Networks by Phased Investment

Matteo Pozzi: Digitalisation of the DHC industry: a review by DHC+ and Euroheat & Power

Daniel Trier: Simple real time monitoring of large thermal storages

Anna Vannahme: Study of the optimization of an existing local district heating network with an increasing degree of digitalization

Karl Vilén: The role of Thermal Energy Storages in Future Heating system – A Long-term Study of an Evolving Heating System

Zhiyuan Xie: Interactions between energy storage and electricity prices in a highly renewable energy system for Europe

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

Shravan Kumar: Integrating excess heat in district energy systems based on a long-term spatiotemporal and dispatch optimisation

Giovanni Dalle Nogare: GIS tool for the individuation of waste heat recovery opportunities

Juan Pedrero: Review of georeferrenced energy planning tools and methods for the assessment of decarbonization scenarios

Robbe Salenbien: Using geographically informed non-linear district heating topology design to support higher level assessment methodologies for the potential of DHN

Marvin Schnabel: Interactive geodata analyses to support the multi-stakeholder process of thermal energy planning

Sreenath Sukumaran: Site suitability Assessment for Solar-Based Snow-Assisted District Cooling System in Estonian Context

Hyunkyo Yu: Heat planning in a rural municipality

ONLINE PROGRAMME SESSION PRESENTATIONS - ACCESSIBLE FROM 8 TO 15 SEPTEMBER

Integrated energy systems and smart grids

Abdulrahmman Azzam: Intelligent Operation Management System for Urban Districts – Conceptualization of a Dynamic Simulation as a Foundation for a Digital Twin

Sigurd Bjarghov: Coordination mechanisms in local energy communities for connection of industry in congested grids

Andra Blumberga: When does Energy Island transfer to Energy Community?

Miguel Chang: Energy transition scenarios on Norwegian islands: The case of Utsira

Sverre Stefanussen Foslie: Leveraging industrial flexibility, sector coupling and wind power production to mitigate power grid capacity limitations

Vladimir Z. Gjorgievski: Optimal management of community energy systems considering different energy sharing incentives

Kushagra Gupta: Integrated Assessments of City Energy Systems: City Planning Vs National Targets

Kristina Haaskjold: Effect and value of end-use flexibility in the low-carbon transition of the Norwegian energy system

Kai Hoth: The Energy Aggregator Problem – A Holistic MILP Approach

Thanh Huynh: Local energy market for thermal-electric energy systems with consideration of temperature flexibility in heating subnetworks

Joseph Jebamalai: Optimization of thermal energy storage in district heating systems using Comsof Heat and GBOML

Lykke Mulvad Jeppesen: Unleashing renewable energy potential through anticipatory grid investments and risk sharing models

Dana Kirchem: Power sector effects of different roll-outs of flexible versus inflexible heat pumps

Igor Krupenski: Geothermal energy implementation in Estonian District Heating Networks

Christine Nowak: Integrated energy system flexibility options when using heat pumps to save carbon emissions

Nicolas Lamaison: Operational long-term management of a salt cavern for green H2 production for industry

Lukas Peham: Implementation of a lifetime prediction model for crosslinked, foamed polyolefin insulation of pit thermal energy storages

Silvia Ricciuti: Modelling the optimal transition of an urban neighborhood towards an energy community and a Positive Energy District

Jim Rojer: Dynamic GROW Model for Heat District Network feasibility by Techno-economic Planning and Design Optimization with a Mixed Integer Linear strategy

Costanza Saletti: Concurrent optimal management of communities of multi-energy prosumers

Rasul Satymov: From Winter Wind to Summer Sun: Unlocking the Arctic Region's Renewable Energy Potential

Jens Schmugge: Transformation of the heat and gas infrastructure for a cost-optimised climate-neutral European energy system

Christian Schützenhofer: Industrial energy demand and GHG emission scenarios under changing technologies

Jan Eric Thorsen: Sønderborg (DK) case example of district heating sector coupling and the related control solution

Renewable energy sources and waste heat sources including PtX for DH

Hamza Abid: Existing and future potential hydrogen demands in Europe

Doris Beljan: Utilization of the available offshore wind potential - case study for the North Adriatic with the focus on HVDC, hydrogen and ammonia infrastructure

Dagnija Blumberga: How to integrate carbon farming in smart district heating energy systems?

Frederik Feike: Different scenarios for the decarbonization of a campus district heating system

Max Fette: CHG - Combined Heat and Gas: what are the potentials and barriers of using the waste heat of electrolysers and how can it be utilised?

Maximilian Fey: A combined stochastic wind power forecasting and operational optimisation approach for off-grid offshore green hydrogen

Markus Fritz: What to do with the excess heat? - Assessing the techno-economic potential of different excess heat transport technologies in the European Union

Gabriele Humbert: Optimal sizing and operation of hydrogen generation sites with waste heat recovery for district heating network integration

Ulrike Jordan: Potential analysis for phasing out coal, oil and natural gas for heat supply in Kassel, a medium-sized city in Germany

Bjarne Jürgens: Covering district heating demand by waste heat usage from data centres – a feasibility study in Frankfurt, Germany

Jacek Kalina: Sizing large-scale industrial heat pump for heat recovery from treated municipal sewage in coal-fired district heating system

Henrique Lagoeiro: The Potential of Crematoria as Waste Heat Resources in the UK

Ana Catarina Marques: A Smart Local Energy System with heat recovery from power stations

Martin Colla: A comparative analysis of the energy return on energy invested (EROI) for different biomass district heating systems

Frederik Dahl Nielsen: Case study of local sector coupling strategies for e-methanol synthesis

Ieva Pakere: Optimizing Energy Independence for Achieving Climate Neutrality Goals

Thomas Pauschinger: IEA DHC Annex TS5 – Integration of Renewable Energy Sources into existing District Heating and Cooling Systems

Michał Raczkiewicz: The use of heat pumps in a district heating in selected European countries

Stefan Reuter: Optimizing the Domestic Production and Infrastructure for Green Hydrogen in Austria for 2030

Luis Sánchez-García: Viability of district heating networks in temperate climates: Benefits and barriers of cold and warm temperature networks

Carina Seidnitzer-Gallien: Transition of district heating and cooling systems to a higher share of renewable energy sources - Outcomes from six European countries

Giulia Spirito: Has the global energy crisis enhanced the potential of district heating?

Anna Volkova: Waste Heat-Based District Heating Network for Industrial Buildings With Low Energy Intensity

Jelena Ziemele: Potential of treated wastewater as an energy source for district heating: a multi-factorial comparative assessment for the cities of London and Riga

ONLINE PROGRAMME SESSION PRESENTATIONS - ACCESSIBLE FROM 8 TO 15 SEPTEMBER

Special session: IEA DHC Annex TS7

Gabriela Jauschnik: How can industrial waste heat be used in district heating networks? Insights on effective project initiation and business models

Thomas Kohne: Planning District Heating Connections of Multi-Modal Industrial Energy Systems: Optimization Approach from an Industrial Perspective

Peter Sorknæs: Reviewing Methods for Identifying Waste Heat Potentials for District Heating

Lukas Theisinger: Living Lab DELTA: Development of an Interacting Energy-Optimized Industrial District

Special session: IEA DHC Annex TS4

Chris Hermans: Instance-based approach for fault detection in district heating substations

Mohammed Ali Jallal: Advancing Smart Heating and Cooling Networks: Deep Learning-Based Fault Detection for Substation Fouling in Heating and Cooling Networks

Tijs Van Oevelen: Testing and evaluation of a smart controller for peak reduction in an Italian thermal network

Dietrich Schmidt: Digitalization as the basis for efficient and flexible district heating systems

Ulrich Trabert: Flexible Use of Thermal Storage in a Large District Heating Substation using Incremental Deep Learning Heat Load Forecasts

Qinjiang Yang: Identifying Common Faults and Misuses in Large Multifamily Building Heating Systems Through Digitalization: A Survey

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

Diederik Coppitters: Evaluating the Environmental Impacts of Importing Electrofuels Using Planetary Boundaries: A Multi-Objective Optimisation Approach

Aurélia Hernandez: Hydrogen in Power System Adequacy Studies

Lazaara Ilieva: Toward holistic sustainability assessments of CCUS pathways

Carina Jensen: Accelerating Green Transition: Scaling CCUS Technologies and Green Fuels towards Denmark's Climate Goals

Andreas Krogh: Economic and environmental feasibility of biofuel production facilities based on a Geographical Information System approach

Eliana Lozano: Integrated e-methanol and drop-in fuels HTL platform –Techno-economic assessment for flexible operation

Nikola Mößner: Modelling the flexibility of process engineering PtX processes to achieve dynamic operation with volatile energy availability

Federico Parolin: The role of electrofuels in carbon-neutral scenarios of multi-sector integrated energy systems: An analysis for Italy

Shivaraj Chandrakant Patil: Current and Emerging Technologies for Waste-to-Energy Conversion: A Comparative Study with Multi-criteria Decision analysis approach

Dirk Vries: Control strategies for flexible hydrogen production by a 2.5MW electrolyser stack supplying a filling station

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

Enrico Ghidoni: Analysis of the impact of energy savings interventions on key performance indicators of a university campus

Christopher Graf: Domestic Hot Water Preparation in Residential Buildings: Comparison of Current Challenges and Future Solutions

Valentin Kaisermayer: Intelligent Building Control with User Feedback in the Loop

Hanne Kauko: The impact of energy efficiency, heat pumps and district heating on the future power demand in Norway

Peter Lierhammer: Proposal of a Modular Management System to Quantify Suitable Smart Heating Approaches in Existing Buildings

Pernille Seljom: The value and impact of building mass upgrade on the Norwegian energy system transition

Lucas Verleyen: Positive energy districts – Performance assessment of different collective energy systems in a tiny residential cluster of buildings

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

Martin Buitink: Effects of smart control of PVT heat pump systems on PV self-consumption

Stefan Hay: Sustainable Asset Management District Heating - a Future Perspective

Myeongsik Kong: Risk of pipe fault analysis process for safety diagnosis of district heating network pipe

Ding Mao: Study on the identification of critical pipe segments and reliability design methods for district heating networks based on vulnerability

Jonas Ottosson: Accelerate your growth of DHC with Demand Side Flexibility

Constantin Völzel: Open source model of a shallow geothermal heat collector as a component for 5GDHC simulation frameworks

Gerald Zotter: Using of a special heat pump to lift the district heating supply temperature for an industrial facility

ONLINE PROGRAMME SESSION PRESENTATIONS - ACCESSIBLE FROM 8 TO 15 SEPTEMBER

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

Şirin Alibaş: Hybrid heat pump systems as bridging technology in the natural gas independence of Germany's residential buildings

Orestis Angelidis: Operational Designs for District Heating and Cooling Networks with Decentralized Energy Substations: Development and Validation

Isabelle Best: System temperature reduction for new DH systems in low-energy residential areas: cost-effectiveness and eco-efficiency as a function of plot ratio

Marek Brand: Economic comparison of 4GDH&C and 5GDH&C in Rome

Alixe Degelin: Influence of supply temperature and booster technology on the energetic performance of a district heating network

Jakub Garbacik: Heat pumps with thermal energy storage for district heating – standalone or integrated with fossil fuel heat plant

Lucien Genge: Evaluating Germany's Ammonia Economy: A Comprehensive Analysis of Application-Specific Demands and Well-to-Tank Supply Costs

Elisa Guelpa: Solutions to reduce supply temperature in existing small-to-large scale DH networks: lesson learnt by the project "Leave 2nd generation behind"

Aleksandr Hlebnikov: Evaluation of a Technical Solution for Seawater District Heating and Cooling Systems

Rahul Mohandasan Karuvingal: Analyzing Complex Network Hydraulics and Control Strategies in Cold District Heating Networks via Dynamic Thermo-Hydraulic Simulations

Ali Kök: Achieving Carbon Neutrality in District Heating: The Impact of Temperature Levels on the Supply Mix of EU-27 in 2050

Niklas Kracht: Feasibility study of an innovative drilling method for inclined medium-deep borehole heat exchangers in a 5th generation district heating concept

Alessandro Maccarini: Techno-economic evaluation of 4th and 5th gen. DH networks and comparing to individual heat pumps: Idea and concept of a simple decision support tool

Graeme Maidment: Energy Superhubs - the use of supermarkets as local energy centres

Aadit Malla: Modelling the potential for district cooling

Houssam Matbouli: Assessing the ability to reduce the supply temperature of a district heating network following the oversizing of diameters due to building renovations

Tom Naughton: Practical experience of converting a 1970s UK social housing block into a 4GDH network with independent quality assurance support

Henrik Pieper: Heat pump configurations for aquifer thermal energy storage

Eftim Popovski: The role of solar district heat in the energy transition of the German heating sector

Els van der Roest: Flexibility of a low temperature District Heating system with Power-to-Heat and ATES

Thomas Schmidt: Emission-free heat supply for a large new residential area with a smart combination of natural heat sources

Martin Sollich: Unlocking the energy efficiency potential of heating networks through low-temperature design and optimal retrofit

Seyed Shahabaldin Tohidi: Optimal price signal generation for local energy management using flexibility function

Lei Wang: Case study of a local district heating expansion scenario n scenario within the framework of EMB3Rs

Daniel Zinsmeister: Flow direction in district heating and cooling grids with booster heat pumps: Does it make sense to have unidirectional flow?

Electrification of transport, heating and industry

Benjamin Blat-Belmonte: Smart Energy Systems and Electrified Transport: Analyzing the Flexibility Potential of Bus Fleet Operators in Germany

Noémie Jeannin: From PV to EV: Mapping the Potential for Electric Vehicle Charging with Solar Energy in Europe

Alaize Dall'Orsoletta: The systemic impacts of electric vehicles' uptake: A conceptual model

Oliver Ruhnau: Representing electric vehicles in energy system models: an accurate and scalable aggregation approach

Judith Stute: How do dynamic electricity tariffs and dynamic grid charges interact?

Institutional and organisational change for smart energy systems and radical techno-logical change

Anders N. Andersen: Major economic opportunities and challenges for Danish wind farms and district energy plants of German special regulation and netting

Elisabeth Andreae: The impact of offshore energy hub and hydrogen integration on the Faroe Island's energy system

Julia Barbosa: Game-theoretic Analysis of Suppliers' Market Power in Local Multi-Energy Markets

Anna Billerbeck: Is Germany on the right way for the market uptake of large-scale heat pumps in district heating? An analysis of the economic framework conditions

Nina Kicherer: District heating organizational models for a cost-effective energy transition

Kristina Lygnerud: Business models for low temperature district heating - 10 case studies

Hironao Matsubara: Design of smart energy system for decarbonization leading areas in Japan

Bent Ole Gram Mortensen: Consumer empowerment in a time of change in the energy sector

Christoph Neumann: Redispatch approaches in European power systems – towards harmonization or divergence?

Marianne Petersen: Vision of Offshore Energy Hub at Faroe Islands: The Market Equilibrium Impact

Lucy Sherburn: Development of a heat network typology for use within a heat network technical assurance scheme

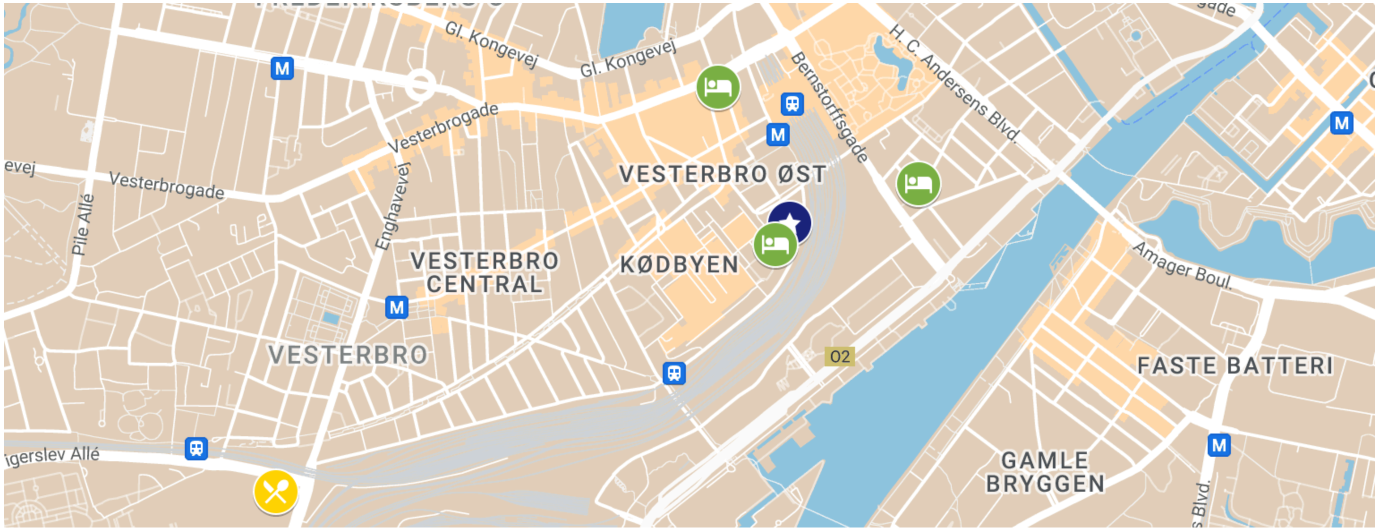
Daniel Møller Sneum: End-users' up-front payments in district heating: Striking the balance between competitive price and long-term risk

Freddie Valletta: Development of a new standardised testing regime to improve performance levels of residential heat interface units in the UK district heating market

Zhe Zhang: Challenges of setting up energy communities involving the Danish public sector: lessons learned

MAP OF COPENHAGEN

Conference area



Conference venue

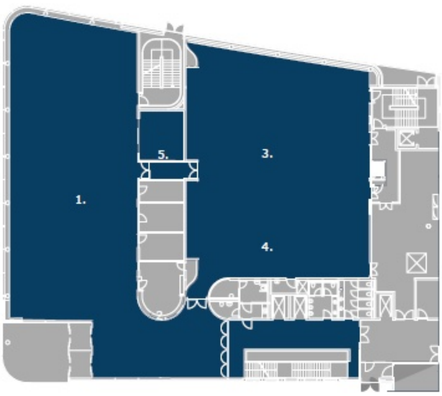
Accomodation

Conference dinner venue

Map of Conference Venue

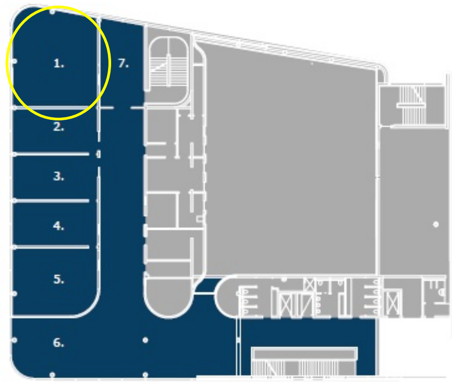
DGI Byen

Map of CPH Conference



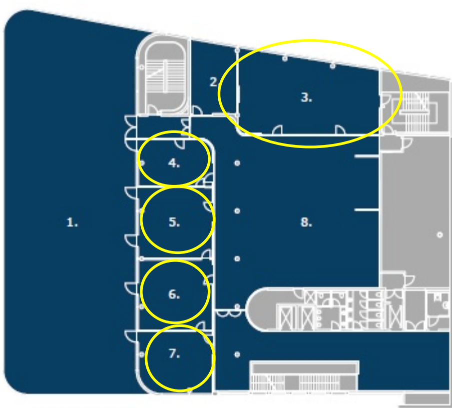
CPH Conference – Stuen

1. Foyér
2. Reception
3. Sankt Hans Torv
4. Nørrebros Runddel
5. Garderobe



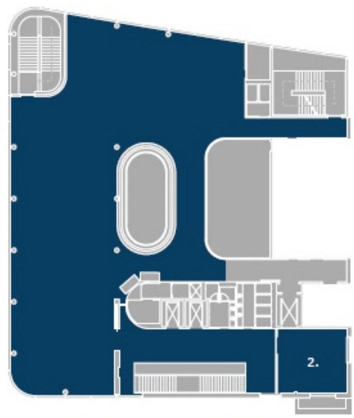
CPH Conference – 1. sal

1. Kastrup Lufthavn
2. Christianshavn
3. Islands Brygge
4. Christiania
5. Amager Strandpark
6. Pause / Loungeområde
7. Pause / Loungeområde



CPH Conference – 2. sal

1. Tagterrasse
2. Istedgade
3. Hovedbanen
4. Tivoli
5. Vesterbro Torv
6. Enghave Plads
7. Kødbyen
8. Pause / Loungeområde



CPH Conference – 3. sal

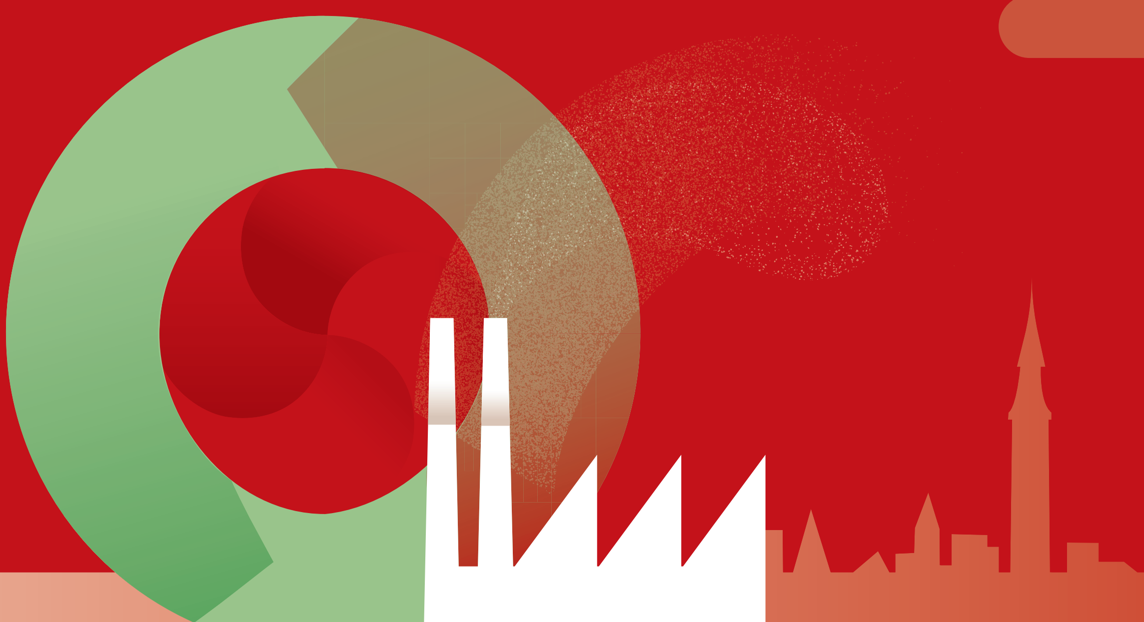
1. Østerbro
2. Trianglen

Excess heat is the world's largest untapped source of energy

In the EU alone, excess heat amounts to 2,860 TWh/y, nearly equivalent to the EU's total energy demand for heat and hot water in residential and service sector buildings. Much of this excess heat could instead be captured and reused.

The solution already exists
Heat recovery technologies can use excess heat from industries, wastewater facilities, data centers, supermarkets, metro stations and commercial buildings. And the excess heat can be reused to supply a factory with heat and warm water or exported to neighboring homes through a district energy system.

Whyee.com
Learn more about how energy efficiency solutions can accelerate the green transition.



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ENGINEERING TOMORROW

Danfoss

HOFOR is the largest Danish multi-utility company supplying district heating, town gas, district cooling, water, and handles wastewater in the capital area of Denmark. In addition, HOFOR owns and operates the Amager Combined Heat and Power Plant plus several wind turbines and solar parks.

HOFOR District Heating has three main ambitions:

- To be as green and sustainable as possible
- To deliver stable and safe heat to our customers
- To offer our customers affordable and competitive district heating

Hence, we are focused on improving the economic efficiency of the district heating network and the performance of the customers' heating systems, thus improving their experience. To achieve this, we use state-of-the-art technology, e.g., smart energy systems.

HOFOR

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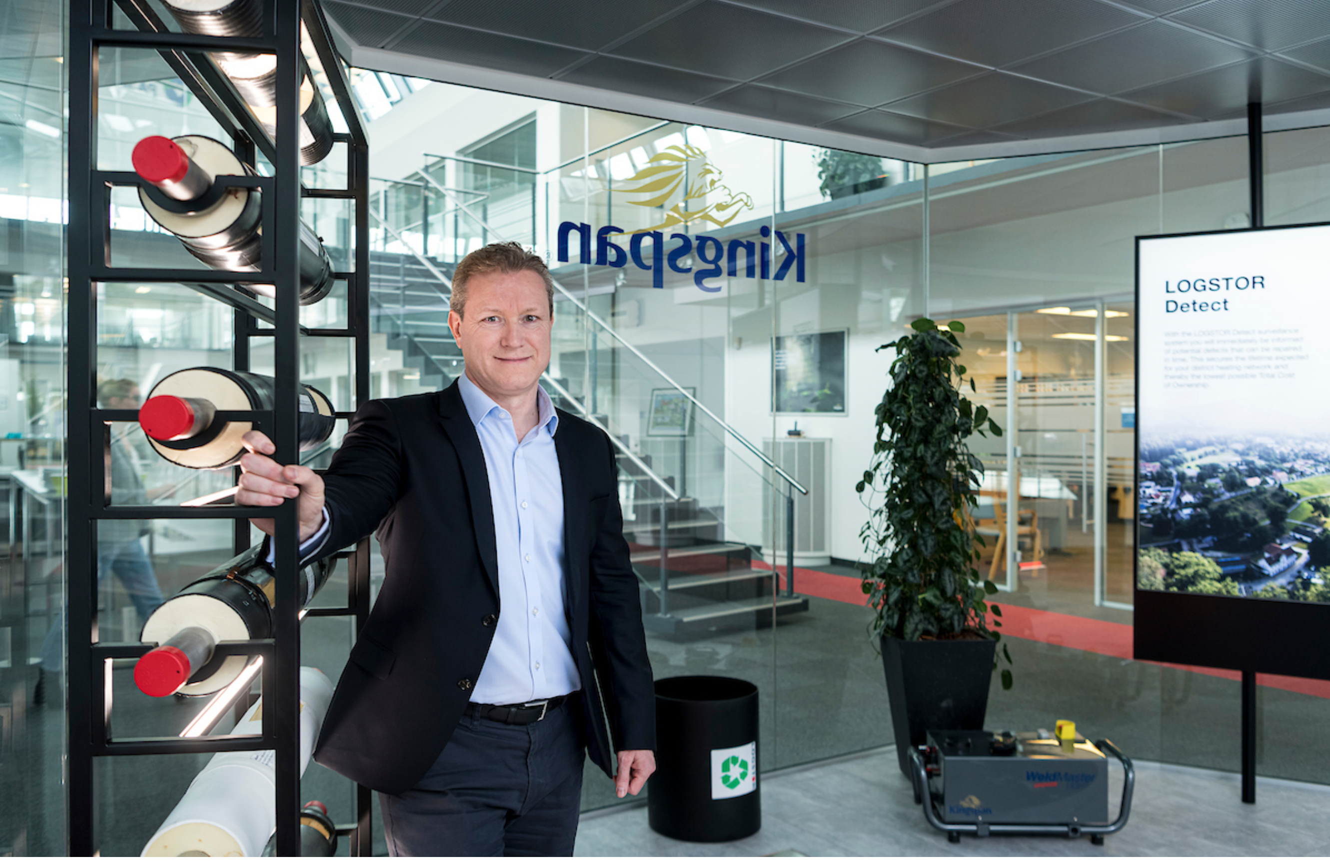
Best Presentation Award is donated by Kamstrup

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.

”We are happy to once again take part in the SES Conference as sponsor. Our focus is on developing data-driven solutions and services that enable utilities to optimise their business and grow the district heating footprint. We are excited to be contributing to reaching a more energy sustainable and efficient energy supply and realising the truly intelligent and integrated energy system of the future” says Steen Schelle Jensen, Head of Business Development, Heat/Cooling at Kamstrup.

Best Presentation Award ceremony 2022. Photo: May-Britt Vestergaard Knudsen



We take our role as a green company very seriously.

We believe that we all play an important role in reducing the energy consumption, and in developing an energy society that counter fights CO_2 emission and has no negative impact on our environment.

We believe that society must be much better at recycling materials and we believe that we need to incorporate recycling into new pre-insulated pipe projects from the outset. Through several "green" projects, we have proven that our vision which aims at 100 % recycling and circular economy holds true.

We do not only care about the flow of hot water in our pipes, whether this is produced from fossil fuel or renewable sources. We also care about how pre-insulated pipe systems are made in a sustainable way to enable the best and cleanest way of heating.

"Based on the above, our green vision goes beyond the basics, so rest assured that we will keep pushing boundaries, thus innovating for our customers and for a better tomorrow", says Terry Mc Givern, Managing Director for Kingspan LOGSTOR.

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Best Presentation Award
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Building value that matters
Copenhagen Infrastructure Partners is a global leader in renewable energy investments and makes significant and meaningful contributions to the green transition. We manage 11 funds and have a market-leading portfolio of green energy projects of more than 100 GW that create long-term value for our investors, local communities and the planet.
Our 2030-ambition of investing 100 billion euros will enable our green energy projects to reduce emissions by more than 100 megatons of CO2.
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Reduce CO2 emissions and operational costs

Gradyent enables district heating companies to optimise, decarbonise, and grow their grids through a real-time Digital Twin Platform. We support district heating companies to take on the climate challenge and to keep delivering affordable and reliable heat. We work with companies across Europe, to improve the grid performance, reduce CO2 emissions, save operating costs, and to make smarter business decisions.

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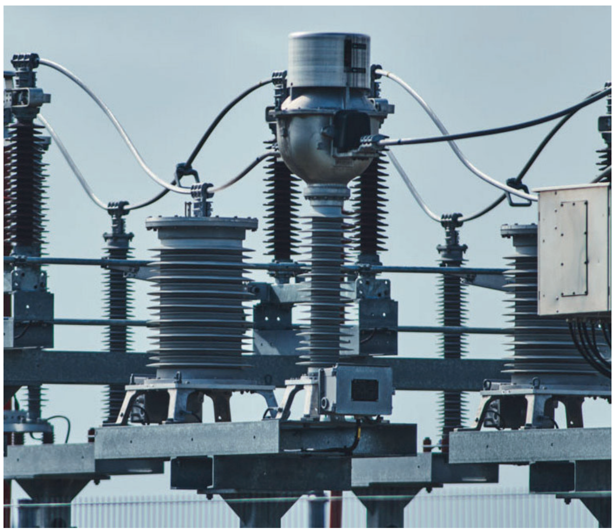
Green Power Denmark is at the forefront of the green energy transformation. We unite stakeholders across the entire green value chain to ensure a rapid shift to green energy for the benefit of our citizens, climate, and businesses.

Join us in this exciting journey towards a greener, more sustainable future with Green Power Denmark!

Read more at: **www.greenpowerdenmark.dk**



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- ACCELERATING RESEARCH, TECHNOLOGY DEPLOYMENT AND DEVELOPMENT WITHIN GREEN FUELS

MISSION GREEN FUELS

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June 2022

Partners
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MissionGreenFuels is a mission-driven public-private partnership with the ambition to contribute substantially to the decarbonization of the transport, aviation and shipping sector and to support Danish research, innovation, growth, job creation and export potential within the field of green fuels.

The partnership is led by the secretariat which consists of Aalborg University, Energy Cluster Denmark and Danish Center for Energy Storage.

AALBORG UNIVERSITY DENMARK · energy CLUSTER DENMARK · DaCES Danish Center for Energy Storage

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Innovation Fund Denmark

This project has received funding from The Innovation Fund Denmark – 1150-00001B.


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CCUS: A key piece of the green puzzle
To effectively address climate change, we need to limit the concentration of CO2 in our atmosphere. The switch to renewable energy sources is critical, but we won't reach our climate targets in time by relying solely on this transition. And time is of the essence…
INNO-CCUS is a collaboration of more than 75 public and private partners working together to accelerate the green transition of society. Our mission is to advance scalable and financially sustainable solutions to capture, store, and use CO2 (CCUS) – paving the road to carbon neutrality.
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Previous winners of the Best Presentation Awards

Best PhD/Postdoc Presentation:

2022: Rasmus Magni Johannsen, Aalborg University

2021: Daniel Møller Sneum, Technical University of Denmark

2020: Martin Heine Kristensen, Affaldvarme Aarhus

2019: Maria Jangsten, Chalmers University of Technology

2018: Britta Kleinertz, Research Center for Energy Economics

2017: Kanau Takahashi, Kyoto University

2016: Magnus Dahl, Aarhus University/AffaldVarme Aarhus

2015: Dorte Skaarup Larsen, Technical University of Denmark

Best Senior Presentation:

2022: Els van der Roest, KWR Water Research Institute

2021: Kristina Lygnerud, Halmstad University

2020: Matteo Giacomo Prina, EURAC Research

2019: Henrik Madsen, Technical University of Denmark

2018: Benedetto Nastasi, TU Delft

2017: Svend Svendsen, Technical University of Denmark

2016: Martin Crane, Carbon Alternatives Ltd

2015: Urban Persson, Halmstad University

CONFERENCE CHAIRS

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

Professor Henrik Lund is Editor-in-Chief of Elsevier's international journal ENERGY and a world leading scientist. He is ranked among the top 1% researchers on the world on the Thomson Reuter's list of highly cited researchers. He holds a PhD in "Implementation of sustainable energy systems" (1990) and a senior doctoral degree in "Choice Awareness and Renewable Energy Systems" (2009). Henrik Lund has 40 years of research experience and involvement in Danish energy planning and policy-making. Among others, he has been involved in the making of the Danish Society of Engineers' proposal for a future 100% Renewable Energy Plan for Denmark. He has headed several large research projects in Denmark and Europe – among others the 4DH research centre. Henrik Lund is the main developer of the advanced energy system analysis software EnergyPLAN, which has several thousand registered users around the world. Henrik Lund has contributed to more than 500 books and articles.

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.

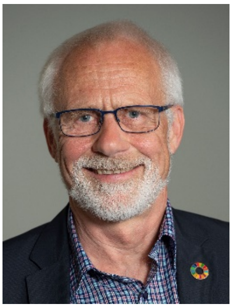
Recently he started the new Elsevier Journal Smart Energy. In addition, he is a member of The Danish Academy of Technical Sciences (ATV), a board member at The Danish Energy Technology Development and Demonstration Programme (EUDP), Radius Elnet and chairman of the Advisory Board of the CIP Foundation.

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.

PLENARY KEYNOTE SPEAKERS

Kristian Jensen will give the keynote speech: Energy Security vs Secure Energy.

Kristian Jensen is CEO of Green Power Denmark, a non-commercial business organisation gathering around 1500 members from across the green energy value chain. Kristian Jensen has been a member of the Danish Parliament for The Liberal Party from November 2007 to March 2021. During this period, he was Denmark's Minister for Foreign Affairs, Minister of Finance, and Minister of Taxation.

Christina Grumstrup Sørensen will give the keynote speech: Supplier of green capital to large scale renewable energy projects.

Christina Grumstrup Sørensen is a senior partner at Copenhagen Infrastructure Partners, the world's largest fund manager of greenfield investments in green energy infrastructure. To date, CIP has raised EUR 19 billion from more than 140 international institutional investors worldwide. In her current role in CIP, she is particularly focused on Investment Management, working with its construction and operating projects as well as the technical and commercial aspects of its investments. Before joining CIP in 2014, Christina Grumstrup Sørensen was Senior Vice President in DONG Energy (now Ørsted), heading offshore wind project development. Before DONG Energy, Ms. Sørensen was an Engagement Manager at global consultancy firm McKinsey & Company for seven years. Christina Grumstrup Sørensen is a member of the board of directors of DSB A/S (the Danish Railway Company) and holds a Master of Science in Engineering (Mechanical Engineering) from the Technical University of Denmark.

Philip Cole will give the keynote speech: Accelerating Wind Energy Growth in Europe: A Call for Robust Industrial Policy.

Philip Cole is Director of Industrial Affairs at WindEurope, the trade association representing over 500 companies in the wind industry. Focused on supporting and growing the wind energy industry's manufacturing presence in Europe, he ensures that the voice of manufactures and the wider supply chain is heard and that they can access the support they need through his established networks within the European Commission, European Parliament, OECD and National Governments. His key focus areas include access to investments for supply chain infrastructure and ensuring a level playing field for European manufacturers. Since 2020, he has been a Board Member of the European Forum for Manufacturing which was established by the European Parliament to ensure that the requirements of the supply chain across Europe were taken into consideration when making policy decisions. Prior to joining WindEurope, he spent 10 years in strategy and commercial roles with a focus on Europe and the Middle East within global manufacturing organisations including Kellogg's, Lindt & Sprüngli and L'Oréal.

Hans van Steen will give the keynote speech: Towards a Sustainable and Resilient European Energy System with Energy Efficiency.

Hans van Steen is Principal Adviser for « an integrated renewable energy strategy towards the 2050 carbon neutrality objective » in the Directorate General for Energy in the European Commission. Mr van Steen holds a Master's Degree in Political Science from the University of Århus, Denmark. He began his career in the Danish Ministry for Education and later moved to the Ministry for Energy as Head of Sector for European and Nordic energy co-operation. He joined the European Commission in 1989 as a Seconded National Expert, working mainly in the area of energy technology dissemination. Following several assignments in the Commission in the fields of energy and transport, he became Deputy Head of Unit for Inter-institutional Affairs (2001 – 2006), Head of Unit for Renewable Energy (2006 –

2013), Head of Unit for International Energy Relations and Enlargement (2013 – 2017) and Adviser on Renewables, Energy Efficiency Research and Innovation (2017 – 2022). He was Acting Director (Just Transition, Consumers, Energy Efficiency and Innovation) from 2018 to 2021. Mr van Steen took up his current position on 16 January 2022.

Aurélie Beauvais will give the keynote speech: Resource efficiency: a new moto for the heating & cooling transition.

Aurélie Beauvais is Managing Director of Euroheat & Power, the European association promoting sustainable district heating and cooling solutions. With extensive expertise in public affairs and political strategy, she spent more than ten years in Brussels shaping key European energy and climate legislation, from the Clean Energy Package to the Fit for55 package. She has held a number of executive and management positions in the energy and climate sector. Aurélie was Deputy CEO and Policy Director of SolarPower Europe from 2017 to 2021, and headed the European Affairs Department of the French Electricity Union from 2012 to 2017.

Goran Krajačić will give the keynote speech: Opportunities for increasing energy efficiency and decarbonisation of heating in the Eastern and South-eastern Europe

Dr.sc. Goran Krajačić is associate professor at the Department of energy power, engineering and environment at University of Zagreb FSB.
His field of work includes energy markets, research in energy planning, energy system optimization; island energy system modelling and optimization, development of models for simulation of energy systems, renewable energy sources, energy storage, energy economics and policy. Since his employment at DEPEE, he has been working on the many international and EU projects as well as on the national project Smart Energy Storage for Sustainable Development of Energy Systems. He worked on the development of SEAPs for local communities on islands and the development of financial mechanisms for support of energy storage

technologies. He was also involved in the development of Strategy for self-sufficient island Unije as well as several other strategies for achieving 100% RES energy systems on islands. Currently, he is coordinating FSB's participation in several Horizon 2020, Horizon Europe and LIFE projects. Since 2002, he has been a member of the organising committee of the Sustainable Development of Energy, Water and Environment Systems (SDEWES) Conference and he is secretary of the International Centre of Sustainable development of Energy Water and Environment systems. He is a member of the Croatian Academy of Engineering. The results of his scientific work were published in more than 100 papers and his h index is 35.

Plenary Keynote: Kristian Jensen

CEO of Green Power Denmark

Energy security <–> secure energy

Abstract

Europe faces a dual challenge in its energy sector: ensuring a sufficient supply for the upcoming winter, and bolstering security against physical and digital threats. With a heavy reliance on imported natural gas, especially from Russia, Europe's energy security is subject to geopolitical tension, price spikes, and potential supply disruptions. Simultaneously, Europe's energy infrastructure is increasingly vulnerable to cyberattacks and terrorism, which could disrupt power supplies, manipulate energy prices, and cause extensive damage to infrastructure.

Mr. Kristian Jensen from Green Power Denmark will present their vision for tackling these interconnected issues. His solution lies in accelerating the shift to renewable energy sources to reduce reliance on imported natural gas. Renewable energy can also provide a decentralized energy infrastructure that is resilient to cyber and physical threats.

Plenary Keynote: Christina Grumstrup Sørensen

Senior partner at Copenhagen Infrastructure Partners

Supplier of green capital to large scale renewable energy projects

Abstract

Copenhagen Infrastructure Partners (CIP) was founded in 2012 as a private equity fund and an industry-based energy entrepreneur linking capital and greenfield energy infrastructure projects. CIP’s 10 funds have a pipeline of more than 100 GW of renewable energy projects across the world. This includes the world’s largest pipeline of offshore wind projects and the world’s largest portfolio of Power-to-X projects. And currently, CIP has taken Final Investment Decision (“FID”) on 34 investments – spread across 24 countries - in large-scale renewable energy infrastructure with a total capacity of approximately 12 GW.

Through its investments, CIP intends to add new, critical renewable energy infrastructure that contributes to the transition towards a clean, reliable, and affordable energy system. Through 2030 CIP’s projects are to reduce global emissions by 100-150 megatons of CO2. This is equivalent of up to 1% of the global emission reductions required by 2030 to stay on track to meet the Paris Agreement emissions reduction goals.

And the momentum for renewables is positive and the capital necessary for investments of this magnitude is plentiful. The current cost-competitiveness of green energy will further accelerate the green transition and the geopolitical tensions, and a soaring climate and energy crisis have forced countries and governments to rethink energy supply and the way we build energy systems going forward.

But how do we ensure that the current positive momentum manifests itself in enough concrete new projects – and how do we make sure that the necessary renewable energy infrastructure projects are not delayed by a supply chain under pressure? And how do you build greenfield projects in respect for the local community and biodiversity?

Plenary Keynote: Philip Cole

Director of Industrial Affairs WindEurope.

Accelerating Wind Energy Growth in Europe: A Call for Robust Industrial Policy

Abstract

Today wind energy plays a crucial role in meeting Europe's electricity demand, currently providing 17% of the total with the EU wanting this to be 43% by 2030. As European wind farms predominantly rely on European-made turbines, preserving existing manufacturing capacity while accommodating increased installation rates is imperative in order to ensure energy security for all Europeans.

Europe needs a robust industrial policy to meet these goals. Particularly at a time when we see increased competition from the US through the Inflation Reduction Act and from China's 'Made in China' industrial roadmap. The Net Zero Industry Act, which is the EU's attempt at creating an industry policy, does not go far enough. While innovation remains crucial, the focus should shift towards enhancing wind energy volumes through streamlined public funding initiatives. By emphasising the scaling up of wind energy projects, we can maximise the sector's potential and drive substantial contributions to Europe's clean energy goals.

Through coordinated efforts, policymakers and industry stakeholders can create a conducive environment to increase wind energy manufacturing capacity, accelerate deployment and successfully fulfil Europe's targets for a sustainable future.

Plenary Keynote: Hans Van Steen

Principal Adviser for «an integrated renewable energy strategy towards the 2050 carbon neutrality objective» in the Directorate General for Energy in the European Commission

Towards a Sustainable and Resilient European Energy System with Energy Efficiency

Abstract

The planet's biophysical dynamics are undergoing significant changes, leading to an increasing frequency and intensity of extreme weather events, as evidenced by the record-breaking year of 2021. This necessitates an urgent response to mitigate the effects of climate change, particularly by limiting global warming to well below 2°C, preferably 1.5°C, as outlined in the Paris Agreement. Moreover, the recent geopolitical events, i.e. the ongoing conflict between Russia and Ukraine, have shed light on the interdependence and complexities of international fossil fuel trade. Recognizing the need for diversification and reduced reliance on specific energy imports, the European Union is prioritizing a transition away from fossil fuel imports from Russia.

Central to achieving a clean, smart, and secure European energy system is the adoption of measures focused on energy savings, energy efficiency, and the deployment of renewable energy sources. The European Union has set ambitious objectives for a sustainable and decarbonized energy system, aligned with the goals of the Paris Agreement in Fitfor55 and on top of the in REPowerEU. Energy efficiency plays a pivotal role in supporting this transformation, providing cost-effective means to achieve climate neutrality alongside the accelerated deployment of renewable energy, actively promoted through frameworks like the recently agreed Renewable Energy Directive (REDIII).

The Energy Efficiency First Principle calls on Member States to prioritize energy efficiency in their planning and investment decisions. This talk aims to explore the efficacy of energy efficiency measures and their impacts, while considering the cost-effectiveness of renewable energy deployment. By addressing these crucial factors, we can pave the way for a resilient, low-carbon economy, ensuring the long-term security and sustainability of Europe's energy future.

This talk will elaborate on EU initiatives and achievements. The European Union has demonstrated its commitment to addressing climate change and advancing clean energy through various policies and actions, in particular the Energy Efficiency Directive (EED), the Energy Performance of Buildings Directive (EPBD), the Sustainable Product initiative (SPI), including eco-design and labelling policies, the EU Action Plan on digitalising the

Energy System, the forthcoming Action Plan on Heat Pumps, etc. etc. The talk will also touch upon the industrial policy aspects, including the Net-Zero Industrial Act.

Plenary Keynote: Aurélie Beauvais

Managing Director of Euroheat & Power, the European association promoting sustainable district heating and cooling solutions.

Resource efficiency: a new moto for the heating & cooling transition

Abstract

Heating and cooling account for half of the EU energy demand. With over 60% coming from fossil fuels. The transition of the heating sector is therefore essential to achieve the EU's climate targets, and break-free from fossil fuel imports dependency. The heating & cooling demand isn't only hooked on fossil fuels. It is by nature a seasonal demand, subject to wide variations which put the European energy system under pressure, and complicate the im- plementation of robust decarbonization strategies. To address this multidimensional chal- lenge, resource efficiency imposes itself as a new moto. But what does it mean?

On its decarbonization journey the heating & cooling sector cannot rely solely on the growth of renewable electricity sources, for which competition in terms of uses and between sectors is becoming increasingly pressing (e.g; transport, industry, hydrogen, etc). It must capitalise on its ability to decarbonise using a wide diversity of clean energy sources, both electric and non-electric, and develop tailored decarbonization strategies adapted to local energy resources and buildings characteristics. This approach would not only acceler- ate the decarbonization of the heating & cooling sector but would also help to ensure a more secure and flexible EU energy system.

Plenary Keynote: Goran Krajačić

Associate Professor at the Department of Energy Power, Engineering and Environment at University of Zagreb FSB

Opportunities for increasing energy efficiency and decarbonisation of heating in the Eastern and Southeastern Europe

Abstract

Energy efficiency in the building sector has been constantly increasing in the Southeast and Eastern Europe region. However, the rates of renovation and initial conditions were relatively low. This, combined with financial barriers and subsidized energy, resulted in a lower impact than expected. Despite the presence of numerous district heating systems in the region, heavily subsidized fossil fuels hindered necessary investments, efficiency improvements, and fuel switching. Furthermore, the expansion of district heating was often impeded by influential lobbying from the fossil gas industry.

Given the European Union's objective of achieving a net-zero scenario by 2050 and complete decarbonization, now is the opportune time to tap into the vast potential for increasing energy efficiency and integrating renewables into the heating sector and buildings. The current geopolitical situation, specifically the war in Ukraine, has raised awareness among many people about the importance of ensuring security of energy supply. Therefore, it is crucial to advocate for solutions that promote the highest efficiency and utilize locally available renewable energy.

This presentation will provide a brief overview of the situation in the region, highlighting the

Felix Agner graduated the MSc Engineering Physics program at Lund University in 2019 and joined the department of Automatic Control in 2020. In 2023 he succesfully defended his Licentiate thesis dubbed "on hydraulic constraints in control of district heating systems".

Numerical Estimation of Improved Heat Transport Capacity using Load Control in a District Heating Grid

Felix Agner, Lund University, Ulrich Trabert, University of Kassel, Janybek Orozaliev, University of Kassel, Anders Rantzer, Lund University

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The transition towards sustainable and efficient heat supply in urban environments requires densification of heat consumption within existing district heating systems. For this purpose, the peak flow rate is a key system property which is bounded by pipe dimensions and pumping capacity. The peak flow rate constrains the number of customers that can be connected, and it may be a limiting factor in the reduction of supply temperatures in the transition to the 4th generation of district heating.
This work concerns the effort of reducing the peak flow rate of a district heating grid using load control. The evaluation is based on a full year of operational data from a subset of customer meters in a district heating system in Germany. This entails the primary side supply-and-return temperatures, along with hourly heat loads, for each customer. The investigation concerns how well the system could have been controlled with full a priori knowledge of this data. Two strategies for reducing the peak flow rate are investigated:
Fistly, a load reduction strategy, where the heat load of each customer is reduced during parts of the day. The reduction of the daily and hourly heat loads is limited. Secondly, a load shifting strategy, where the total daily heat load of each customer is maintained but shifted to different hours. Both methods are based on convex optimization schemes. A local and global version of each strategy is compared, such that either each building only minimizes their own peak flow rate, or such that all the buildings coordinate to minimize

the total grid peak flow rate. These methods are then compared to a crude baseline consisting of employing a static maximum flow limitation for each building. In the end, we compare the impact of the different strategies on the peak system flow rate and consequently heat transport capacity as well as flow-weighted return temperature.

Keywords: District Heating, Demand Response, Load Control, Pumping Power, Heat Transport Capacity

Arnau Aliana is a PhD fellow at ETH Zürich. His research focuses on building a bridge between policy-makers and energy planners. Tuomas Vanhannen is a PhD fellow at Tampere University. His research aims to remove barriers to the integration of low-emission energy into the energy system globally.

Policy representation in Energy System Models in context of Sector Coupling: A review

Arnau Aliana (1), Tuomas Vanhanen (2,3)**

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Sector coupling (SC) focuses on the integration of renewable electricity to end-use sectors and infrastructures of energy carriers such as heat, electricity, and gas. SC poses a complex challenge from a technical perspective, but with the technological developments in recent years, it also requires direct policy actions [1].
Energy system models (ESMs) are useful tools that enable the exploration and analysis of future energy scenarios and the evaluation of different policy options. Hence, ESMs are often used in energy policymaking, both for policy design and policy analysis.
In this study, we review the range of approaches to represent policy instruments in state-of-the-art bottom-up ESMs with relevance to SC. There are numerous techno-economic analyses of the future energy system including SC, but their detail in policy representation is unclear and policy-focused studies are scarce [2].
Our research question is: How are the main policies included in ESMs in relation to SC? This question is divided into sub questions: 1) What are the main studies based on ESM analyzing policies for SC in the European context? 2) Which SC applications are typically included in these studies? 3) How are policy instruments and policy mixes represented in these studies? 4) What policies are most often present in the analysis of SC applications? 5) Are there gaps or inconsistencies in policy representations?
Our work suggests that there is a research gap in assessing policy mix implications in SC. Our work underlines the need for further research and qualitative analysis for policy makers to better quantify the costs and benefits associated with SC related policies. We

expect that better representation of policies in ESMs could contribute to bridging the gap between modelers and policymakers, giving the latter better tools to guide the energy transition.

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Keywords: Energy system model, Sector coupling, Energy policy.

GBA leads the Renewable Energy and Thermodynamics research group. The research is concerned with the use of storage, transmission networks and energy conversion technology to facilitate integration of wind and solar energy in the energy system at all scales from continental to national and cities.

Exploring 2030 decarbonization scenarios of the European electricity sector using Modeling All Alternatives

Gorm B. Andresen, Tim T. Pedersen, Mikael Skou Andersen, Marta Victoria, Aarhus University
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Climate change mitigation is a global challenge, but it must be resolved by national-level authorities, resembling a “tragedy of the commons”. This paradox is reflected at the European scale, as climate commitments are made by the EU collectively, but implementation is the responsibility of individual Member States. In this study, we use a brownfield electricity system optimization model in combination with the Modeling All Alternatives methodology to investigate a wide range of different effort sharing scenarios that are all in line with the 2030 ambitions of the European Union. The result show that it is viable to achieve between 55% and 75% decarbonization, but only very particular effort sharing schemes can achieve the theoretical minimum system cost. In most cases, an additional cost of at least 5% is incurred. The results also show large variations between individual countries: for some countries, e.g. with good hydro and/or existing nuclear capacities, full decarbonization is cost optimal. Other countries, e.g., with a large existing fleet of coal power plants, face high abetment costs. Countries with good renewable resources represents typically represents a category in-between where abatement costs are initially low, but rise as their penetration increase. The Modeling All Alternatives methodology extends the Modelling to Generate Alternatives methodology as all feasible solutions to the problem are identified instead of only a relatively small selection. The method allows rigorous statistical analysis of the results an aim to reduce modeler bias.

Keywords: Energy justice, EU ETS, Energy System Optimization, Modeling to Generate Alternatives

Daniël Bakker works in the Energy and Circular Systems team of KWR Water Research

Institute as a researcher and project manager. Daniël focuses on the integration of different pieces to the puzzle, such as solar energy, green hydrogen and ATES into a sustainable, 'water-wise' solution.

Advancing the use of datacenter waste heat, solar thermal, power-to-heat and heat storage with a digital twin for district heating supply in Groningen

Daniël Bakker, 1
Dirk Vries, 1
Els van der Roest, 1
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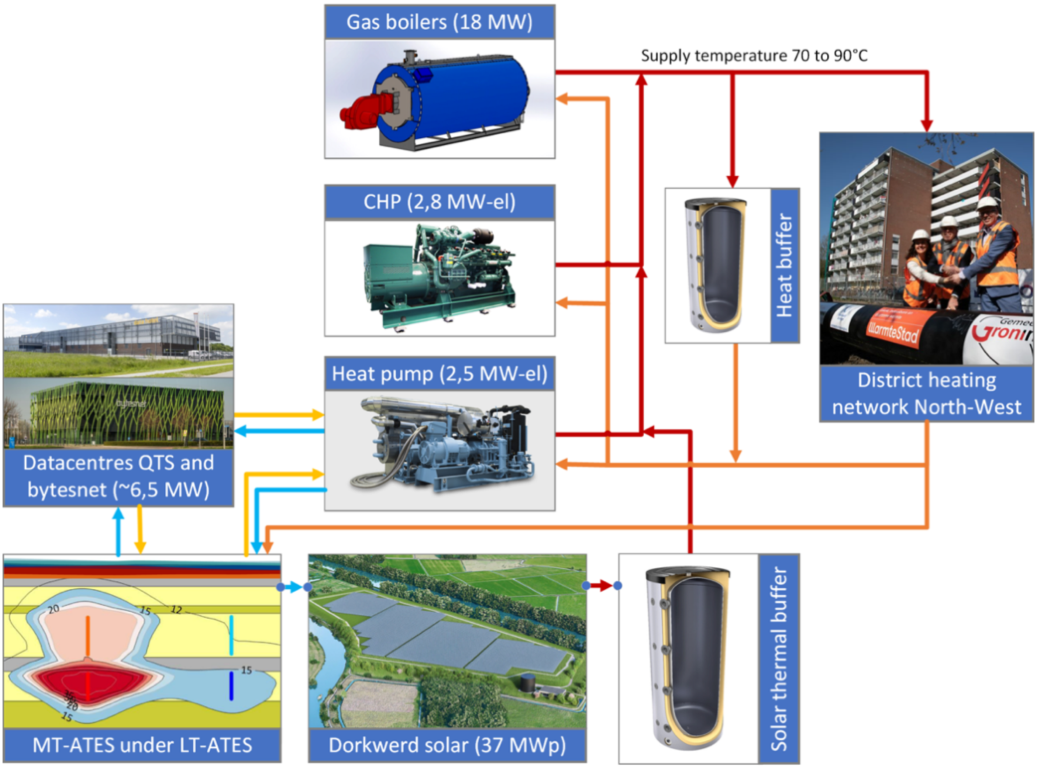
Heat supplier WarmteStad is expanding their facilities to provide heat to approximately 10.000 housing units in the north-western part of Groningen (The Netherlands) using a district heating network. In their heat plant, WarmteStad upgrades the waste heat of two nearby datacenters (up to 6,5 MWth) to reach the supply temperature (70-90°C) using heat pumps. The electricity for the heat pumps is provided by CHPs, adding additional heat production. In order to operate the heat pumps and CHPs steadily, a heat buffer is applied to smoothen the peaks in the heat demand profile. WarmteStad employs a predictive control strategy to improve the performance of the heat buffer within its physical boundaries. Gas-fired boilers provide peak capacity.
In the upcoming years WarmteStad will expand their production by purchasing renewable heat from a solar thermal collector field (37 MWp-th) connected to an additional buffer tank. This solar heat mostly covers the heat demand from May up to September. During these months the waste heat from the datacenters and any excess solar heat are stored for use during winter. A layered aquifer thermal energy system (LT above MT) will be realized for this purpose. Moreover, the open multi-source approach of WarmteStad enables new opportunities for the addition of renewable heat sources such as waste heat from food industries or regionally produced green hydrogen.
In cooperation with WarmteStad, KWR Water Research Institute develops a digital twin of the heat plant. The digital twin provides insight into the performance of the heat plant

and any potential modifications of the heat source strategy. Here we present the first results obtained using the digital twin. We show the performance of both present and future designs of the heat plant. In addition, we elaborate on the efficacy of different strategies aimed at a higher fraction of renewable heat delivered to the end-users, on the way towards net-zero.

Keywords: district heating supply, digital twin, power-to-heat, ATES



Moritz Bitterling is an Engineer/Physicist with expertise in optimization, control and machine learning for intelligent operation of solar energy systems. He studied in Freiburg, Montpellier, Trondheim and Longyearbyen, and obtained a M.Sc. in Applied Physics from the University of Freiburg in 2019.

Evaluating different artificial neural network approaches for forecasting heat demand in district heating networks

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Simon Gölzhäuser, Fraunhofer-Institut für Solare Energiesysteme ISE, Freiburg, Germany.
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District heating networks form complex systems that must be operated under widely varying boundary conditions (weather, user behaviour, energy afervailability, power grid requirements). Smart control of the heat generation based on forecasted demand is particularly important for energy efficient operation. Having precise information available about the future behaviour of the different heat sinks and fluctuating heat sources can help operators to control their energy production and distribution much more effective. Such an approach allows at the same time meeting heat demand, minimizing cost/emission and maximizing energy efficiency.
In this contribution, we evaluate different Artificial Neural Networks (ANN) methods for predicting information about the heat demand which can then be used in various control processes. We compare simple low-cost methods such as linear regression and small Feedforward ANN with more sophisticated methods such as Recurrent Neural Networks and with Convolutional Neural Networks. The aim is to have an ANN with a good generalization capability that produces high-quality results for the diverse profiles of the various heterogeneous heat sources and sinks. The methods are evaluated based on data from a real District Heating Network at Stiftung Liebenau Meckenbeuren, Germany with multiple fossil and renewable sources (CHP, biomass, natural gas, oil, waste combustion) and a variety of heat sinks (residential, laundry, green house, workshop, medical station). The results show that the more advanced models outperform the simpler ones and trends are well captured and predicted. However, dynamic peaks of heat demand are much harder to predict.

We evaluate different options to utilize the new forecast information for improved heating network operation. Comprehensible confidence interval description of the forecasted values is one important key in this sense. A conservative economic estimation of the benefit/cost ration has been conducted for the reference case of the DHN in Liebenau. It leads to the conclusion, that such an approach is interesting also from an economic point of view, since the investment is very low. Follow-up work aims at integrating the developed forecast method into an existing network control system to optimize operation.

Keywords: District Heating Networks, Time Series Forecasting, Artificial Neural Networks, Predictive Control, Smart Operation

Andreas Bott is a PhD student at the Institute for "Energy Networks Information & Systems" at the Technical University of Darmstadt. His research focuses on ML-aided methods for probabilistic state estimation in district heating networks.

Efficient Training Data Generation for Learning-Based State Estimation in 4th Generation District Heating Grids

Andreas Bott, Technical University of Darmstadt. Florian Steinke, Technical University of Darmstadt.

Andreas Bott (presenter) andreas.bott@eins.tu-darmstadt.de

Determining the grid state, i.e., pressures, temperatures, and mass flows, for a known supply and demand behaviour is a recurrent task when analysing district heating grids. For the commonly used steady-state formulation of the grid equations, deep neural networks (DNN) can be used as state estimators to reduce the computational burden. This is particularly important for applications where state estimators are solved repeatedly, e.g., in probabilistic settings.

This work proposes and compares two approaches to train such a DNN. First, a classic sample-based approach minimises the DNN's deviation from precalculated training samples. We propose a novel importance-sampling-based algorithm (IS) to generate the samples efficiently. The second approach is a physic-aware, sample-free training procedure that directly minimises state equation violation.

The baseline approach to generate data for the sample-based training approach is to draw samples from a prior distribution over the heat powers and feed-in temperatures and then obtain the grid states by solving the grid equations for each sample. The literature discusses different algorithms for this step, which can be grouped into decomposed, integrated and combined approaches. The algorithms are all iterative, making this approach computationally costly.

For our IS algorithm, we draw samples from a proxy distribution over the mass flows and feed-in temperatures at the supplies and demands. We then calculate the corresponding grid state and the heat powers based on the sampled mass flows. The calculation steps are similar to the decomposed model; however, solving each sample requires only a single iteration. The deviation between the proxy and the original distribution can be compensated via sample weighting. Fig. 1 illustrates the data flow of both algorithms.

Depending on the grid's layout, our IS algorithm is about one order of magnitude faster than the baseline. This allows using larger training data sets for learning the DNN, improving their quality.

For the second approach, we train the DNN in a physics-aware way by directly minimising the violation of state equations. Although the DNN training itself is more complex, the advantage of this training scheme is that it does not require precalculated state samples.

Keywords: District Heating, Numerical Analysis, Deep Neural Network, Physics-aware Neural network, Importance Sampling

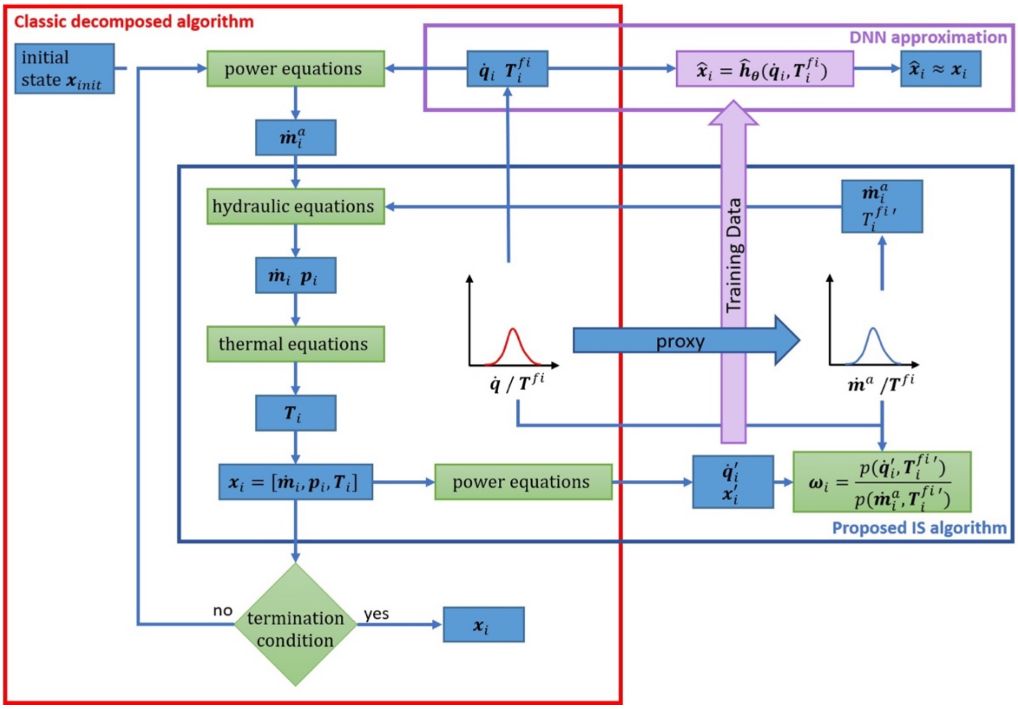

Figure 1: A DNN can be used to approximate a state estimator (purple box). We propose a new IS algorithm (blue box) to generate training samples for such a DNN. Opposite to the classic decomposed method for state estimations (red box), the IS algorithm solves the hydraulic, thermal and power equations only once per training sample.

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 optimization of low-temperature district heating supply concepts based on renewable energies and waste heat.

IEA DHC Annex TS8: Experimental investigations of district heating systems

Anna Cadenbach (née Kallert), Fraunhofer Institute for Energy Economics and Energy System Technology and Dennis Lottis, Fraunhofer Institute for Energy Economics and Energy System Technology

Anna Cadenbach (née Kallert) (presenter) anna.cadenbach@iee.fraunhofer.de

To meet the climate targets the transformation of existing and the construction of new district heating (DH) grids are a central measure. To reach these goals new approaches for flexibilization, digitalisation and sector coupling are of great importance. However, especially for multivalent and volatile usage of heat sources, new operating strategies and the conversion of supply infrastructures are necessary. The examination and enhancement of new DH supply strategies as part of laboratory investigations and field experiments in conjunction with digitalisation applications (e.g. digital twin) contributes to improving system performance and promoting the expansion of thermal networks. In addition, the experimental investigation offers a number of advantages over software-based analyses, like a more realistic depiction of the physical behaviour. On top of that, experimental investigations can also support the improvement (e.g. validation) of software and the quality of the calculation data (e.g. for experiments) used.
Beyond this background the recently initialised cooperation project "IEA DHC Annex TS 8 – Experimental investigations of DHC systems" aims to advance and demonstrate empirical research for DH expansion by identifying appropriate digital technologies, robust data bases, and linking experimental facilities.
To realise the project targets, the project is divided in subtasks, which take up and connect the individual focal points. The first subtask deals with the analysis of requirements for flexible experimental studies for future DH supply and thus represents the essential working basis. Based on these findings, the next task is on the collection and compilation of design and control methods of test facilities using digital approaches. In order to achieve reliable results, the identification and consolidation of available data bases for

software-based and experimental investigations will be implemented as part of the third subtask. The fourth and the fifth task aims at documenting the existing test facilities and their networking potential. In the course of the sixth subtask, knowledge is transferred to business (e.g. overview of test facilities available worldwide, etc.) and the results are documented.

Keywords: experimental investigation of district heating, new operating strategies, laboratory investigations, field experiments, digitalisation

John Counsell is Professor of Digital Energy and Control Systems at the University of Chester. Previously he was the Professor of the BRE Centre in Energy Utilisation at University of Strathclyde. He pioneered DSR for electric heating inventing the CELECT standard in UK in 1995 at EA Technology.

Intelligently Controlled Solar Powered Energy Storage & Air-Source Heat Pump Home Heating System

John Counsell, University of Chester
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This paper builds on 15 years of research in to how to incorporate Demand Side Response (DSR) and building integrated solar energy generation (e.g. PV panels) and energy storage (e.g. Lithium Ion Battery or Feolite Thermal Battery) in to the dynamic operation of home heating systems using an Air-Source Heat Pump (ASHP) technology. The paper presents an integrated thermal storage and ASHP design by the innovative micro-SME Advanced Control Partnerships (ACP) and is modelled using the UK building regulations (i.e. BREDEM 12/SAP10.2) verified dynamic home heating system model methodology IDEAS+. IDEAS+ is a state-space represented dynamic model implemented using Matlab Simulink for open-source dissemination. IDEAS+ state-space model is used to design an innovative artificially intelligent thermostat to simultaneously control the home's thermal comfort whilst minimising the carbon emissions of the heating system. The results of ASHP with energy storage and DSR controls are presented and compared with the IDEAS+ results for a gas condensing boiler and ASHP powered from the national grid supply only.
The paper concludes that a PV powered high temperature thermal energy store can significantly enhance a ASHP heating system's responsiveness and controllability but without detriment to running costs and carbon emissions without the need for expensive Lithium batteries. This system also provides a viable alternative to gas condensing boilers in terms of running costs and much reduced carbon emissions. It is also shown that this system is superior in terms of energy efficiency and controllability compared with a grid power supplied only ASHP heating system.

Keywords: ASHP, Battery Storage, BREDEM, Control, CO2, Demand Side Response, Energy Storage, Heat Pump, Home Heating Systems, Modelling, PV, Simulink

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 the Forschungszentrum Jülich in Energy Systems Engineering (IEK-10). Her field of research is the modeling and simulation of district heating and cooling networks.

Development of the simulation tool HeatNetSim for thermal networks

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Sector coupling is a very promising approach to achieve decarbonization targets on a national and international level. The joint consideration of power, heat and gas grids enables the intelligent operation of these energy grids and thereby reveals synergies which cannot be recognized by the isolated consideration of the different energy grids. In order to be able to accurately analyze the potentials and limitations of the synergies, suitable simulation tools are required. These should allow a stand-alone simulation of the corresponding energy grid and at the same time guarantee the functionality of coupling with other energy grids. In this work, we present the steady-state simulation tool HeatNetSim, which fulfills the above-mentioned properties and focuses on the modeling and simulation of thermal networks.

As relevant components for the simulation of heating networks, we model a source, a sink, a pipe, a pump, and a heat pump, whereby the location of the components is according to the structure of 4th generation heating grids. In order to perform a simulation, input data is needed that includes the network structure, thermal demands, temperature levels and necessary parameters of the modeled components.

As a highlight, HeatNetSim is also suitable for modeling 5th generation thermal networks, which are defined by their bidirectionality. The bidirectionality enables the balancing of heating and cooling demands within the network contributing to a reduced residual energy supply by external sources. The modeling is implemented by placing the decentralized pumps in the substations together with the heat pumps. The heating and cooling demands of the substations then determine the flow direction, as flow reversal within the network is possible in HeatNetSim.

The presented simulation tool is a further development based on the open-source steady-state gas network simulation tool GasNetSim and is supposed to become open-source as well. It is developed in the programming language Python. This ensures an easy combination of both tools and at the same time no additional training in proprietary software is required. Furthermore, it opens up the possibility to run simulations of coupled energy systems to analyze the potential benefits and risks of sector coupling.

Keywords: District Heating Grid, Bidirectional Network, Energy System Simulation, Simulation Tool, Sector Coupling, Pipeline Network

Cameron Downing is a Researcher at the University of Chester funded by an EPSRC project to research the modelling of an innovative solar thermal storage solution in collaboration with Durham University. He has created the IDEAS+ model/ methodology for assessing heating solutions within a home.

A Simulink Based Dynamic Home Heating Model Calibrated with BREDEM 12

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The human race strives for lower global CO2 emissions, but poorly insulated homes especially in the UK require a number of interventions to achieve a near Net Zero Carbon impact. Space heating accounts for more than 2/3rds of the energy use in these homes and requires an accurate energy and thermal experience/comfort assessment model to verify the merits of any proposed intervention from the perspective of carbon emission, economics and required utility infrastructure. This paper presents a simplified state-space based dynamic model implemented in Matlab Simulink as the dynamic energy flow assessment model and its calibration with the UK Building Regulation's calculation method BREDEM 12. BREDEM 12 is based on empirical data sets and simplified thermodynamics of constructional physics. The presented calibrated model enables the energy usage and type of fuel used by the heating system to be assessed in terms of the reduction in energy use, CO2 emissions, impact on running costs and peak energy demands for grid supply infrastructure requirements. There is presently a gap in the readily available (i.e. freely disseminated) methods and models in the UK and perhaps globally to assess the impact of energy efficiency measures and alternative lower carbon heating technologies in homes using a dynamic model calibrated with real home empirical data. To plug this gap, the Inverse Dynamics based Energy Assessment and Simulation (IDEAS) methodology was conceived in 2012 by Murphy, Counsell et al. IDEAS has since been then updated to IDEAS+ to include a new thermal comfort method. This paper presents an update to the IDEAS+ methodology by adding in new models for the free heat and solar gains using BREDEM 12 documentation. In this paper IDEAS+ parametric values with a degree of uncertainty are calibrated using predicted data from the empirical based method BREDEM 12 by using a notional dwelling located in Sheffield in England. The comparative results of IDEAS+ model and BREDEM 12 are discussed to conclude that IDEAS+ is fit for purpose to assess the impact of low carbon heating technologies, energy

efficiency measures and intelligent/advanced control solutions including demand side response measures.

Keywords: BREDEM, Calibration, CO2, Control, Energy Efficiency, Heating Systems, Mod-elling, Simulink

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.

A Systematic Approach for Data Generation for Intelligent Fault Detection and Diagnosis in District Heating

1) Jonne van Dreven, Blekinge Institute of Technology and Flemish Institute for Technological Research (VITO). 2) Veselka Boeva, Blekinge Institute of Technology. 3) Shahrooz Abghari, Blekinge Institute of Technology. 4) Håkan Grahn, Blekinge Institute of Technology. 5) Jad Al Koussa, VITO. 6) Emilia Motoasca, VITO.

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District Heating (DH) systems contain the potential to play a significant role in the ongoing energy transition. However, some research suggests that DH substations may run sub-optimally due to faults, leading to a decreased efficiency of the DH network.
Intelligent Fault Detection and Diagnosis (FDD) can help to reduce the impact of faults. While conventional FDD methods have predominantly relied on (annual) manual inspections, it is impractical given the large size of DH networks. Machine Learning (ML) approaches have emerged as promising tools to enhance FDD.
A significant challenge in developing intelligent FDD methods is the lack of labeled data on machine health states. Obtaining labeled data from real-world DH systems is costly and impractical. Therefore, we propose a data generation approach through laboratory emulations that involves the creation of a physical replica of a system, retaining the original system's typical functionality and complexities, i.e., emulations can reproduce the intricacies present in real-world DH systems.
The initial task of our study aims to generate time series data with a 10-second interval of a typical Belgian winter in a residential building. The setup consists of an indirect substation that receives heat from the laboratory's infrastructure and connects to various radiators situated within a climate chamber. Each experiment spans two weeks, comprising one week of training and validation data. Sensors for measuring temperatures and volume flow are strategically positioned on both the primary and secondary sides. We intend to collect data from various scenarios containing normal and faulty behavior, where the faults are based on the literature, reproducibility, real-world occurrence, and

hypothesis. Experimental complexities such as faults, thermostatic valves, and variable supply temperatures will be progressively added.

We expect to generate realistic ground-truth data in the next two months, which will serve as the foundation for training and validating accurate FDD ML models. Our research endeavors to address the existing research gap—namely, the scarcity of labeled data—within the domain of intelligent FDD for DH systems by proposing a systematic approach to data generation and a labeled data set.

Keywords: Artificial intelligence, data generation, machine learning, fault detection and diagnosis, district heating

Hermann Edtmayer is a research associate at Graz University of Technology, Institute of Thermal Engineering and has his main field of research in the topics of renewable urban energy supply, building energy modelling and simulation and spatial energy planning.

Virtual reality digital twin for immersive energy research and communication

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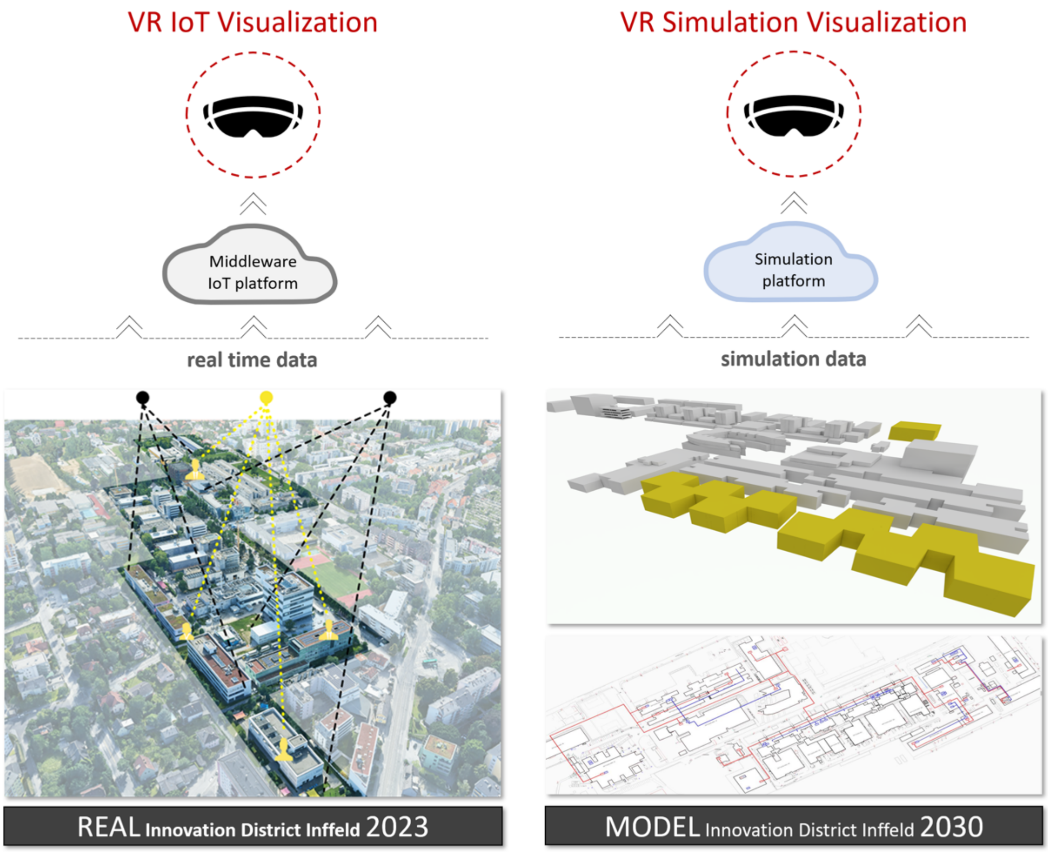
In this conference contribution we would like to present our work on the development of a virtual reality digital twin for energy research. Buildings and city districts are increasingly being developed in an integrated way, involving many disciplines simultaneously. As a result, the diversity of research elements and results as well as their interrelationships are becoming increasingly difficult to grasp. Traditional methods of data analysis, visualisation and communication are clearly reaching their limits here. However, making this content easy and intuitive to use for scientists, planners, decision-makers and other stakeholders is key to developing and implementing energy transition and climate change adaptation policies.
In the work presented here, we are addressing this issue by developing an immersive digital twin research and communication environment using virtual reality (VR) technology. The VR digital twin of the given test site, its buildings and energy infrastructure, is created using the tools Blender and Unreal Engine. The IDA ICE building simulation models and the IoT data feed from the live data acquisition are then connected to the digital twin. In order to implement this prototype in an effective and user-oriented way, the wishes and needs of selected user groups are integrated into the development from the very beginning with the support of social science. The immersive nature of VR opens up diverse and previously untapped opportunities to interact with simulation and monitoring data. As our brain perceives the virtual environment as real, there is no need for lengthy thought processes – the user is directly immersed. Complex content is intuitively grasped, parameters can be changed interactively, data is immediately visible and core

statements are easy to understand. The central result of the project will be a Virtual Reality digital twin environment of the test site "TU Graz - Innovation District Inffeld", see Figure 1.

Keywords: virtual reality, digital twin, immersive research interaction, integrative city development



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.

Development of simplified models for future district heating networks

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To date, fossil fuels account for the largest share of heat generation, and there are major efforts to replace them with renewables in order to reach climate targets such as reducing CO2 emissions. District heating is a proven technology for distributing heat over both large and small distances from central plants to various consumers. It also has a great potential to decarbonize the heating sector, as it can combine heat from different sources. This could not only help to use heat from renewable and waste heat sources, but also increase flexibility in the operation of district heating networks. Since district heating networks have existed for several decades, two fundamental questions arise: How can they be transformed into future-oriented networks and what should these future networks look like?
When modeling large district heating networks, simplifications are necessary to carry out simulations with reasonable effort. This concerns e.g. the grid topology (e.g. pipe bends, house connections) or an adequate grouping of consumers instead of the represention of individual buildings. This applies in particular to future district heating systems, which will be significantly more complex compared to today's networks. There are multiple reasons for the increasing complexity, e.g. decentralized heat sources, instead of one central generation plant, as well as challenges in operation such as reversal of flow direction. Especially when different scenarios are to be simulated and compared, an appropriate level of detail in the model is crucial.
Within this work, a simplified model of the district heating network of the Technical University of Darmstadt was set up using the modeling language Modelica. Its object-oriented and physics-driven approach is beneficial when modeling thermo-hydraulic phenomena such as the reversal of mass flow direction and pressure states at different locations. The comparison of the simulation results with measurement data shows that

the simplifications made are suitable for performing realistic simulations and obtaining meaningful results in terms of network conditions and operation parameters. Hence, the model can serve as a basis for the development and comparison of prospective scenarios in future work.

Keywords: future district heating networks, simulation, model simplification, Modelica

Paula Ferreira is Associate Professor at the Department of Production and Systems, University of Minho, Portugal. Her research interests are in the socio-economic impact assessment of industrial and energy systems, energy planning and project evaluation in line with the sustainable development.

Citizens' attitudes towards energy policy to foster the energy transition

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This paper is an initial approach to better understanding the energy consumers' attitudes towards policymaking. This issue becomes pressing for countries to promote energy transition, in the context of climate change and sustainable development targets. This work aims to address the topic and presents the results of an exploratory study that resorts to microdata from the public opinion surveys conducted by Eurobarometer, focusing on citizens' attitudes on EU energy policy, for the case of Portugal. A statistical analysis of about 1000 responses collected for Portugal in 2019 was conducted and allowed to assess how sociodemographic variables correlate to perception and priorities and how this can affect energy policymaking. The results demonstrate the importance assigned to investments in renewable energy sources, encouragement of energy research and innovation, empowerment of cities, communities and consumers and facilitating consumers' choices. All these factors can be closely related to three aspects that stand out in energy discourses: decentralization, digitalization, and decarbonization showing an overall positive attitude towards policies that can support this energy transition. Moreover, citizens' role and involvement are clearly highlighted and should be seen as one means to foster the energy transition. Our results reinforce the already established general perception that the clean energy transition cannot be achieved through technology and markets alone. Citizens' participation and social innovations are key strategies and legislative and non-legislative policies targeting these initiatives play a key role and tend to be generally welcome by the inquired population.

Keywords: Portugal, social involvement, statistical analysis, Eurobarometer, microdata

Pascal Friedrich is a PHD Student at the Economics of Multimodal Energy Systems Lab at Technical University of Darmstadt. He works on market-driven heat network modeling in the context of the project EnEff:Wärme – MeFlexWärme, funded by the German Ministry for Economic Affairs and Climate Action

Effects of network model simplifications in local heat markets on district heating system operation

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The transition towards climate-neutral energy systems requires significant changes in the thermal sector which accounts for around half the global final energy demand. To efficiently use local heat potentials in urban areas, district heating systems incorporating a diverse set of suppliers gain importance. As ownership and physical properties of decentral heat sources may vary, challenges in operational planning and adequate pricing of heat production arise, which can be addressed by the use of local heat markets. However, to account for energy losses and temperature changes that occur during heat distribution, physical properties of the heating network must be considered in market matching. Accurate representation of network physics leads to nonlinear boundary conditions in a mathematical market model. Model simplifications are necessary that compromise between efficient numerical solvability, economic optimality and feasibility in operation.
We present different modeling approaches of district heating networks in the context of a market matching problem for operational day-ahead planning. The market model maximizes the social welfare under steady-state network conditions. The network models cover different levels of simplification of physical network boundary conditions, including mixed-integer linear and mixed-integer non-linear approaches. The discussed models are solvable with standard solvers in a reasonable amount of time for networks of realistic size. Time-delays in water transport are neglected to enable synchronous market matching.

The different models are applied on a use-case scenario representing a realistic district heating system in Germany. The obtained operation schedules are evaluated based on techno-economic indicators.

Furthermore, the different schedules are passed to a detailed physical simulation using the modeling language Modelica, closely approximating real system behavior including time-delays in water transport. Based on the simulation results, effects of simplifications in operational planning on actual system operation are discussed, with emphasis on the effects of steady-state assumptions in market matching. We conclude with a discussion of necessary model depth for operation scheduling in district heating networks.

Keywords: Local energy market, Local energy systems, district heating systems, model simplification, nonlinear optimization, time-dependent simulation

The researcher combines ESOM and LCA methods to achieve sustainable energy transitions with minimal environmental and health impacts. Their work offers decision-makers comprehensive assessments and nuanced insights into the technical and economic viability of the transition.

Integrating Energy System Optimization and Life Cycle Assessment for a Comprehensive Assessment of Sustainable Energy Transitions

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The transition to sustainable energy systems requires reducing greenhouse gas emissions but also mitigating environmental and health impacts. Energy System Optimisation Models (ESOM) are used to study the technical and economic viability of the energy transition. In addition, life cycle assessment (LCA) methods are used to quantify environmental and health impacts. However, these two fields are independent, which only allows limited insights to a sustainable energy transition.

To provide a more comprehensive assessment, we combine an ESOM with LCA software. This is crucial for linking a climate objective with environmental ones and thus providing a robust solution. The proposed methodology is applied to the Belgian case. The transition will change the critical greenhouse gas indicators to other indicators. The quantification of these indicators is key to nuances insights and thus support decision makers. In addition, it opens the way for a multi-criteria decision analysis.

Keywords: Energy transition, Energy systems, Energy System Optimization Models (ESOM), Life cycle assessment (LCA), Multi-criteria analysis, Greenhouse gas emissions, Environmental impacts

Jonas Gottschald has been a research assistant at the University of Applied Sciences Düsseldorf in the Center for Innovative Energy Systems for 10 years. There he works on research projects in the field of renewable energies and energy efficiency.

Lessons Learned: On the Potentials and Challenges of a Model Predictive Controlled DHN Heat Supply

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Hybrid heat supply concepts, consisting of several heat and power generators with different energy sources and a high proportion of renewable energies coupled via heat storage, enable an energy supply for heating networks that is climate-friendly and cost-efficient by means of their flexibility. Retrieving all flexibility options requires a control of heat and power generation that acts as optimally as possible. Non-linear dependencies as well as endothermic variables, such as the temperature stratification in the heat storage, pose a particular challenge. For these reasons, machine learning methods are used in this work for multilevel nonlinear mapping and prediction of the complex thermal and electrical behavior. Combined with forecasting key constraints, a metaheuristic optimization can be used in a model predictive control scheme to generate hourly rolling schedules. The comparison with a rule-based control system used by heat network operators as standard for an economic operation enables an evaluation of the developed operation optimization. However, a direct comparison as well as the potentials and challenges to be derived from it is non-trivial, among other things, due to the mutual influence and the always different boundary conditions. For an evaluation as objective as possible, the generators are alternately controlled by both operation modes. The evaluation of measured data shows that a time interval of two days each is sufficient. For the derivation of potentials and challenges, the year 2022 with the strongly fluctuating energy prices represents a particularly interesting year, at least from the project point of view. Thus, potential cost savings in the double-digit percentage range can be achieved at times. On the other hand, however, a large number of non-negligible challenges stand in the way of optimized operation. For example, the optimum is often close to or exactly on the operating limits, and any unavoidable forecast error can lead to one of these limits being exceeded and thus to additional costs due to unnecessary energy use.

Keywords: District Heating, Machine Learning, Model Predictive Control, Monitoring

Mominul Hasan is a PhD candidate and Research Associate at the Energy and Environmental Management Department, Europa-Universitaet Flensburg in Germany. Mominul is from Bangladesh, and Bangladesh's energy transition is the main topic of his PhD research.

Techno-economic and geospatial opportunities for meeting Bangladesh's energy demand by solar PV systems

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The energy system of Bangladesh is highly reliant on domestic natural gas and imported solid and liquid fuels. Except for solar energy, the renewable energy potential is limited in the country. In the light of a fast developing energy demand in a densely populated country, this paper explores the possibilities of maximizing solar PV integration to facilitate decarbonization. For multiple demand sectors, such as electricity, transport, and cooling, we develop scenarios for the target year in 2041 using the EnergyPLAN model to increase the share of solar PV in the energy system. We use geospatial methods to quantify cooling demand and solar PV potential by means of freely available state-of-the-art geospatial data. To estimate transportation demand, we use Bangladesh's statistical data on the transport sector and apply a bottom-up approach. Since solar irradiation varies according to geographic location and time, we apply a geographic smoothing method in the solar distribution profile to optimize the share of solar PV. The result of this research discusses the maximum share of solar PV in the system, the implications in reducing dependency on imported fossil fuel, and the environmental benefits. In addition, we address the limited freedom in land allocation for solar PV and discuss strategies for Bangladesh to achieve a higher share of solar PV by implementing different types of PV systems.

Keywords: Energy System Modelling, EnergyPLAN, Solar Photovoltaic Systems, Sector Coupling, Smart Energy System, District Cooling, Electric Mobility

He is a physicist specialising in networked energy systems, virtual power plants, and sustainable buildings. He designs innovative solutions to optimise energy use and reduce carbon emissions. As a researcher and thought leader, he is passionate about creating a more sustainable future.

Decarbonizing Municipal Utilities: A Strategy for Achieving CO2-Neutrality by 2035

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Municipal utilities (so-called Stadtwerke) play a crucial role in terms of the decentral Energiewende in Germany. The national way to accomplish the energy transition with a massive expansion of renewables requires local actors to participate actively. Thus, we developed a decarbonization strategy to supply a 12.000+ municipality CO2-neutral till 2035. This considered that the influence of the municipal utility is limited to its own electricity and natural gas grid as well as municipal buildings and vehicles.
Our study focused on the optimal expansion of sustainable energy generation coupled with short- and long-term storage options and transformation of consumption (mobility, power-to-heat, power-to-gas) of the existing local distribution grids. We aimed for a high autarky respecting long-term economic efficiency and high self-consumption of renewables. Natural gas should be replaced by alternatives as far as economically possible.
Energy consumption was determined and separated into domestic, commercial, and industrial and together with hourly generation profiles from existing renewables used to remodel the known annual consumption. Likewise, the hourly generation profiles from existing renewables were considered. The resulting degree of self-sufficiency (e.g., physical autarky) and annual share of renewable energy (accounting self-consumption) was calculated.
From this status quo, we developed future scenarios to answer the following questions:

- What impact will the transformation to power-to-heat and electromobility have on the electricity demand up to 2035?
- How do the parameters self-consumption and self-sufficiency behave for the respective expansion of the technologies PV systems, wind turbines and battery storages?

- What is the techno-economic optimal combination of PV systems, wind energy systems and battery storage and what is the potential for hydrogen?
- In what way does the injection of biogas and hydrogen affect the electricity and natural gas grids?

Based on the load and generation profiles, we have adjusted the type and scope of the technologies used. Thereby, the local conditions were again considered to only implement feasible concepts. A techno-economic analysis was carried out to plan an optimal transformation.

Keywords: Decentral Energiewende, Decarbonization strategy, Sustainable energy generation (Wind, PV, Biogas), Self-sufficiency, Self-consumption, Surplus energy, Power-to-heat, Bio-methane

Jelger Jansen is a PhD student in the Thermal Systems Simulation (The SySi) group at KU Leuven under supervision of professor Lieve Helsen. His work focuses on model predictive control of fourth generation district heating networks.

Model predictive control of a 4th generation district heating network – comparison with rule-based control and impact of prediction uncertainties

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District heating (DH) networks will, next to electrification, play a key role in decarbonising the residential heating sector, which is essential in reaching the European climate goals. Fourth generation DH (4GDH), which aims at increasing the share of renewable and residual energy sources in the DH network, is the leading technology to be part of the future smart energy system. These advanced networks offer a lot of flexibility in the form of thermal energy storage systems, thermal inertia of the buildings, and the network itself. Model predictive control (MPC) can exploit this flexibility to provide thermal comfort in the buildings while minimising a cost function like operational cost. We present an MPC which considers important non-linear physics in its controller model and optimises the entire DH system (including the buildings' heating system) such that the MPC serves as a system integrator to improve the overall system efficiency.
First, we present the results of a simulation-based study applied to an existing fully-renewables-based 4GDH network of 12 buildings, which shows that an MPC with perfect predictions outperforms the currently used (well-tuned) rule-based controller (RBC) in terms of thermal comfort and overall system electrical energy use. The MPC achieves these results by lowering the network temperatures, using its anticipatory ability, and exploiting the flexibility of the building thermal inertia.
Second, we perform a similar simulation study, but this time the MPC uses realistic predictions of the system's disturbances, being weather and occupancy. These results show that the inclusion of prediction uncertainties negatively impacts the MPC performance, but that the quantitative effect is limited and MPC still outperforms RBC.

Keywords: Model predictive control, non-linear optimisation, 4th generation district heating, heat pumps, simulation study

Rasmus Magni Johannsen is a PhD fellow at the Department of Planning, Aalborg University. His research focuses on energy system modelling, specifically, the application of energy system modelling for decentralised energy planning.

Developing energy system scenarios for municipalities - introducing MUSEPLAN

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Poul Alberg Østergaard, Aalborg University
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The value of energy system scenarios is increasingly asserted in a decentralised and municipal context. There is, however, a lack of suitable tools for designing such scenarios, particularly tools that empower local planning practitioners in active participation. With this study, we introduce a novel tool designed specifically for municipal energy system modelling, thus bridging the gap between model developers and planning practitioners. The applicability and suitability of the new MUSEPLAN tool is investigated through its application in a case municipality, revolving around the needs of planning practitioners, supporting the build-up of modelling capacity, and focusing on the practical development of energy system scenarios. MUSEPLAN draws on the specialist simulation model EnergyPLAN but provides an environment for integrated design and comparison of multiple scenarios while reducing complexity for some of the advanced options. The study concludes that municipal planners value both the modelling process undergone and the resulting energy system scenarios as a starting point for continued strategic energy planning. In conclusion, MUSEPLAN resolves the identified challenges to the integration of energy system modelling in municipal energy planning, while simplifying the modelling and scenario evaluation process.

Keywords: Energy planning, Energy system modelling, Energy scenario-making, Municipalities

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 the coupling of thermal and electrical network grids.

Design and simulation of district heating and cooling networks: A review of modelling approaches and tools

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District heating and cooling (DHC) systems are an important component in the efforts to mitigate greenhouse gas emissions and achieve the climate targets in the near future. The available software tools for analysis of DHC networks use different modeling approaches, whose adequacy depends on the particular use case of interest. Therefore, the practitioners often face a challenge of selecting the most appropriate tool considering specific modeling requirements of the use case.
To address this challenge, the paper provides a review of currently available DHC network modelling and simulation tools. The tools are assessed by comparing modeling approaches of pipelines, pumps, heat exchangers, and valves, as well as tools' scope of application and functional capabilities.
Firstly, the basic concepts and principles of mathematical modelling in the context of DHC networks will be described. Subsequently, an overview of the various components in a DHC network and their mathematical models are provided. Furthermore, this work covers various numerical methods that have been used to simulate and analyze the mathematical models and discusses the advantages and disadvantages of each method. The scope of the paper is to provide a valuable reference for researchers and practitioners in the field of DHC network modelling, and to encourage the further development of tools for DHC network design and simulation.

Keywords: District heating, District heating and cooling, Modelling, Tools, Simulation

Ari Laitala M.Sc. (Tech.) works as a project manager in Sykli Environmental College and leads research related projects in the field of real estate, energy efficiency and carbon neutrality.

A hybrid city – how the combined production curve of solar and wind electricity looks like in urban locations?

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The production of solar electricity is still growing quickly in smaller and in larger scales. This is even though there is a huge number of "zero" hours in Northern locations, like in Finland. The rule of thumb suggests that average efficiency of the PV-electricity production during the year is about 10% of the peak power. This is especially because of the short days during the long winter period.

But, like well known, wind power production can be efficient throughout the year and during the night-time as well. Is it so, that wind energy could be utilized in urban areas and in lower altitudes as well? Could it be possible to find micro locations in cities where conditions for small scale wind energy production exist. And would there be potential even "environmentally friendly" vertical axis wind generator solutions. And finally, could this all be economically profitable?

Open weather data gives firsts insights about the wind conditions in applicable altitudes. In Finland the best source is the Finnish Meteorological Institute data. Hourly wind data is available from the most weather stations but hourly sun radiation only from a very few. In this presentation some comparisons between the PV and wind energy potential are made but the possibilities for the hybrid solutions are discussed as well. This approach opens new possibilities to find cost minimums and to find the optimality for the investment cases.

In this presentation hourly wind and radiation data (year 2021) is studied in Helsinki area and the amount of yearly potential energy production is estimated based on small 1 kW devices (both solar and wind). The base case is the data of Helsinki Kumpula weather station (about 4 kilometres from the city centre) but also the (possibly) best locations for the wind energy production are studied.

And further, some preliminary investment calculations are shown. It seems to be possible to achieve even 40% average wind energy production efficiency in the city area in relation to peak power. This corresponds to a large-scale wind energy production solution.

Keywords: Wind energy, weather data, solar energy, electricity, urban area, wind generator, production curve

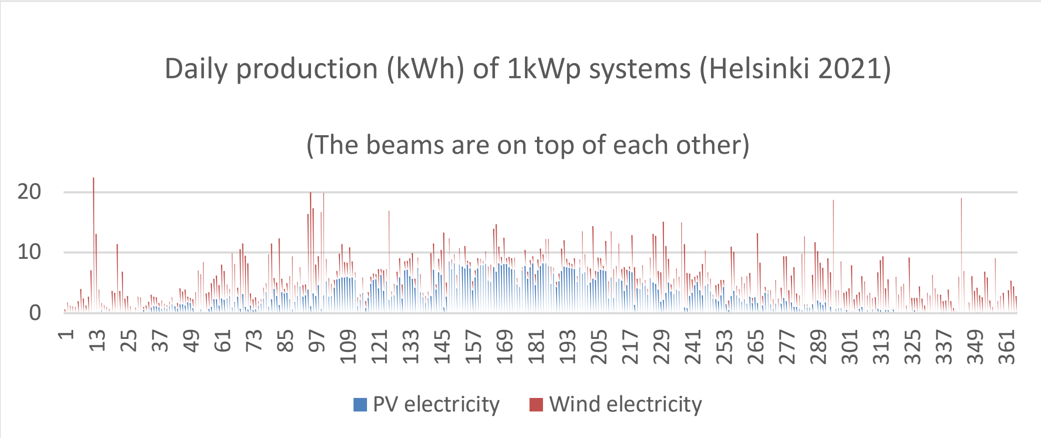

Figure 1. Daily production (kWh) of 1kWp systems both solar and wind electricity generation. Location is Helsinki/Kumpula. In this location, the wind energy potential is about 30% higher than the PV electricity potential. But significantly better locations for wind electricity generation can be found from the city area.

Kertu Lepiksaar is a PhD student in Tallinn University of Technology Research Group of Smart District Heating Systems and Integrated Assessment Analysis of Greenhouse Gases Emissions.

Integration of solar energy into district heating and cooling systems – Tallinn case study

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Using solar energy is one way to integrate sustainable, clean and non-combustional energy to energy mix. Globally, the share of solar energy has significantly grown over the last decade because of increased public awareness, declining costs, rising energy tariffs, and government incentives. The versality of solar energy and modularity of solar collectors makes it suitable for different energy applications. Also, there is a possibility to combine the solar energy system with other energy systems. The adoption of low temperature district heating and renovation of old buildings in Europe provides favorable atmosphere towards the use of solar heat. In spite of having these benefits, solar energy is not fully explored in district heating and cooling sector. There is a visible relation between solar energy production curves and cooling energy consumption curves which indicates that using solar energy in cooling sector would be efficient way to use solar energy. In district heating and cooling sector in Estonia solar energy has not been used, although there is a significant solar energy potential. Due to lack of practical examples, utilisation of solar energy in Estonia is skewed towards water heating and electricity generation. There is a need to fill this knowledge gap by studying the effectiveness of integrating solar energy into district heating and cooling system in Estonian context. In this paper Tallinn district heating and cooling system has been used as case study to investigate how solar energy can be used most beneficially and efficiently. Different kind of technical configurations are considered, from the side of harvesting solar energy (different photovoltaic panels, different solar collectors) and energy transformation to heat or cooling energy (heat pumps, electric and absorption chillers, electric boilers). These configurations are examined in terms of different techno-economic parameters such as solar energy fraction, levelized cost of heat, net present cost and energy efficiency and flexibility.

Potential share of solar energy in Tallinn district heating and cooling network is estimated and the influence to overall heating and cooling network operation is also discussed.

Keywords: district heating, district cooling, solar energy, renewable energy, green transition

Manuela Linke received a master degree in physics from the University of Tübingen, Germany in 2017. She joined the HTWG Konstanz in 2018 and is pursuing a PhD at the University of Freiburg, Germany. Her research focuses mostly on grid operation management using machine learning algorithms.

Grid operation management with Convolutional Neural Networks

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Accelerating the electrification of the transport sector and the rollout of renewable energy sources in the EU [1] can affect the stability of existing distribution grids due to the stochastic nature of the energy flows.
To counter possible disturbances we propose a grid operation management system utilizing state-of-the-art convolutional neural networks (CNNs). CNNs have shown outstanding results in computer vision tasks like image recognition via learning complex dependencies of neighbouring data points. Therefore, different arrangements of the input data were investigated to reflect the relationships between neighbouring nodes as imposed by the network topology.
Our models show excellent results in detecting patterns in the generation and load data that lead to disturbances in the grid, and suggest a suitable solution without performing time-consuming load flow calculations. As disturbances we consider
- Voltage deviations >= 3 % of the nominal voltage at any point in the grid
- Overloads of transformer stations or line capacities

As possible countermeasures we use changes of the tab position of the transformer stations as well as remote controllable switches installed in the grid.
We are using a virtual grid based on actual measurement data from the Cossmic project [2] for training and testing of our algorithms. The optimal countermeasures are selected from all reasonable grid configurations via Newton-Raphson calculations beforehand.
The CNN models show superior results compared to previous works utilizing fully connected neural networks [3]. Our preliminary results show outstanding test accuracy of >92% for the solution of disturbances in the investigated grid.

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[2] Open Power System Data, „Data Package Household Data. Version 2017-11-10.“ 2017.

[3] M. Linke, et al. „Artificial neural network based decision support system for the present power grid accounting for the successful integration of renewable energy sources such as pv systems“. Proceedings of the 36th European PV Solar Energy Conference and Exhibition, 2019.

Keywords: Grid operation management, Convolutional Neural Networks, Smart Grid, Machine Learning, Classification

Dennis Lottis is a research associate and PhD student at Fraunhofer IEE in Kassel. After graduating in mechanical engineering, he worked for 6 years as a calculation and simulation engineer at a consulting company. Since the detailing of his simulations there was superficial, the desire to deal with these topics in a more in-depth and scientific way grew, so that he finally started working at Fraunhofer IEE in 2020. There, he is currently working on detailed thermo-hydraulic simulations in the context of district heating and is supporting the planning and construction of a test facility for this topic. In the course of his doctoral thesis, the subject of mathematical optimisation will also be added.

Collaborative Laboratory Testing of District Heating Networks Using a Hardware-in-the-Loop Framework: A Proof-of-Concept Study

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Fourth and fifth-generation district heating networks face significant challenges, including integrating decentralized and fluctuating renewable energy sources, bidirectional heat transfer with buildings, new storage concepts, low-temperature operation, customized heat supply, data handling, and developing new, robust, advanced control strategies. To provide a safe and cost-effective testing environment for these new concepts, hardware-in-the-loop (HIL) testing can be employed, allowing for transparent and consistent experimental development, investigation, and validation, also considering extreme scenarios.

This publication introduces a HIL framework designed to facilitate joint experiments across multiple remote laboratories for analysing various components within a district heating system. The framework is demonstrated through a proof of concept, in which individual parts of an example district heating network are integrated across four geographically distributed Fraunhofer Institutes, using physical hardware and emulated models. In the first experiment, an existing test building and a ground-source heat pump located in a different laboratory are coupled with emulated models of a district heating network and a geothermal heat source for the district heating network. The models differ in terms of the tools they use. The experimental results of a two-week operation of the district heating network are presented, validating the operation of the virtually joint HIL framework.

The framework is aimed at manufacturers, grid operators, and research institutions of district heating networks, enabling laboratory collaboration to address their needs and allowing them to test new technology in a safe environment before field deployment. The core implementation of the framework is set up with the open-source protocol "AMQP" which allows an asynchronous and encrypted data communication. With this framework, testing can be conducted while considering the interactions of various components and solutions at different remotely located testing facilities and different testing scenarios without the need for the same hardware and software setup. This enables a broad variety of test scenarios to be included.

Keywords: District Heating Networks, Predictive Control, Smart Operation, Hardware-in-the-Loop, HIL

Pia studied Renewable Energy Technology and Systems Engineering. Since 2017 she is a PhD candidate and researcher at the Competence Center Energy Technology and Energy Systems at Fraunhofer ISI. Her research focuses on disrict heating, spatial analysis and the link to EU-wide energy system analyses.

Heating density as main factor for district heating: Empirical data analysis and outlook

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Climate-neutral heating needs to be based on renovation of buildings, electrification of heat generation and district heating. In spatial planning and energy systems modelling, the heating density is used as a main factor for the identification of areas that are most suitable for district heating. As the distribution costs are directly linked to the delivered amount of heat, this approach seems feasible. However, also other factors could play a role for the installation of new district heating systems, that are not incorporated with this single factor.

We present a two-step analysis for the case of Germany: first, we validate the concept of heating density with the correlation of the number of district heating connections, based on different souces of empirical data on hectare level and spatial analyses. We correlate the share of district heating connection the heating demand per hectare. The district heating connections are taken from Census data and validated. We can show that the heating density is only one factor for the existence of district heating, nevertheless, the significance of this concept can lead to a cost-effective district heating expansion. Therefore, we apply in a second step energy system modelling to identify suitable regions. This shows that heat planning should incorporate local characteristics, even though the concept of heating density is viable for the identification of future pathways.

Keywords: energy efficiency, system modelling, spatial analysis, heat decarbonisation, district heating

Nicolas Oliver Marx completed his Master's degree in Industrial Energy Technology at the University of Leoben. Since 2021, he has been working as a Junior Research Engineer at the Austrian Institute of Technology. His current work focuses on district heating and decarbonisation of the industry.

Heat transmission network design optimization and robustness analysis for a case study in Tyrol

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The majority of district heating (DH) networks today are fueled by combustion processes based on fossil or biogenic fuels. For the decarbonization of DH networks various uncertainties regarding the future development of key factors, such as energy prices, need to be considered. Within the project "HeatHighway" a hypothetical inter-regional heat transfer network (HTN) in the region of the Inn valley in Tyrol, Austria was investigated. This HTN enables the interconnection of several waste heat and renewable heat sources, local district heating networks and storages. Thus, reducing the above-mentioned risks. In previous works, the economic efficiency of two boundary cases was compared: the HTN with 90% connection rate of all buildings in the region, and the decarbonization of the individual supply of each building without any HTN.

The optimal HTN configuration lies somewhere between the boundary cases. Accordingly, a deterministic optimization of the HTN design in terms of connected buildings and supply units is added up front in order to find the optimal configuration. For the uncertain coefficients, like the energy prices, an average value is used to solve the optimization problem deterministically. Then, a Monte Carlo simulation with respect to these uncertainties is performed. In this two-phase analysis, the optimal HTN in Tyrol is determined in phase one, aiming to minimize the system costs while satisfying the demand constraints of the network, while phase two contains the risk assessment via Monte Carlo simulation.

The results of the Monte Carlo simulations provide insights into the robustness of the optimized configuration, allowing for a better understanding of how the HTN performs under different scenarios. One major result in previous works was that the HTN performs better under higher prices than individual supply options, because risk is better diversified. By combining the deterministic optimization with Monte Carlo simulation, a more comprehensive analysis of the HTN network can be performed, leading to a more reliable and robust configuration. By this two-phase analysis, a powerful tool can be provided for engineers to optimize the design of heat transmission networks, leading to improved energy efficiency and cost savings.

Keywords: future district heating, waste heat sources, 4th generation DH, heat transmission networks, deterministic optimization, Monte Carlo simulation

Klaas Mielck is a graduate student in Sustainable Energy Planning and Management at Aalborg University, working in the R&D department of the software company EMD International. He specialises in the intersection of energy planning and data science.

Permutation-based Feature Importance Analysis for Medium-Term Heat Load Forecasting in District Heating Systems

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Heat load forecasting is key to the intelligent operation of district heating systems (DHS). However, data-driven forecasting approaches are often black boxes. This study addresses the problem of explainability by offering a methodological framework that combines a direct multi-step forecasting strategy with a permutation-based feature importance analysis to examine the influential features of each forecast step individually. The framework was applied by taking the example of a medium-scale DHS in Denmark and Extreme Gradient Boosting (XGBoost) forecast models. The importance of weather, time, and lagged heat load features of the previous 25 hours were analysed. The results indicate that the feature importance shifts from lagged heat load values to the outdoor temperature with an increasing forecast horizon. In addition, the solar radiation and the hour of the day influence the heat load forecasts slightly. The methodological framework increases the explainability of data-driven "black-box" models for medium-term heat load forecasting and applies to other case areas and forecast algorithms. Furthermore, this study supports the feature selection regarding the data availability and forecast horizon requirements in practice.

Keywords: Heat load forecasting, District heating, Permutation importance, Feature importance, Direct forecasting strategy

Sara Månsson is currently working as a product manager at Swedish company Utilifeed, focusing on maintenance and management in district heating systems. In August 2021, she obtained her PhD, which focused on automated fault handling in buildings in DH systems.

Enhancing Efficiency and Reliability in 4th Generation District Heating: Insights from Automated Fault Detection Implementations

Sara Månsson, University of Lund

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When moving into the 4th generation of district heating, it is important that the individual components in the systems work as well as possible. Faults in the DH substations and internal heating systems of the connected buildings often lead to suboptimal performance in the DH system.

This means that efficient fault handling and elimination will be an important aspect in the 4th generation of DH. Recent studies have shown the need for automated fault detection methods, utilizing the customer data that is collected for billing purposes. This presentation focuses on the learnings from implementing such methods in a number of DH systems.

The presentation will also include a discussion of the importance of a successful implementation of the methods. This includes improved workflows related to fault handling, understanding the actual value of reducing the amount of faults, and getting the DH customers involved in the process.

Keywords: Fault detection, Data Analysis, fault handling, 4th Generation District Heating, Automation, Machine Learning, AI

Benedetto Nastasi is Assistant Professor in Smart Energy Systems at Sapienza University of Rome. World Top 2% Scientist according to Stanford ranking in 2019, 2020 and 2021 in “Energy” and “Building & Construction”. Author of 100+ publications. His Scopus H-Index is 35 with 2300+ citations.

Digitalization and Smartness of Energy Systems from interactive models to Digital Twins

Benedetto Nastasi, Sapienza University of Rome, Daniele Groppi, University of Tuscia, Davide Astiaso Garcia, Sapienza University of Rome

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Global and national energy systems are being reshaped by the energy transitions, and proper decision-making processes are required to impact change in response to urgent global concerns. Institutions of government, business, academia, and civil society all take part in this global transformation in various ways. To encourage open research practices and foster successful science-policy interaction, open energy models and related data are crucial. For instance, by upgrading them in comparison to the state of the art, they can promote multidisciplinary research that addresses the co-evolution of energy technology and human behavior more transparently and, more generally, they can improve the interaction of many linked models and data. In this study, we analyze the characteristics of open energy models and open data lakes for building systems, system of systems up to the harmonization into Digital Twins.

Keywords: open data, energy analytics, digital twin, system of systems

P. Paulau got his PhD in mathematical and physical sciences. He worked in Universities as well as in a company, planning technical building equipment. He recently started a new University job with Focus on Informatics, Geosciences and Buildingphysics.

Building physics monitoring with open standards

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Our overall goal is to develop a heating and ventilation control systems, which keep the energy consumption as low as possible while still providing a high level of comfort for people. This could be achieved for example by reducing the interior temperatures when rooms are not used because no one is in them. We monitor the energy consumption and various physical parameters of buildings over time and look for ways to save energy, e. g. by raising awareness among users or by making technical or structural improvements to buildings.

As our research results should be transferable, we focus on open standards. The OGC Sensorthings API was selected to store and provide sensor data in a uniform manner. We have implemented the transfer of different sensor data to the FROST IoT server which supports the OGC standard. We use two technologies to work with devices: the wired bus technology KNX in a new building and the wireless technology LoRaWAN in an old building. Additionally, we have connected our data with the visualisation tool Grafana, which allows us to provide dashboards and panels to users for realtime observation of the state of buildings.

By using the OGC Sensorthings API, our data model is compatible with future spatial data infrastructures (SDI) and digital twins such as Smart Campus or Smart City . We have started working on artificial intelligence (AI) to control actuators using the sensor data and a trained AI agent called "digital janitor".

Keywords: Energy savings, building physics, OGC Sensorthings API, IoT server, LoRaWAN, KNX, spatial data infrastructure, digital twin

Aljoscha Pollmann is working as research assistant at the Fraunhofer ISI. He received his Master's degree in Climate and Environmental Change from the University of Mainz in 2023. His research interests include district heating, renewable energy and energy efficiency.
As part of the EU Horizon 2020 research and innovation program "Act!onheat", Aljoscha conducted research on the potential trade-offs when planning district heating networks supplied by excess heat. He conducted the research using the open source online planning tool THERMOS in a case study in Zelzate, Belgium.

Waste heat as a driver for greenfield heat networks? Planning trade-offs illustrated using a case study for Zelzate, Belgium.

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Many studies see district heating (DH) as an important lever to reduce greenhouse gas emissions in the building sector. Here, excess heat can drive the development of new heating networks in greenfield developments. However, determining the optimal size of a new network presents a question: should it be constructed to fully utilize waste heat, maximize project NPV, or connect as many buildings as possible? Consequently, trade-offs may arise during planning. For instance, the size of a network has implications on investments and heat losses due to increased piping. In short, smaller networks result in lower heat losses and investments, while larger networks benefit more households. We investigate this trade-off in a Belgian municipality that considers options for building a new DH network utilizing excess heat from a nearby steel mill.

We investigate the above mentioned trade-off using THERMOS, a tool to design and simulate DH networks. To achieve this goal, we create three network designs that connect a different number of buildings to the DH network to be built in Zelzate (Belgium), each with unrefurbished or refurbished demand - resulting in six technical scenarios. Using indicators such as heat distribution costs and excess heat share in the DH network, we compare and evaluate the results of these simulations.

Our results indicate that the designs analyzed have their specific advantages and disadvantages. For example, heat distribution costs are significantly lower for designs where fewer buildings are connected than for designs where more buildings are connected. For example, the heat distribution costs for the unrefurbished scenario, where 30% of the demand is connected, are about 4.3 ct/kWh; for the design where 100% is connected, they are about 6.9 ct/kWh. In summary, our case study indicates that the aforementioned trade-off in greenfield planning is indeed relevant. For example, in the case study analysed, project developers tend to choose planning approaches where fewer buildings are connected, although larger networks could also be beneficial in the future. Therefore, further research is needed to find out which planning heuristics, technologies and/or strategies could help to deal with such trade-offs.

Keywords: District heating, Excess heat, Energy system planning

Matteo Giacomo Prina hold a PhD in energy engineering. He is a senior researcher at Eurac research, institute for renewable energy. His expertise varies from the development of algorithms for energy system modelling to data analysis and visualization.

Machine learning with EPLANopt to speed up the optimization process and explore uncertainty in energy system modelling

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In the field of energy system modelling, increasing complexity and optimization analysis are essential for understanding the most effective decarbonization options. However, the growing need for intricate models leads to increased computational time, which can hinder progress in research and policy-making. This study aims to address this issue by integrating machine learning algorithms with EnergyPLAN and EPLANopt, a coupling of EnergyPLAN software and a multi-objective evolutionary algorithm, to expedite the optimization process while maintaining accuracy.
By saving computational time, we can increase the number of simulations, thereby enabling deeper exploration of uncertainty in energy system modelling. This allows researchers to better understand the trade-offs and best practices for decarbonization, which could lead to more informed policy decisions and optimized energy systems. This article introduces a novel approach to energy system modelling optimization by integrating machine learning algorithms with EnergyPLAN and EPLANopt. The resulting methodology can accelerate the optimization process and provide deeper insights into uncertainty, ultimately contributing to more effective decarbonization strategies.

Keywords: Energy system modelling, Energy scenarios, Energy planning, machine learning

She is a is a PhD fellow from the Fluids and Energy group at Aarhus University. Her research interests include energy system modelling, with an emphasis on distributed generation, and citizens' roles in the energy transition.

Distributed photovoltaics provides key benefits in a highly renewable European energy system

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Distributed photovoltaic (PV) systems, also called rooftop solar, are more expensive than utility PV plants but have many social advantages (increased reliability, raising energy awareness, mitigating energy poverty), and are often funded by private citizens and other non-traditional actors of the energy system. Distributed PV systems are usually not well represented in large-scale energy system studies as it is difficult to model distribution grids. In this paper, we explore the role of distributed PV in a highly decarbonised European energy system to determine whether this technology has any benefits for the system to overcome its higher costs compared to utility PV. We use PyPSA-Eur-Sec, an open model of the European energy system that includes a representation of the long-distance transmission lines and a simplified lumped model of distribution grids. The model allows for incorporating distribution grid costs and efficiency, and differentiates between distributed and utility-scale generation and storage. Modelling is done with high spatial and temporal resolution, representing the European power network using 181 nodes and 2-hourly time-step.

The results show that when modelling the power sector, including distributed PV leads to cost savings equal to 1.4%. Moreover, when the power system is coupled with the heating, transport, and industry sectors, the cost saving thanks to distributed PV is increased to 3.0%. The savings are mainly due to a peak reduction in the power flowing from high-voltage to low-voltage grids thanks to self-consumption from distributed solar. For the power system, results indicate that distributed PV systems are strongly dependent on the presence of home batteries in the system to be cost-efficient. However, for the sector-coupled model, having both heat pumps and battery electric vehicles at the low-voltage level, the distributed PV potential is fully utilised, bringing benefits to the system without any need for additional forms of distributed storage.

Keywords: Distributed solar PV, energy system modelling, distribution grids cost and losses.

Lea Rehlich is a PhD student in the optimization group in the Department of Mathematics at the Technical University of Darmstadt. Her work focuses on the Mixed-Integer Nonlinear Optimization of Heating Networks within an interdisciplinary research project.

Mixed-integer nonlinear optimization approach for district heating networks

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To reduce carbon emissions the transformation of the heating sector is of great importance. In particular, district heating networks combined with renewable energy generation and waste heat play a major role. Therefore, existing heating networks need to be adjusted to lower temperatures and decentralized structures with flexible consumers. However, the resulting increase of complexity makes the development of adequate operation strategies for such networks more challenging.

We consider a global optimization approach that aims at finding cost-optimal operation strategies. The system state in a network is described by the underlying nonlinear physical equations including the operating parameters such as mass flow rate, temperature and pressure in the network. Additionally, binary variables are included to determine flow directions in the network pipes. We focus on the stationary case that can be coupled over time via a heating storage. The resulting optimization problem is a Mixed-Integer Nonlinear Optimization Problem which is solved with the solver SCIP.

The solving process for real-sized district heating networks leads to high computational costs, especially for future networks with flexible components and bidirectional flow. To lower the costs we include a heuristic for fixing flow directions on the flexible components and reducing the number of binary variables in the resulting optimization problem. Further, we simplify the constraints for the temperature mixing in the nodes to reduce the number of nonlinear equations. To solve problems with time coupling via a heating storage we develop a two stage approach to determine in which time steps the storage is discharged. We evaluate our developed methods with numerical results based on real district heating networks.
Keywords: optimization, mixed-integer, nonlinear, district heating networks, operation strategies, bidirectional

Marius Reich has been a research assistant at the University of Applied Sciences Düsseldorf in the Center for Innovative Energy Systems for six years. There he works on topics related to the application of machine learning methods for the analysis of energy systems

Prior-Approximation of Rule-Based Energy System Simulation for Fast Design Optimization

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Energy supply systems for the building sector are usually operated over decades. This requires the installed system to be deliberately designed, fulfilling the utmost standards. With the growing numbers of high-efficiency technologies in conjunction with increasing renewable energy sources, the design possibilities increase significantly. These trends demand more systematic design optimization tools, specifically directed at a non-scientific audience. The acceptance of such depends on the ease of use as well as the possibilities for further analysis. Rule-based simulations are capable of describing a desired system in excessive detail while intrinsically not able to perform design optimization. Sampling information from the simulation for specific designs and fitting a metamodel using these information allows for fast approximation and thus for rapid design optimization by e.g. using a metaheuristic algorithm. However, this approach has the disadvantage of high computational effort and substantial know-how requirements, limiting the hitherto application to a scientific environment. The presented work aims at reducing computational effort for the user by sampling and approximating the simulation prior to the user's interaction. This prior-approximation is done by creating classified boundary conditions and considering these as independent variables, resulting in a library of prior-approximations for each meaningful combination of boundary conditions. For optimization, the user-specific boundary conditions are then utilized to identify the most fitting approximation used for optimization. Results indicate that a substantial reduction in optimization time at a comparable optimization performance can be achieved, thus allowing non-scientific users to perform complex and formerly time-critical analyses in a fraction of the initial computing times.
Keywords: Energy supply systems, Rule based simulation, Design Optimization, Metamodeling

Dipl.-Ing. Patricia Reindl, BSc completed her bachelor's and master's degree at the Salzburg University of Applied Sciences, where she also works as a Junior Researcher in the field of Smart Building since 2017. In addition, she works as a civil and energy engineer in an architectural office.

Redensification potentials through building renovation in a test area in Salzburg considering the existing district heating network

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Due to the current climate and energy crisis, the European Commission has set ambitious targets for energy efficiency and renewable energy. A large share of the energy consumption can be traced back to the building sector. For this reason, the increase of the renovation rate in the European Union is a key parameter for the implementation of the strategies and the achievement of the targets set by the European Commission. According to the document "A Renovation Wave for Europe" (2020), the current weighted annual rate of energy renovations is only around 1 %. One of the targets in this regard is to at least double the annual rate of energy renovations of residential and non-residential buildings by the year 2030.

However, these planned renovations will impact existing infrastructure systems in the respective areas. In order to assess the impact of changes in the building stock on the existing energy infrastructure, the energy demand must be considered integrally at the city or state level rather than just at the building level, leading to an increasingly important method of urban building energy modeling.

Therefore, this study aims to investigate the impact of energy efficient renovations and redensifications of residential buildings on the district heating infrastructure. Building renovations can reduce the energy consumption of existing residential areas, allowing for redensification within the capacity of the existing district heating infrastructure.

The calculations are carried out using a recently developed UBEM (Urban Building Energy Modeling) approach, which represents the investigated area by simulating detailed physical building models in IDA ICE using predefined archetypes. The investigations are based on the building stock of a test area in Salzburg. For this purpose, the existing buildings are assigned to archetypes and simulated for the area in its current state. Afterwards, simulations of different future scenarios for renovation and redensification are carried out. In addition to a common renovation scenario, an additional scenario considering a high thermal renovation standard is used and integrated into the simulation model.

Keywords: Urban building energy modeling, future scenarios, renovation, redensification, energy efficiency, district heating network, building energy simulation

Ard de Reus (Msc, MA) is solution consultant at Gradyent, a company that develops Digital Twins for district heating and serves many of the largest utilities across Europe. It is his responsibility to translate (technical) district heating market developments back to Digital Twin product strategies.

Real-time non-linear optimization of three district-heating connected heat pumps and a buffer with a Digital Twin

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A real-time Digital Twin of a district heating system optimizes the operation of three heat pumps for a small district heating operator in the Netherlands, resulting in 20% higher COP on average. The heat pumps are co-optimized with the heating network temperatures and pressures in real-time. The current and next 24 hour network demand are taken into account, and a small buffer of 12.5 m3 that is able to provide 500kW of power, is exploited during the optimization. The three heat pumps are all connected to a low-temperature waste heat flow from a chemical company. Also, as input for the compressor power of each heat pump, the Digital Twin uses live intraday electricity market prices, ensuring sector coupling.
The basis for this technology is a real-time district heating digital twin, an online thermo-hydraulic model based on network topology and timeseries datasets. In this digital twin, each source and network component has a dedicated physical sensitivity model, ensuring that all modeled components are suitable to be applied in different district heating contexts with various characteristics. Additionally, the live E-market inputs, thermal storage, multiple heat pump sensitivities and network hydraulics make the optimization problem highly non-linear and computationally demanding to solve in real-time, since thousands of combinations are tested every minute to find the cost-optimal and CO2-optimal setpoint.
The outcome of the optimization are optimal setpoints for each heat pump in real-time. The dispatched setpoints are power (MW), flow (l/s) and forward temperature (C) for each individual unit. These are provided per heat pump to ensure the optimal high- and low-temperature side setpoints for the highest COP possible, but also for the buffer (charge- and discharging setpoints) and peak gas-boilers, to ensure that the full production schedule is optimized. The provided setpoints are always within the hydraulic constraints of the network and the operating ranges of the heat pumps. The combination of

set-points always satisfies the actual heating demand, making the setpoints reliable to use for direct control in day-to-day operation.

Keywords: Digital Twin, Heat pump, buffer, real-time, district heating, sector coupling, electricicification, low-temperature heat sources, flexibility

Xavier has spent the first part of his PhD thesis in assessing the role of electrofuels under uncertainties for the Belgian energy transition, by carrying out. He's now addressing the robust optimization of the pathway towards sustainability via a reinforcement learning based-framework.

Robust policy optimization for the pathway towards a sustainable energy system using a hierarchical multi-objective reinforcement learning approach

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The transition towards carbon-neutrality of a whole-energy system (i.e. including all streams of energy carriers and demands) is uncertain. Therefore, instead of establishing single-shot definitive plans towards 2050 (and beyond), i.e. perfect foresight, policy makers rather go through multiple rolling-horizon short-term decisions, i.e. myopic approach. Yet, these decisions can have long-term impacts, 20 to 50 years. Meeting the environmental objectives while minimizing the cost of the system, accounting for this decision-making process, the uncertainties, and potential shocks/crisis, require therefore a framework to assess the relevance and the timing of the decisions throughout the transition. For this purpose, a reinforcement-learning agent has been trained, interacting with its environment, a cost-based whole-energy system model (EnergyScope). Starting from the initial state of the energy system in 2020, the agent takes every five years a set of actions until reaching 2050. Although, these actions are taken every five years, they impact the system, for the next ten years - their time window. The intermediate solutions obtained in the middle of the time window are used as a new starting point for the agent that makes a new series of decisions for the next ten years, etc. Repeating the whole transition with different sequences of actions-states allow the agent to come up with a robust policy towards sustainability, considering the variation of the parameters of its environment. This framework has been applied to the case of Belgium. Given the ambitious CO2-budget target, the main lever of action is to ban fossil fuels as soon as possible. Incentivizing renewable technologies (i.e. what has actually been done in the past) has a much weaker impact on the chance of meeting the objective.
Keywords: Energy modeling, Whole-energy system, Reinforcement Learning, Myopic Pathway Optimisation, EnergyScope

Since July 2021, he has been a research associate in the Energy Systems research group at the IMS with the goal of obtaining a doctorate. The research focus here is the design and implementation of mathematical optimization environments for sector-coupled multimodal microgrids.

SlothBrAIn: a holistic energy operating system

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The energy industry is undergoing a fundamental transformation. In order to reduce greenhouse gas emissions and thus achieve the planned climate protection targets, renewable energy sources such as photovoltaics and wind power are being expanded. At the same time, more and more large conventional power plants are being taken off the grid. As a result, energy is being produced and consumed more closely in smaller decentralized energy systems. In addition to renewable energy sources and consumers, such energy systems also include energy storage systems. These are needed to balance out the fluctuations of the renewable energy sources. For these energy systems it is necessary to have an energy operating system (EOS). The task of such an operating system is to control the energy flows in a system as efficiently as possible. A system usually has one or more inputs – single or multi input systems – and one or more outputs – single or multi output systems. If this system paradigm is transferred to general energy systems, the aim is to reduce the cumulative energy quantity of the inputs while keeping the cumulative energy quantity of the outputs (final consumption) constant, and thus to increase the overall system efficiency. Implementing a smart EOS can result in an increase in overall system efficiency, depending on a system's degree of flexibility. The degree of flexibility should be understood as the number of potentially controllable energy flows in an energy system. This degree of flexibility is directly related to the degree of complexity of a system, since in complex systems greater potential can be leveraged by an intelligent operating system compared to standard operation due to more complex interdependency effects and synergies. The levers that an integral EOS has compared to standard energy system automation are the coordination of individual system components with each other (e.g., CHP, heat pumps, storage, and distribution grid interconnec-

tions), considering future system behavior (through forecasts), and the automatic adaptation of the operation strategy to changes in external influences. The EOS developed in this paper reaches an increase in system efficiency of 15 % for a multimodal, residential housing district.

Keywords: optimization, scheduling, energy efficiency, energy flexibility

Alessandro Sartori graduated in Computer Science at the University of Trento, Italy, and is now pursuing a PhD on multi-objecive optimization of Energy Systems and Renewable Energy Communities.

Optimizing the integration of renewable energy sources, energy efficiency, and flexibility solutions in a multi-network pharmaceutical industry

Alessandro Sartori, FBK & University of Trento. Francesco Ghionda, FBK. Zijie Liu, University of Trento. Md Shahriar Mahbub, Ahsanullah Univeristy of Science & Technology. Francesco Pilati, University of Trento. Matteo Brunelli, University of Trento. Diego Viesi, FBK.

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In the industrial sector, improving the efficient and flexible coupling among different energy demands (electricity, heating and cooling) and exploiting the integration of Renewable Energy Sources (RESs) can lead to drastic reduction in CO2 emissions. To address this topic, the EU founded Horizon Europe FLEXIndustries project that promotes sustainable processes in energy-intensive industries and contributes to the flexibility of local grids.
This work is dedicated to the optimized modeling of the case study SUANFARMA Italia, a pharmaceutical industry located in Rovereto. In the FLEXIndustries layout there are various types of energy demands supplied by multiple energy networks and technologies: (I) two separate heat demands (hot water and steam) are managed by natural gas trigeneration and boilers, (II) two cooling demands (low temperature glycol and low temperature water) are served by natural gas trigeneration, heat pump, and natural cooling (groundwater and tap water), (III) a city district heating network is fed from industrial waste heat produced by natural gas trigeneration and heat pump, (IV) the electricity demand is satisfied by natural gas trigeneration, a biogas generator, an onsite PV with a battery energy storage system to provide flexibility, and the local national grid. Moreover, to explore additional decarbonisation targets other technologies/sources could be considered such as solar thermal, steam generating heat pumps, biomass, hydrogen and industrial processes flexibility.
The coupling among networks is tight and needs to be modeled with precision. In order to face such a complex problem, the EnergyPLAN software is considered and further

adapted to gain a dynamic and integrated hourly balance between productions and demands together with evaluation of economic and environmental parameters. An ad-hoc novel framework considers additional constraints beyond the capabilities of EnergyPLAN, in particular to include a double-effect heat pump that couples cooling and heating demands. Moreover, to address the optimization challenge, EnergyPLAN is paired with a Multi-Objective Evolutionary Algorithm (MOEA), a type of optimization that mimics nature to improve two contrasting measures – in this case CO2 emissions and costs.

Keywords: pharmaceutical industry, energy system optimization, EnergyPLAN, multi-objective evolutionary algorithm, energy efficiency, energy system integration, flexibility, renewable energy sources

Kevin Michael Smith is an Associate Professor in the Department of Civil and Mechanical Engineering at the Technical University of Denmark. His research interests include the design and ongoing commissioning of heating and ventilation using equation-based simulation and grey-box modelling.

Utilizing Digital Twins to Optimize District Heating Substations and Minimize Return Temperatures

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In buildings connected to district heating networks, domestic hot water (DHW) thermal storage tanks help reduce peak demand. However, suboptimal charging of these tanks often leads to excessive return temperatures, negatively impacting network efficiency through increased heat losses and reduced condensing biomass boiler efficiency. Thus, it is crucial to detect and diagnose poorly controlled tank charging systems in district heating networks. Many of these systems feature internet-connected controllers and heat meters, which provide valuable data for constructing digital twins to monitor and enhance their performance.
The authors collaborated on a study involving eight identical heating substations in similar, newly constructed apartment buildings, all exhibiting higher-than-expected DHW system return temperatures. The researchers developed digital twins of the tank systems using Modelica, validated the models, and identified the causes of the high return temperatures. This analysis yielded recommendations for improving return temperatures, applicable to both the studied buildings and future constructions using similar prefabricated volume modules. The generic digital twin can also be used to monitor and maintain other heating substations with comparable configurations.

Keywords: digital twin, domestic hot water, district heating return temperature, Modelica

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 while working on his PhD.

Creating a labelled district heating data set: From anomaly detection towards fault detection

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With the ongoing digitalization of heat meters and the transition to 4th generation district heating, using the data stream from individual district heating substations for anomaly or fault detection has become increasingly popular.
Increased customer satisfaction, higher efficiency, lower operating costs, and better maintenance and repair scheduling are among the advantages motivating this trend. However, according to our literature review for SESAAU 22, current works primarily use unlabelled data sets for anomaly detection. We also find that simulated faults or completely simulated data sets are used to avoid a lengthy and expensive labelling process. In total, only two out of 25 publications used labelled, real-world data sets. In addition, faults are not labelled consistently with labels ranging from Boolean values to numerical values depending on fault severity.
We present our methodology for and insights from creating a labelled data set based on historical data (2019-2022) in a German district heating network covering 3.5 years and up to 1,500 customer substations. We cover different timestamps such as fault occurrence, customer complaint, and fault end, how to label spontaneous and creeping faults, and fault categories for cause and location.
Furthermore, we look at how different labels provide additional insights for utility companies which can also influence the development process of a fault detection system. An example is the delay between the fault occurring and the customer calling to report an issue, as this limits the reaction time of a fault detection system. Likewise, by looking at

the recovery time after the substation is repaired until normal behaviour is re-established, we can determine whether it is possible to react to a fault before the customer notices a decline in temperature. Similar evaluations can be done for predictive maintenance and creeping faults.
Our goal is to provide a data science perspective on how to create suitable labelled data sets for supervised learning methods with a focus on future-proofing while avoiding unnecessary work during the labelling process. We also show how those insights can influence the development of fault detection systems regardless of the underlying method used.

Keywords: District heating, Fault Detection, Data Science, Supervised Learning

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.

Automated separation of existing district heating networks for the utilisation of available heat sources

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Integrating available waste heat and renewable heat sources into district heating systems is essential to replace the mainly fossil-based heat supply of the building sector. However, integrating a heat source into an existing district heating system can be challenging, e.g., an unfavourable location of the heat source to the network structure can lead to pressure cones. Furthermore, the temperature levels of available heat sources often do not match the network temperatures, so a heat pump system is required to raise the heat source temperature. Alternatively, the temperature of the district heating network can be reduced accordingly to directly use a low-temperature heat source, which requires additional adaptions at many supplied buildings.
The resulting difficulties that arise while integrating heat sources in an existing district heating system can be tackled by, e.g., separating the network structure into two independent networks, where the utilised heat source supplies the separated network and the conventional heat source still supplies the remaining network. In this way, the operation of the remaining network is only slightly affected, as only some network branches are separated, which makes difficult control adaptions for the entire district heating system unnecessary. For efficient usage of the newly utilised heat source, the separated network forming a new standalone district heating system could be further adapted with less effort than adapting the whole system.

In this work, we present a methodology for the automated identification of suitable separation options for existing district heating networks. We apply a clustering algorithm that identifies clusters in the network topology. Based on these clusters and the new heat source's geographical location and heat capacity, we derive possible options for network separation. For all options, a Modelica simulation model is automatically generated and executed to verify the operability of both the separated and the remaining network. In addition, we evaluate the options for network separation by deriving key performance indicators resulting in the most beneficial separation option to integrate the new heat source from both an economic and an ecological point of view.

Keywords: District Heating, Separation, Existing Network Structures, Utilisation of Heat Sources

Goran Stunjek is a PhD student at Faculty of Mechanical Engineering and Naval Architecture at University of Zagreb. His field of work is related to studying the joint operation of water and energy systems powered by the RES and storage technologies.

Data-Based Correlation Analysis and Modelling of Water and Energy Systems on an Island Using Renewable Energy Sources for Desalination

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This paper presents a study on the use of large data sets of weather, water usage, desalination plant electricity consumption, and household-level water and energy usage to create a correlation analysis and model integrated water and energy systems on an island using renewable energy sources for the desalination process. The objective of the study was to develop a data-based model that incorporates simple machine learning methods to assess the feasibility and efficiency of integrated water and energy systems using renewable energy sources. The study used data from various sources, including temperature, precipitation, wind speed and direction, brackish water usage for the desalination plant, desalination plant electricity consumption, and water usage on the household level. The data were analysed to determine the correlation between the different parameters and to develop a water-energy nexus model for the Unije Island case study. The results show that the model can effectively simulate the water and energy system, providing insights into the feasibility and efficiency of renewable energy sources for desalination purposes. The study provides valuable insights into the potential of renewable energy sources for desalination and highlights the importance of using data-based modelling techniques to optimize water and energy systems.

Keywords: water-energy nexus, data-based modelling, renewable energy sources, desalination

Signe completed an MSc in Smart Cities and Urban Analytics from University College London in 2021, having previously graduated with a BEng (Civil Engineering) in 2019. Since joining Arup she has been heavily involved in delivering local area energy plans for numerous local authorities across the UK.

Combining Diverse Datasets for Whole Systems Local Area Energy Planning

Alice Stamp, Arup; Signe Swarttouw, Arup; Rebecca Carter, Arup; Steven Gough, Arup

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Whole systems energy planning has become increasingly important as communities look to transition to low-carbon energy systems. A key challenge in this process is how to integrate data from diverse organisations to develop cohesive energy strategies that cross different modes including heat, electricity and transport. This presentation will describe Arup's Energy Systems Optimisation Planning process, that combines data from multiple organisations to drive local whole systems energy optimisation and develop a plan leading to net zero.

We present the outcome of our work with a community in the UK, where we used our data-driven model to analyse local area energy supply, demand and storage options. The model integrates data from the local distribution network operator, local government, environmental bodies, water utility, gas network, and local industries to cover a wide range of information including transport details (both personal and commercial), waste heat sources, electrical and gas network constraints, and environmental considerations. Our model considered different scenarios based around different assumptions for the community, for example differing uptake rates of electric vehicles, or centralised vs decentralised approaches to decarbonising heat. We included the impact of building retrofits to the heat demand as well as network constraints.

Our modelling process was able to identify key challenges and opportunities for the community and enabled us to develop a comprehensive set of recommendations for the community to implement for their energy transition. Furthermore, the process helped build relationships between the different organisations, helping to pave the way for future cooperation.

Keywords: energy modelling, energy planning, heat planning, electrification of transport, data management, UK

Paolo is a PhD candidate at the UClouvain, where he conducts research on energy system modeling with a whole-energy approach. Specifically, he is developing EnergyScope Multi-Cells, an open-source optimisation model for multi-regional whole-energy systems.

The role of renewable fuels in a fossil-free European whole-energy system

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With the Green Deal, the European Union has committed to transitioning to a fossil-free energy system, and recent energy crises have highlighted the importance of energy sovereignty in Europe. Renewable fuels, derived from renewable biomass or electricity, have been identified as a critical vector for achieving this goal due to their versatility for many applications such as seasonal storage, energy transport, and potential use in hard-to-abate sectors. They are often referred to as the "Swiss Army Knives" of the energy transition. However, their production is expensive, and often less efficient than alternatives like direct electrification. Therefore, renewable fuels can be considered scarce and strategic resources, and experts have proposed criteria, such as the hydrogen ladder, to prioritize their use.

Despite their potential benefits, the integrated use of renewable fuels at the European scale has been little studied. This study addresses this gap by applying a multi-regional whole-energy system optimization model, EnergyScope Multi-Cells, to develop a fossil-free European energy system by 2050. This model considers all energy sectors and several energy carriers, enabling a direct comparison of renewable fuels with competing alternatives. We examine various scenarios, including the deployment of a hydrogen network, the phase-out of nuclear energy, the import of renewable fuels from outside Europe, lower potentials for renewables due to social acceptance, the use of dedicated energy crops, and energy sufficiency measures. We also analyze the strategic use of renewable fuels in each scenario, providing guidelines on their quantities for key applications such as storage, the chemical industry, and energy exchanges within Europe. Furthermore, we analyze the origin of these fuels in the different scenarios: whether they are imported or produced in Europe, and the implications for energy sovereignty.

Overall, our study provides valuable insights into the strategic use of renewable fuels in a fossil-free European energy system. The guidelines and analyses we provide can inform policymakers, industry stakeholders, and researchers in their efforts to promote sustainable and secure energy systems.

Keywords: Energy System Optimisation Model, Sector-coupling, Whole-energy system, EnergyScope, European energy system, Electrofuels, Biofuels, Renewable fuels, Fossil-free energy system

The presenter is a PhD student at KU Leuven and Vito and develops optimal routing and design methods to improve the efficiency and cost of modern District Heating Networks.

The Role of Demand Variability and Intermittent Supply on the Optimal Routing and Design of District Heating Networks

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The design of modern district heating networks is challenging due to the need to connect heat sources of different temperature levels with diverse heat demands, ranging from large commercial demands to private houses with different levels of renovation and user behavior. To assist in the planning phase of these modern networks, a generative design tool for the optimal routing and design of heating networks (PATHOPT) was previously developed. This tool applies density-based topology optimization to District Heating Networks and provides promising results both in scalability and spatial detail , but lacks thus far the ability to accurately model temporal variations in heat demand and intermittency of heat producers.
In this talk, we present an improved density-based topology optimization approach that combines the high spatial detail of nonlinear physical models of network components with the temporal detail of a multi-period optimization approach. With present results on the optimal routing and design of a heating network development project in a neighborhood in Genk, Belgium, where residential and commercial demand is connected to a low-temperature waste heat source and a peak gas boiler. In this context, we study the effects of different design scenarios on both the topology and the design of the optimized heating network, comparing worst-case, average, and multi-period designs. The study shows an increase in the number of connections between the waste heat source and the peak boiler as the temporal resolution is increased, which improves the network's ability to freely shift loads between the two producers and maximize waste heat utilization. Another result observed in this study is the use of temperature boosting in the optimized design to further increase the waste heat share in the operation of the network. Here, the temperature of the waste heat source is increased with the heat from

the peak boiler to make it available to distant consumers. Furthermore, the influence of the intermittency of the waste heat source on the optimal design is investigated.

Keywords: optimal routing, topology optimization, nonlinear optimization, multi period

Dr Thibaut Wissocq is a research engineer in the field of energy system optimization. He joined the CEA in 2021 and he is involved in industrial projects related to district heating or industrial areas for their optimal design and control

Strategies for decarbonisation of a heat district network using an optimization tool: Application to Grenoble city

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Loïc Giraud, CCIAG (Compagnie de chauffage intercommunale de l'agglomération grenobloise), France

Thibaut Wissocq (presenter)

Ambitious carbon neutrality targets have been set in Europe. To achieve this goal, decarbonisation of heat production is essential. In this context, the district heating network of Grenoble wants to achieve a renewable energy rate of 100% by 2033, while today, 20% of their heat come from fossils fuels.
This study aims to investigate the best options to decarbonize their heat production. To do this, a methodology based on the internal CEA optimization software PERSEE has been developed. The first step is the modelling of the actual production plants of Grenoble district heating network as a reference for comparison. Then, bibliographic studies, integrating local authorities inputs, are carried out to pre-identify a range of technical solutions. These technologies are modelled in the PERSEE tool within a superstructure in order to select the most relevant ones. The pre-identified technologies include low-carbon fuels (biomass), renewable energy, fatal energy recovery, electric boilers, fuel cells, carbon capture & power-to-gas, biomass-to-X and thermal energy storages. Lastly, a multi-objective optimization is carried out (minimization of the CO2 emissions and maximisation of the Net Present Value) and a Pareto front of optimal solutions is obtained.
For tractability reasons, a methodology is developed with different time step precision. First, computations are done with a 4-hour time step without considering thermal energy storages, but offering a good compromise between computation time and accuracy. A Pareto front is obtained, where each simulation, corresponds to a maximum carbon emission authorized and an optimal NPV. Three optimal architectures are then selected,

corresponding to three different type of solutions: carbon capture, biogenic fuel and fossil fuels. Then thermal storage (sensible heat and building inertia) are included in the optimisation of these three architectures with a 1-hour time step.
Results show that different paths for district heating decarbonisation exist. In any case, biomass plays a crucial role in the zero-carbon emission objectives. The integration of thermal storage and building inertia also enhances the load factor of cogenerations, shifting the solution from operating of electric boilers to that of biomass.

Keywords: optimisation, district heating network, low-carbon energy, carbon capture, techno-environmental-economic study, multi-objective

PLANNING AND ORGANISATIONAL CHALLENGES FOR SMART ENERGY SYSTEMS AND DISTRICT HEATING

Prof. Maarten Blommaert is an assistant professor at the Energy Research Section of KU Leuven Campus Geel and is associated with EnergyVille. His research group IDEAL investigates generative design techniques for the design optimisation of thermal energy components and systems.

Automated Design Strategies for Low-Temperature District Heating Networks with Multiple Producers

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The design of district heating systems is becoming an increasingly challenging task, with growing need to operate at low temperatures, maximize the integration of renewable energy and waste heat, and at the same time achieve a high return on investment. Automated design strategies can assist in this process of selecting the best heating network design, including routing, operating conditions and combination of heat sources. While several automated design strategies have been proposed in recent years, many of them fall short for the design of next generation district heating networks, either because they do not scale well to practical network sizes, or because model simplifications do not allow accurate assessment of the technological feasibility of low temperature, multi-producer networks. The recently developed Penalizing Adjoint-based Thermal network Optimization Toolbox (PATHOPT) [1,2] avoids these problems by building the automated design loop on a nonlinear flow and heat transfer simulation of the heating network. At the same time, efficient gradient-based optimization strategies ensure good scalability to larger networks [3].

In this presentation, we will give an overview of several recent developments in this design tool that enable new applications in the optimal design of heating networks. Firstly, we will show how it can automatically suggest an approach to retrofitting existing networks by making a cost-optimal choice of substation retrofits that allows the operating temperature of the network to be reduced. It is shown how the investment of substation retrofitting for this temperature reduction is easily recouped through the increase in generator efficiency. Secondly, optimization can be used to achieve cost-optimal design of a heat production portfolio including both traditional and intermittent renewables, while always meeting consumer heat demand. Thirdly, a newly developed approach allows the design of heating network layouts that account for future expansion plans in a phased investment approach. Different realistic heat network projects are used to assess the merits of these developments.

[1] M. Blommaert et al., Applied Energy, vol. 280, 2020.
[2] Y. Wack et al. Energy, vol. 264, 2023.
[3] Y. Wack et al. DOI:10.48550/ARXIV.2302.14555, 2023.

Keywords: Low-temperature district heating, Automated design, Renewable energy integration, Phased investment planning, Optimal retrofitting

Dhekra Bousnina is an energy engineer specialized in energy systems optimization. She is currently carrying out a PhD research with the Center for Applied Mathematics of Mines Paris, France, under the direction of Professor Gilles Guerassimoff, on optimal energy management in Smart Energy Systems.

Optimal Multi-Energy Management in Smart Energy Systems: a Deep Reinforcement Learning approach and a case-study on a French eco-district

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This research work introduces a novel approach to energy management in Smart Energy Systems (SES) that leverages the power of Deep Reinforcement Learning (DRL) algorithms. We propose a Smart Energy Management System (SEMS) that optimizes the management of flexible energy systems in SES, including heating, cooling and electricity storage systems as well as District Heating and Cooling Systems (DHCS) such as district-level Thermo-Refrigerating Heat Pumps. The proposed approach is applied on Meridia Smart energy (MSE), a new demonstration project for SES that is currently under construction within the Nice Meridia eco-district in the south of France. The eco-district involves 50 buildings, many of which are equipped with photovoltaic (PV) panels. The occupants will be supplied with heat and cold produced locally in the eco-district thanks to a geothermal Fourth Generation DHCS. In addition to local electricity, heating and cooling production, the SES also integrates multi-energy storage systems, namely an innovative heat storage system by phase-changing materials, a cold storage by ice storage tanks and a battery storage offering additional flexibility. The energy management systems developed within the present research work aim at reaching strategic objectives set by the French Environmental and Energy Management Agency (ADEME), funder of this demonstrator project. Among these strategic objectives, we consider raising the renewable energy share to more than 70%, maximizing the energy autonomy of the eco-district and minimizing its carbon footprint.

The decision making problem is addressed using a DRL approach. The proposed DRL framework is based on actor-critic architecture and is benchmarked against Model Predictive Control (MPC), which is one of the most widely used methods for advanced process control in both industrial and academic level.
Simulation results demonstrate that the proposed DRL approach achieves rewards close to the theoretical MPC optimum in terms of energy cost reduction and environmental sustainability. This work represents one of the first studies in the literature to benchmark DRL and MPC approaches for multi-energy management in SES and suggests that DRL is a promising technique for energy-efficient and sustainable management of SES.

Keywords: Smart Energy Systems, District Heating and Cooling Systems, Optimal Energy Management, eco-district, Deep Reinforcement Learning, Model Predictive Control, geothermal thermo-refrigerating heat pumps

Alessandro Capretti is Head of DH Network Planning and design in A2A Calore e Servizi, Italian multi-utility.

City-scale, multi-year and multi-stakeholder optimal district heating network developments planning

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2) Alessandro Capretti*, A2A Calore & Servizi srl*
3) Andrea Bettinelli, Optit srl
4) Nicolò Gusmeroli, Optit srl
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A2A Calore & Servizi (ACS) owns and manages several District Heating (DH) systems in the North of Italy.
Under the pressure of decarbonization, resiliency requirements and the EU climate action plan, opportunities to evaluate either the expansion of existing systems or the creation of new ones are becoming more and more frequent (based, for instance, on the availability of industrial waste heat). Carrying out comprehensive analyses requires the capability to run a pre-feasibility assessment that, in case of large systems, must navigate virtually limitless opportunities to properly design a DH distribution network, while aiming for a sustainable return on the investment, involving multiple internal and external stakeholders throughout the decision-making process.

The planning phase of a large project requires comparison of a wide range of scenarios that take into account technical, economic, urban and operational constraints, to allow the key stakeholders consolidate a strong understanding of the main decision drivers and impacts. Optit has been supporting this process for almost a decade, leveraging on an advanced digital solution that provides the optimal layout and dimensioning of district heating networks, in compliance with thermal-hydraulic limits, with a given production mix, optimizing investment's net present value (NPV).

The most recent features add the capacity to support a multi-year perspective to the economic optimization. In fact, limitations to the development roadmap are often dictated by budgetary or operational constraints, factored in the mathematical models to produce not only the optimal final design, but also the most effective and convenient expansion roadmap, managing explicitly multi-year development phases that embed optimality criteria.

Based on a real-life project, the methodology and the solution will be reviewed, exploring not only the scientific criteria managed in the objective function (and related constraints), but also how these relate to the actual decision-making process of a leading European utility in its strategic planning and engineering departments, streamlining the design process up to the discussion of a consistent development plan with all the stakeholders involved in the project (e.g. authorities, citizens).

Keywords: district heating network, urban planning, project management, climate action, optimisation, digitalization, decarbonization, stakeholder engagement

Mostafa is a researcher associate and PhD candidate at the Energy Economics Group (EEG). He joined the EEG in October 2016 and significantly contributes to energy system modelling, notably in the context of H&C (Heating and Cooling) potential analysis and system/grid planning.

Validation of calculated heat demand of the building stock using consumption data under GDPR

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Bottom-up methods use various data on building use, construction period, renovation status of the building, heating system, footprint, and heated gross floor area to estimate the heat demand of buildings. Once the estimation is done, the plausibility and validity of the results should be checked. In the case of the validity checks, the obtained results should be compared to consumption data to have a robust basis.

Directive 2007/2/EC elaborates on establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) and aims to create a spatial data infrastructure within the EU. This should facilitate the exchange of spatially relevant information between organizations in the public sector and public access to spatial data across Europe. Non-personal geodata falls into this category. In contrast, combining those data with personal data or civil register falls under General Data Protection Regulation (GDPR). Sharing the consumption data is not allowed due to GDPR restrictions. As a result, the validation of the building stock heat demand cannot be easily done and requires cooperation between DSOs and third parties.

The heat demand calculation used in this work originates from Spatial Energy Plan (SEP) project, funded by Green Energy Lab, and covers buildings in Vienna. We focus on buildings with single-use (no mixed-use) and single energy carrier usage (here, Natural gas). First, a subset of data sets representing all buildings in Vienna is selected. We consider construction periods, end-use, renovation status, footprint and heated gross floor area for categorizing buildings.

The buildings are categorized into groups containing 5 buildings with similar characteristics. The calculated demand of each building and their group code is shared with the DSO. In the next step, the DSO compares the calculated demands with the consumption data (which are adjusted to the heating degree days) from different years. The results of comparison are reported for each group of buildings in an aggregated manner. Based on the reported deviations, validation of calculated heat demands is performed.

Initial results show an overestimation of demand in buildings with low specific heat demand an underestimation of demand in buildings with high specific heat demand.

Keywords: Validation, Building stock, Heat demand, GDPR, data protection law

Seán Harty is a technical sales engineer with Heatgrid Ireland who are currently developing district heating networks in Ireland. He has previous experience working for large suppliers in the heating and cooling industry, most recently maintaining and operating several large communal heating schemes in Ireland. His educational background comes in the form of a degree in Renewable Energy and Energy Management from the Munster Technological University.

Starting a district heating network in locations with no experience of district heating

David Connolly, HeatGrid Ireland

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Ireland is a world leader in renewable electricity with almost of half of all electricity now supplied by wind energy along with a small contribution from solar and hydro. However, Ireland is worst country in Europe in terms of renewable heat, placed bottom of the list in terms of renewable heat share at approximately 5%. Countries with the leading share of renewable heat in Europe also have the leading share of district heating, so in recent years, a number of studies have investigated the potential of district heating for Irish towns and cities. This culminated in the 'National Heat Study' which was released by the Irish energy agency, SEAI, in 2022, concluding that up to 50% of all Irish buildings should be converted to district heating. Even thought district heating is not a new technology, Ireland has very little district heating so going from almost zero today to up to 50% of buildings with district heating in the future is huge challenge. But you must start somewhere, and HeatGrid Ireland is currently Ireland's only company developing early stage district heating projects across a number of Irish towns and cities. This has created many challenges but also opportunities in trying to establish where and how to build district heating networks in locations with no experience of district heating. Identifying the correct sites, developing attractive customer propositions and providing clear business structures have proved vital to progressing these district heating schemes. Even though the initial number of clients being connected is small, they represent large volumes of heat and therefore create a backbone for a wider city district heating network to grow in the years ahead.

Keywords: District heating, mapping, feasibility studies

► Research Associate in the field of Smart Energy Systems, Renewable Energy, and Sector Coupling.
► Expertise in analyzing and understanding the complex interactions between energy generation, consumption, and flexibility
► Open mind for new approaches, knowledge, and discussions!

Cost-optimized decarbonization strategy for an existing residential area in Germany

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This paper addresses the following question: How to supply an existing residential area in a CO2-neutral, decentralized, and cost-optimized way using smart energy systems?

First, we analysed the local conditions of the area with over 800 residents in 11 multi-family houses including 115 parking lots. The residential area with multiple owners is a mixture of unrenovated, renovated, and newly constructed buildings. Currently, the houses are connected to an existing local district heating network. The required heat of 2 GWh/a is produced by natural gas boilers. Further, each building has a separate electrical connection to the external distribution system operator.

For this, we developed a suitable technology portfolio for the decarbonization of the residential area. Based on our analysis, we have determined that the maximal capacity for photovoltaic (PV) installation is 930 kWp. The natural gas boilers can be replaced by a heat pump (HP) or a combined heat and power (CHP) unit with hydrogen. For the 115 parking lots, a smart charging solution is necessary. Thus, an hourly optimization model was developed to simulate the cost of electricity, heating, domestic hot water, and mobility. In scenarios, we analyse potentials from the perspective of today, potentials that can be realized in the future, and potentials under optimal conditions. Due to volatile energy prices and a not yet existing market price for hydrogen, the economy is analysed with different price scenarios for electricity, natural gas, and H2.

As a result, we found that decentral and smart energy systems enable a CO2-neutral and economic transformation of the residential area. For this, the renovation of a part of the buildings is required. Further, the sector coupling of heat and mobility enables a high self-consumption rate (85%), especially with the smart charging of EVs. On the other hand, the large PV potential ensures a significant self-sufficiency rate and therefore price stability. However, the economic benefits of self-consumption are a challenge from the regulatory point of view. Further, the decision of the economics between an HP or CHP unit depends on the pricing of electricity and H2. According to the current price situation, the HP with PV self-consumption is the most economical.

Keywords: Residential area, Decarbonization, Smart Energy Systems, Sector coupling, Decentralized

Steen Schelle Jensen has a strong passion for district energy as a key technology for decarbonizing heating and cooling of buildings. He is driven by unlocking the enormous potential of data-driven solutions and services to connect the entire value chain from production to buildings and end-users … and vice versa.

Consumers role in the transition to low temperature heat networks

Steen Schelle *Jensen, Head of Business Development, Kamstrup A/S*

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Low Temperature Operation is crucial for sustainable and eco-friendly district heating systems. DIN Forsyning, a Denmark-based utility, understands the importance of digitalization across the entire value chain. They have actively sought a solution to identify and prioritize buildings that are key to establishing the conditions necessary for lower temperatures. An Energy Consultant at DIN Forsyning, is responsible for assisting consumers in improving faulty heat installations that strain the district heating system. However, the daily process can be complex and time-consuming.

In collaboration with DIN Forsyning, Kamstrup has developed the Digital Low Temperature Assistant, an advanced solution that continuously monitors heating installations and efficiently identifies problematic installations. This digital tool prioritizes installations that have the most impact on the supply network. However, the prioritization of installations is not enough to influence the network temperature, as it is consumer actions that are crucial to reach an effect on network temperature. The Digital Low Temperature Assistant excels in facilitating customized consumer letters, ensuring effective and easily understandable communication with consumers. This information increases consumer reaction due to the sense of urgency a customized letter creates. And while the utility's tracking and analysis efforts are valuable, meaningful change occurs when consumers adjust their heat installations, thereby influencing the return temperature. If corrective measures are required, consumers are redirected to qualified plumbers who can effectively adjust installations.

Significant financial benefits can be achieved through temperature reduction. Theoretical analyses indicate that the costs per degree are considerably higher for renewable energy sources, approximately 6-7 times higher. According to DIN Forsyning, a reduction of 5°C results in savings of DKK 7.7 million per year. Another utility also experiences savings of DKK 2.3 million per year per °C. These examples highlight the significant untapped economic potential that lies in automating and qualifying the process of identifying and repairing faulty heating installations.

Keywords: Green transition, low temperature heat networks, consumer involvement, digitalization, district heating system, heating system control.

Peter Lorenzen has been working as a researcher in the field of district heating at the Hamburg University of Applied Sciences since 2014. Through parallel employment at a supplier (2014-2019), he could gain practical experience. In 2022, he completed his dissertation focusing on the green transition.

A new classification for district heating activities and the gap of a comprehensive methodology for the green transition

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Nina Kicherer, Hamburg University of Applied Sciences
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The green transition of the district heating (DH) sector is an important task to provide heat in a socially acceptable way. It affects all activities throughout the entire lifetime of a district heating system (DHS). But what are these activities? This study presents the results of a systematic literature research for DH activities and a new classification for these. It was conducted as part of a dissertation and its objective is to identify existing methodologies for enabling the transition as well as the gaps they leave. As a novelty, this classification combines the activities in all contexts: before, during, and after the implementation of DHSs.

To do so, eight so-called "DH scopes" were derived from practical experience and a global literature research. Then, a systematic literature review was carried out for 1300 titles resulting in 21 selected publications. The criterion for their selection was to cover at least two of the DH scopes.

The result is summarized in the figure. Each DH scope sets a context for different activities. A higher-level scope defines the conditions for the subordinate scopes. For each scope, the identified methods and tools to facilitate the transition are summarized. This description is presented in the dissertation.

Further it was evaluated, if the identified publications cover the DH scopes in a comprehensive way. The result is that there are numerous methodologies for the strategic heat planning (scope III). They consider the preconditions, the policies, and partly the organization scopes (scopes I-IV). In contrast, for the scopes of organization, design, operative planning, operation, and evaluation (scopes IV-VIII) no methodology was found that facilitates the transition in a comprehensive way.

The new DH scopes provide an orientation for all stakeholders who are involved in the DH sector. They help to organize the large amount of literature. When solving specific challenges of the transition, it can be identified in which DH scope(s) the problem must be solved. In addition, the DH scopes can be used to identify problems between different contexts. Finally, the DH scopes were used in the dissertation to develop a framework as a contribution to fill the identified gap.

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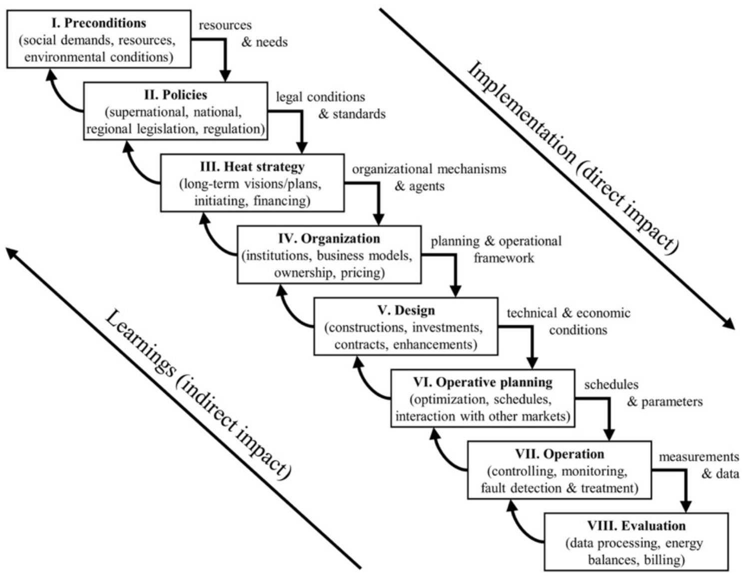
Keywords: district heating activities, organizing district heating, transition methodologies



Andreas Möbius is member of the team heat transformation at FfE. He works as energy consultant for communal and develops energy system tools.

Heat transformation tool to support communities with "municipal heating planning"

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Approximately 50 % of the final energy consumption in Germany in 2022 was used by the heating sector for heating homes, domestic hot water and process heat in the industry. To further accelerate the heat transition in Germany, it is currently discussed that every larger commune should be obliged to create a "municipal heating plan" within the next two years. In Baden-Württemberg, this is already mandatory from 2022 and these have to be finalized in 2023. However, no freely available toolset for modelling the transition are recommended by the authorities or solution providers. Nevertheless, it is crucial for a system-optimal municipal heat planning to estimate costs, energy system effects and interdependencies.

Along practical projects for municipal heating plan for Munich, Cologne and Stuttgart such an heat transformation analysis tool was developed in order to compare the effects of different scenarios for heat supply configurations.

The main purpose of the tool is to show, building by building and year by year , how the heating supply per energy source changes in a city and the resulting CO2 emissions as well as costs. The tool processes building-specific parameters such as building type, type of current energy supply technology, annual heat supply as well as superordinate parameters for the scenarios such as renovation rates and depths as well as energy-economic framework parameters. The tool can be applied to any municipality, even outside Germany, once the necessary status quo data has been collected and the heat transformation strategies are ready to test. In the paper the effect of a change in the most relevant scenario parameters, will be discussed.

Keywords: Municipal heat planning, heat transformation, modelling, heat transformation strategies

Ralf-Roman Schmidt is working at AIT since 2009, where he is responsible for the development and management of projects in the field of district heating and integrated energy systems. He holds key positions in international networks and received a PhD in the field of thermo-fluid dynamics in 2013

Risk minimization for decarbonizing heating networks via network temperature reductions and flexibility utilization – concepts and measures

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Many large urban DH networks are heavily depending on gas. Since the use of renewable fuel alternatives will be very limited in the future, and the connection of more customers to the DH networks can be expected, significant amounts alternative heat sources such as heat pumps, waste heat, solar- and geothermal energy will be required to secure and decarbonize the DH supply.

This presentation highlights the opportunities and challenges related to the optimization of the building stock in terms of return temperatures and flexibilities, network hydraulics, bi-directional operation, the integration of seasonal storages, as well as consumer involvement and business models. Also, related uncertainties regarding energy prices, availability of alternative heat sources and seasonal storages as well as implementation of retrofitting and optimization activities will be discussed.

Finally, concepts and measures followed in the project DeRiskDH will be introduced, focussing on solution on the technological and a strategic level as well as innovative business models towards building owners and end users for handling the technical challenges and minimizing the investment risk in alternative heat sources.

Keywords: District heating, Monte-Carlo-simulations, temperature reductions, seasonal storages

Hinnerk Willenbrink has been working in the field of municipal energy planning for many years to date. As a long-time employee at Münster University of Applied Sciences, he is part of the steering group of a 40-member research group. In this function, he manages R&D projects from EU to local level.

The new housing area "Warendorf In de Brinke" - 5GDH: from project to principle?

Hinnerk Willenbrink, FH Münster, University of Applied Science, Tobias Ahlers, Stadtwerke Warendorf GmbH

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The German heating market's dependence on natural gas and oil imports has proven to be a security risk and a major obstacle to climate protection efforts in the building sector. In response, Münster University of Applied Sciences conducted two large INTERREG projects to explore alternative heating supply methods. One of these projects (WiEfm - Wärme in der EUREGIO) resulted in a low temperature district heating system for a new housing area in Warendorf. The area spans 18 hectares and includes 200 buildings with up to 500 residential units.

The project was driven by the downward trend in gas sales, high investment costs for gas networks, high energy efficiency of new buildings, and high customer willingness to switch to renewable energies. The local energy supply company, Stadtwerke Warendorf GmbH, commissioned an external study to compare alternative supply options to standard development using gas pipelines and self-supply using heat pumps/solar thermal energy. The study focused on the applicability, energy consumption, costs, and environmental compatibility of such systems. The results showed that a 5th generation district heating network (5GDH) was the preferred option.

The 5GDH system is designed to use more than 100 geothermal heat probes as the heat source and more than 5.000 m uninsulated brine containing pipe system as energy carriers. This results in a balance sheet energy gain, with the required temperatures raised by heat pumps in residential buildings. The federal government's funding in the "Wärmenetze 4.0" programme supported the decision in favour of this system. However, the transferability of this good example to other building areas is not without problems.

The presentation will explore the opportunities and risks for municipalities, utilities, and project developers in the development and operation of 5th generation heating networks. It will also provide insights into the project's key findings and contributions to the field. This includes the use of renewable energy, low temperature district heating, and the potential for replication in other areas.

Keywords: 5th Generation District Heating, heating system, new housing area, geothermal heat source, geothermal energy, residential heating, project funding

SMART ENERGY INFRASTRUCTURE AND STORAGE OPTIONS

Torstein Balle is a PhD student at the University of the Faroe Islands. He is studying in the field of energy, working on design of domestic heat supply systems for optimal use of renewable energy.

Inspection of added thermal storage to increase the match of consumption and renewable generation, analysed for domestic heating on the Faroe Islands

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Demand-Side-Management (DSM) incorporates load shifting, which aims to transfer parts of the electrical grid load to a different schedule with more desirable features. Energy storage is one way to achieve load shifting by storing energy during periods of abundant electricity generation and drawing from it during times of scarce generation. The purpose of this study is to explore the potential of incorporating thermal storage for heating in the Faroe Islands, utilizing renewable power generation. The study will utilize historical data of heat consumption for buildings equipped with heat pumps, coupled with wind power production, to assess whether additional storage can enhance renewable power consumption, ultimately reducing oil-generated consumption. During periods with high wind power production and low heating requirements, and subsequent periods with no wind and high heating needs, additional storage may prove advantageous in avoiding non-renewable generation and reducing variability in the generation-to-consumption balance. Forecasting generation and load is essential for proper storage management, and the paper will examine and assess the weather forecast precision necessary to maximize the benefits of this setup. Examining the data for potential and actual wind power production and electricity consumption for heating in the Faroes shows both periods with wind power surplus and deficit, creating an excellent case for added energy storage, and as many of the periods of overlap are short, a short-term storage option such as a small thermal storage is very interesting.

Keywords: Load shifting, Demand-side-management, Heat pumps, Thermal energy storage, Generation forecasting

Mathematical modelling of energy systems, under uncertainty, is his main research focus. His further research interest include besides modelling of energy markets, transmission and generation expansion planning in electricity systems.

The Value of Information – How Enhanced Load Profiles Save Costs for Local Congestion Management

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The integration of renewable energy generators and the electrification of transport and heating sectors have brought new challenges for managing grid congestions in distribution networks. Congestion management is more effective if the DSO has access to real-time and predictive information on the grid's current and future status. As a result, digitalization and smart meters have become increasingly important for distribution system operators (DSOs) to gain insights into local load patterns of consumers, leading to better congestion management measures and cost savings.

The objective of our research is to evaluate the value of improved load forecasts for better managing local congestion in electricity distribution grids. We will quantify this value using the "value of perfect information" metric. In addition, we aim to shed light on related questions, such as how to measure the economic potential for flexibility, and how to optimally coordinate flexibility usage within a local distribution grid.

Our research methodology is based on three main components. First, we evaluate the improvement in residential load forecasting when comparing a “standard load profile” with a load profile forecast based on smart meter data. Second, we use a Monte Carlo simulation to generate multiple load forecasts based on the error distributions we have identified. Third, we conduct an AC power flow simulation using the load forecasts to calculate power flows and voltage levels. We use these data exogenously for our congestion management model, which minimizes costs associated with necessary actions to avoid congestion, such as flexible generation and load regulation.

Overall, we contribute to the established stream of work focused on modeling the operation of distribution grids using local generation and demand side flexibility options for managing congestions. Additionally, we provide an economic assessment of the value of having more detailed knowledge about load profiles in this context. Our results are relevant for DSOs, stakeholders with an empirical and methodological interest in electricity networks, and the energy modeling community.

Keywords: Active Distribution Network, Congestion Management, Load Forecast, Flexibility

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.

Energy system modelling of a future zero-emission neighbourhood with seasonal thermal energy storage

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Nyhavna is an industrial area in central Trondheim, Norway, which today mainly consists of light industry and office buildings. In 2019, the municipality decided that Nyhavna will be transformed into a zero-emission neighbourhood, with a planned area of new buildings of more than 400,000 m2. The area will predominantly consist of residential buildings, but there will also be commercial buildings, such as offices, hotels and shops. The transformation is planned in three construction phases, starting around 2025 and finishing in 2040-2050.

The area will have a local district heating network, with a heating central connected to boreholes for seasonal thermal energy storage and a large-scale seawater heat pump. The local heating central will use and also supply heat to the main district heating network of Trondheim, making it part of optimising the heating network of the entire city. The seasonal storage can be charged by the district heating network in the summer, utilising excess heat from the waste incineration plant in Trondheim. In the colder seasons, heat from the seasonal storage and the seawater heat pump will cover the area's heating demands. Additionally, PV panels will be used for local electricity production, which can in turn be used to power the seawater heat pump. In order to reach the zero-emission target, the emissions related to building and operation of the neighbourhood should be compensated for with export of locally produced electricity or heat.

The aim of this study is to evaluate different scenarios for the system in Nyhavna using Integrate, a software system for the optimisation of integrated energy systems. The scenarios include low- and medium-temperature distribution in the local heating network, as well as different scenarios with respect to production and storage of electricity. Ultimately, this study will give important insights into the potential and challenges related to transforming Nyhavna into a zero-emission neighbourhood, as well as general insight regarding optimal development of integrated energy systems.

Keywords: integrated energy system modelling, sector coupling, low-temperature district heating, seasonal thermal energy storage

Toke works within the field of sustainable energy planning with a main focus on district energy systems. In his field of work he combines both local and holistic planning approaches while researching cross-sectoral synergies and energy conversion- and storage opportunities.

The Role of Thermal Energy Storages in Smart Energy Systems

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Henrik Lund, Aalborg University

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Energy Systems with high availability of intermittent energy sources require adequate energy storages for optimal integration, higher utilization and added flexibility within the energy system – thus further exploiting cross sectoral synergies such as in the Smart Energy System approach. Exploiting these synergies, the Danish district heating systems and thermal energy storages play an increasing and important role. Yet there is still a need for comprehensive scenario calculations in order to provide adequate and proactive planning at specific energy systems.

Hence, this article has a twofold objective. Firstly, the article reviews state-of-the-art thermal energy storage technologies in the context of smart energy systems and their applications in terms of 4'th generation district heating in Denmark. Secondly, the article examines the relevance of the different thermal energy storage technologies in the context of the future district heating system of Aalborg (2030) as a case, which is expected to consist of large amounts of excess heat from various industries and PtX facilities supplemented by large scale heat pumps. The article focuses on the potential benefits in terms of flexibility, peak shaving, security of supply, and economic feasibility as well as applicability in terms of moving towards lower temperatures in the district heating grids (4GHD).

Keywords: Thermal energy storage, Seasonal storage, Sensible heat storage, Smart energy systems, 4th generation district heating

Dr Sleiman Farah is a mechanical engineer with industry experience in design of mechanical systems in buildings. Dr Farah is interested in the renewable energy transition, focusing his research on optimising renewable energy systems with electrical and thermal energy storage technologies.

Investment-based optimisation of energy storage parameters in a grid-connected hybrid renewable energy system

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Decarbonising the electricity grid by transitioning away from fossil fuels towards renewable energy sources is essential to reduce greenhouse gas emissions and combat climate change. However, the integration of intermittent renewable power sources, such as solar and wind, increases the difficulty of managing the electricity grid and maintaining the balance of electricity supply and demand. Grid-connected hybrid renewable power systems with energy storage can reduce the intermittency of renewable power supply to the grid. Nevertheless, the techno-economic characteristics of emerging energy storage technologies need to be improved to compete with batteries, especially lithium-ion batteries, to reduce the levelised cost of energy. Improving these technologies by optimising their parameters is technically challenging; considering the parameters as independent optimisation variables breaks the linearity of the energy system model and complicates the system optimisation. To overcome this challenge, this research presents a novel investment-based optimisation method that consists of two main steps: linear optimisation of the renewable energy system, and another linear investment optimisation. The method is applied to four energy storage technologies, namely, thermal energy, pumped thermal energy, molten salt, and adiabatic compressed air in a grid-connected hybrid renewable power system. The overall results show that investments are allocated first to improving the discharge efficiency for all storage technologies. Investments for improving energy storage capacity cost and the discharge capacity cost can also become important. However, investments for improving the charge capacity cost and especially the charge efficiency are the least important. The results also provide a detailed improvement path of parameters for each energy storage technology at different operation conditions. These improvement paths can assist energy storage developers allocate resources optimally for improving energy storage technologies. Therefore, the developed investment-based optimisation method and the results from this research can help increase the techno-economic competitiveness of emerging energy storage technologies and reduce the reliance on batteries in renewable energy systems.

Keywords: renewable energy, energy system optimisation, energy storage, electricity grid, electricity cost, energy storage parameters, batteries

Alaa is a mechanical engineer, with experience in infrastructure. He is sepcialized within techo-economic optimziation of infrastructure systems. He holds a PhD in process engineering.

A Novel Aggregator Algorithm for Coordinated Control of Multiple Battery Energy Storage Systems

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Energy Storage Systems (ESSs) are increasingly recognized as key components for integrating renewable energy systems, providing flexibility on both the production and consumption sides of the energy system. However, the prohibitive investment costs of ESSs, particularly battery ESSs (BESS), have led to the practice of providing remunerated services, such as frequency regulation and energy trading, using these systems. Operating multiple BESSs together presents challenges, but also offers advantages and synergies that a diversified system can bring. In particular, this can be beneficial when dealing with large building or industrial complexes, such as airports where multiple BESSs can be installed.

In this study, we propose a novel aggregator algorithm for coordinated control of multiple BESSs, considering different optimization horizons and use cases including frequency regulation service provision, energy trading, and energy management. The proposed methodology utilizes mature optimization techniques (Mixed Integer Linear Programming) to efficiently allocate energy storage capacities among ESSs, considering factors such as energy demand, prices, and state of charge (SOC) limits. The goal is to optimize energy dispatch from BESSs, aiming to minimize overall costs while ensuring reliable and stable grid operation.

This study presents a promising approach for managing multiple BESSs with varying optimization horizons and provides valuable insights for grid operators and energy system planners in developing effective strategies for controlling energy storage systems.

This is performed based on the development on energy management systems within the framework of the ALIGHT project (grant n. 957824), which is funded by the European Commission, aiming to make aviation more sustainable with Copenhagen Airport as lighthouse for the implementation of smart and green solutions.

Keywords: Energy Mangement, Frequency Regulation, Multi-Horizon Optimization

Ebbe is a PhD Fellow at the Department of Mechanical Engineering at Aarhus University. His research focuses on the modeling of large-scale highly renewable energy systems, with special attention to the integration of gridscale electricity storage.

Cost and efficiency requirements for a successful electricity storage in a highly renewable European energy system

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Future highly renewable energy systems might require substantial storage deployment. At the current stage, the technology portfolio of dominant electricity storage options is limited to pumped-hydro storage and Li-Ion batteries. It is uncertain which storage design will be able to compete with these options. Considering Europe as a case study, we derive the cost and efficiency requirements of a generic electricity storage technology, which we refer to as storage-X, to be deployed in the cost-optimal system. This is performed while including existing pumped-hydro facilities and accounting for the competition from stationary Li-ion batteries, flexible generation technology, and flexible demand in a highly renewable sector-coupled energy system.

Based on a sample space of 724 storage configurations, we show that energy capacity cost and discharge efficiency largely determine the optimal storage deployment, in agreement with previous studies. Here, we show that charge capacity cost is also important due to its impact on renewable curtailment. A significant deployment of storage-X in a cost-optimal system requires (a) discharge efficiency of at least 95%, (b) discharge efficiency of at least 50% together with low energy capacity cost (10€/kWh), or (c) discharge efficiency of at least 25% with very low energy capacity cost (2€/kWh). Comparing our findings with seven emerging technologies reveals that none of them fulfill these requirements, based on their current development stage. The Thermal Energy Storage (TES), also known as the Carnot battery, is, however, on the verge of qualifying due to its low energy capacity cost and concurrent low charge capacity cost.
Finally, we assessed the system impact of the integration of storage-X. Exploring the space of storage designs reveals that system cost reduction from storage-X deployment

can reach 9% at its best, but this requires high round-trip efficiency (≥90%) and low charge capacity cost (35€/kW).

Keywords: electricity storage, sector-coupling, parametric sensitivity analysis, PyPSA

Lukas Hofmann is a first-year Ph.D. student at CEA (French Alternative Energies and Atomic Energy Commission). His research work focuses on the coupling of electricity and heat with the aim of decarbonising the French energy system.

How seasonal heat storage can benefit power system flexibility and power-to-heat integration? An optimisation on the scale of the French territory.

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Like most European countries, France consumes mostly fossil fuels for heating. Heat demands from residential and tertiary sectors have a strong decarbonising potential through electrification — as long as the electricity production remains low-carbon. Due to the seasonal nature of heating patterns, its electrification will generate an increasing need for seasonal flexibility of the power system. Today, long-term flexibility is largely provided throughout Europe by CO2-emitting dispatchable power plants. In the context of a decrease in such dispatchable capacities in favour of intermittent sources, more flexibility will be required. Therefore, the present study aims to evaluate the synergies between heat and electricity on the scale of the French territory and assess what additional flexibility thermal storage can provide to the power system.

To this end, we developed a capacity investment model (based on a Linear Programming optimisation) of a coupled electricity-heat system at the French scale. Then, electricity and heat production technologies (e.g. gas turbine, heat pump, combined heat and power) along with electrical storage capacities (short and long-term) and thermal storage were gradually added to the model. In doing so, we aimed to catch the impact of these technologies on the system as a whole.

In general, the developed methodology allowed us to determine the areas of relevance of different heat generation strategies. The main findings are as follows: Firstly, multiple sensitivity analyses provided findings on the potential role of thermal storage for greater energy system flexibility. Secondly, we assess the trade-offs between electric and fossil fuels heating, as well as trade-offs between individual and collective heating (by considering district heating systems).

Keywords: Sector coupling, Electrification of heating, District Heating, Seasonal thermal storage, Flexibility, Heat Pumps, Combined heat and power, Power-to-heat, Capacity investment modelling

Kristians field of work, is to supply sustainable, resilient and competitive district heating for all customers in Copenhagen.

The age of Digitalization and Flexibility - from consumer to FLEXUMER in the district heating system

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To enable the future renewable energy system, a digitalized and Smart Energy System is needed.

With a fully digital district heating system it will be possible to maximize energy efficiency, utilize energy flexibility, integrate more renewable energy sources and reduce CO2.

The digitalization, will also make it possible for consumers to participate in the green transition by becoming flexumers, meaning consumers not only consuming energy, but also offering valuable energy flexibility to the district heating system making it possible to reduce the usage of fossil fuels in the peak load production.

This can be done because the buildings and their substations are on-line and also because all buildings to some extend can be compared to batteries; batteries of heat that is; that can be both charged and discharged, depending on the requirements of the district heating system.
Buildings are different in size, age, usage, state of insulation, automatization etc. and represent various battery capacities and sizes, but in general they have a thermal mass that can be activated for hours, without compromising indoor comfort.
The flexumer concept includes other potential benefits and values for the district heating companies like:

- Optimization of power-to-heat production like electrical boilers and heat pumps by reducing production at high electricity prices and vice versa

- Facilitating ancillary services for the electricity system from power-to-heat production
- Reducing bottlenecks in the district heating networks
- Balancing networks in cases of shortage of supply

For the customers other benefits from being flexumers could be:

- Actively taking part in the green transition
- Remote energy consultancy and optimization
- Realistic energy savings in the range of 3-5% due to better on-line weather compensation taking a.o. solar irradiation into account
- Receiving alarms in case of malfunction of the substation making it possible to solve problems fast
- Fewer and more dedicated O&M visits to the substations due to the on-line control and possibility of having problems identified in advance
-

Having an on-line district heating substation often also makes it possible to upgrade to other smart energy saving services focusing on improved indoor comfort and climate.

Keywords: Smart energy system, district heating system, peak load, flexibility, ancillary services, digitalization, district heating substations, energy efficiency, energy savings, consumers, flexumers.

Pascal Häbig, M.Sc., is an industrial engineer and has been a research associate and research group leader at the Institute of Energy Economics and the Rational Use of Energy at the University of Stuttgart since 2018. His focus is on small-scale flexibility, business models and ICT in smart grids.

Quantifying the Standardization Gap in Smart Energy Systems: Standardizing Information and Communication Interfaces for Small-Scale Flexibility

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Decentralized small-scale flexibility, e.g. battery storage, heat pumps, or charging of battery electric cars, offers immense potential of efficient integration of volatile renewable generation. Integrating this type of flexibility into the system could result in significant cost reductions. However, currently, the amount of available and usable flexibility is comparably small in relation to the installed capacity. This can be attributed, in part, to the low economic benefit from an individual perspective, as well as the lack of market opportunities and high information and communication costs associated with small-scale flexibility.

The conference contribution aims to address these challenges by exploring how standardization of information and communication interfaces can lower transaction costs and reduce barriers to energy system integration. The research question is centered around the impact of data and communication standards on a smart energy system. However, it is important to note that increasing the number of standards may widen the gap to an optimally designed system.

The objective of the conference paper is to quantify the standardization gap between centralized and decentralized decision-making, both generally and for the specific use case of a smart energy system in an urban district. The standardization gap refers to the difference in system costs resulting from the two approaches.

The paper first discusses the technical basics and theories related to transaction costs and the standardization gap. Secondly, it focuses on modeling the problem and the data used. Finally, the study's results are presented, evaluated, and critically discussed.

The study's findings indicate that a standardization gap can lead to inefficiencies and hinder the realization of the flexibility potential. However, determining a specific standard could potentially impede technological developments and limit their benefits.

Keywords: Standardization Gap, ICT-Interfaces, Small-Scale Flexibility, Smart Energy Systems

Emanuela Marzi is a PhD student in Industrial Engineering at the University of Parma, Italy. Her research interests are related to the intelligent control and optimization of multi-energy systems, with particular focus on the integration of Power-to-X solutions in such systems.

Coordinating multiple Power-to-Gas plants for optimal management of e-fuel seasonal storage

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Integrated energy systems or multi-energy systems, namely systems in which multiple energy carriers interact with each other in an optimal way, are essential to ensure the full integration of renewable energy sources, necessary in the decarbonization pathway. Another key feature when a high share of electricity is generated using renewable energy sources is seasonal storage, which must be included in the planning of future energy systems. Nevertheless, due to their large size, seasonal storages may be used to serve different integrated energy systems, which are generally managed independently. Power-to-Gas (PtG) technologies represent a promising solution in this regard. Indeed, they allow to directly convert surplus renewable electricity into e-fuels (e.g. green hydrogen or methane) and store them in the long-term. Their utilization allows the integration of the electrical, fuel and heating sectors, by converting the surplus renewable electricity into fuels and by recovering the waste heat of the process. In such a configuration, advanced management and control tools are required to design the most profitable strategy for the storage and the system as a whole. In this work, a novel control method is proposed, to manage the interaction of multiple multi-energy systems which are integrated by means of a shared e-fuel seasonal storage. Each single multi-energy system has its own short-term control logic, based on Model-Predictive Control (MPC), which manages the day-ahead energy exchanges, while a long-term MPC controller takes into account yearly dynamics and the interactions between the different energy systems, and manages the seasonal storage. It gives additional constraints to the

short-term controllers, which ensure that the yearly goals are met. With the developed control architecture, a multi-temporal and multi-spatial control is obtained. The proposed management is verified in a Model-in-the-Loop configuration, and the benefits of the novel control strategy are quantified, by comparing the results with the ones obtained using a conventional control logic.

Keywords: Power-to-Gas, Model Predictive Control, Multi-Energy Systems, Long-term storage, Hierarchical control.

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Design of a renewable district heating and cooling plant for a university Campus in Cyprus

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Heating and cooling equipment, which has been in use for a prolonged period, is often relatively inefficient, partly due to wear and tear, and partly due to lack of technology optimization. District heating and cooling systems can operate on renewable and natural sources, including, but not limited to solar heat and ambient air in combination with thermal energy storages. This abstract aims at proposing a renewable district heating and cooling solution for the University of Cyprus in Nicosia, Cyprus. Detailed dynamic modelling will be used to analyse the system's performance.

The University of Cyprus occupies 430,000 m2 of land in the city of Nicosia. The current district heating network provides heating and domestic hot water for 98,520 m² offices, lecture halls, laboratories, and student accommodations. Likewise, the district cooling network provides cooling and air conditioning for 91,422 m² offices, lecture halls, laboratories, and student accommodations. The heat is generated by oil fuelled boilers, while cooling is generated by air cooled heat pumps. However, the boilers are old and out-dated and in need of refurbishing. Moreover, the university is planning on increasing the size of the campus and wish to decrease the cost of heating and cooling as well as the carbon footprint of both the university and its students. The university therefore presents an ideal opportunity for a solar and absorption-based district heating and cooling system supported by a thermal energy storage.

The university campus has both heating and cooling demands throughout the year. The demand for heating and hot water peaks during winter, while the cooling demand peaks during summer. The university needs cooling to keep e.g., laboratories as well as work and storage spaces at specific temperatures. The heating and cooling demands fluctuate from approximately 250 – 3000 kW and 0 - 6500 kW, respectively, and according to the previously mentioned seasonal pattern.

To comply with the heating and cooling demands of the university, the proposed technical solution includes a solar thermal field, heat pumps, absorption chillers, advanced renewable energy air conditioning units, a biomass boiler, and a thermal energy storage. Oil fuelled boilers and air-cooled chillers will act as backup systems for heating and cooling. The proposed simulation scenarios will examine heat produced by solar thermal collectors and stored in a thermal energy storage as well as heating and cooling produced by heat pumps. Furthermore, the operation of the designed district heating and cooling plant will be analysed and studied.

TRNSYS will be used to complete the dynamic simulations and to generate the energy production profiles to meet the recorded energy demands of the University of Cyprus. The district heating and cooling plants developed within the framework of the WEDISTRICT project are modelled in TRNSYS and the heating and cooling demands are inputs for TRNSYS.

The purpose of the simulation is to design a renewable district heating and cooling system, which supports the University of Cyprus in reducing the cost of heating and cooling as well as the CO2 emissions. The proposed solution's performance will be described by the main indicators: 1) renewable energy ratio, 2) the primary energy consumed, 3) CO2 emissions and 4) the levelized cost of energy.

Keywords: Renewable energy, solar-thermal, thermal energy storage, district heating, district cooling, absorption chillers, heat pumps

Optimal Extension Planning of District Heating Networks by Phased Investment

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District heating networks can be a climate friendly and efficient way to heat homes, however their initial costs often prove prohibitively expensive. Building a network in multiple phases is an interesting approach to overcome this challenge. This thesis extends the optimization framework by Blommaert et al to optimally design a multi-phase heating network for Eeklo. The network is built in two predefined investment phases, optimized simultaneously. In comparison to classical greenfield design, it is demonstrated that the initial costs can be significantly reduced using this method, at the penalty of a higher break even cost per kWh of heat that the consumer would need to pay. The optimal expansion is compared to the expansion of a network which is sequentially optimized, meaning that the first phase is built without incorporating a possible expansion in the initial design. This scenario is used to demonstrate that incorporating later extensions in the initial design has value. Not doing so has a cost attached to it, which amounted to 2.9 M€ for the considered case. This can be compared to the opportunity cost of designing a network for an expansion which is not carried out, which is 0.7 M€. Investing at a later time is shown to be disadvantageous. The main reason for this is that a part of the consumers are served for less time, meaning that there is less overall revenue. An analysis of the impact of the choice of the initial investment zone on the optimal solution shows that the linear heat density should not be the only considered factor, as it is insufficient to predict return on investment. The location of the backbone in the greenfield design should also be taken into account.

Matteo Pozzi is Partner and CEO of Optit, an Italian company that develops Decision Support Systems for the DIstrict Energy industry. He is also Vice-Chair of the DHC+ Platform, Research & Innovation Hub of Euroheat & Power, where he coordinates the working group on digitalisation.

Digitalisation of the DHC industry: a review by DHC+ and Euroheat & Power

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The complexity involved in designing and managing modern District Heating & Cooling systems is constantly rising, due to several concurrent factors:
- The conventional approach of relying on single, programmable, large heat or CHP plants is being replaced by an increasing share of distributed, renewable or waste heat sources.
- The deployment of smart heat meters enables the automatic collection of large amounts of consumption data with high granularity, paving the way to involve the end customer in virtuous energy management behaviours.
- The integration of multiple production and coupling technologies is transforming the district heating systems into a key balancing player in the decarbonisation path of the energy sector, yet at the cost of reacting to increasingly volatile energy and capacity prices.

This transformation requires unprecedented data processing capability, which can be met relying on an increasingly mature set of digital approaches.
DHC+ Platform released in 2019 the 'Digital Roadmap for DHC', which presented a wide range of solutions to support strategic and operational decisions throughout the whole value chain. In 2022, after a vast pandemic that changed the general perception of the role of Information and Communication Technology in our society, the DHC+ Working Group on Digitalisation launched a survey to suppliers (digital solution providers) and users (mostly DHC utilities) of digital tools in the District Energy Industry to assess

progress, challenges and issues faced by the business community with regards to digitalisation.

Based on the results of the survey and the discussion that followed, a Report on 'Digitalisation of District Heating and Cooling systems' was produced, aiming to to support operators across the value chain in understanding and addressing the opportunities and challenges of digital innovation for decarbonising heat supply.

The document provides insights about the role of digitalisation in modern DHC and the transition path, emphasising the still untapped potential of end-user and building's involvement and digging into customer data exploitation under GDPR. The report also suggests a logical roadmap to foster digital uptake and showcases a few selected best practices to inspire action.

Keywords: district heating and cooling, climate action, digitalisation, decarbonisation

Daniel Trier is based at PlanEnergi's office in Copenhagen. Besides several research projects, he works as client consultant handling tendering documents, contracts and supervising the progress during the construction phase in projects involving storage, solar thermal and heat pumps.

Simple real time monitoring of large thermal storages

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Data from various sensors installed at large thermal storages in Danish district heating systems are gathered and stored in an online open access data hub. The associated website allows users to select a desired period and time resolution for the data to be downloaded for further analysis. The parameters include energy content, charged/discharged thermal power and temperature levels.

The website also enables monitoring of the current storage status since the different parameters are illustrated in real time with only minutes between each data point. Besides this, KPI values for the storages are calculated and presented on the website. This is done by continuously calculating the energy balance of the storage illustrating charged energy, discharged energy, storage losses and change in energy content. The number of parameters required for this is limited and it should be noted that the website does not replace the need for operation managers' own surveillance via their SCADA system. However, it may help to identify deviations in the performance, which may be experienced as long-term degradation or short-term changes in case of a leakage. This enables timely action to address any issues. At the same time, the data hub can represent a proof of performance characteristics for systems implemented in real applications. This way the gathered experiences may benefit a wide range of stakeholders working with smart energy systems including large thermal storages.

The website address is heatstoragedata.eu – or in Danish varmelagerdata.dk.

Keywords: Thermal storage, online real time monitoring, performance, public data access

Anna Vannahme obtained her M.Sc. degree from the TU Munich. Her research focuses on district heating systems in rural areas and their optimization possibilities. Her main research interests are the analysis of substations for single-family homes and innovative operating strategies.

Study of the optimization of an existing local district heating network with an increasing degree of digitalization

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By 2017, 9000 biogas plants had been built in Germany [1]. With the ending of the Renewable Energies Act subsidy after 20 years of CHP operation, the efficient use of heat is now becoming the focus of the operators. This simulation-based study focusses on measures to optimize an existing DHN.

The current thermostatic control of the substations does not always guarantee the accurate maintenance of set-points, resulting in excessive water flow rates compared to energy consumption for the indirect connected DH substations. A validated model of the DHN is used to assess the economic efficiency and energy savings of three optimization scenarios with increasing levels of digitalization (cf. Figure 1).

In the first scenario an investigation is conducted to determine the impact of regulating the mains pump based on the return temperature monitoring at the primary side of the DH substations, without improving the DH substation itself. A lower mass-flow at the primary side results in longer remaining times of the warm water in the substations, thereby lower return temperatures. Consequently, lower DHN losses and less electrical energy used for the mains pump are expected.

In the second scenario examined, only the worst performing substations are upgraded with an electronically controlled valve on the primary side. This valve is designed to close completely when there is no demand for energy from the consumer.

An electronically controlled valve is utilized to upgrade all consumers in the third scenario. A new control strategy for the mains pump is then evaluated, wherein the opening degree of the valve in each DH substation is monitored and the data is sent to the heating plant to enable the mains pump to work in its optimal operation point for each desired flow rate.

The economic viability of digitization and its potential to conserve energy will be determined for the scenarios by the end of the analysis.

[1] Fachverband Biogas. Anzahl der Biogasanlagen in Deutschland in den Jahren 1992 bis 2022. [March 21, 2023]; Available from: https://de.statista.com/statistik/daten/studie/167671/umfrage/anzahl-der-biogasanlagen-in-deutschland-seit-1992/.

Keywords: Upgrading, Optimization Measures, Degree of digitalization, local district heating, substation, system simulation, improving energy efficiency, low-investment measures

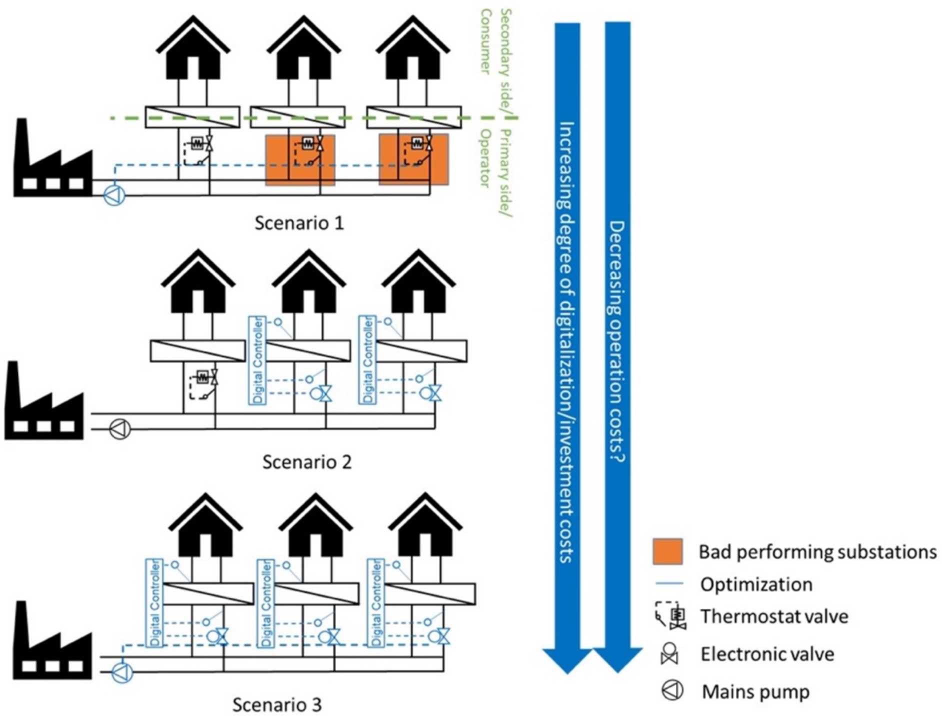

Figure 1: Increasing degree of digitalization from scenario 1 to 3. Picture of scenario 1 shows the domain of operator and consumer

Karl Vilén is a PhD student at Chalmers University of Technology who studies evolving heating systems, with a focus on interactions between the evolving supply and demand sides. The heating solution for new housing built in the future is often in focus in his work.

The role of Thermal Energy Storages in Future Heating system – A Long-term Study of an Evolving Heating System

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The use of seasonal thermal energy storages (TES) enables energy systems to reduce the use of peak power during colder seasons. Due to the low heat demand during summer, otherwise unutilized heat production units can increase their respective utilization time for charging the TES. The TES can thereby be discharged during colder seasons.
Existing heating systems do have sufficient heat production capacity to provide heat during all year, and additions of TES to these kinds of systems may be beneficial, both in economical and environmental terms. However, as time passes, there is a need to replace existing heat production plants within the existing systems as the plants reach their respective end of technical lifetime. This provides future system to reduce the sizing of new production plants by instead making investments into seasonal TES, thereby also possibly increasing the utilization of the new heat production units.
In this study, a long-term optimization of an evolving local heating system is performed. The existing system consists of different types of heat production units which reach their respective technical lifetime in the studies period. New housing of different types is also added annually, for which the heating solution is not predetermined. The system is investigated under different investment costs for the TES, as well as for different electricity prices.
The results indicate that investments into TES is economical for all TES investment costs and electricity price cases if biogas is not available for the use in the heating system. The size of the storages is lower for the scenarios with the higher investment costs. Some investments are made already in the beginning of the studies period, but additions are

also made at the time where most existing production plants reaches their respective end of technical lifetime. Investments into TES are also economical if biogas is available for the electricity price cases and TES investment cost scenarios, but the size is smaller compared to if no biogas is available.
It is mostly heat pumps which are utilized more if investments are made into TES. Also, expansion of district heating into new housing built in the future is mostly unaffected whether investments are made into TES or not.

Keywords: Thermal energy storage, District heating, Local energy system modeling, TIMES, Housing

PhD candidate Zhiyuan Xi from Aarhus University is a hardworking individual with a strong commitment to his research. His dedication to understanding the role of energy storage in the transformation of energy systems demonstrates his desire to make a meaningful impact on the future of sustainable energy.

Interactions between energy storage and electricity prices in a highly renewable energy system for Europe

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To achieve a low-carbon society by 2050, a complex energy system transformation is required. Energy storage is expected to play a crucial role, and studying its impact on electricity prices can provide insights into the wider implications. This study uses the PyPSA-Eur-Sec energy system model to analyze how different types of electricity storage interact with electricity prices across various sectors and energy demands. The impact of storage on electricity prices is evaluated under different scenarios in the transition towards 95% reduction carbon emissions relative to 1990 values by 2050. The findings indicate that using electricity storage systems like batteries and hydrogen can manage supply and demand flexibly, stabilize prices during high demand and reducing them during low demand. Furthermore, the study reveals that an increase in renewable energy may lead to a high spread of electricity prices and low-medium electricity prices, but energy storage can have a positive effect, forming a mutually beneficial relationship with renewable energy.

Keywords: Electricity storage, Electricity price, Energy system transmission

GEOGRAPHICAL INFORMATION SYSTEMS (GIS) FOR ENERGY SYSTEMS, HEAT PLANNING AND DISTRICT HEATING

Shravan is as a PhD student at the division of energy systems. His research is focused on the inclusion of excess heat in district energy systems and analysing the decarbonisation of district energy system through coupling with other sectors.

Integrating excess heat in district energy systems based on a long-term spatiotemporal and dispatch optimisation

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Excess heat recovery from industries has the potential to significantly contribute to decarbonization efforts while also offsetting emissions in the heating and cooling sector. To achieve this, Energy System Models can be used to plan for investment, scheduling, and operation of district energy systems based on the recovered excess heat. This study aims to optimize the integration of excess heat into Swedish district heating systems (DHS) by conducting a spatial-techno-economic analysis that considers current energy policies and the availability of key resources. The proposed method includes a soft link between three special purpose tools: Spatial, Capacity Investment, and Unit Commitment Dispatch. By coupling the industry and building sectors, this approach provides a robust evaluation of the cost-effective amount of excess heat that can be reused. The results of this study provide a plan for the least-cost extension of the thermal grid from both spatial and temporal perspectives. The capacity investment model focuses on the long-term development of DHS within Sweden until 2050, with consideration of the integration of existing sources of excess heat that is mapped from the European Heat Atlas. The dispatch optimization focuses on a few key years from the long-term optimization, to demonstrate the hourly, operational feasibility of the optimized heat integration. The analysis is conducted at a national scale for conventional sources of excess heat from industrial activities like steelworks, refineries, and the chemical industry. The study finds that 37% of the technical potential for excess heat recovery is economically feasible for Sweden, and here the results are examined in sensitivity depending on “biomass prices”, “distance from existing grids”, and “electricity prices”. The distance from existing grids is found to have a significant impact on economic feasibility, with all integrated sources being within 10 km. The volume of excess heat is also a determining factor for larger sources. Results indicate a higher capacity of economically feasible excess heat in the base year than what is currently used. Additionally, there is potential for new low-temperature sources to be integrated into smaller low-temperature district heating islands.

Keywords: Industrial Excess heat, Urban excess heat, District heating, Spatio-temporal optimisation, techno-economic optimisation, long-term planning, dispatch modelling

Giovanni Dalle Nogare is a junior researcher from Italy, with a specialization in environmental engineering and GIS. Currently, he works at the Institute for Renewable Energy of Eurac Research, where he applies his expertise in GIScience to improve energy efficiency and advance district heating.

GIS tool for the individuation of waste heat recovery opportunities.

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Maps can provide a visual representation of the physical characteristics of a district, including the location of buildings, roads, and other infrastructure. This information is critical for the design and planning of district heating (DH) systems.

Maps can also be used to identify potential sources of heat for DH system. In addition, maps can help DH planners to identify potential challenges or constraints in the district that may affect the design and implementation of the system, such as natural features, zoning restrictions, or access to existing services.

However, it is important to recognize that maps are not objective or neutral representations of reality. The selection and emphasis of certain features on a map can influence the way in which the map is perceived and interpreted: maps are typically created with the goal of providing a useful and informative view of the area in question.

From this perspective, we have designed a GIS tool for waste heat (WH) mapping, implemented into a QGIS plugin, one of the most popular open-source geographic information system applications in recent years. It uses reliable low-cost data from Google Maps, OpenStreetMap and user's data.

The mapped WH sources come from the service and industrial sectors: supermarkets, malls and groceries, swimming pools and water recreational centers, bakeries and butchers, industrial firms.

The WH has been estimated by proxies and literature coefficients for urban WH, while by coefficients related to the economic activity (NACE code) and the number of employees for industrial WH.

The plugin can find application for several purposes and be useful for DH utilities, to identify decarbonization opportunities for existing networks or to plan additional systems/expansions, for public decision makers and private investors, to understand which territories are more suitable for the DH technology, as well as for software houses, to implement new applications.

The plugin has been developed and validated over three municipalities (Aalborg/Denmark, Heerlen/Netherlands, Ospitaletto/Italy), related to the demonstration activities of the Life4HeatRecovery project (https://www.life4heatrecovery.eu/, funded by the LIFE Programme of the European Union under contract number LIFE17 CCM/IT/000085).

Keywords: GIS,Tool,QGIS,Plugin,OpenStreetMap,Google,Overpass,API,Mapping,Spatial Analysis, Waste Heat, District Heating, Energy, Conservation, Efficiency, Recovery, Opportunity Individuation, Source Identification.

Graduate in renewable energy engineering and MSc in Marine Offshore Renewable Energy, he works as a researcher in energy planning at Tecnalia. His field of work focuses on energy planning projects for decarbonisation at urban and regional scale, as well as projects for industrial decarbonisation.

Review of georeferrenced energy planning tools and methods for the assessment of decarbonization scenarios

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As cities strive to transition to cleaner energy sources, and are already setting ambitious objectives for descarbonisation, the paradigm of energy consumption is rapidly evolving with electric vehicles and heat pumps as strong actors. Effective planning tools and analytical frameworks are essential to accurately assess the issues that such evolution and changes will have upon energy infrastructures. Due to the growing interrelationships between energy sources, it is increasingly critical to ensure integrated planning of the different energy infrastructures associated with them. Therefore, specialised tools and methodological frameworks must be able to assess the interactions of infrastructures such as electricity distribution networks with distributed heating and cooling networks, the gas grid, and other networks for emerging vectors such as hydrogen, as well as their interactions with electric mobility, distributed generation and energy storage. This paper critically reviews energy planning tools and methods focusing on their ability to spatially assess at city level the impact that a a scenario of high decarbonisation through electrification may have on the energy infrastructures. The capacity of GIS based tools to evaluate aspects such as analysis for mass deployment of EVs and heat pumps, as well as aspects of demand flexibility through bi-directional EV charging strategies, V2X (V2G, V2B) and electric and thermal storage, will be assessed.

Keywords: Modelling, Energy, Decarbonization, Planning, Scenarios, Infrastructure, Storage, Networks,

Dr. Robbe Salenbien is a senior researcher within the thermal energy systems group of the Flemish institute for technological research. His main focus is on automated topology optimization of future district heating networks, multi-source and -temperature.

Using geographically informed non-linear district heating topology design to support higher level assessment methodologies for the potential of DHN.

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Yannick Wack, VITO/EnergyVille/KU Leuven
Martin Sollich, EnergyVille/KU Leuven
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Local communities and cities have a vital role to play in the transition to a low-carbon future. In 2050, half of all existing European buildings will still be in use. Optimising the energy profile of our cities has therefore become a top priority, requiring the right balance to be struck between energy efficiency, renewable energy and flexibility. In more densely built urban environments, a large part of the transition could be facilitated through district heating (and cooling). To date, several initiatives exist that attempt to assess how large the potential is for district heating technology. E.g. HeatRoadmapEurope provides strategies on national level for the EU, and many cities have ordered heat zoning studies. In Belgium, the EPOC 2030-2050 project also seeks to address the energy policy challenges using long-term energy planning models.

To cope with the scale of the problem, many of these initiatives resort to statistical analysis and problem simplification. However, for district heating in particular the geographic context is of great importance. Cost- and energy effectively transporting heat in an environment with multiple possible producers, consumers and even prosumers, depends critically on the spatial distance between them. Therefore, neglecting such information introduces an uncertainty. In this presentation, we seek to quantify that impact by comparing a detailed, non-linear bottom-up approach (PathOpt) against a top-down version (Inspiratiekaart Warmtezonering). The Inspiratiekaart is digital platform dividing the region of Flanders into areas most suited for collective or individual heating solutions by means of statistical clustering and problem simplification. On the other hand, PathOpt, a generative design tool for the optimal routing and design of heating networks, is combined with geographic information systems (GIS) to determine the optimal DHN topology within such clusters. The detailed approach can than be used to increase the validity of the generalized approach.

Keywords: DHN design, topology, optimization, heat mapping, digitalization, non-linear design

Marvin Schnabel is a researcher in the field of geodata analyses in the context of thermal energy planning. The focus of his investigation is to support this multi-stakeholder process by interactive geodata analyses.

Interactive geodata analyses to support the multi-stakeholder process of thermal energy planning

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Due to the german climate goals the heat supply must be climate-neutral until 2045. Today, a large part of the heat supply is provided by fossil fuels. A thermal energy transition is necessary. In the future the heat supply must be based on renewable energies. Examples for possible technologies are heat pumps, solar thermal energy or geothermal energy. To plan the transition, the heat demands, the potential to use renewable energy for the heat supply and the potential to reduce heat demands must be known. The planning of the thermal energy transition is complex because many stakeholders are involved. A key role is related to the municipalities. Other stakeholders are grid operators, energy supplier and residents. Therefore, thermal energy planning can be considered as a multi-stakeholder process. To ensure that the goals can be achieved a lot of communication and information exchange about planning processes (e. g. grid planning, urban land use planning) between these stakeholders is needed. To support the thermal energy planning process geodata analyses can be used to calculate several indicators on different spatial levels like grids or housing blocks. The indicators describe the suitability for decentral technologies like heat pumps or central technologies like districted heating. As the relevant stakeholders do not have detailed knowledge about geodata analyses, geoinformation systems are used only for complex precalculations and suitable Business Intelligence (BI) software is used as an interactive presentation layer. BI software provides the opportunity to visualize the data for the thermal energy planning process and results of geodata analyses on interactive dashboards. With these interactive dashboards, stakeholder can discover the database and vary the calculation of indicators through filtering. The result are dashboards with cartography representation of several information like heat demand, the potential to use renewable energy for the heat supply or information of buildings. The dashboards present parameterizable metrics that stakeholders can discuss in the planning process. Moreover, users can perform visual analytics to identify the most suitable heat supply technology for planning areas.

Keywords: Thermal energy planning, thermal energy transition, multi--stakeholder process, interactive geodata analyses

Sreenath Sukumaran is working as a postdoctoral researcher in Tallinn University of Technology. His research work is focused on Solar Energy, District Heating & Cooling, Energy Sustainability. He has authored/coauthored handful of good quality journal publications such as Energy, Solar Energy, Energy Reports.

Site suitability Assessment for Solar-Based Snow-Assisted District Cooling System in Estonian Context

Sreenath *Sukum*aran, Tallinn University of Technology; Anna Volkova, Tallinn University of Technology; Jakewook Chung, Tallinn University of Technology; Kertu Lepiksaar, Tallinn University of Technology

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Due to global warming and climate change, the cooling loads in urban area is on rise. Significant amount of greenhouse gases is emitted from cooling systems in commercial and residential sector. In this regard, development of district cooling networks is getting attention worldwide.

To maximize the decarbonization of the district cooling sector, proper selection of cold-water sources and clean energy technology is important. Snow collected during winters can be stored in thermally insulated storages that can be used as cold source for cooling plants. Carbon emissions from cooling plant can be reduced by utilizing solar energy technologies. However, the feasibility of such system involves different multifaced challenges.

On one hand, snow's thermal energy potential is rarely exploited. On the other hand, solar energy utilization for cooling is yet to be explored. Hence, the concept to utilize solar energy in snow cooling facility is a relatively new. The integration of solar systems with snow cooling facility is not fully explored in the context of district cooling. In this paper, the objective is to identify suitable sites for solar-based snow-assisted district cooling system in Estonia. Also, a preliminary design will be carried out for such system in the context of university campus as a case study. The developed methodology can be applied in any cold regions, irrespective of its location.

The selection criteria involve technical, economic, environmental, and geographical parameters. The site selection methodology is based on advanced Multi-Criteria Decision Making (MCDM) techniques and Geographic information system (GIS) tools. In this study, technical feasibility of solar PV and thermal route will be considered separately. The most suitable locations will be ranked according to its site suitability index. In this study, it is anticipated that the location of snow dump/storage and cooling load area are detrimental. From the preliminary analysis, it is expected that solar energy could fully meet the energy requirement in the cooling facility during the peak summer season. This study is intended to raise awareness on utilization of snow deposit and solar energy in district cooling sector.

Keywords: District Cooling, Heat Pumps, Solar Energy, Snow Storage, Energy Sustainability

Hyunkyo is currently pursuing a PhD at the Division of Energy Technology. With a background in urban planning and environmental planning, she specialises in local heating system and energy systems modelling, cost optimisation, participatory modelling, and spatial analysis.

Heat planning in a rural municipality

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Heating is a critical aspect of daily life and industrial processes, accounting for 50% of global final energy consumption and contributing 40% of global carbon dioxide emissions. Decarbonising heating is, therefore, a crucial step towards achieving the 1.5°C mitigation pathway. Municipalities, as local authorities, play a vital role in local energy transitions by planning and implementing local energy strategies. While urban areas have received increasing attention in local energy planning, rural areas have been largely neglected despite their unique energy infrastructure networks, resource availability, and energy prospects.

While there is increasing research on local energy planning in urban areas, rural areas have received less attention despite their unique energy infrastructure networks, resource availability, and energy prospects. Rural heating demand is often dispersed, with large spaces within municipal boundaries that do not require heating, indicating the need for an understanding of the spatial dimensions of the heat transition in rural municipalities. As a result, a thorough understanding of the spatial dimensions of the heat transition is necessary to develop effective solutions for rural municipalities. Rural areas also offer different prospects for energy resources, including substantial availability of bioenergy resources and excess heat that can be integrated into district heating networks as an alternative for heat decarbonisation.

The aim of this paper is to explore how rural heating systems can achieve local climate goals by making the most use of local resources while focusing on the challenges and

features of heat transition in rural areas. The TIMES modelling framework is applied to a rural municipality in Denmark to explore different scenarios, including excess heat utilisation, biogas integration, seasonal district heating storage, and cost optimal. The results demonstrate that district heating can be expanded to a large scale when there are excess heat potentials. Investing in storage can also encourage the expansion of district heating with renewable energy.

Keywords: Heat planning, rural municipality, energy systems modelling, heat transition, spatial analysis

Abdulrahmman Azzam is PhD fellow at the University of Stuttgart.

Intelligent Operation Management System for Urban Districts – Conceptualization of a Dynamic Simulation as a Foundation for a Digital Twin

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Decentralized smart energy systems are considered a promising approach in the municipal sector. For example, an intelligent operational management system for urban districts could enable the unlocking of flexibility potentials and thus improves the integration of renewable energies. However, success depends crucially on how the interests of the heterogeneous structure of stakeholders involved can be considered as those approaches base very often on collaborative action within urban districts.

A virtual reality based on a digital twin could be used to make the impact of such intelligent operational management system experienceable. This could create an opportunity to involve all stakeholder groups, take their needs into account and evaluate the impact on the stakeholders living in the area. To this end and as a foundation for a digital twin, a dynamic simulation will be developed to quantify the flexibility potential for an urban district with different configurations. Furthermore, it should be possible to illustrate implications resulting from intelligent operation management system.

For this, the basics of urban district supply, their operation management and the flexibility potential of decarbonization measures will be discussed. Methodologically, the conference contribution will deal with the specification of the research scope and, based on this, derive the requirements for a dynamic simulation. Subsequently, a corresponding concept for a possible implementation will be developed and presented. Based on the data provided by the involved stakeholders, the campus of the University of Stuttgart itself is employed as a first reference frame for the implementation of the dynamic simulation. As a further extension of the simulation, coupling with further grid and system models is also possible.

With dynamic simulation, interactions and dependencies between buildings, urban districts and the energy system can be studied on a scenario basis with model experiments. In addition, it should also be possible to carry out an energy system analysis. The dynamic simulation for urban districts can contribute to integrate municipal stakeholder groups by creating a virtual experience of the decarbonization measures and simulating relevant impacts.

Keywords: Intelligent Operation Management System, Urban District, Dynamic Simulation, Digital Twin, Integration of Stakeholders

Sigurd Bjarghov received the M.Sc. and Ph.D. degree in electric power engineering from NTNU, Trondheim, Norway, in 2017 and 2022, respectively. His research interests include local energy communities, grid tariff design, flexibility markets, demand response and optimization.

Coordination mechanisms in local energy communities for connection of industry in congested grids

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The power system is challenged as new and existing industries require significant grid capacity. In Norway, the number of grid connection requests has increased rapidly over the last few years. This has, in turn, led to connection queues with a waiting time of up to ten years, due to long lead times on grid construction.

To solve this problem, the distribution system operator (DSO) may in some cases allow industrial consumers to connect under "condition-based connection agreements". Using this agreement, a new consumer is allowed to connect under the condition that they may be fully or partially disconnected if the DSO needs to manage grid congestions.
In this paper, we suggest a business model where the new industrial consumer forms a local energy community (LEC) together with existing consumers in an industry park and connect using the condition-based connection agreement. However, rather than the new entrant being disconnected by the DSO which could disrupt the industrial processes, the LEC as a whole commits to staying below a specific capacity.

Since the existing consumers in the industry park have no incentive to reduce their capacity use, the new consumer must purchase the right to use capacity from the other consumers in a local market. To ensure that the aggregated capacity use does not exceed the limit agreed upon with the DSO, flexibility from the industrial processes must be used, such as thermal flexibility. The local market allows the LEC to use the most efficient flexibility resources to avoid exceeding the capacity limit.

This framework is applied to a case study represented by four consumers in an industry park. The case study is investigated by formulating an optimization problem that minimizes the cost of each consumer. The problem can be reformulated and solved as a game-theoretic equilibrium model which simulates perfect competition.
Expected results show the consumer costs, the resulting load profiles, and flexibility use. The model solves the local market problem endogenously and hence provides the local market clearing capacity volumes and prices from trading with other LEC members. The main contribution is to demonstrate how the smart energy system approach with industrial flexibility can lead to faster electrification.

Keywords: Local energy community, industrial consumers, congested grids, coordination mechanism, local market

Professor Andra Blumberga is an expert with large experience in system dynamics in different projects and research domains. She has vast experience by leading international projects related to energy efficiency and energy policies. She is author of 138 papers in peer-reviewed international journals.

When does Energy Island transfer to Energy Community?

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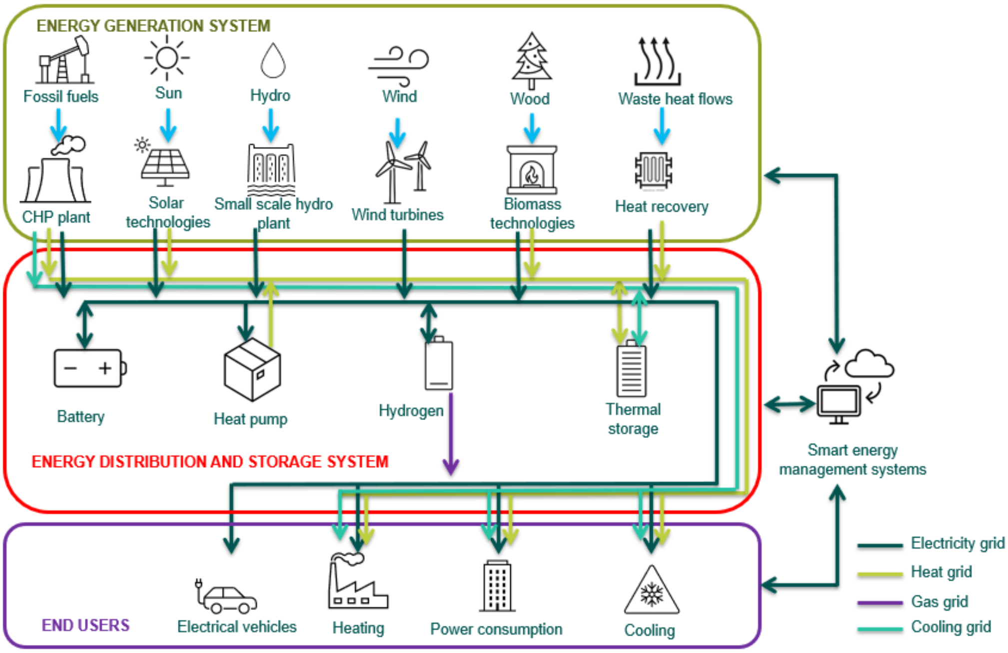
The transition from a natural gas-based energy system to renewable energy sources has become a crucial consideration in both national-scale planning processes and local-scale energy system planning. Research has been conducted to seek technical solutions for a specific district of a university campus to implement a smart energy system with multiple energy sources, storage systems and demand-side management. The energy community solutions have been modelled based on the system dynamics approach to simulate the performance of the energy system and identify the most sustainable energy conservation and generation options.

The solutions for the transformation of Energy Island to an Energy Community include power generation by building integrated solar panels, with different power storage alternatives, such as batteries, electric vehicles, hydrogen, and fuel cells. Additionally, a wind park located outside the urban area with hydrogen storage has been evaluated due to the urban area conditions. The simulation also evaluates the potential for heat recovery and waste heat integration from the data centre, wastewater, and cooling systems to cover the heat demand. The interlinkage with demand-side management through improved building management systems provides an opportunity to increase renewable energy sources utilisation rates and improve overall energy efficiency. To provide a holistic overview of the future development of the urban area, the research also compares the connection to the district heating network.

The interactive simulation interface has been developed based on the system dynamics model which provides a platform for stakeholders to evaluate different sustainable energy generation alternatives. By simulating the performance of the energy system, it is possible to identify the most efficient and cost-effective ways to generate and use energy.

Keywords: Energy communities, renewable energy systems, energy storage systems, system dynamics modelling



Miguel is a research scientist at the Institute for Energy Technology (IFE) in Norway. His research work focuses on energy system modelling and sector coupling.

Energy transition scenarios on Norwegian islands: The case of Utsira

Miguel Chang, Institute for Energy Technology; Kristina Haaskjold, Institute for Energy Technology; Kari Aamodt Espegren, Institute for Energy Technology

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The energy transition on islands is particularly challenging due to remoteness and dependence on energy imports from mainland regions to cover local demands. However, islands with vast amounts of variable renewable resources also present an opportunity to act as living labs, where new technology can be implemented to both meet local energy demands and illustrate the potential role of emerging solutions for redesigning the energy system. In this context, this study analyses Utsira's energy system, an island in west Norway. Currently, the island's electricity demands are covered with electricity generation from onshore wind and transmission from the mainland via a sea cable, while passenger transport to and from the island is done by ferry. In the future, new renewable capacities are expected on the island, as well as alternative options for transport, and new end-use demands.

Thus, an energy system model of the islands has been developed to showcase the system's operation with an hourly resolution and to assess the impacts of these developments. The model is used in the analysis of future scenarios for Utsira, which are in line with national scenarios developed for Norway. In these scenarios, we investigate different options for expansion of the onshore wind capacity in the island, as well as alternative balancing options to the expected increase in electricity supply, such as the implementation of hydrogen production, potential electrification of maritime passenger transport demands, and the use of utility-scale batteries. We also include an analysis of the potential increase of transmission line capacity to the mainland. In addition to these, new demand developments are also considered, illustrating the potential for sector coupling with the utilization of by-products from hydrogen electrolysis to cover these new expected demands. The results of the analyses illustrate the role of the different solutions in Utsira's transition and potential cost-optimal configurations of the island's energy system.

The case study for Utsira is part of the research project Hydrogen Pathways 2050, financed by the Research Council of Norway, Gassco, Equinor and Statkraft.

Keywords: energy system analysis, island energy, energy systems modelling, energy transition, sector coupling

Sverre S. Foslie is a researcher in thermal energy in SINTEF Energy Research, and is currently doing a PhD in integrated energy systems and industrial flexibility at NTNU. He has worked as a researcher at SINTEF for 6 years, mainly focusing on industrial energy efficiency and heat pump processes.

Leveraging industrial flexibility, sector coupling and wind power production to mitigate power grid capacity limitations

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This study examines the potential for industrial demand response in flexible processes to mitigate power grid capacity limitations in the presence of wind power production. As renewable energy sources become more prevalent and industrial establishment and electrification increases, utilizing flexibility in thermal and industrial processes to enable demand response becomes increasingly important to enable a fast decarbonization of industry.

Limited knowledge exists regarding the technical and economic potential of industrial demand response, as well as the impact industrial flexibility may have on transmission grid demands. For how long, and how much the demand may be reduced during the most critical hours in the grid is also scarcely investigated. We therefore investigate the technical potential for industrial flexibility to handle the critical hours in the transmission grid, and how this is affected by connecting offshore wind production to the area. We apply this to a real case study in a process-industry cluster in Norway.

We develop and use a cost-optimization model to evaluate the operational effects of variations in wind production and grid capacities for an industrial area with specific industrial loads, including hydrogen production and thermal demands. The combination of industrial processes and multiple energy carriers significantly increases the potential for flexibility, enabled by fuel switching, energy or product storage or load shedding. The

study demonstrates the technical potential for demand response in industrial loads, reducing strain on the grid during high-demand, low wind production periods. We investigate variations in wind production combined with different industrial processes aiming to identify coincidence factors, and minimizing the need to build excessive grid capacity that largely goes unused.

Our research sheds light on how industrial flexibility can facilitate the transition towards faster decarbonization and electrification of existing industrial demand and enable new industry establishments. Further research is needed to assess which market mechanisms may be suitable to activate the identified flexibility.

Keywords: Industrial electrification, demand response, thermal energy, sector coupling, wind power integration

Vladimir Z. Gjorgievski is an Assistant Professor at Ss. Cyril and Methodius University in Skopje, Faculty of Electrical Engineering and Information Technologies. His research interests are related to the decarbonization of energy systems through sector-coupled community energy systems.

Optimal management of community energy systems considering different energy sharing incentives

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Local energy sector coupling provides a platform for communities to maximize the benefits of energy sharing by leveraging the flexibility of distributed assets such as heat pumps, storage units, and electric vehicles. To stimulate energy sharing, governments around Europe are beginning to introduce different financial incentives. However, as regulation on energy sharing is rather recent, these mechanisms vary widely and range from tax exemptions and reduced network charges, to direct reimbursements for the shared energy. Despite the significant impact of these incentives on cost savings, they are seldom studied in the scientific literature on optimal management of community energy systems. This paper aims to address this research gap by proposing a general optimization model for managing a community energy system that incorporates various financial incentives for energy sharing. As the optimization problem is non-convex, an equivalent mixed-integer linear representation is derived. The proposed model is used to optimize a community energy system with a solar photovoltaic generator, heat pumps, and storage units. By analyzing diverse electricity tariffs and financial incentives, the paper demonstrates how the proposed model can be tailored to represent energy sharing frameworks in different countries. Furthermore, we compare the results of the proposed method with those obtained with a benchmark approach which does not account for the financial incentives. The findings highlight the critical importance of accurately modelling financial incentives when optimizing local sector-coupled energy systems.

Keywords: energy sector integration, integrated energy systems, optimization, energy sharing regulation, energy policy.

He is a doctoral student at Chalmers University. He is working in the field energy systems transition at the city level's working closely with the municipal authorities. He is currently working on developing Policy-Driven cost optimized energy systems model using TIMES Modeling Framework.

Integrated Assessments of City Energy Systems: City Planning Vs National Targets

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With rapid urbanization and increasing demand for energy services in combination with climate mitigation targets, cities need to deal with the energy trilemma. On one hand, authorities need to ensure energy security and equity for their citizens, while at the same time ensuring that the energy system is transitioning towards mitigating climate change impacts.

At the local level, energy planners have set energy plans to ensure a transition toward a secure and decarbonized urban energy system. And, at the national level countries have committed to achieving net-zero energy systems in compliance with the Paris Agreement. As cities are major contributors to energy consumption and GHG emissions at the national level, they play a crucial role in the successful transition towards a net-zero energy system. To analyze the contribution of short-term energy plans towards system decarbonization this study aims to evaluate the effectiveness of short-term city energy plans and identify the need for additional recommendations to achieve the desired long-term national mitigation targets.

A technology-rich cost-optimization model using TIMES with intra-sectoral and inter-sectoral integration is developed. Explorative scenarios are developed to identify the role of short-term energy plans and normative scenarios are applied to evaluate long-term pathways to achieve the national decarbonization targets.

The modeling framework is applied to the City of Gothenburg and the results provide crucial insights into the long-term transition of the heating, electricity, and transportation sectors. The results suggest that with the application of energy plans, stringent

abatement of greenhouse gas emissions can be achieved. With the application of demand and supply-side measures under normative mitigation constraints, transition pathways combining different technical solutions are obtained. The model results also signify competition for resources among sectors in the transition towards a carbon-neutral energy system. In conclusion, this study presents a modeling framework with the integration of intra-inter sectoral interactions. The model application provides optimal mixes of different technological solutions under different scenarios and uncertainty analyses.

Keywords: Energy systems modeling, urban energy modeling, TIMES, city energy planning, sectoral integration, energy systems transition, system uncertainty

Kristina is a researcher working with energy system analysis. She develops models and scenarios that explore the transition of the Norwegian and European energy system, including competition and interaction between technologies and energy carriers and the value of flexibility.

Effect and value of end-use flexibility in the low-carbon transition of the Norwegian energy system

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With more weather-dependent renewable electricity supply and electrification of end-use, there is an increased need for flexible solutions to adapt to variability and uncertainty of supply and demand. Significant flexibility potential exists at the end-use level, provided by resources such as local batteries, demand response and electric vehicles. For the electricity sector, end-use flexibility can contribute to increased integration of renewable energy, improved grid stability by providing reserves for balancing markets, and reducing the need for capacity expansion in generation and infrastructure. For the end-use sectors, it can contribute to lower energy costs by shifting the energy consumption to hours of lower electricity price.

This study presents a techno-economic analysis of the role of end-use flexibility in the transition to a Norwegian low-carbon energy system towards 2050. The long-term optimization model of the Norwegian energy system, IFE-TIMES-Norway, is used, with both a deterministic and stochastic modelling approach of European electricity prices. The analysis quantifies how operation and investments of end-use flexibility influence the revenues and costs of the different parts of the energy system, including power production, district heat, buildings, and electricity trade. The analyzed flexibility options in the building sector includes batteries, flexible electric heating of hot water and flexible charging of electric vehicles.

Results indicate an accelerated investment in building applied PV (BAPV) when end-use flexibility is present, with more than a doubling in production in 2030. Moreover, both the morning and evening peak of a typical winter day is flattened, with the highest peak reduction of 7%. When comparing the revenues of power producers, it can be observed a small decrease of 1% corresponding to 0.8 billion NOK/year, where hydropower is the main looser. On the contrary, end-use flexibility lowers the electricity bill of buildings by 18%, corresponding to 8 billion NOK/year. Hence, the overall energy system largely benefits from end-use flexibility. Further, the results show that the future role and value of flexibility is sensitive to the methodology, where stochasticity lead to e.g., increased battery investments.

Keywords: End-use flexibility, energy system model, long-term optimization, stoachstic modelling, intermittent renewable energy, batteries, flexible EV charging, flexible hot water tanks

Kai Hoth received M. Sc. degree in 2017 from Leibniz University Hannover in Engineering and Business Administration. He is currently pursuing the Ph. D. degree at TUHH in the field of Operations Research. He has previous working experience at Spenjoy GmbH, at ALTEN GmbH at Hamburg University.

The Energy Aggregator Problem – A Holistic MILP Approach

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Future energy systems require efficient management of decentralized and renewable energy resources (DERs). Energy Aggregators (EAs) provide a promising solution for managing these resources by aggregating DERs of multiple prosumers. The EA problem involves scheduling different types of DERs with specific technical restrictions and trading energy on external markets as well as internally between prosumers of the same EA.

In this work, we propose a MILP approach to solve the holistic EA problem. The approach considers the technical restrictions of DERs in detail and integrates power-to-heat-systems with heat pumps and heat storages considering the inherent thermodynamic relations. The model includes external trading options on wholesale level and on local market level, which enables its application in different system concepts and allows to pursue economic as well as sustainability goals. By considering specific restrictions of different DER types, the proposed model can accurately represent the behavior and interaction of DERs in the system, allowing for precise scheduling and trading decisions. To test the model, we apply it to a case study of one EA with 111 aggregated households and different DERs such as power-to heat systems with heat pumps, electric vehicles, battery storages, time-shiftable loads, and photovoltaic systems. The presented results of the case study verify the functionality of the EA model and reveal the synergetic potential of EAs by aggregating different types of DERs.

Keywords: energy aggregators, smart grids, DERs, local energy markets

Thanh is pursuing his PhD in collaboration with Siemens AG and TU Darmstadt, doing research on multi-modal energy markets. Prior to his time as PhD student, he graduated with a master's degree in electrical engineering from RWTH Aachen University.

Local energy market for thermal-electric energy systems with consideration of temperature flexibility in heating subnetworks

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Pascal Friedrich, Technical University of Darmstadt.
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The transition towards climate-neutral energy systems requires significant changes in the thermal sector which accounts for around half of the global final energy demand. District heating systems are critical in this transition as they enable a close coupling of the thermal and electric energy systems, allowing for the integration of renewable energy sources and the efficient use of local energy resources. However, thermal losses remain a major challenge in such energy systems and are responsible for considerable efficiency losses.

To address this challenge, a novel method is presented that incorporates the temperature of subnetworks of district heating systems into the market matching of a local energy market for thermal-electric energy systems. This market-based coordination approach includes a linear formulation of market orders for a local energy market that are tailored to the needs of consumers, producers, and prosumers in local multi-modal energy systems. Complementary market commodities are introduced that enable market participants to define boundaries for the supply temperature of their adjacent subnetwork in the district heating system. The physical models of the underlying thermal district heating network and electric distribution grid are formulated linearly, making the market matching viable for complex interdependent energy systems.
The method is applied to a case study representing a German district heating system, and the results are compared to a conservatively operated system. Among others, the

results lead to the conclusion that thermal losses in the district heating system can be reduced by incorporating the temperature of subnetworks into the market matching of a local energy market.

Keywords: Local energy market, market design, sector coupling, local energy systems, multi-modal energy systems, prosumers, district heating systems, subnetwork, temperature optimization, thermal energy

Joseph Jebamalai is working as an innovation engineer at Comsof, an IQGEO business in Ghent, Belgium. He has done his PhD on the design of 4th and 5th generation district heating systems at Ghent University, Belgium. His areas of interest include district heating and thermal energy storage.

Optimization of thermal energy storage in district heating systems using Comsof Heat and GBOML

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In Europe, district heating systems have been used for a long time and have gained popularity for their energy efficiency, reliability, and convenience. Because they can utilize renewable energy sources and reduce the need for individual boilers in each building, they offer a more sustainable and environmentally friendly method of heating buildings. It can be more effectively integrated with intermittent renewable energy sources by including thermal energy storage (TES). Also, at times of high demand, TES can aid in reducing the peak load on the district heating network, negating the need for extra heat generation or network enhancements. However because there are so many variables and a large network, optimizing these systems for optimal performance and lowest total network cost is a difficult challenge.

In this conference, we will discuss how to optimize thermal energy storage size in district heating systems using Comsof Heat and Graph-Based Optimization Modeling Language (GBOML). Comsof Heat is a GIS based automated design tool to perform feasibility study of district heating systems. GBOML is an open-source and effective tool that enables the modeling of complex systems and the optimization of multiple objectives with mixed integer-linear programming techniques. The use of Comsof Heat and GBOML in a case study involving a district heating system in a large urban region will be discussed. We will show how GBOML may be utilized to optimize the system for optimal energy usage, low network investment cost, and low environmental impact. The potential and problems that come with using GBOML in this context, such as model complexity, calculation time, and computing needs will be studied. This study will emphasize the potential advantages of this method about using GBOML for optimizing thermal energy storage in district heating systems.

Keywords: Thermal energy storage, District heating system, Comsof Heat, GBOML, mixed integer linear programming

Lykke Jeppesen professional carrier has focused on climate and energy regulation both in the private sector (DONG Energy/Ørsted) and as Danish civil servant. Today she is heading the Energy Economic teams in Ørsted focusing on regulatory issues related to activities in Denmark and in the EU.

Unleashing renewable energy potential through anticipatory grid investments and risk sharing models

Lykke Mulvad Jeppsen

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Offshore wind energy will play a crucial part in reaching Europe's net-zero targets. Collectively, Europe has an offshore wind energy target of at least 100 GW offshore wind installed by 2030, and studies point to 450 GW of offshore wind being needed by 2050 for Europe to become climate neutral. An efficient integration of these large amount needs a higher integration between the regional electricity markets and new interconnectors are needed to utilise the electrones and infrastructure the best way.
Denmark and Belgium have taken an important step in this direction with the concrete plans of building hybrid projects that connects the electricity markets in two or more countries with offshore wind parks through a hub or Energy Island. But the discussion around the decision making has been complicated since these new types of investments needs to be taken under a higher risk than business as usual.
Current infrastructure planning and approval doesn't allow the TSOs to take the full risk of those projects and the question is if TSOs and by that the national electricity consumers are the right actors to take the risk if the potential future benefiters are in other countries or sectors. At EU level the Cross Border Cost Allocation guidelines are up for discussion and the questions is if EU can agree on a model of how to distribute cost and benefit not only cross border but also across time and under uncertainty. For the concrete hybrid projects the challenge is that the regulatory regime is developed along with the investment decision of the hybrids, and this adds further to the risk and uncertainties in the decision-making.
In this presentation Lykke Mulvad Jeppesen will elaborate on the barriers for unleashing hybrid projects with higher risk-profiles under the business-as-usual regulatory regime and approval methodologies by NRAs and come with suggestions for how a more holistic

approach on infrastructure planning and financing might be the key for accelerating the green transition of EU.

Keywords: Transmisison grid, hydrogen grid, socio economic calculations, cross border cost/benefit allocation, risk sharing, offshore wind, grid integration, green transition, energy islands, hybrids

Dana Kirchem is a research associate in the department Energy, Transportation, Environment at DIW Berlin. Her dissertation at UCD Dublin and the ESRI Dublin dealt with energy demand flexibility in integrated energy-water systems. Her research interests include the energy transition sector coupling.

Power sector effects of different roll-outs of flexible versus inflexible heat pumps

Dana Kirchem, German Institute of Economic Research (DIW Berlin). Alexander Roth, DIW Berlin. Carlos Gaete Morales, DIW Berlin. Wolf-Peter Schill, DIW Berlin

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The electrification of heating with heat pumps is seen as an efficient measure to reduce the fossil fuel use in the heating sector. The German government recently declared a target of six million installed heat pumps by the year 2030. Given the current stock of around 1.6 million heat pumps, such a transition implies an increase in the electricity system load. In addition, it is also expected that the electricity needs for mobility and other energy services will increase substantially at the same time. In this study, we explore the effects of different heat pumps roll-outs in Germany on the electricity sector in the year 2030. In particular, we focus on different degrees of flexibility in the heat pump operation by varying the maximum heat storage capacities, with fully inflexible heat pumps as a “worst-case” scenario. We use the open-source energy system model DIETER (Dispatch and Investment Evaluation Tool with Endogenous Renewables) to investigate the effects of different heat pump roll-outs on the electricity system. DIETER is a capacity-expansion planning model which minimizes system costs and determines power system investments and operation in an hourly resolution. We model Germany in the year 2030 in interconnection with its electric neighbor countries (and Italy). We assume 100 percent renewable energy supply for heating, while the renewable energy target for all other electric loads is 80 percent in the yearly balance. Under these assumptions, an increased deployment of heat pumps requires additional investments in renewable energy sources if heating is supposed to be provided using only green energy. Our results show further that the even small heat storage capacities of two or six hours can reduce the power generation and storage capacities by balancing diurnal fluctuations in renewable energy supply. Though a fast roll-out of fully inflexible heat pumps induces an additional need for short-term electricity storage, additional investment needs in power generation capacity are negligible. We find only minor power sector effects of increasing the heat storage capacity beyond six hours.

Keywords: power sector modelling, energy systems, heat pumps, heating, sector coupling, electricity, flexibility

Igor Krupenski represents HeatConsult (Fimpec Group)

GEOTHERMAL ENERGY IMPLEMENTATION IN ESTONIAN DISTRICT HEATING NETWORKS

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Previous studies have proven that geothermal heat cannot be utilised in Estonia's existing district heating systems. The greatest barrier to its utilisation was related to the low temperatures of the heat obtained from boreholes. More research on the integration of geothermal sources into district heating is necessary due to the development of district heating, the decrease in heating network temperatures, and the current trend of utilising heat pumps in district heating.

In some cases, geothermal solutions can replace existing fossil fuel-based heat sources (gas and oil). Geothermal power plants take up less space (in comparison to biomass boilers) and provide a potential solution for converting gas or oil-fired boilers to a more sustainable solution. In this research paper, two case studies from Estonia were examined: a district heating network with five boreholes and another with one. Five geothermal boreholes with a depth of 500 metres will be built in Roosna-Alliku, Estonia, to replace an oil-fired boiler house. Heat is extracted from geothermal boreholes at 15°C and boosted to a temperature of up to 80°C by the heat pump for district heating network supply. In another case study, heat from a 500-meter-deep geothermal borehole will be used to replace heat produced by a gas-fired boiler in Tiskre, Estonia. The temperature will be raised to 70°C in this instance. Data on existing heat demand and geothermal energy availability will be used for a techno-economic assessment that will focus on project feasibility, investments, and technical issues such as electricity consumption for heat pumps and circulation needs, as well as payback period and heat price impact.

Keywords: Geothermal Energy, District Heating, Transition, Heat Pumps, Sustainability

Christine Nowak studied mechanical engineering at Ruhr-University Bochum, Germany, and has been a research assistant at the Chair of Energy Systems and Energy Economics since mid-2020. Her research focuses on energy system modelling to investigate how to reduce carbon emissions using heat pumps.

Integrated energy system flexibility options when using heat pumps to save carbon emissions

Christine Nowak, Ruhr-University Bochum (Germany). Donal Finn, University College Dublin (Ireland). Valentin Bertsch, Ruhr-University Bochum (Germany).

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Addressing the ongoing climate change is of immense importance. Particular attention is paid to the decarbonisation of the energy sector. Although the expansion of renewable electricity generation has made significant progress in Europe, the shift to renewable heating technologies has been slower. Therein, heat pumps are a commonly used technology in both Ireland and Germany, currently very topical in both countries. Additionally, heat pumps provide the possibility to exploit synergies between the electricity and heating sector. As it is imperative to reduce carbon emissions as quickly as possible, one solution can be integrated energy system flexibility options when using heat pumps. This will allow for the utilisation of electricity during times when there are a lot of renewable energy sources available in the electricity mix, resulting in fewer carbon emissions.
Therefore, the research questions of this work are: How much can the operation of heat pumps reduce carbon emissions and decouple energy demand and supply by making the heating demand of building occupants more flexible, such as through the thermal mass of buildings or thermal storage? Additionally, how do geographical variations, e.g. between Ireland as one of the northern islands of Europe and Germany as a country on the European mainland, affect the potential for carbon emission reduction?
To investigate the research questions, a detailed smart energy system model for residential buildings in Ireland and Germany is developed using the open-source optimisation framework called Backbone. The model considers typical parameters for residential buildings in both countries to create a building structure and generate endogenous heating and cooling demands. The thermal flexibility of building masses and heat storage tanks will be analysed to shift heating and cooling demands based on variable electricity

emission factors. By evaluating possible carbon emission savings, insights into the path to climate neutrality are gained.

Keywords: integrated energy system flexibility options, carbon emission savings, smart energy system modelling, heat pumps, thermal mass of buildings, thermal storage

Dr. Nicolas Lamaison is a research scientist in the field of district heating modeling and optimization at CEA (Chambery, France) since 2016. Within this topic, his main current interests are 5GDHC operation, innovative substation and decentralized storage.

Improved pre-calculation of solar thermal production for MILP-based optimization problems

Nicolas Lamaison and Thibaut Wissocq, Univ. Grenoble Alpes, France
Nicolas Lamaison (presenter)

The decarbonisation of heat supply in district heating network can be achieved through the utilisation of solar thermal systems, providing a carbon-free and competitive energy. The latter become very interesting when integrated with large-scale thermal storage in order to store heat during warm days for winter use, enhancing solar fraction. Those systems are often subject to optimization tools in order to minimize the costs and to attest the performance of the system. In these tools, solar thermal production is generally considered as an input of the problem. However, this can lead to miscalculations as solar thermal production is strongly influenced by the behaviour of the system. The presence of a thermal storage especially influences both the temperature and the mass flow observed by the solar plant. In this context, a good prediction of solar production and storage setpoints is crucial for better computation of the system. In this way, we propose here a 5-step methodology based on simulation in Modelica and optimisation models for thermal solar prediction in solar district systems:

1) A Modelica model of a solar plant is used to estimate the solar production in W/m2 considering the network return and departure temperature trajectory but no limitation on mass flow rate
2) The solar plant is sized in order to have the desired solar fraction
3) The seasonal thermal storage is designed, from the remaining solar energy produced during the year.
4) Charge and discharge thermal storage setpoints are estimated thanks to an optimisation framework.
5) A new simulation of the solar thermal plant with the calculated storage setpoints as input is done, giving a new thermal solar production, taking into account the influence of the storage.

This new thermal solar production time series is then used in an optimisation tool in order to optimize the whole production system (other production units, storage behaviour, etc.). The methodology is applied on a district heating network composed of a solar plant, a pit thermal storage and a gas-fired thermal plant, for six different boundary conditions. Comparing the predicted solar thermal production with the one finally obtained has resulted in an average of error of 4.5% on the solar production on these six case studies.

Keywords: solar thermal, simulation, Dymola, Modelica, long term storage, district heating.

Lukas Peham completed his bachelor's and master's degree in polymer technologies and science at the Johannes Kepler University in 2020. Since than he has been working on his PhD entitled "Global ageing behaviour of polyolefinic material formulations for thermal energy storages".

Implementation of a lifetime prediction model for crosslinked, foamed polyolefin insulation of pit thermal energy storages

Lukas Peham, Institute of Polymeric Materials and Testing, University of Linz, Austria; Gernot M. Wallner, Institute of Polymeric Materials and Testing, University of Linz, Austria; Per Alex Sørensen, PlanEnergi, Denmark
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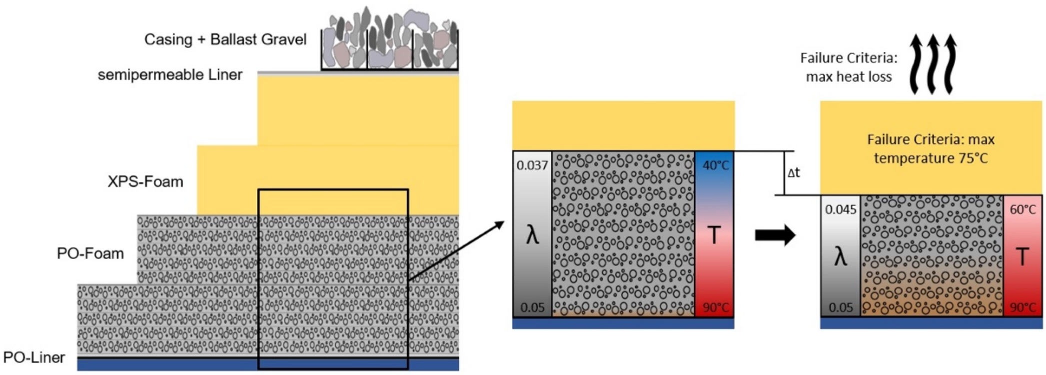
To compensate fluctuating renewable energy sources and heat demand, large thermal energy storages are of utmost importance in district heating networks. In pit thermal energy storages (PTES) hot water up to 90°C is stored in large, excavated basins. The top of the PTES is covered with a thermally insulated floating lid. A high temperature resistant polyolefin liner is commonly used as water barrier. On top, several layers of crosslinked polyolefin (PO) foam are protecting the energy storage from heat loss, followed by an extruded polystyrene foam for structural reasons.

Ageing of polyolefinic materials results in time-dependent physical and chemical changes and a decay of the multi-functional property profile. Lifetime estimation procedures are often based on the extrapolation of the time to embrittlement at elevated to lower, service-relevant temperature levels using Arrhenius relationships. Elevated temperatures are accelerating the oxidation process by a specific factor. The main objective of this paper was to systematically investigate the ageing behaviour of crosslinked polyolefin foam in hot air and under damp heat conditions. To accelerate the ageing process, a temperature range from 75 to 105°C was chosen. After defined intervals, specimens were removed and tested. Degradation indicators were evaluated. So far, material properties were monitored up to an exposure time of 14,000 hours. While specimens are already fully degraded at 95 and 105°C, characterization of foam samples at 85 and 75°C is still ongoing.

Based on the experimental endurance times and the temperature loading profiles a cumulative lifetime prediction model for the floating lid structure is implemented. Therefore, a stepwise embrittlement of thin foam layers is considered. Temperature dependent thermal conductivity values are used to calculate the temperature of individual foam layers and the gradient within the lid cross-section. The ultimate failure criteria are a defined thermal energy loss limit or the maximum service temperature of XPS (i.e., 75°C).

Keywords: thermal energy storage, lid construction, foam insulation, polyolefin, degradation, lifetime model



She is a researcher in the sustainable energy applied to buildings at the Fondazione Bruno Kessler. She has been working in several energy research projects and currently she has been focusing on energy communities.

Modelling the optimal transition of an urban neighborhood towards an energy community and a Positive Energy District

Silvia Ricciuti, Fondazione Bruno Kessler, Gregorio Borelli, Free University of Bolzano, Md Shahriar Mahbub, Ahsanullah Univeristy of Science & Technology, Matteo Brunelli, University of Trento, Francesco Pilati, University of Trento, Andrea Gasparella, Free University of Bolzano, Giovanni Pernigotto, Free University of Bolzano, Federico Battini, Free University of Bolzano, Diego Viesi, Fondazione Bruno Kessler.

Silvia Ricciuti (presenter) sricciuti@fbk.eu

Renovating both public and private buildings is a key initiative to promote energy efficiency, integration of renewable energy sources (RESs) and reduction of CO2 emissions. Emerging research is dedicated to Positive Energy Districts (PEDs) which are "energy-efficient and energy-flexible urban areas which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy". PEDs can exploit local energy communities to promote RESs sharing and the integration of different energy systems and infrastructures.

In this work, an urban district of 6 buildings (Santa Chiara District) in Trento (Italy) is considered to explore PED and energy community scenarios. This district is also one of the 3 case studies of the Horizon Europe InCUBE project. Firstly, the 6 buildings were modelled with the Urban Modeling Interface (UMI) tool to evaluate the environmental performance with respect to operational and embodied energy use. Then, the EnergyPLAN software coupled with a multi-objective evolutionary algorithm (MOEA) was used to investigate energy decarbonisation scenarios based on different RESs, energy system integration and energy sharing. Two conflicting objectives were considered: cost and CO2 emission reductions. The Baseline scenario, based on the InCUBE interventions, was compared with three additional scenarios considering a larger set of decision variables (technologies) promoting energy decarbonisation: I) Optimized scenario without energy community incentives, II) Optimized scenario with energy community incentives

and III) Optimized scenario with energy community incentives based only on hydrogen vs fossil fuels.

The results show, on the one hand, the key role of sector coupling technologies such as heat pumps and electric vehicles in exploiting local RESs and, on the other hand, the higher costs in introducing both electricity storage to achieve a complete decarbonization and hydrogen as an alternative strategy in the electricity, thermal and transport sectors. As expected, the availability of energy community incentives is a strong driver for promoting a complete decarbonization up to PED approaches at competitive costs.

Keywords: Energy community, Positive Energy District, Renovation Wave, Urban Modelling Interface, EnergyPLAN, multi-objective evolutionary algorithm, Energy System Integration, renewable energy sources

Jim Rojer received an MSc degree in Control and Simulation from Delft University of Technology in 2017. In 2018, he joined TNO as a scientist where he contributed on a series of heat network projects. In recent years he focused on combined design an operational optimization for heat nertworks.

Dynamic GROW Model for Heat District Network feasibility by Techno-economic Planning and Design Optimization with a Mixed Integer Linear strategy

1) Jim Rojer, TNO. 2) Femke Janssen, TNO. 3) Thijs van der Klauw, TNO. 4) Martijn Clarijs, TNO.
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The Netherlands with over 90% of homes heated by natural gas is currently in the early phases of the heat transition and needs to find alternative solutions towards 2050. According to ambitions of the Ministry of Economics and Climate up to 40% of future implemented heating systems in the built environment will use Heat District Networks. However, their investment-heavy nature makes it challenging to establish viable business-cases for supply-side parties in the early planning phase. This causes a chicken and egg type of problem where a security of demand is challenging to get, as there is no integral estimate for the cost of heat over the lifetime.

This paper proposes a network integral techno-economic optimization with minimal a-priori assumptions, the Dynamic GROW Model. An integral network cost enables to achieve a considerably more reliable cost of heat in the early planning phase, cracking the chicken and egg problem. GROW optimizes the investments, operational strategy and roll-out phase. A Mixed Integer Linear Problem approach is chosen to capture the physics as well as the financial choices. Linearization of the physics are chosen with a conservative impact on the cost estimates. The optimization uses a staged approach: first the ideal end scenario network is optimized where the placement and size of sources, storages and pipes are optimized together with the operational strategy. The second stage is the roll-out optimization; in this stage the most economically viable route for realizing the network is determined.

The workflow was applied to a greenfield scenario network for the municipality of Rijswijk. It was shown that a 25% reduction in Total Cost of Ownership in the primary grid

could be achieved by introducing seasonal and decentral storage. The roll-out optimization was optimized for profit over 30 years with a constraint on the investment rate of 15M€ per year. The network would be financially feasible from the start. It is foreseen that the Dynamic GROW model can help municipalities in their heat transition and act flexible by re-running the workflow for different scenarios and updated circumstances. The Dynamic GROW Model can be extended to innovative 5th generation heat network concepts and will become open source available.

Keywords: District Heating Network, design and operational optimization, pipe and asset sizing, Mixed Integer Linear Problem, roll out strategy, seasonal thermal energy Storage, decentral thermal energy storage

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 smart control of integrated energy systems and district heating and cooling networks.

Concurrent optimal management of communities of multi-energy prosumers

Agostino Gambarotta, University of Parma; Mirko Morini, University of Parma; Costanza Saletti, University of Parma

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Over the last years, energy systems has undergone a sharp transformation from fully centralized to decentralized systems. Before, energy was converted into its different forms in large central plants and sent to the users e.g. through the power grid or district heating. Today, on the other hand, energy conversion systems of different size and composition are distributed closer to the users. Indeed, it is more and more common to find energy communities with prosumers, namely customers that are equipped with generation plants and are, at the same time, local energy producers and consumers. This emerging structure, which is generally intended for the electrical sector but can bring benefits also in its extension to heat (e.g. waste heat recovery), is particularly suitable for increasing the penetration of renewable energy technologies, installed locally where the resource is available.

Since distributed generators highly interact with the energy community, the optimal operation of a plant seen individually may not correspond to the most profitable operation of the global system. Hence, the optimal management of an entire energy community comprising a large number of prosumers and distributed plants, as well as traditional centralized units, constitute a large-scale problem with significant challenges.
This work presents a control method for coordinating the operation of generic prosumers in a community fed by a heat distribution network and a centralized multi-energy system. Each building is provided with a local multi-energy system with variable structure and accepts demand side management actions, meaning that heat can be stored in the building heat capacity or taken back when considered effective. Different local optimizers have the goal of managing the production within the different prosumers, while a global optimizer operates the central plants and distribution network. The bidirectional

communication between local and global optimization algorithms leads, through an iterative procedure, to the best solution for the global community. The control framework is formulated and tested on a case study. It is finally shown that it can be reported to different scales, e.g. the generic prosumer can be a building but also an energy community with aggregated features.

Keywords: distributed production; prosumers; integrated energy systems; district heating; demand side management; Model Predictive Control; optimization

Energy systems researcher from Lappeenranta, Finland, focusing on techno-economic assessment of wind and ocean energy potentials and energy transition in Europe

From Winter Wind to Summer Sun: Unlocking the Arctic Region's Renewable Energy Potential

Rasul Satymov, LUT University; Dmitrii Bogdanov, LUT University; Christian Breyer, LUT University
Rasul Satymov (presenter) rasul.satymov@lut.fi

Lapland is the northernmost region of Finland largely within the Arctic Circle with close to 100% renewable electricity supply. A fully tapped hydropower potential and a strongly growing wind power supply allows the region to meet almost all of its electricity demand domestically with renewable energy (RE) sources. The region has a potential for significant expansion of electricity generation with excellent wind resources in winter and almost uninterrupted solar photovoltaic (PV) supply in summer. Plans are in place for an expansion of the wind capacity in the region with grid development projects to transmit the Northern electricity to the demand centres in the South. However, Lapland has a potential to go beyond supporting the domestic electricity supply. The abundance of land, good RE resources and access to the sea could enable the region to become an Arctic energy hub, housing energy intensive industry and producing e-fuels/chemicals for export.

This study aims to evaluate the potential of Lapland to become an Arctic energy hub and act as a blueprint for other Arctic regions in the world. The LUT Energy System Transition Model is applied to investigate the optimal transition for the region and estimate the cost structure of such an energy hub.

The results show that the power generation capacity can grow from 2 GW today to at least 8 GW in 2050, with 5 GW of onshore wind and 1.5 GW of solar PV. With levelised cost of electricity at 30 €/MWh and over 2 GW of fuel conversion units (1.4 GW of water electrolysers and 0.7 GW of Fischer-Tropsch units), the region can generate electricity and e-fuels both for domestic industry and transport sector demand, and in addition 4.5 TWh of e-fuels for export, utilising CO2 captured at point sources from the pulp and paper industry.

The Arctic energy hub can help Finland phase out its net electricity imports, cut CO2 emissions and sustain the fiscal revenue of the Arctic region. Beyond the energy export potential, the waste heat from fuel conversion units can be used for further value creation, e.g., to provide heat for greenhouses similar to geothermal-based practices in Iceland to enable agricultural production via greenhouses. Energy-food nexus enabled locally grown produce can be of great value for Arctic regions.

Keywords: Arctic energy hub, Lapland, 100% renewable energy, energy system transition, energy-food nexus

Jens Schmugge has been working at the DLR as PhD candidate since March 2021. His work is focused on finding cost-optimal pathways to a climate-neutral European energy system using the energy system optimisation framework REMix. The main emphasis is on the representation of the gas infrastructure.

Transformation of the heat and gas infrastructure for a cost-optimised climate-neutral European energy system

Jens Schmugge; Hedda Gardiam; Hans Christian Gils, German Aerospace Center (DLR), Institute of Networked Energy Systems, Curiestr. 4, 70563 Stuttgart, Germany

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The need to advance towards zero-emission energy systems goes along with the need to build sector-integrated energy systems. We therefore present a geographically, temporally and technologically highly resolved linear optimisation model of the European energy system to investigate promising pathways to a cost-effective decarbonised future.

Our model is built using the energy system optimisation framework REMix and consists of 70 nodes representing regions in Europe, more than 100 different types of energy sources and storage options. We consider electrification of heating and transport as well as the production and import of hydrogen from several regions as major options to link sectors.
The objective is to minimise system costs while meeting the hourly demand of all considered energy carriers at all nodes through expansion and usage of energy conversion, storage and transport options. The analysis particularly evaluates the future gas pipeline infrastructure.

Our results indicate that the electrification of heat supply caters for most demand of that sector in a cost-optimal decarbonised future. Significant cost reductions can be achieved by using the flexibility that heat and hydrogen storage can provide to the power system through sector integration. With the buildup of electrolysis capacities throughout Europe combined with some overseas imports, a hydrogen transmission network provides flexibility to the system and leads to a significant decline of overall system costs compared to the sole use of the electrical grid.

Keywords: sector integration, power-to-heat, power-to-gas, gas infrastructure, decarbonisation, cost-optimised pathway

Christian Schützenhofer has degrees in theoretical physics, pure math and electrical engineering and is working on his doctorate in management and operations research at the University of Vienna. At AIT he is in charge of decarbonization of the Austrian industrial sector.

Industrial energy demand and GHG emission scenarios under changing technologies

Christian Schützenhofer, Austrian Institute of Technology. Peter Nagovnak, Montanuniversität Leoben.

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Energy scenarios have proven to be a valuable tool to generate the necessary information for stakeholders to envision the right steps in preparing this transition. The manufacturing industries represent an especially important sector to investigate, due to both high energy consumption and GHG emission figures and great economic value for member countries. We argue that in order to provide the necessary information for decision making, a novel approach to industrial energy and GHG emission accounting should be adopted. This approach should include a subsector-resolved analysis of all industrial production processes while considering both transformation processes and final energy-application. In addition, both scope 1 and 2 GHG emissions of manufacturing industry should be assessed. To compare scientifically necessary technology deployment for decarbonisation with existing industry plans, we propose the integration of a stakeholder-based scenario, that takes into account mid to long-term planning of key industrial representatives, thereby going beyond existing scenario narratives (e.g. WEM or WAM scenarios according to the European Monitoring Mechanism). To address these points, we have chosen Austria as a case study. Results indicate that industry stakeholders already envision investments towards a low-carbon pathway for their respective subsectors. In contrast to today's diverse picture of fossil energy carrier supply, the manufacturing industries of the future rely on the following main energy carriers; electricity, CO2-neutral gases, and biomass.

Keywords: Industry decarbonization, national emission model, energy data aggregation.

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

Sønderborg (DK) case example of district heating sector coupling and the related control solution

Jan Eric Thorsen (*), Director, Global Application Expert, Hydronics, Danfoss DCS, Denmark
Oddgeir Gudmundsson, Director, Projects, Hydronics, Danfoss DCS, Denmark
Tue Gejl Christensen, Head of project development and R&D, Sønderborg Varme, Denmark
Lars Troldahl, Business Development Manager Software, District Energy, HydronicS, Danfoss DCS, Denmark

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The Sønderborg district heating system is a great example on how a small-scale district heating system can contribute to a smart, efficient and sector coupled energy system. Sønderborg commune covers several towns in the area, and some of those towns have historically operated their own district heating systems. To realize the full potential of the district heating system the long-term plan is to connect these systems via a transmission line, as well as to connect new towns and settlements that are currently gas supplied.

In this way the heat generation plants and storages invested in one city can be used as a source in another city, providing a higher flexibility, increased resilience and increased potential for cost-effective utilization of green and low carbon sources. As a consequence, the district heating system becomes more complex with several interconnected hydraulic networks, a variety of heat generating plants and distributed thermal storages, which enable moving heat between the relevant parts of the system to overcome capacity limitations in the transmission system. The large number of distributed heat-generating plants, thermal storages and transmission system limitation calls for a capable and holistic control solution, for optimizing the heat generation across the heating plants, operation of the distribution network as well as the demand side, or in other words an end-to-end control solution.

This presentation includes a tour around the wider Sønderborg district heating system, focusing on the heat sources and the interaction with various sectors, among others waste incineration-based CHP, biomass incineration, solar thermal, industry surplus heat and biofuel boilers. It will give an overview of the development of the end-to-end control solution that is being developed for the wider Sønderborg district heating.

Keywords: District Heating, Sector Coupling, Control, Software

RENEWABLE ENERGY SOURCES AND WASTE HEAT SOURCES INCLUDING PTX FOR DH

Hamza is a PhD researcher at the sustainable energy planning research group in Copenhagen. His work focuses on the offshore energy islands in the North sea and holistic energy systems analysis, encompassing sector coupling and smart energy systems approach to regional energy planning

Existing and future potential hydrogen demands in Europe

Hamza Abid, Brian Vad Mathiesen, Poul Alberg Østegard, Iva Ridjan Skov, Aalborg University

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Hydrogen at present is being seen as a promising energy carrier that can not only enable the transition to a low-carbon economy but also help Europe deal with its security of supply challenges. However, the future demand for hydrogen is uncertain and depends on various factors, such as technological choices, policy support, and cost competitiveness. This study aims to provide a comparative review of existing and future hydrogen demand potentials in Europe by well- reputed leading European public and private institutes. The existing, short-term (2030), and long-term (2050) hydrogen demand potentials from these institutes are compared based on end-use. The review shows that hydrogen for refining accounts for around 50 % of the hydrogen demand at present, a demand that would ideally be in decline if Europe moves towards its decarbonization goals. Ammonia production for fertilizers at present and in the future will likely remain a big market for hydrogen. Hydrogen for synthetic aviation fuel production could prove to occupy a larger share than hydrogen-based fuels for shipping. Direct hydrogen use for transport is still noted by some studies to occupy a significant share of future hydrogen needs

Keywords: Hydrogen demand, electrofuels, Power to X, energy systems

Doris Beljan is a teaching assistant and PhD student at Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb. Her research work focuses on renewable energy sources, energy planning, energy transition and energy economics.

Utilization of the available offshore wind potential - case study for the North Adriatic with the focus on HVDC, hydrogen and ammonia infrastructure

Doris Beljan, Luka Herc, Neven Duić, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb
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The power generation systems play a crucial role in the energy transition by meeting the energy requirements for decarbonizing various sectors. These systems provide clean and reliable energy to support technologies such as electrical heating, industrial applications, and transportation. Additionally, the power system must supply the energy needed to produce feedstocks and fuels for other sectors. However, there are challenges in generating energy or feedstocks due to disparities between the generation and consumption locations. The existing electricity transmission grids are inadequate to handle the demands, especially when it comes to highly concentrated sources of generation and demand. Therefore, additional investments into energy transmission infrastructure are required. This research focuses on the case of offshore electricity generation in the North Adriatic area. The study explores potential use cases for the generated electricity or feedstocks, specifically targeting big industrial consumers in the area where ammonia or hydrogen are the primary demand. Various infrastructure investments and utilization methods for the available energy are examined, including high voltage direct current lines, hydrogen, and ammonia pipelines, as well as other forms of transportation. Additionally, different combinations of storage and feedstock generation arrangements are considered. The implementation is evaluated alongside national energy modeling and is carried out in the H2RES energy modelling and optimization tool. Results of the optimization indicate the most viable option for utilizing offshore wind potential for production of needed feedstock and fuels for different industrial demands.

Keywords: Offshore wind generation, HVDC, Hydrogen, Ammonia, Feedstocks, Energy transfer, 100% Renewable Energy, H2RES

Prof. Dagnija Blumberga is the author of more than 450 scientific publications and has experience in more than 15 international projects as a researcher, expert, and project leader. She is an expert in a very wide research field from sustainable energy systems to efficient use of resources.

How to integrate carbon farming in smart district heating energy systems?

Dagnija Blumberga, Girts Bohvalovs, Ieva Pakere, Edgars Kudurs, Krista Laktuka, Andra Blumberga, Institute of Energy Systems and Environment, Riga Technical University, Latvia

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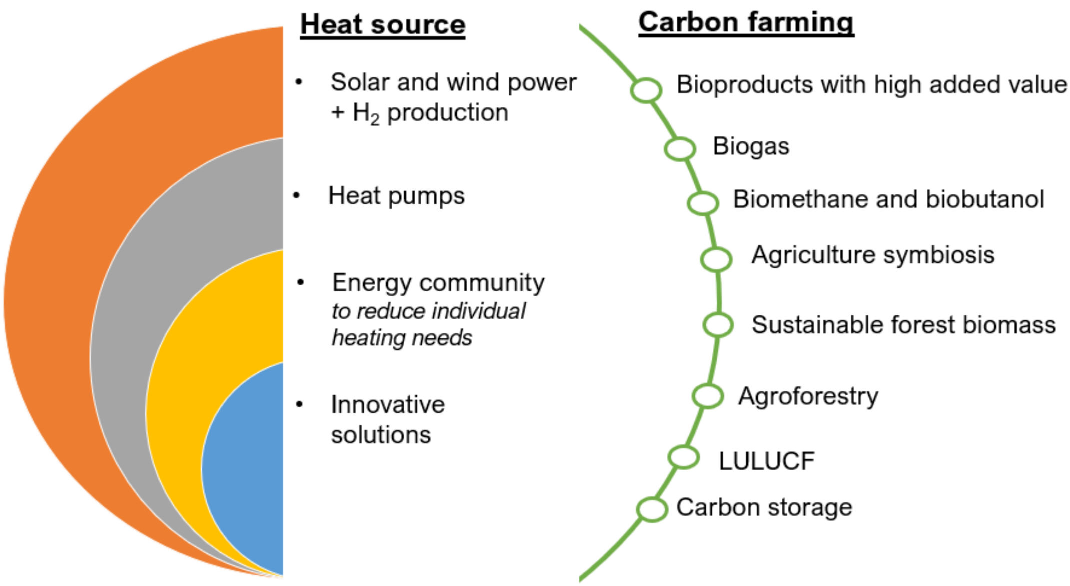
To reach climate neutrality in 2050 it will be necessary to change the attitude towards sustainable use of available biomass resources. However, the question of what will replace the use of biomass for the energy sector remains open. Despite the significant progress that has been made towards decarbonizing the power sector in recent years, the question of what will replace the use of biomass for energy generation remains open.

The development of agriculture and forestry is changing, and it is increasingly moving towards carbon farming. Current issues are not only the use of biomass to produce products with high added value but also the improvement of biogas and its quality to produce biomethane, n-butanol and biobutanol with the integration of renewable solar and wind energy resources to produce hydrogen. Another development direction of carbon farming is related to the gradual introduction of agricultural symbiosis. At the same time, the problems of LULUCF sector decarbonization and carbon storage in the soil are relevant.

This will significantly affect the development of district heating systems, in which the proportion of renewable energy resource - biomass use is relatively high. It is also important to emphasize the reduction of the proportion of individual heat energy users, integrating them into the concept of energy communities. Four different scenarios of heat supply development were analyzed with the help of the system dynamics model so that two different sectors and the national economy could develop towards achieving the goals of climate neutrality.

Keywords: Climate neutrality, sustainable biomass resources, carbon farming, renewable energy systems



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.

Different scenarios for the decarbonization of a campus district heating system

Frederik *Feike*, Frank Dammel, Peter Stephan, Technical University of Darmstadt, Germany

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Heating accounts for a large share of the final energy demand, but in Germany only 17,4% of the demand in this sector is covered by renewable heat sources. Especially in urban areas, it is difficult to replace individual fossil heating systems with renewable alternatives. The use of district heating systems can play a significant role in replacing decentral fossil heating systems, because heat from different renewable heat sources can be integrated into one supply system and transported over a certain distance to the consumers. While it is relatively easy to build a new district heating system that is entirely supplied by emission-free heat sources, the biggest challenge is to decarbonize existing district heating systems. These systems are operated at high temperatures because the connected buildings require these high temperatures due to their poor energetic quality and their heating systems with relatively small heat transfer surfaces. The renovation rate of the building stock is low and a thorough renovation of the building envelope is cost and resource intensive.

At TU Darmstadt, various measures to reduce the network temperatures without renovating the building envelope have been implemented and are currently being investigated. In order to decarbonize the existing district heating systems, the currently existing central fossil heat generation plants have to be replaced by locally available renewable heat sources. In this work, the decarbonization of the existing district heating system of the university campus Lichtwiese at TU Darmstadt is investigated. For this purpose, a numerical model of the district heating system is developed in MATLAB Simulink using the CARNOT toolbox, and different decarbonization scenarios are compared economically and ecologically. The technologies considered are solar thermal,

ground and air source heat pumps, direct electric boilers and excess heat from a high performance computer and from the central cooling generation. To match the fluctuating supply and demand, short- and long-term heat storages are integrated. Different ways to reduce network temperatures are considered, and their importance for the integration of renewable heat sources is investigated.

Keywords: Decarbonization, district heating, temperature reduction, heat pump, solar thermal

Max Fette is a researcher at the Fraunhofer IFAM. He has previously worked as a project engineer and consultant for CHP applications. His research work concentrates on the fields of district heating and how this sector can be de-fossilised using sectoral coupling, large heat pumps and CHP.

CHG - Combined Heat and Gas": what are the potentials and barriers of using the waste heat of electrolysers and how can it be utilised?

Max *Fette*, Fraunhofer IFAM
Leander Kimmer, Fraunhofer IFAM
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Green hydrogen, produced with electrolysers and using electricity from renewable sources, notably solar and wind is seen as a major element to de-fossilise energy sectors that are difficult to deal with on an "electricity only route" (e.g. heavy load transport, steel production, other industrial processes).

The conversion efficiency of current alkalic or proton exchange membrane electrolysers is currently between 65 and 80%, meaning that significant amounts of the input electricity is dissipated as waste heat.

The presentation will show results from two ongoing research projects:

- "Roadmap Gas-Transition" and
- "hyBit" (hydrogen for Bremens industrial transformation).

The first research project is using different scenarios for the transition of the European gas-system until 2045 to assess the effects on the operation of power to gas units in Germany on a theoretical level. The second research project is looking at a more practical example: the transformation of an existing steel plant, which will need large amounts of hydrogen in the future, part of which is to be produced on site, giving the opportunity to utilise the waste heat within the existing and growing district heating network in Bremen.

Both projects are investigating the following aspects on how this waste heat can be used in heat networks:

- How can the efficiency of electrolysers be increased? (using both energetic and exegetic efficiencies as a basis)
- What are the requirements of heat networks to accommodate this heat and, if heat pumps are needed to raise the temperature, how do they compare with heat pumps using alternative heat sources such as ambient air or the water of rivers?
- What are the effects on the electricity system if the additional heat pumps are running at the same time as the electrolysers?
- What is the economic viability of using the waste heat of electrolysers? Can the additional income pay for the supplementary infrastructure needed? (such as district heating pipes to connect the system to heat consumers).
- How can the regulatory framework be changed to encourage the utilisation of waste heat?

The presentation is addressing these questions in detail, showing results that are have been modelled with energy system modelling tools of the Fraunhofer IFAM.

Keywords: Electrolysis, sectoral coupling, electricity, heat, gas, district heating, fluctuating renewable energy, energy infrastructure, smart operation, low-temperature district heat sources

Maximilian's research centres around variable renewable energy forecasting and the modelling of power-to-X processes. He previously worked as an R&D engineer for a leading European energy company and holds a B.Sc. degree in Chemical Engineering as well as a double M.Sc. degree in Energy Engineering.

A combined stochastic wind power forecasting and operational optimisation approach for off-grid offshore green hydrogen production

Maximilian *Fey*, Institute of Energy Economics and Rational Energy Use (IER), University of Stuttgart;
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Hydrogen and hydrogen-derived synthetic fuels are envisioned to play a key role in the decarbonisation of hard-to-abate sectors, such as the chemical industry, steel production, shipping and (long-haul) aviation. The economics of electrolytic hydrogen production depend highly on the cost of electricity sourcing. For the case of offshore wind, which today represents a competitive technology to produce electricity from an abundantly available renewable energy source, the infrastructure connecting wind parks with onshore power systems constitutes a significant part of the total investment. Against this background, several ongoing research projects investigate the possibility to spare the grid connection and produce hydrogen offshore in direct vicinity to a wind park. In comparison to grid-connected systems, the off-grid operation of electrolysers co-located with wind parks introduces a series of additional challenges. Particularly when also including energy and material storages and in view of the stochastic availability of power from the wind park, the operational scheduling of such production systems becomes an interesting optimisation problem, which ideally should be approached by the application of stochastic methods. In the proposed work an early-stage implementation of a stochastic wind power forecast coupled with a stochastic optimisation for the operation of an exemplary system as outlined above will be presented. The machine learning model producing the forecast is trained and tested with historical wind and power measurements from a real wind park in the North Sea. The developed forecasting and optimisation solutions are combinedly used to simulate the operation of an offshore off-grid green hydrogen production system over the period of

one year. The simulation results are 3compared to the ones for a deterministic reference model and to the ideal operation under perfect foresight. It is expected that the application of stochastic optimisation methods has the potential to increase overall hydrogen production by making best use of the intermittent power source and consequently improve project economics, thereby increasing the competitiveness.

Keywords: green hydrogen, offshore electrolysis, dynamic processes, stochastic optimisation, wind power, forecast uncertainty

Markus Fritz is a senior researcher at Fraunhofer ISI. He co-hosts "en-Power", the largest German interview podcast on the German energy transition since February 2020. His research focuses on energy efficiency in industry and buildings, particularly using waste heat and district heating.

What to do with the excess heat? - Assessing the techno-economic potential of different excess heat transport technologies in the Euro-pean Union

Markus *Fritz*, Fraunhofer ISI; Dorian Werner, Fraunhofer ISI; Ali Aydemir, Fraunhofer ISI

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Utilizing industrial excess heat for eco-friendly and efficient heating can play a crucial role in meet-ing the European Union's climate objectives. To achieve ambitious CO2 targets, it is necessary to significantly reduce CO2 emissions from the heating sector. District heating is presently the main method of transporting excess heat to end users in the EU. However, constructing district heating networks is costly and time-consuming. Other transportation technologies may be more feasible depending on the circumstances. This is the starting point of our research, which aims to answer the question: How high is the techno-economic potential of different excess heat transport tech-nologies?

To answer the research question, we determine the economic excess heat potential for residential heating, considering different transport technologies. For this purpose, we develop a bottom-up optimisation model, which uses over 6,000 excess heat sources in Germany, heat demands in a resolution of 100mx100m and four different excess heat transport technologies: i) District heating networks, ii) Sewer networks, iii) liquid-gas absorption cycles, iv) Phase Change Materials & road transport. The optimisation is carried out for 2 different objective functions: (1) minimising the transport costs, and (2) maximising the amount of excess heat used.

The results show that about 12-17 TWh of excess heat can be utilised up to a cost threshold of 0.1 €/kWh. For cost optimisation, we see that district heating is the most selected technology, as it has the lowest transport costs for many network configurations. However, when maximizing the amount of excess heat used, niche technologies such as transport via sewer or Phase Change Ma-terials are used as well.

This is often the case for configurations with low excess heat amounts and/or short distances, resulting in low heat losses. In summary, our results indicate that from an economic point of view there are no one-size fits all solutions to transport excess heat, as there are areas in which niche technologies, such as transport via sewer networks, make sense. In con-clusion, industrial excess heat transport technologies are available, but the next step is market penetration and up-scaling, even of niche technologies.

Keywords: waste heat, excess heat, residential heating, district heating, levelized cost of energy

Gabriele is a post-doctoral researcher at the Urban Energy System Laboratory at Empa (CH). His research focuses on the optimal design and operation of energy systems to enhance performance and minimize emissions and costs.

Optimal sizing and operation of hydrogen generation sites with waste heat recovery for district heating network integration

Gabriele *Humbert*, Urban Energy Systems Laboratory, Empa, Dübendorf, Switzerland;
Hanmin Cai, Urban Energy Systems Laboratory, Empa, Dübendorf, Switzerland;
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The transition towards smart energy systems requires the efficient and sustainable utilization of hydrogen production technologies. In this context, the integration of waste heat recovery from electrolyzers can en-hance the energy efficiency and cost-effectiveness of hydrogen generation sites. This work presents a novel approach for the simultaneous optimization of the sizing and operation of hydrogen generation sites, con-sidering waste heat recovery and its integration in a district heating network. The investigated energy sys-tem employs PV panels and Lithium-ion batteries as the power source for a PEM electrolyzer, while heat pumps are considered to meet the temperature level requirements of the district heating network.

The optimization problem is formulated as a mixed-integer linear programming (MILP) model, which aims to minimize the investment and operational cost of the system while meeting the hydrogen demand. Only a few studies have been devoted in the literature to the assessment of the benefits deriving from the waste heat recovery of hydrogen generation sites. Besides, these studies often considered sizing and operation as separate steps of the design process, ultimately leading to sub-optimal solutions. The proposed approach is applied to a case study, and the results demonstrate its effectiveness in achieving lower costs compared to conventional design approaches. The key contributions of the work can thus be summarized as follows: (i) development of a numerical framework for the simultaneous optimal sizing and operation of hydrogen gen-eration sites; (ii) quantification of the benefits deriving from the waste heat recovery from low-temperature electrolyzer technologies; (iii) assessment of the benefits deriving from the proposed simultaneous optimiza-tion approach compared to conventional design approaches. Ultimately, this work contributes to the devel-opment of smart solutions for the sizing and operations of hydrogen generation sites with waste heat recovery and elucidates the link between optimal sizing and operation of such energy systems.

Keywords: Hydrogen production, electrolyzer, waste heat recovery, optimization, MILP, sizing and operation

Ulrike Jordan is associated professor at the University of Kassel. She is co-leader of a researchers' team in the department of solar and systems engineering, working on municipal heat planning, district heating, industrial process heat and liquid desiccant systems.

Potential analysis for phasing out coal, oil and natural gas for heat supply in Kassel, a medium-sized city in Germany

Ulrike Jordan, Isabelle Best, Hagen Braas, Tim Vaupel, Oleg Kusyy, Janybek Orozaliev, Klaus Vajen, University of Kassel

Ulrike Jordan (presenter)

The study presents scenarios that show which measures would make it possible to phase out coal, oil and natural gas combustion for heat supply in the city of Kassel in Germany (200.000 inhabitants). A heat map of the city was developed and a potential analysis for the use of waste, residue and sewage sludge incineration, as well as renewable energy was carried out.

First, Kassel's heat consumption was evaluated on a building-by-building basis and a scenario for the seasonal distribution of heat consumption was developed for various consumption sectors for the year 2030. In addition, scenarios for heat supply were created. These indicate that it would be favourable to expand the district heating system from 20% of heat supply today to almost 50% of the future heat supply in 2030. In the scenario, the district heating supply is composed of approx. 56 % combustion heat (waste, sewage sludge, waste wood) and approx. 40 % heat supply with large heat pumps. The remaining share (approx. 4 %) is accounted for by waste heat utilization, large-scale solar thermal systems, and peak load coverage, e.g., by biogas.

A prerequisite for the full utilization of this heat supply potential are sufficient seasonal storage capacities and the expansion of the district heating supply. For an underground storage tank, storage volumes of approx. 0.8 - 1 million m³ were evaluated.

Moreover, for decentralized, building-specific heat supply and for small district heating systems potentials for the installation of geothermal probes are also considered and the number of necessary heat pumps as well as their heat supply and electricity consumption are estimated.

Keywords: Municipal heat planning; district heating; heat map; heat consumption scenarios; renewable heat supply, large-scale heat pumps

In 2022, M. Sc. Bjarne Jürgens graduated with a master thesis about the effect of temperature changes on pipe lifetime in district heating networks. Until now, his research focus is the simulation of district heating networks and estimating future heat demand and heating system distribution.

Covering district heating demand by waste heat usage from data centres – a feasibility study in Frankfurt, Germany

Bjarne Jürgens, University of Kassel

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Currently, most waste heat from data centres remains unused, but due to its sheer potential it can't be ignored for the decarbonization of the heating sector. Here, a feasibility study is presented for covering the heat demand of two districts of Frankfurt (Germany) mainly by data centre waste heat. Contrary to existing projects and other studies, the waste heat shall supply existing buildings, the total heat demand is very high (144 GWh/a) and it should be covered almost exclusively by waste heat usage. First, the waste heat potential was estimated by electricity data and discussions with data centre owners. Second, the current and future heat demand was calculated and third, a heat supply concept was proposed to link potential and demand. To ensure the practical realisation a network route was developed including solutions for critical points and the corresponding costs were estimated. In the end, the concept was evaluated regarding technical realization and CO¬2-emissions and the levelized cost of heat (LCOH) were calculated for the proposed concept and compared to the costs of decentralized heat pumps.

As a result, the usage of data centre waste heat is technically possible and the most promising way for decarbonizing the heating sector in this area. With high-capacity heat pumps (37 MWth), gas boilers (20 MWth) and a storage for daily peaks, 97.5 % of the heat demand can be covered by waste heat usage. This is economically favourable compared to decentralized heat pumps for all types of buildings, and probably also favourable compared to gas and oil boilers due to rising energy carrier costs. Surprisingly, an implementation with smaller heat pumps and an increased usage of gas would increase the total costs. With the proposed concept, CO_2-emissions in the network area are reduced by 78 % on average between 2025 and 2044 and by 96 % in 2044. It was also

shown that waste heat usage is very expensive or impossible in most existing data centres in the area considered, but in newly planned buildings it is easy to implement. Therefore, laws to oblige the waste heat usage in data centres are recommended.

Keywords: feasibility study, waste heat recovery, data centres, 4th generation district heating, high-capacity heat pumps

Jacek Kalina has been working in the field of energy systems since 1997. He is employed in the position of Associated Professor at Silesian University of Technology at Gliwice, Poland. He specialises in distributed small-scale cogeneration, modelling and optimisation of energy systems, and energy management.

Sizing large-scale industrial heat pump for heat recovery from treated municipal sewage in coal-fired district heating system

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Integration of sectors, circular economy, and electrification of district heating and cooling are among the key pillars of future energy systems. Regarding the energy supply and use patterns, energy harvesting, use of distributed resources, and distributed generation are envisioned as key activities. This, however, requires considerable progress in changing current practices, and the uptake of new technical and non-technical concepts and already demonstrated good practice examples. In the district heating (DH) sector, a faster rollout of energy transition must take place to meet energy and climate policy.
This paper discusses the problem of optimal sizing of large-scale high-temperature heat pumps using treated sewage water as a heat source into a coal-fired district heating system. The aim of the study is to assess the technical feasibility and level of profitability of the investment project under the conditions of the Polish energy system. The case study takes into consideration given site-specific technical, economic, ecological, and legal constraints, weather conditions, hydraulic performance of the heating network, and variability of loads within the sewage and the district heating systems. In addition, it is proposed that the heat pump system is integrated with a dedicated PV power plant. Based on the data collected, key factors have been identified that influence the technical and financial feasibility of the project, and the optimum heat pump output. The results revealed that under current market conditions, projects of such type can be profitable if the heat pump is appropriately sized and operated. In such a case the Net Present Value (NPV) can be positive and Disouted Payback Periods (DPB) below 15 years are possible. In the given case study, the recommended solutions are the ones with a relatively long annual time of operation. The optimum size of the heat pump for a city of around 180

000 inhabitants is around 12 MW under maximum winter load. A higher capacity heat pump will result in a longer operation under part load conditions as well as in shorter annual service time. On the other hand, a smaller heat pump will run in parallel with the coal-fired heating plant for an extended time, which will lower the decarbonisation effect.

Keywords: district heating, heat pumps, sewage treatment plants, energy planning, sector integration, renewable energy

Henrique is a research fellow at London South Bank University, where he investigates how the potential to recover waste heat from several sources in urban areas can be unlocked by district heating and become a key technology in the transition towards low-carbon and cost-effective energy systems.

The Potential of Crematoria as Waste Heat Resources in the UK

1) Dr Henrique Lagoeiro, London South Bank University
2) Dr Gareth Davies, London South Bank University
3) Dr Catarina Marques, London South Bank University
4) Prof. Graeme Maidment, London South Bank University

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Cremation is an energy intensive process that represents the most popular funeral rite in the United Kingdom. Typically, the cremation process lasts for 80 minutes, and furnaces are heated with natural gas, reaching temperatures of up to 1000°C. The flue gas from the cremation process is therefore at a very high temperature and must be cleaned to remove pollutants such as mercury, a process which involves cooling down the flue gas to temperatures below 160°C, offering a significant opportunity for high-grade waste heat to be recovered and reused. Recent case studies have estimated that from 200 to 400 kW of waste heat is released during a typical 80-minute cremation. This paper aims to investigate the potential of crematoria as a source of waste heat in the UK by estimating the thermal energy output from 315 crematoria across England, Wales, Scotland, and Northern Ireland. Possible configurations for waste heat recovery systems from cremation flue gas are also presented, and these are applied to assess the potential benefits that could be obtained if waste heat from a crematorium in London was captured and reused. A number of applications will be evaluated, such as the generation of electricity, e.g. using the Organic Rankine Cycle, or the provision of heating to nearby buildings via a district heating network. Although the case study is based in the UK, the methodology hereby described can also be applied to evaluate the potential for heat recovery from crematoria in other countries.

Keywords: Waste heat, cremation, energy recovery, decarbonisation, high temperature

Catarina is a Senior Research Fellow at London South Bank University (LSBU) with 15 years' experience working on funded research projects in the areas of Refrigeration and District Heating and Cooling.

A Smart Local Energy System with heat recovery from power stations

Marques, A.C.1, Jones, P.2, Dunham, C.3, Turnell, H.1, Lagoeiro, H. 1, Maidment, G.G.1; 1London South Bank University, 2Building Low Carbon Solutions Ltd., 3Carbon Decent Projects Ltd.

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This paper demonstrates the opportunity for UK local authorities to utilise waste heat from local sources to meet their net zero emissions targets. It presents a feasibility study for a smart local energy system (SLES) in an urban area in West Yorkshire, UK. The network design included heat recovery from two power stations with 40MW of heat available and assuming a 90/50^{o}C district heating flow and return it provides up to 315GWh of heat (at 90% availability). This is enough to supply approximately 21,000 existing homes or 53,000 new homes. This SLES adapts the concept developed initially for Islington, London, tailored to local council demands and local energy sources. The scheme would be built in five phases to connect both existing buildings and new developments. The CAPEX for the scheme is estimated at £68M with the main heat network piping accounting for 28% of the total network costs. The techno-economic model shows a positive internal rate of return over a 40-year period and significant carbon savings of up to 3,954 tonnes of CO2 per year over a counterfactual of gas boilers in existing buildings and individual air source heat pumps in new buildings.

Keywords: smart local energy systems, district heating, power stations

Martin is a researcher focusing on the role of lignocellulosic biomass in energy systems from a systemic perspective. He has previously worked one on the optimal role of biomass in the Belgian energy system towards carbon neutrality and one on the potential of miscanthus on marginal lands.

A comparative analysis of the energy return on energy invested (EROI) for different biomass district heating systems

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Julien Blondeau, Thermo and Fluid dynamics (FLOW) - Faculty of Engineering - Vrije Universiteit Brussel (VUB) - 1050 Brussels Belgium.
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Guillaume Boissonnet, Commissariat à l'énergie atomique et aux énergies alternative - CEA, I-Tésé - Energy Systems And Carbon Cycle Multi-Criteria Assessments - 38054 Grenoble, France.

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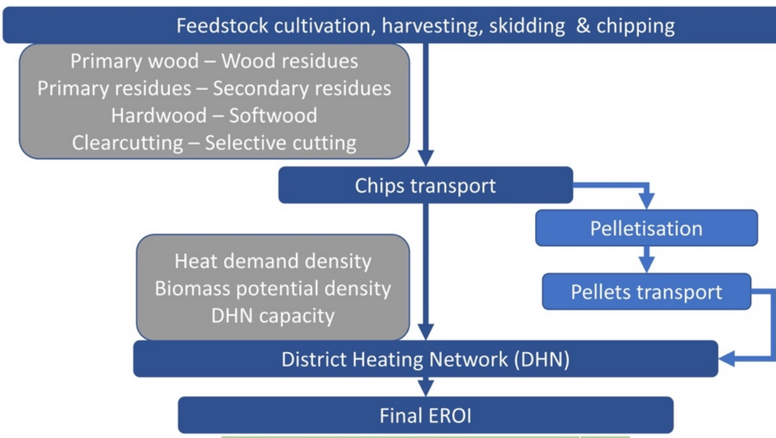
The Energy Return On Energy Invested (EROI) is a useful indicator that is largely used in the literature for evaluating the net energy contribution of an energy production system. For biomass, the EROI is often discussed in the liquid biofuels debate, to evaluate if it is higher than 1. However, today, the main source of bioenergy is forest biomass used for heat production. In parallel, district heating networks (DHN) have proven to be efficient systems for low-temperature heating. Although, there is little discussion on the EROI of such systems. This study proposes to examine the EROI of DHNs fed with biomass and to discuss (i) the impact of biomass types (primary wood, primary residues, or secondary residues) and forestry practices, (ii) the forms of biomass (chips or pellets), and (iii) the installation size and localisation which influence the required amount of biomass and its transportation.

First, we estimated generic EROIs with different biomass feedstock for the DHNs. Secondly, we developed a methodology to estimate the EROI of different DHNs based on their location and availability of biomass feedstock, with Belgium as case study. The first results showed that the EROI for woodchips used for heat production in DHNs varies from 6 to 70, depending on biomass types and the methodology for energy investment allocation regarding by-products. The maximum value is for secondary residues when no energy investment is considered for the forestry and sawing steps. The minimum value represents the same product but with a volumetric allocation of all the energy investments. For heat from primary residues, the EROI is about 27, while from primary wood it varies from 16 to 23 depending on forest types and practices. If pellets are produced, the maximum EROI drops to 7 due to the large additional energy investments. For the second step with the Belgian case study, the methodology is based on the locally available biomass potential (from the ENSPRESO database) and the heat density for the residential sector (from EU hotmaps) with a geographical resolution of NUTS02. We were able to map the EROI of biomass-fed DHNs per region, and thus identify the areas where such installations would be particularly relevant from an EROI perspective.

Keywords: EROI, Biomass, Heating, DHN, forestry, wood residues



Primary wood - hardwood	**23-32**
Primary wood - softwood	**16-24**
Primary wood - coppice	**20**
Primary residues - hardwood	**27-36**
Secondary residues - softwood	**8-70**
Pellets from secondary residues softwood	**3-7**

Figure 1 Graphical abstract with main methodology steps and general results. The blue boxes are the different considered steps (the lighter blue is an alternative route), the grey boxes represent the considered variables, the green table shows the range of the main results.

Frederik Dahl Nielsen is a PhD Fellow at Aalborg University, Department of Sustainability and Planning. His primary research focuses on sustainable energy planning, energy systems modeling, Power-to-X, and integrated energy systems.

Case study of local sector coupling strategies for e-methanol production

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The transition towards sustainable energy has given rise to electrofuels as a promising solution for decarbonizing hard-to-electrify sectors. Electrofuels, which are synthetic fuels generated through the concept of Power-to-X (PtX), have the potential to play a pivotal role in integrating variable renewable energy sources into the broader energy system. This study employs the energyPRO modeling tool to conduct a techno-economic analysis of local sector-coupling strategies for a large-scale PtX plant producing e-methanol. The analysis focuses on the utilization of excess heat derived from electrolysis and methanol synthesis within a network of district heating (DH) grids situated in Sønderborg Municipality, located in the Region of Southern Denmark. The study encompasses various system configurations, and the primary objective is to identify and propose viable sector-coupling strategies suitable for the conditions of case study.

Keywords: Excess Heat, District Heating, Power-to-X, Electrofuels, Energy Systems Modeling

Ieva Pakere, Phd has wide experience in energy system-related research due to participation in several international and national projects related to sustainable development of energy systems. She is author of more than 45 high quality scientific articles and co-author of two monographies.

Optimizing Energy Independence for Achieving Climate Neutrality Goals

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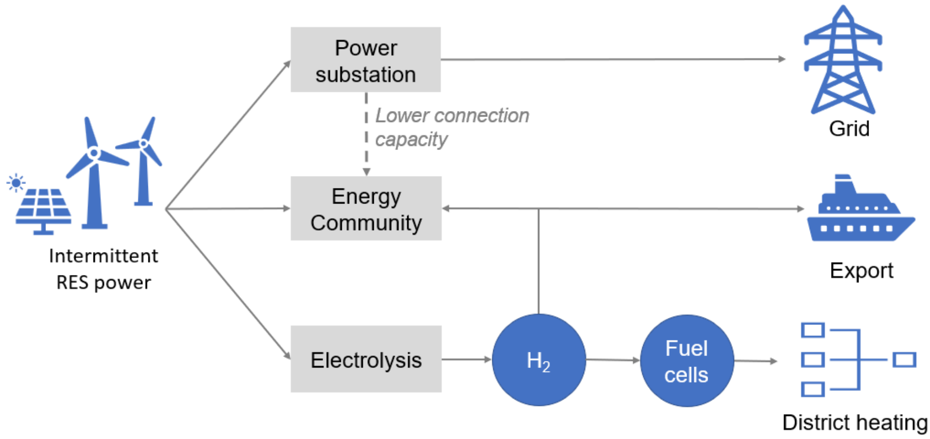
The development of a smart grid that integrates intermittent renewable energy sources (RES) such as solar and wind power poses a significant challenge due to high investment costs for balancing the network. Strategies for integrating these sources must be carefully considered to ensure grid stability and reliability. Additionally, reducing connection power is crucial in enhancing the efficiency of the system while minimizing costs. To economically justify the consumption and production of reduced emissions, rigorous economic analysis is necessary to evaluate the cost-effectiveness of different energy alternatives.

In this study, the TIMES linear optimisation model is used to conduct optimization based on economically justified production and reduced emissions. The comparison is made between two alternatives: establishing hydrogen plants interlinked with wind turbines and solar panels and establishing energy communities. The Base scenario assumes the traditional energy system with a traditional connection scheme. The reduced emissions scenario analyses the energy communities with increased use of surplus energy and partially independent energy supply. It is essential to replace inefficient and fossil-based individual heating solutions with the energy system of the energy community. The third scenario is the hydrogen production and accumulation scenario, which foresees different hydrogen pathways, such as direct use in energy communities, production of fuel cells for district heating, and export of surplus hydrogen.

It is crucial to consider the implications of each scenario on the local energy demand and supply, community preferences and policies, and environmental impact. Therefore, comprehensive analyses and evaluations are necessary to identify the optimum location for establishing energy community systems. The study results provide insights into the potential economic and environmental benefits of utilizing renewable energy sources in smart energy systems under various conditions and technical solutions.

Keywords: renewable power, energy communities, smart grid, linear optimization model, hydrogen production



Thomas Pauschinger represents AGFW, Frankfurt.

IEA DHC Annex TS5 – Integration of Renewable Energy Sources into existing District Heating and Cooling Systems

Thomas Pauschinger, AGFW

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IEA DHC Annex TS5 is an international, task shared R&D cooperation focussing on topics related to the "Integration of Renewable Energy Sources into existing District Heating and Cooling Systems (RES DHC)". The cooperation is organized worldwide under the IEA's Technology Collaboration Programme on District Heating and Cooling (IEA DHC). It started in the year 2021 and will last until 2024. Active R&D organizations come from the IEA DHC member countries AT, CA, CN, DE, DK, FR, IT, KR and SE.
In many countries, 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. In order to facilitate the transformation of existing DHC systems and to support their operators and other branch stakeholders with the necessary know-how and methodologies, the R&D work of IEA DHC TS5 addresses following key challenges:

- Harnessing RES technologies for DHC systems
- Methodologies for assessing the local potentials of RES DHC
- Transformation of DHC as a holistic long term process with technical and organizational challenges
- Decentral integration of RES DHC generation in DHC systems
- Organizational and non-technical aspects of DHC transformation processes

The general approach of IEA DHC Annex TS5 is to upgrade existing RES DHC knowledge to international level, to develop a common base and understanding and to promote its use in the national markets.
Two already available results of IEA DHC Annex TS5 are RES DHC technology and application fact sheets summarizing a reliable knowledge about the existing enhanced solutions for the technical and operational integration of RES into existing DHC systems

as well as national state-of-the-art reviews of the RES DHC sectors of the participating countries.
Upcoming guidelines will address RES DHC transformation processes and the decentral integration of RES into DHC systems. A systematic overview on RES DHC potential assessment methods will result from an ongoing intense literature review.
Beside these available and expected outcomes, we will present the work of IEA DHC Annex TS5 in its wider technical, political and market context of DHC transformation.

Keywords: IEA, district heating and cooling, renewable heat, potential assessment, transformation

Michal is a seasoned energy professional with experience in GCAP projects, financial analysis, and energy audits in industry. He has worked for Arup and the National Energy Conservation Agency, and also helped build financial and mathematical models at Agencja Rynku Energii SA

The use of heat pumps in a district heating in selected European countries

Michał Raczkiewicz, Arup

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The report discusses the use of large heat pumps in district heating systems as a means of decarbonizing heat in buildings across several European countries. It emphasizes the importance of low-carbon sources of heat production and highlights heat pumps powered by renewable electricity as a potential key technology in the decarbonization of industry. The integration of heat pumps into heat networks has been successful in some European countries, and the report explores existing systems to determine which types of systems can be economically and environmentally beneficial. The analysis also considers the cost of energy utilities, the scale of the district heating system, and the nature of its operation as important factors in determining the attractiveness of this type of investment. The report provides a case study analysis to demonstrate an alternative energy mix to achieve the greatest decarbonization effect in a cost-effective manner, identifying six key indicators for each case study. The analysis is conducted through a dedicated energy-economic model that enables quick analysis with scenario analysis. Overall, the report suggests that heat pumps have significant potential for large-scale applications, but economic and environmental factors must be carefully considered before investment in heat pump technology

Keywords: Large heat pumps, district heating systems, decarbonization, low-carbon sources, renewable electricity, economic analysis, environmental analysis, case study analysis

Stefan Reuter completed his studies in 2020 and holds a master's degree in Energy Engineering. Since 2021 he is working as Research Engineer at the Austrian Institute of Technology. His main field of work is in the area of market integration of renewable gases.

Optimizing the Domestic Production and Infrastructure for Green Hydrogen in Austria for 2030

Stefan *Reuter*, AIT Austrian Institute of Technology. Stefan Strömer, AIT Austrian Institute of Technology. Matthias Traninger, AIT Austrian Institute of Technology. Anton Beck, AIT Austrian Institute of Technology

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The decarbonisation of the Austrian energy system is expected to be facilitated by the uptake of hydrogen-based technologies, which requires the establishment of a hydrogen infrastructure to meet the rising demand. While large quantities of hydrogen are expected to be imported in the future, current developments in the energy market suggest that domestic production of hydrogen should not be ignored to ensure the security of supply. As domestic production ramps up, locating electrolysers to ensure optimal system integration is still an open question. To address this challenge, the "HyTechonomy" project developed an optimisation model that identifies the most promising domestic locations for green hydrogen production and optimal means of hydrogen transport for the year 2030.

The model is node-based, with each node representing a single political district. Within the political districts, time-resolved hydrogen demands from industry, mobility and the power sector are collected, RES potentials are mapped and local heat sinks for electrolysis waste heat are considered. The electricity transmission network is modelled with nodes and line capacities. In addition, the European Hydrogen Backbone [1] is added as a possible H2 transmission network, where the connection of a district to the network is a decision variable of the optimisation. Regarding the electrolysis integration concept, a distinction is made between decentralised integration (electrolysers located at renewable or demand sites) and centralised integration (large electrolyser located at neuralgic points between high-capacity electricity and H2 networks). In addition, the additionality of renewable generation is considered.

The optimisation is performed on an hourly basis using a mixed integer linear programming formulation, avoiding non-linear model characteristics. The results reveal the locations of centralised and decentralised electrolysers, operating schemes, and component sizes of the required hydrogen infrastructure, such as storage, pipelines, and trailers. These findings can serve as a basis for the development of the hydrogen infrastructure in Austria by relevant stakeholders.

[1] Guidehouse. (2022). European Hydrogen Backbone: A EUROPEAN HYDROGEN INFRASTRUCTURE VISION COVERING 28 COUNTRIES.

Keywords: hydrogen infrastructure, energy system modelling, MILP optimisation, centralised / decentralised electrolysis

Spanish civil engineer passionate for district heating technology

Viability of district heating networks in temperate climates: Benefits and barriers of cold and warm temperature networks

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The decarbonization of the heat supply and the attainment of a higher security of supply demand the transition towards zero-carbon heating solutions. In dense urban environments, where the construction cost of a pipe network is relatively low, heating and cooling networks can deliver heating and cooling at a lower cost compared to individual solutions.

This paper builds on prior research by these authors mapping heating and cooling energy use in Bilbao, Spain, a city characterised by mild oceanic climate and a dense urban pattern. Areas within the city where heating and cooling networks could be more feasible have been identified taking into account the building stock characteristics and energy use, together with other urban and resource parameters, and a city district has been selected for further study.

Warm networks deliver heat at a sufficiently high temperature to be directly used by the consumers whereas cold networks employ lower temperatures, thus requiring heat pumps at the consumers premises. Research has highlighted as advantages of this newer configuration the possibility of delivering both heating and cooling with the same network, the lower capital costs of these networks and negligible heat losses.

Nonetheless, comparisons between the two technologies have been seldom performed in the literature. In this paper, an economic comparison between these two solutions is presented for the selected district of Bilbao. Results show that cold networks require a lower investment in the actual network infrastructure but the distributed heat pumps increase the costs to a higher total CAPEX than in warm networks. Overall life cycle costs of heat are also slightly higher for cold networks than for warm networks. Other benefits and barriers for each of the solutions, for example regarding necessary space or speed and modularity of the implementation of the network are also discussed.

Keywords: Warm District Heating; Cold District Heaitng; Distribution Technology; Heat Density, LCOH

Researcher with specialization in energy and environmental technology and several years of experience in international and national projects in energy system analysis, in the field of RES in DH. Furthermore, she is an expert in economic an ecological evaluation of energy technologies and systems.

Transition of district heating and cooling systems to a higher share of renewable energy sources - Outcomes from six European countries

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The decarbonisation is one of the biggest challenges of our time. The ambitious European targets for reducing greenhouse gas emissions by 55 % until 2030 can be achieved by improving energy efficiency and by a consistent and sustainable replacement of the fossil energy sources used today, with renewable alternatives. The H2020 project RES-DHC stands for a wider introduction of renewable energy sources (RES) in the district heating and cooling (DHC) sector. The main objective is to transform existing DHC systems into a high share of renewable energy sources in district heating and cooling. In six participating regions (DE, AT, IT, PL, FR and CH) technical and organizational solutions for a sustainable and effective transformation were developed and initiated. The market-oriented implementation process was tracked by the formation of regional stakeholder advisory groups to trigger the development of strategy and action plans for the regions. In the collaborative decision-making process, the most relevant strategies and actions were selected and realised to generate sustainable

progress on decabonisation in the regions. The technical measures range from different feasibility studies on integration of waste heat sources, geothermal energy, storage technologies, large-scale solar thermal plants, and supply options from the district heating return flow to concrete case study demonstration and the development of energy planning tools to support the implementation of DH systems mapping. Besides the technical solutions, the project focused on the economic analysis and evaluation of a sustainable, renewable district heating system. Actions have also been launched to improve the legal and policy framework, to see whether tax reduction for renewable technologies appropriate or other subsidies are support the steps towards decarbonisation of DHC systems. Overall, all measures aim at stimulating market acceptance and raising awareness of renewable energy sources in DHC systems and trigger the transformation to climate-neutrality. The structured methodological approach of the project, as well as the different realisations in the 6 regions demonstrate several concrete cases to push decarbonisation ahead.

Keywords: Renewables, DHC, Decarbonisation, Roadmap, Transition

Energy engineer, Giulia is currently a Ph.D. student at Politecnico di Milano. Her research focuses on district heating potential assessment at local and national scales. She manages tools to holistically design and optimize renewables- and excess heat-based DH networks.

Has the global energy crisis enhanced the potential of district heating?

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One of the major benefits of a higher diffusion of decarbonized district heating (DH) systems, from a user and system perspective, is the stability given by the independence from fossil fuels markets fluctuations. Since the economical sustainability of DH compared to individual heating systems depends on the cost of the delivered heat, renewable-based DH could have an increased potential in a higher energy prices scenario such as the current one.

This paper presents the improvements and further upgrades of an open-source spatial optimization model, based on the oemof framework, conceived to assess the potential of district heating at country level and presented in this conference in 2021. In response to the current global energy crisis, the study has been updated and further developed in a wider energy system perspective by comparing DH to other decarbonized technological options. A sensitivity analysis has been conducted on the basis of changes in the fuel prices and with different constraints on the greenhouse gases (GHG) emissions in line with the European decarbonization goals.

As expected, in a higher fossil fuels' prices scenario, the potential of renewable-based DH increases significantly. The results of the assessment almost doubles the potential, from 38TWh/year estimated in pre-crisis period, to 65.6TWh/year. This latter value corresponds to 23% of the envisaged EBPD-compliant heat demand in 2030, which can be potentially met by district heating fed for the most part by renewables and excess heat sources.

Moreover, as the limits on the GHG become stricter, in all the price scenarios for electricity and gas a common trend highlights the progressive reduction of the use of

natural gas-fueled CHP plants and the significant uptake of renewables and waste heat. In other words, the solution with the minimum cost for a decarbonized system includes high shares of renewables and of waste heat sources that are seen as expensive in the current unlimited emissions scenarios. The results in scenarios of tight emission constraints have a considerable importance for systems with an expected life of several decades such as DH. They give an insight on how today's installed infrastructures will need to adapt in a highly decarbonized and very near future.

Keywords: District heating; District heating potential; Energy planning; Optimization algorithm; Sensitivity analysis; Energy crisis; Energy system; Excess heat recovery

Anna Volkova is TalTech professor and a head of research group ”Smart District Heating Systems and Integrated Assessment Analysis of Greenhouse Gases Emissions” in the Department of Energy Technology, developing the topic of district heating and cooling.

Waste Heat-Based District Heating Network for Industrial Buildings With Low Energy Intensity

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The transition to more sustainable technologies and approaches to meet industrial heating demand is crucial for achieving ambitious environmental goals. Industrial waste heat recovery solutions are one of the key technologies with considerable potential to contribute to energy decarbonization in heating systems. Theoretical and experimental studies revealed that a significant amount of waste heat could be recovered from electrolysis. A feasibility study was conducted to estimate the integration of waste heat from food industry and electrolyser into a district heating system, which would provide heat to industrial buildings with low energy intensity. According to the results of this study, waste heat recovery from industries and electrolysis have tremendous potential to contribute to sustainable industrial processes. Because isolated industrial parks with various energy intensities are common, the findings of this research may be useful for improving energy efficiency through the integration of waste heat-based small district heating networks.

Keywords: waste heat, electrolyser, district heating, industrial district heating

Jelena Ziemele has a background in energy systems and environmental engineering technologies. Her professional interests for the last 10 years are related to energy systems and their transformation into zero-emission, smart energy systems.

Potential of treated wastewater as an energy source for district heating: a multi-factorial comparative assessment for the cities of London and Riga

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Recovering waste heat (WH) from urban infrastructures is becoming increasingly important as governments around the world strive for decarbonisation and energy security. Even though all cities have a large potential for recovering heat from wastewater (WW), either raw or treated, it is still an underutilised resource in Europe. This study presents a comparative assessment for the cities of London and Riga, which is based on a multi-factorial decision support tool that can analyse the competitiveness of integrating treated WW heat into existing district heating (DH) systems. Two heat networks are chosen as case studies, in countries with significantly different stages of development of the DH industry. In London, a growing market with high development potential, and in Riga, where there is a well-developed DH system with more than half a century old tradition. This study aimed to develop a methodology that combines energy, environmental, economic, and social key performance indicators for assessing the potential to recover heat from treated WW, considering its use in a DH system transitioning from 3GDH towards 4GDH, with heat supply temperatures decreasing from 90 °C to 55°C. The proposed methodology can estimate the WH potential from wastewater treatment plants (WWTPs) using an analytical framework that combines governance aspects with a spatio-temporal model of supply and demand.

The study examines the use of two types of heat pumps (HPs) – compression and absorption – and investigates how the economic, social and environmental performances of DH systems can be improved by incorporating waste heat under three different scenarios. In scenario 1, the existing DH system is based on natural gas heat-only boilers (HOB); in scenario 2, the existing DH system is based on biomass HOBs; and in scenario 3, the DH system is a newly developed network using WH from a WWTP as the main heat source. Sensitivity analyses for the price of energy carriers (i.e. natural gas, biomass and electricity) are also performed to compare the results of each scenario under different market conditions.

Keywords: District heating, 4GDH, waste heat, excess heat, effluent heat recovery, de-carbonisation, techno-economic analysis, energy efficiency

SPECIAL SESSION: IEA DHC ANNEX TS7

Gabriela Jauschnik is part of the interdisciplinary team of the Energy Economics Department of the Energieinstitut an der JKU Linz. The thematic focus of her research activities in national and international projects is particularly on decarbonization of industry and district heating.

How can industrial waste heat be used in district heating networks? Insights on effective project initiation and business models

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The recovery of industrial waste heat and its reuse in district heating networks can be economical for both the industry and the district heating operator. While the potential for external use of industrial waste heat remains significant, there are a large number of implemented practical examples. The aim of this paper is to use the Austrian practical examples to analyze (i) how they were initiated and implemented, (ii) how the business models were designed, and (iii) how the risks and uncertainties associated with the cooperation were managed. Based on a survey, we find that good personal relationships are essential and that local politicians can be crucial for initiation. Major changes in the industrial supplier or district heating company are triggers for contact and implementation. Another clear finding is that partners need to feel they are being treated fairly for negotiations to be successful, which requires a high level of transparency. The most commonly used business model is the use of clear interfaces, i.e. a single point that separates investment, billing and responsibility. Billing is usually per kWh, possibly supplemented by other contractual arrangements such as take-or-pay. The lower the industry's share of the joint investment, the less it receives for the waste heat. Conversely, the more guarantees and risks the industry takes on (e.g. full-service provider), the higher the price per kWh.

Keywords: Industrial symbiosis, district heating, waste heat, business model, socio-economics

Thomas Kohne, M. Sc. M. Sc. (*1991) works as research associate at the PTW, TU Darmstadt, since 2018. He is coordinator of the living lab DELTA and has been head of research in climate neutral production. As PhD candidate his research include industrial heat integration and climate strategies.

Planning District Heating Connections of Multi-Modal Industrial Energy Systems: Optimization Approach from an Industrial Perspective

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Thomas Kohne (presenter)

Energy suppliers seek to reduce emissions in district heating networks by integrating low emission heat sources. Here, industrial waste heat has a huge energetic potential. From the perspective of an industrial company, the district heating connection of its energy system is embedded in a planning process, conducted by the energy management department. The department must negotiate with the energy supplier, responsible for heat prices, security of supply and specific emissions of the district heating networks. Whether a connection is economically advantageous for the industrial company depends on investment costs and potential revenues and savings. As industrial companies operate multi-modal energy systems on-site with cascading heating and cooling networks, a district heating connection must be planned comprehensively. Lack of transparency and procedures for holistic design operability planning are major obstacles for the industrial company and could cause these projects to fail already in early concept phases.

Mathematical programming offers a variety of general and problem-specific models and methods for design operability optimization of energy systems. Within the living lab DELTA, we develop an optimization methodology to optimize the district heating connection of industrial energy systems from an industrial perspective. Besides applying basic models and methods for energy system optimization we included the consideration of future developments of the industrial energy system and its uncertainty (transformation scenarios), as the planning process integrates longer time frames. Moreover, several pricing schemes in district heating are currently developed and tested. The pricing schemes result in different participation models for industrial companies in energy purchase and sale which must be considered within the optimization methodology. The presentation focuses on the descriptive model of as well as a semantic for the overall optimization methodology.

The authors gratefully acknowledge the financial support of the project Living Lab: DELTA (grant agreement No. 03EWR002A) funded by the Federal Ministry for Economic Affairs and Climate Action and managed by the Project Management Jülich. Find more information on the project here: www.delta-darmstadt.de.

Keywords: Industrial Energy Systems, District Heating, Cascaded Heating Networks, Waste Heat, Energy Efficiency, Heat Transfer Station

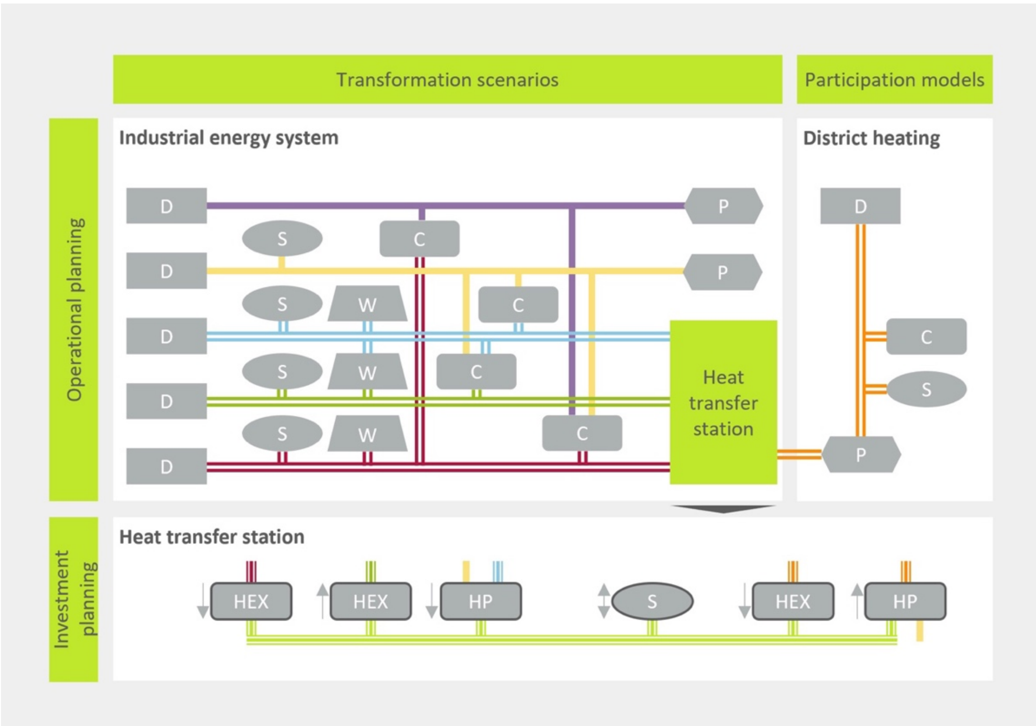

Figure caption: Descriptive model with semantic of the optimization methodology (D: Energy demand, S: Energy storage, W: Waste heat, C: Energy converter, P: Energy procurement, HEX: Heat exchanger, HP: Heat pump, colored lines for energy forms – violet: gas, yellow: electricity, blue: cooling water, light and dark green: warm water, orange and red: hot water)

Peter Sorknæs is part of the Sustainable Energy Planning Research Group at Aalborg University, where he works with energy markets and hourly cross-sectoral energy system modelling of energy systems of different geographical scales with a focus on the heating sector.

Reviewing Methods for Identifying Waste Heat Potentials for District Heating

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The utilization of waste heat in district heating (DH) has been important for achieving low-cost supply of heating. Historically, waste heat has to a large extent been supplied by combined heat and power plants (CHP) mostly utilizing fossil fuels. However, as energy systems are transitioning to more renewables, fossil plants are expected to be decommissioned, and the remaining CHP will experience a reduction in operation as the electricity demand will be largely covered by variable renewable electricity sources, such as PV and wind power. At the same time, a further reduction in the temperatures of DH grid is expected in future DH systems, allowing for a more efficient utilization of lower temperature waste heat sources, e.g., energy intensive industrial process and other unconventional excess heat sources from data centers, metro stations, buildings, wastewater treatment plants, food production and retail. Also, new energy technologies are expected to be implemented into future decarbonized energy systems, such as Power-to-X facilities, that can provide new sources of waste heat that can be utilized in DH. Due to this, many studies have been carried out to identify waste heat potentials both at the local level for individual DH systems but also for larger geographical areas covering, e.g., nations or international regions. In such studies, a range of different methods and data have been developed and utilized to identify waste heat potentials, such as analyses using statistical data in geographical information systems (GIS), utilization rates in energy system models, and bottom-up approaches investigating the individual waste heat sources in detail. The goal of this work is to identify the different methods that have been utilized in such studies, as to categorize the methods used and potentially identify how they differ in resulting potentials. The initial findings of this work will be presented in the SES conference. The work is part of IEA DHC Annex TS7 Industry-DHC Symbiosis.

Keywords: district heating, waste heat, excess heat, GIS, energy system analysis

Lukas Theisinger, M. Sc. (*1995) works as research associate and PhD candidate since 2021 at the PTW at Technical University of Darmstadt. His personal research fields include planning and operational optimization of industrial energy supply systems.

Living Lab DELTA: Development of an Interacting Energy-Optimized Industrial District

Lukas Theisinger and Thomas Kohne and Fabian Borst, Institute for Production Management, Technology and Machine Tools (PTW), Technical University of Darmstadt, Darmstadt, Germany, and Martin Beck, ETA-Solutions GmbH, Bensheim, Germany, and Jeannette Wiesner, Merck KGaA , Darmstadt, Germany, and Martin Freystein, ENTEGA AG, Darmstadt, Germany, and Matthias Weigold, Institute for Production Management, Technology and Machine Tools (PTW), Technical University of Darmstadt, Darmstadt, Germany

Lukas Theisinger (presenter)

The Darmstadt Energy Laboratory for Technologies in Application (DELTA) researches on the urban energy transition by realizing interacting energy-optimized districts. The living lab DELTA aims to demonstrate that the theoretical and technical potential for reducing emissions in urban districts can be implemented economically. To achieve this, technical pilot projects are planned by developing and applying methods and models to increase energy efficiency and flexibility in energy systems. Hereby, DELTA focuses on reducing emissions in all sectors of urban energy systems through increasing energy efficiency and flexibility, waste heat utilization, and sector coupling. In one of the seven subprojects, we research and work on the realization of an interacting energy-optimized industrial district of the company Merck KGaA in Darmstadt, Germany. Firstly, production processes and on-site energy supply systems are analyzed and adapted with the aim of increasing energy efficiency. As central element, low-temperature heating networks are designed to provide heating demand efficiently and enable a holistic use of waste heat directly from production process and energy converters as well as from the cooling water networks by using heat pump technology. For connecting the low temperature heating network with the other heating and cooling networks, energy hubs with energy converters and storages are designed. Since the waste heat cannot always be used on-site, a connection to the local district heating network of the company ENTEGA AG is evaluated.

The presentation focuses on the overall approach to transform the multi-modal industrial energy system considering several cascaded heating and cooling networks, gives a short summary into the current planning and implementation state as well as the ecological potential.

The authors gratefully acknowledge the financial support of the project Living Lab: DELTA (grant agreement No. 03EWR002A) which is funded by the Federal Ministry for Economic Affairs and Climate Action and managed by the Project Management Jülich. Find more information on the project and the interacting energy-optimized industrial district here: www.delta-darmstadt.de.

Keywords: Industrial Energy Systems, District Heating, Waste Heat, Low Temperature Heating Networks, Energy Efficiency

Figure caption: Interacting energy-optimized industrial district (EH: Energy hub, HTS: Heat transfer station, CHP: Combined heat and power, CA: Compressors for pressurized air, CT: Cooling tower, CC: Compression chiller, HEX: Heat exchanger, HP: Heat pump, colored lines: heating and cooling networks on different temperature levels)

SPECIAL SESSION: IEA DHC ANNEX TS4

Chris Hermans obtained his PhD in Computer Science (2011) at Hasselt University, specializing in the area of Visual Computing. Since joining VITO in 2016, he has performed research in the domain of algorithms, modelling and optimization. His interests include computer vision and machine learning.

Instance-based approach for fault detection in district heating substations

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There is an increased interest in recent years in fault detection in 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, more customer data has become available, which has made it possible to use advanced fault detection and diagnosis algorithms to detect anomalies in the customer installations. Faulty or sub-optimal substations lead to an increase in the district heating return temperature and in the volume flow in the network, resulting in a decrease of the efficiency of the DH network on the production, transmission and the consumption sides. We have developed an innovative fault detection method that automatically detects anomalies in district heating substations, based on the data read from a single instance's energy meters. Our method uses an ensemble of black-box models, each representing a different state of the substation, trained at a different point in time. By establishing confidence intervals for each model in this ensemble, and comparing the predictions of the models to the observed measurements at the substation, we can detect anomalies indicative of a fault. In addition, because we have an ensemble of models representing the substation at different times, we can distinguish between abrupt faults, or those caused by slow degradation. This approach has been tested on a limited set of data, but work will be further done to test on a small network in Belgium where data is being collected. 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

Mohammed Ali Jallal is a research scientist specializing in developing hybrid Artificial Intelligence techniques, Biologically Inspired Optimization Methods, and Machine Learning Algorithms. He applies his expertise in these cutting-edge technologies to solve complex real-world problems across multiple sectors.

Advancing Smart Heating and Cooling Networks: Deep Learning-Based Fault Detection for Substation Fouling in Heating and Cooling Networks

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Substation fouling (SF) is a prevalent issue in district heating and cooling substations, which can significantly impact their performance and energy efficiency. In this study, we propose an accurate deep learning-based fault detection algorithm specifically designed for SF in district heating and cooling substations. Our algorithm utilizes artificial neural networks (ANNs) to automatically learn and identify patterns associated with fouling in sensor data. To train and validate the algorithm, we generated a synthetic dataset of sensor measurements, including temperature, pressure, and flow rate, based on a simulation of a district heating and cooling system that accounts for various factors such as outdoor weather conditions and energy usage patterns. The developed algorithm consists of an artificial neural network with fully connected layers for classification, and hyperparameter tuning techniques were employed to optimize its performance. The algorithm's performance was evaluated using accuracy, precision, recall, and F1-score as performance metrics.

Experimental results demonstrate that our proposed deep learning algorithm achieved high accuracy in detecting fouling faults in heating and cooling substations, indicating its robustness and effectiveness. The algorithm can be seamlessly integrated into existing supervisory control and data acquisition systems in industrial facilities to enable real-time monitoring and detection of fouling faults, as well as for large dataset annotation. Our developed deep learning-based fault detection algorithm offers a reliable and efficient solution for SF detection in heating and cooling substations, with the potential to improve energy efficiency, reduce maintenance costs, and enhance system performance by enabling timely detection and mitigation of fouling faults. Further research can focus on validating the generalizability and scalability of the algorithm using larger real-world datasets from diverse operating conditions.

Keywords: District heating and cooling, Substation fouling fault detection, Deep learning, District heating system simulation, Time series

Tijs Van Oevelen is senior researcher in the Thermal Energy Systems team of VITO, the Flemish Institute for Technological Research (Belgium), since 2017. His current research work involves technologies for improving the sustainability of district heating systems.

Testing and evaluation a smart controller for peak reduction in an Italian thermal network

Tijs Van Oevelen (VITO), Thomas Neven (VITO), Faran Ahmed Qureshi (VITO), Dirk Vanhoudt (VITO)

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We have developed and tested a smart controller for reducing the peak heat load in district heating systems. This smart controller builds further upon the results of the Horizon 2020 STORM and TEMPO projects. In STORM, a building heat demand response system was developed to manage and optimize the heat supply power profile. The TEMPO project continued on this path, introducing two novelties. On the one hand, the use of additional energy flexibility through supply temperature control was enabled. On the other hand, the modeling of district heating assets was extended with increased physical detail, i.e. transitioning from thermal power-flow modelling to thermal-hydraulic modelling.

This system has been tested in an isolated branch of the district heating network of Brescia, Italy. A cloud-based platform is used to collect real-time data from various sources and to communicate control signals calculated by the smart control algorithms. Previously, tests have already taken place in the heating season 2021-2022. Development has since then further progressed, and a new series of tests was performed in 2022-2023. The test results will be presented and discussed.

Keywords: Decarbonization, smart control systems, energy flexibility, building demand response, supply temperature control, heat load peak reduction

Dietrich Schmidt is affiliated to the Fraunhofer IEE and works as head of research field Thermal Energy Technology.
He is responsible for various research projects within the field of energy utilization in buildings and communities, district heating systems and digitalization strategies.

Digitalization as the basis for efficient and flexible district heating systems

Dietrich Schmidt, Fraunhofer Institute for Energy Economics and Energy System Technology IEE; Markus Gölles, BEST - Bioenergy and Sustainable Technologies

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Information must be digitally available and automatically utilised in order to boost the effectiveness of district heating systems and make them more adaptable. Furthermore, greater integration of renewable energy sources increases system complexity, which must be managed. Many tasks will become manageable only with digital process management. Increased digitalization is clearly required as part of the transition to a sustainable energy and resource system. Different technologies must function together very flexibly in such a system, there are various obstacles to overcome (technical, legal,...), and there are very limited time and manpower resources available. Digitalization enables more automation and the adoption of standardized (more efficient) processes as well as more sophisticated methods. However, many systems still lack a high level of digitalization. With more complexity, flexibility, and so forth, more powerful tools and approaches (and hence increased digitalization) will simply 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 preliminary findings 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

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 DH systems with a focus on optimised control for large DH substations based on economic and environmental system evaluation.

Flexible Use of Thermal Storage in a Large District Heating Substation using Incremental Deep Learning Heat Load Forecasts

Ulrich Trabert, University of Kassel; Felix Pag, University of Kassel; Janybek Orozaliev, University of Kassel; Klaus Vajen, University of Kassel

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The decarbonization of urban district heating (DH) systems requires increased heating grid efficiency in combination with the development of new heat sources like renewable and waste heat. While industrial sites bare the potential to provide flexibility and deliver waste heat, their impact on the whole DH system due to size and complexity of existing secondary infrastructure is a challenge for the development of sustainable business cases for DH utilities.
Therefore, this work investigates how the operation of a thermal storage at a new innovative DH substation for an industrial site within a city can be beneficial to the whole DH system. The main innovative feature of the new substation is that the return line of the substation can be fed back into the supply line of the DH grid in case of a high return temperature of the industrial consumer. Consequently, consumers in the subsequent DH grid receive a lower supply temperature and the return temperature at the DH production plant is reduced. This reduces heat losses, facilitates the integration of renewable heat, and increases the efficiency of the current heat generation.
An efficient operation of the thermal storage at this substation requires accurate heat load and return temperature forecasts of the industrial consumer as well as the DH grid. Therefore, the keras library in python is used to build forecasting models based on long short-term memory (LSTM) neural networks. Since the systems are subject to continuous changes resulting in adapted load and return temperature characteristics, the models are continuously updated through incremental learning.
Based on the forecasts, a methodology for shifting the load through storage usage is developed. It includes the objective of smoothening the load profile for peak shaving on

the one hand, but also minimizing the return temperature of the DH grid by shifting the time for feedback of the return line into the supply line on the other.
The input parameters to the load shifting methodology in combination with different storage sizes are varied. Finally, the results are used to evaluate the impact of the industrial consumer on the DH grid and which storage size is required to improve the efficiency of the DH system.

Keywords: Large District Heating Substations, Thermal Storage, Forecasting, Demand Response

Qinjiang Yang is a PhD student in the Department of Civil and Mechanical Engineering at the Technical University of Denmark. His research interests are centered on low-temperature district heating and building energy systems.

Identifying Common Faults and Misuses in Large Multifamily Building Heating Systems Through Digitalization: A Survey

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Due to the impulse of the European Energy Efficiency Directive (EED 2012/2018), the growing digitalization of building heating systems, including space heating and domestic hot water preparation, has enabled the collection of valuable data for better understanding and optimization of these systems. In some building cases, it has been observed that faults and misuses in buildings limit energy performance. This study aims to identify and document common faults and misuses in space heating and domestic hot water systems by analyzing measurements from meters, submeters, and temperature sensors under existing levels of digitization. Our survey offers an overview of issues such as inadequate radiator controls leading to high return temperatures, suboptimal weather compensation control, and overflow in domestic hot water substations causing unnecessary peaks and elevated return temperatures. These observations were made using digital tools in building cases from Denmark and Belgium. This study can provide knowledge for building operators or other relevant individuals on how to identify and address faults using digital tools. By addressing and correcting these problems, building energy efficiency can be improved, a fairer billing system established, and the transition towards low-temperature district heating systems advanced, ultimately fostering a more energy-efficient and sustainable approach to heating in large multifamily buildings. This process is cost-effective and yields a high return on investment.

Keywords: Building heating system, Faults and misuse, Digitalization, Space heating, Domestic hot water

CCUS AND PTX TECHNOLOGIES AND THE PRODUCTION AND USE OF ELECTROFUELS IN FUTURE ENERGY SYSTEMS

Diederik Coppitters is a Post Doctoral Researcher at Université catholique de Louvain. His research includes uncertainty quantification, optimization, and the performance evaluation of various energy systems under techno-economic and environmental uncertainty.

Evaluating the Environmental Impacts of Importing Electrofuels Using Planetary Boundaries: A Multi-Objective Optimisation Approach

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Belgium is expected to surpass its local renewable energy potential in terms of energy demand. Consequently, Belgium will depend on importing renewable energy from electrofuels, such as hydrogen and its derivatives. Producing these electrofuels in distant locations rich in renewable resources and transporting them to Belgium consists of various steps that affect the environment. While most studies focus on the Life Cycle Assessment (LCA) of local hydrogen production, there is limited research on the LCA of international hydrogen supply chains. Additionally, producing other electrofuels is receiving less attention in environmental analyses, with studies seldom considering other impacts besides climate change. Finally, in the LCA of power-to-X systems, component sizes are vaguely defined, the performance of renewable energy systems is simplified to full load hours, and the grid is often viewed as a balancing system that ensures continuous processes like hydrogen liquefaction. However, as these systems will likely be designed as standalone, off-grid configurations, a grid connection is unlikely in remote locations.

In this research, we optimised the design of standalone power-to-X systems (hydrogen, methane, methanol, and ammonia) in several promising locations (Spain, Morocco,

Chile, Australia, and Oman). Our primary objective was the Levelized Cost of Energy (LCOE), as economic performance remains a critical driver for such projects. We also evaluated 18 midpoint indicators defined by the ReCiPe method to provide a holistic assessment of the environmental impact of importing electrofuels. For each indicator, we assigned a safe operating space based on the planetary boundaries principle, allowing us to quantify the absolute impact of the proposed designs on the environment for each indicator. We included those with a significant impact on the safe operating space as optimisation objectives, resulting in multi-objective design optimisation of the power-to-X systems.

Our results will indicate the primary advantages and disadvantages of each electrofuel regarding a wide range of environmental indicators. Moreover, we will propose designs that remain within the allocated safe operating space, and we will analyse the trade-off with the cost-optimal designs.

Keywords: electrofuels, life cycle assessment, planetary boundaries, multi-objective optimisation.

Aurélia Hernandez is a PhD student at the Université Catholique de Louvain in Belgium. Her research lies in the domain of power systems adequacy and is part of the project BEST (Belgian Energy System) which studies the role of electro-, bio-, and synthetic fuels in the future Belgian energy system.

Hydrogen in Power System Adequacy Studies

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Green hydrogen, i.e. hydrogen produced by low carbon energy sources is in the spotlight as it could play a role in future energy systems. Indeed, used as a feedstock, a fuel, or a storage medium, hydrogen could help decarbonize i) mobility and industry which are hard-to-decarbonate sectors as they cannot be fully electrified, and ii) the power sector. The technologies that this hydrogen integration implies are among others, electrolyzers and hydrogen-to-power units. The latter link the hydrogen sector to the electricity sector, and for this reason, it seems relevant to integrate hydrogen in electrical power system studies. Moreover, probabilistic adequacy studies which assess whether the power system is able to supply the consumers at all time, and all places is of high interest since more and more intermittent renewable sources are integrating power systems.
In this context, this works integrates the hydrogen energy vector in a sequential Monte Carlo adequacy tool based on a multi-period DC optimal power flow specifically tailored for long time horizons (e.g. one year). To do so, electrolyzers, hydrogen-to-power units, hydrogen storage units, and hydrogen pipelines are integrated into the developed adequacy tool.

This methodology is applied to a modified test system to grasp insights on the impact that hydrogen imports, demand, and storage can have on power system adequacy and operation. The test case is representative of future transmission grids, i.e. a high renewable penetration level at the outskirts of the system representing offshore wind farms, and two hydrogen hubs connected through a pipeline.

Different scenarios have been studied: the impact of i) increasing the hydrogen system size (i.e. installed capacity of electrolyzers, hydrogen-to-power units, and hydrogen storage units) and comparing the effects with an increased installed capacity of offshore

wind power, ii) integrating a flexible vs. a non-flexible hydrogen demand, and iii) allowing hydrogen imports from outside of the system.

Keywords: Adequacy, electrolyzers, hydrogen, multi-period DC optimal power flow, sequential Monte Carlo simulations.

Lazaara Ilieva is a PhD student in the Sustainable Energy Planning group at Aalborg University, with a background in Sustainable Design (M.Sc.) and Mathematics (B.A.). Her research interests include sustainable energy planning, system integration, more-than-human approaches, and biodiversity.

Toward holistic sustainability assessments of CCUS pathways

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Anthropogenic climate change is the preeminent challenge currently facing humanity. In response, an urgent political vision to decarbonise society has crystallised globally, calling for immediate action within and across governance levels, industrial sectors, socio-technical and socio-ecological systems. A central pillar in this vision is the transition to a fully decarbonised energy system as energy production accounts for over 75% of total global greenhouse gas emissions. In response to this vision, multiple strategies, technological pathways, and conceptual frameworks are currently developing, many of which centre around key measures related to renewable energy, energy efficiency, energy storage and conversion solutions, system integration as well as Carbon Capture, Utilisation and Storage (CCUS) technologies. This diversity means that it is crucial to develop frameworks that enable broad assessments of these pathways in order to ensure that the energy transition does not unfold at the expense of other equally pressing sustainability challenges and generate problematic externalities in diverse implementation contexts. Specifically, this paper focuses on CCUS pathways and their impacts across social, ecological and technical dimensions, by employing a holistic sustainability perspective rooted in the concepts of smart energy systems and socio-technical-ecological systems, in order to begin addressing the largely nuanced and complex discourse surrounding these technologies. Considerably few studies have contributed to a cohesive integration of the assessment of CCUS technologies to support their sustainable implementation and integration within smart energy systems and socio-ecological contexts. This is largely due to the inherent complexity and relative technological nascency of CCUS pathways, in tandem with the plural methodological assumptions, system boundaries, and indicators of holistic sustainability assessments. The aim of this paper is therefore to provide a comprehensive overview of CCUS pathways and their potential impacts across multiple

dimensions, as a starting point for the cohesive analytical integration of various sustainable CCUS considerations and the ultimate operationalisation of such analyses within planning perspectives and processes.

Keywords: Carbon Capture, Utilisation and Storage; sustainability, impacts, smart energy systems, socio-ecological-technical systems

Carina Jensen is Partnership Director of MissionGreenfuels.

Accelerating Green Transition: Scaling CCUS Technologies and Green Fuels towards Denmark's Climate Goals

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As the world strives for rapid decarbonization, Denmark's mission-driven partnerships INNO-CCUS and MissionGreenFuels are at the forefront, leading the change towards a sustainable future. This presentation discusses the current status of these two monumental InnoMissions, their challenges, and their strategies for making the green transition scalable, efficient, and economically viable.
Firstly, we delve into INNO-CCUS, a state-sponsored partnership fostering innovation and collaboration among around 60 entities in the CCUS field. We'll cover how INNO-CCUS supports the development of carbon capture, utilization, and storage technologies - tools paramount to Denmark's climate goals. The emphasis lies on the roadmap's key deliverables, showing how it can bridge the emission gap, transform carbon from a problem into a resource, and outline necessary research and development strategies, while addressing socio-economic and environmental externalities.
Next, we turn our attention to MissionGreenFuels, an initiative centered on fostering sustainable, non-fossil-based fuels for transport, aviation, and shipping. We examine its role in decarbonizing these sectors, highlighting the industrialization and upscaling of flagship projects, research and innovation activities, and the importance of an agile, dynamic partnership committed to deliver over the next five years and beyond. Additionally, we delve into the partnership's vision of avoiding historical pitfalls and creating a flexible, optimal use of resources, while maintaining socio-economic transparency.

Ultimately, this presentation illuminates how these InnoMissions embody Denmark's commitment to accelerating the green transition. It underscores the importance of cross-sectoral collaboration, knowledge-sharing, innovation, and scaling technology in achieving the climate goals while illustrating the path to a CO2-neutral Denmark by 2045.

Keywords: Carbon Capture, Utilization, and Storage (CCUS), green fuels, power2X, decarbonization, sustainable fuels, electrofuels, innovation

Andreas is a Phd researcher at the Department of Energy at Aalborg University. He is working with strategy and modelling for economic and environmental feasible implementation of advanced biofuel production into the existing and future energy system.

Economic and environmental feasibility of biofuel production facilities based on a Geographical Information System approach

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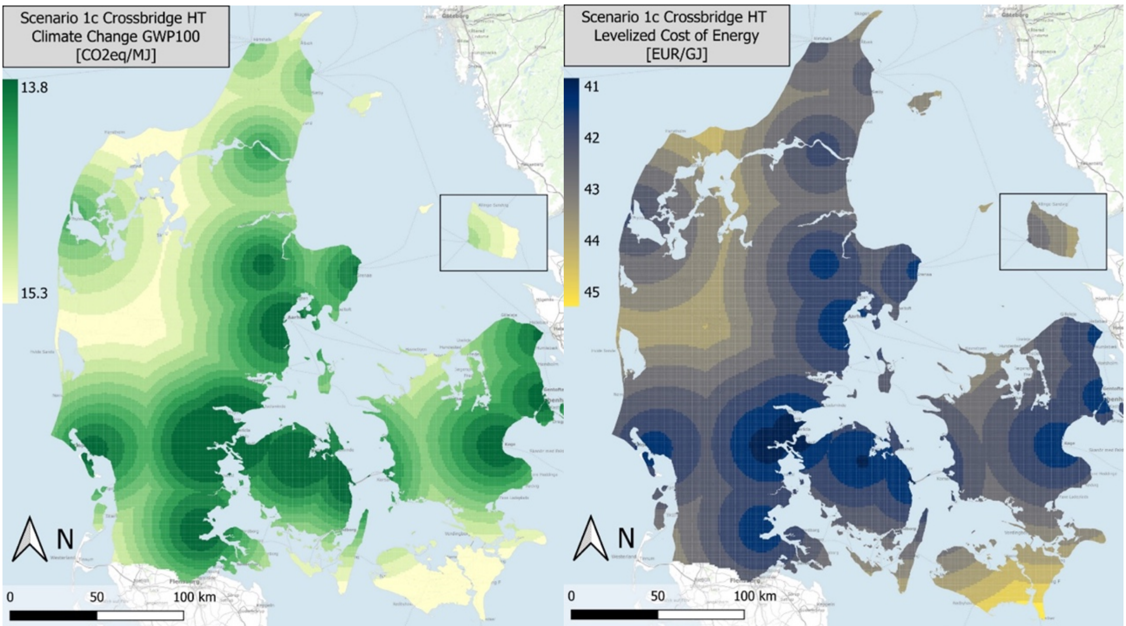
The decarbonization of the energy system calls for interconnection of renewable electricity, sustainable biomass resources, heat, and transportation in an integrated system. Sustainable biomass can serve both as a stabilizer for the energy system and provide a carbon source for sectors which is not feasible for direct electrification. It is, however, a limited resource and it is therefore crucial that it is utilized efficiently and that the entire energy system is considered when determining where it is best used. In the production of sustainable liquid biofuels via Hydrothermal Liquefaction (HTL), biomass is used to produce fuels for the maritime and aviation sectors which is not feasible for direct electrification.

HTL has shown promising results in pilot plants and has been identified as the most feedstock efficient technology among different biomass conversion pathways such as pyrolysis and Fischer Tropsch. Hydrogen is the primary resource in the biocrude upgrading in order to obtain a marketable product that meets the specifications of commercial marine and jet fuel. This provides an opportunity for HTL to utilize surplus electricity, via hydrogen from electrolysis, to produce sustainable biofuels and allow for indirect electrification of the heavy transport sector.

For optimal deployment of large-scale advanced liquid biofuel production, the energy system and infrastructure need to be considered. In this study both economic and environmental feasibility of large-scale HTL biofuel production are assessed by considering the entire value chain from feedstock to the finished fuel being delivered at the ports and airports. The assessment is based on mass and energy balances and includes supply

of chemicals, renewable electricity, hydrogen from future hydrogen grid, waste handling, and all transportation between the feedstock, processes and end-users. A Geographical Information System approach are then used to evaluate the economic and environmental performance differences between locations in a Danish case study. The results are presented on a nationwide 1x1 km grid and show up to a 10 % increase in both Levelized Cost of Energy and greenhouse gas emissions between the worst and best locations in Denmark.

Keywords: Hydrothermal Liquefaction, Geographical Information System, infrastructure, biofuel supply chains, techno economic assessment, Life Cycle analysis



Eliana Lozano is postdoc researcher associated in Aalborg University and currently works as guest researcher at TU Delft in The Netherlands in the field of renewable fuels and process integration. Her background is in Chemical engineering and holds a PhD in energy technology from AAU.

Integrated e-methanol and drop-in fuels HTL platform –Techno-economic assessment for flexible operation

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This study investigates the integration of biomass liquefaction to drop-in fuels and e-methanol synthesis using hydrothermal liquefaction (HTL) as technology basis. Process simulation is used to compare carbon capture technologies, maximize hydrogen use and explore possibilities for flexible operation modes.

Research on bio-e-fuels based on gasification/anaerobic digestion is extensive, however, the integration of biomass-to-liquid technologies with e-fuels remains largely unexplored. In these technologies, besides the bio-oil main product a pressurized CO2-rich gas phase is obtained that can be turned into e-fuels adding flexibility to the process. In this study, an integrated HTL + e-methanol system is evaluated from a techno-economic and environmental perspective building on prior research. Biocrude hydrotreating and fractionation is included addressing the full conversion from biomass to final drop-in fuels, and CO2 purification through physical absorption and oxyfuel combustion is discussed based on mass, energy, and exergy analysis. Results show that the physical absorption configuration has a higher exergy efficiency and a total electrical consumption of 5.7 kWh/kg of total fuels produced, with 2.6 kWh/kg attributed to the e-methanol add-on being significantly lower than state-of-the art literature. This higher efficiency is possible due to the higher energy entry point of the biomass, the high pressure available in the HTL baseline and excess H2 from biocrude hydrotreating. Preliminary economic assessment indicates that for the integrated HTL+ e-methanol platform the minimum fuel selling price of the drop-in fuels is in the range of 1-1.2 EUR/kg with a competitive methanol price of 350-400 EUR/t if the electricity price is below 40 EUR/MWh. Above this price, CO2 storage is evaluated as an alternative as methanol production becomes too expensive. Environmental assessment indicates a relatively low carbon footprint of the bio-e-methanol estimated in 12.7 kg CO2eq/GJ on top of 22 kg CO2eq/GJ of the HTL fuels. These results are expected to contribute to the state-of-the art literature of bio-e-fuels and HTL and to the discussion of the potential of advanced biofuels technologies in the context of future integrated energy systems.

Nikola Mößner, M.Sc., is working as a research associate in the Intelligent Distributed Energy Systems group since 2021. Ms Mössner studied Engineering Cybernetics, specialising in mathematical modelling and energy economics. She researches the complexity of modelling distributed energy systems.

Modelling the flexibility of process engineering PtX processes to achieve dynamic operation with volatile energy availability

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Independence from fossil fuels is currently being pursued both socially and scientifically. The produc-tion of easily transportable, synthetic energy from wind power and electrolysis at sea, known as Power-to-X (PtX), is seen as a promising future technology. However, the process technology used to date has been designed for stationary operation. Its ability to cope with fluctuating energy supplies is limited, so its use in a self-sufficient island operation requires a conceptual rethink. For dynamic operation, the flexibility of such PtX production plants must be adequately represented, which is the key issue.

The first step in this paper is to examine and define the concept of flexibility in the context of pro-cess engineering. In addition, it is shown which basic possibilities exist to make process engineering more flexible (process configuration; plant design; process control). Selected Demand Response approaches will be presented and compared. A special focus will be put on Demand Side Manage-ment (DSM). DSM is being investigated as a promising solution. It is mainly used in energy intensive process industry (metal processing; chemical industry), especially for heat generation. An implemen-tation for a PtX production system does not yet exist. In this paper, flexibility is understood as a deliberate change of an originally planned project (e.g. timetable) based on an external signal (e.g. forecast update). The investigation refers to a PtX production system (methane) in island operation.

The configuration of the PtX process chain is presented and the characteristics of the sub-processes (direct air capture, seawater desalination, electrolysis, PtX synthesis,

product storage) are briefly described. This provides the basis for implementing a modelling approach. Different flexibility opti-ons will first be carried out separately for each sub-process and then considered in an integrated way for the entire PtX process chain. Using historical time series of offshore wind energy supply, initial model calculations will be performed. Finally, the results are interpreted and discussed.
This work therefore fills a research gap and could contribute to independence from fossil energy sources through the location-independent production of green synthetic fuels.

Keywords: flexibility, modelling, dynamic operation, synthetic fuels

Federico Parolin is a PhD researcher at the Department of Energy of Politecnico di Milano (Italy), with the Group of Energy Conversion Systems (GECoS). His research activities are related to energy system modelling at multi-regional scale and to the optimisation of the hydrogen supply chain.

The role of electrofuels in carbon-neutral scenarios of multi-sector integrated energy systems: An analysis for Italy

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Carbon-neutral liquid fuels are expected to be central for the decarbonisation of hard-to-abate sectors. In this regard, biofuels obtained via biomass conversion and electro-fuels produced from H2 and CO2 represent the main options.
This work aims to assess the role of electrofuels in net-zero-emissions energy systems, adopting the OMNI-ES framework to investigate a 2050 scenario for Italy. The studied system features an electric demand of 450 TWhe/y, supported by nearly 500 GWe of intermittent renewable power capacity and a hydrogen final demand of 190 TWhLHV/y. The liquid fuel demand is 150 TWhLHV/y, for uses in road transport, aviation, shipping, and industry.

The model combines the domestic production of biofuels and electrofuels and the international import of carbon-neutral fuels. Biofuels have higher efficiency but are constrained by biomass availability. Electrofuels must be produced from CO2 obtained from biogenic sources or via DAC. The study details a sensitivity analysis on the minimum (imposed) share of domestic liquid fuel production, considering three scenarios where it is imposed to 10%, 40%, or 90% of the total demand.

The import allowance is saturated in all scenarios (at a cost of 1.4 €/l), and domestic production is limited to the imposed lower boundary. In the 10% scenario, electrofuels are marginal compared to biofuels (3 vs. 12 TWhLHV/y). The latter saturate the biomass potential in the 40% scenario, reaching the production limit of 28 TWhLHV/y, while electrofuel use increases to 33 TWhLHV/y. Electrofuel production is massively higher in the 90% scenario, reaching 110 TWhLHV/y. The system undergoes a dramatic surge of electricity consumption to support the additional H2 production and to provide neutral CO2

through DAC (+67 and +50 TWhe/y). Consequently, the PV and wind generation potential is almost saturated (nearly 600 GWe) and the reliance on H_2 import increases. Overall, biofuels are prioritized over electrofuels, which become relevant only when the biomass availability is saturated. Serving as example for many European countries, the Italian case study suggests that the availability of carbon-neutral fuel imports will be crucial to ensure the economic sustainability of the energy transition.

Keywords: Electrofuels, Net-zero CO_2 emissions, CO_2 utilisation, Energy system modelling, OMNI-ES

He is currently pursuing PhD in a 100% renewable energy project at the Department of Electric Energy at NTNU, Trondheim. One of the objectives of his PhD is to investigate the potential role of waste-to-energy technologies consisting of CHP, Biofuels etc. in future renewable energy infrastructure.

Current and Emerging Technologies for Waste-to-Energy Conversion: A Comparative Study with Multi-criteria Decision analysis approach

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In response to the rise in waste crisis and the possibility of energy utilization, there has been increasing interest in Waste to Energy (WtE) conversion technologies, hence it needs intense scientific attention. However, there are multifarious WtE technologies referred to different waste types and required multidisciplinary decision support. To help identify the most promising choice, this paper presents a Multi-criteria Decision Analysis (MCDA) tool to compare their economic, technological and environmental viability. The types of technologies compared in this study include 4 widely used technologies as Incineration, Anaerobic Digestion, Gasification and Pyrolysis and 2 innovative WtE conversion technologies as Hydrothermal Carbonization and Dendro Liquid Energy. In order to compare, we used various aspects of technologies consisting of energy efficiency, scalability, flexibility, and compatibility with other renewable energy sources. Geographically, we focused on the technologies used in European countries, and we collected data through a literature review. The results show MCDA strategies can be efficiently used by decision-makers to select a potential best WtE technology out of all the present and emerging diverse technologies to handle waste efficiently. Further, results represent the hierarchy structure arranged so that the main components are divided into sub-components with substitutes at the structure's base.
The Main contributions of this paper are:

- Limited research exists on emerging WtE technologies compared to established ones. This study aims to compare operational WtE technologies with emerging ones.

- Methodological contribution provides a structured and systematic way of assessing the viability of different options, supporting decision-makers to make informed choices based on multiple aspects.

Keywords: Waste to Energy Technologies, Multi-Criteria decision analysis, Emerging Technologies Technological Environmental and Economical comparison

Dirk Vries joined KWR Water Research as a researcher on water treatment in 2009. From 2020, he joined the Energy Transition and Circular Systems Team of KWR to strengthen its knowledge base at the interface of energy management, water technology and resource recovery, and modeling and control.

Control strategies for flexible hydrogen production by a 2.5MW electrolyser stack supplying a filling station

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In the transition towards a renewable energy system, there is an ever-increasing need for smart coupling of renewable energy production with energy storage and conversion of energy in order to meet energy demand at all times. Green hydrogen is an energy carrier that holds promise for integrated energy system approaches where energy supply is balanced with energy demand. We present the results of a research project referred to as 'H-Flex' based on a real-life case in Nieuwegein, The Netherlands. In this case, a complete hydrogen value chain from production to demand is realised. Hydrogen will be produced with a 2.5 MW electrolyser and transported to a 350/700 bar hydrogen refuelling station (HRS) at the site of a local contractor. The realisation of the HRS is driven by the development of and investment in dual-fuel and fuel cell electric vehicles. The research focuses on how flexible control of the hydrogen supply can be achieved. To this aim, a model-based controller of a 2.5 MW electrolyser stack is designed that meets two criteria: (1) the hydrogen fill level of the buffers, i.e. hydrogen trailers, should be sufficient to meet the hydrogen demand, and (2) revenues should be maximised by using best available forecasts of the day ahead market prices of electricity. The supply of hydrogen is calculated with a prediction time horizon that keeps shifting forward on an hourly basis, i.e. forecasts of electricity prices and hydrogen fuelling are fed into a hydrogen supply model to determine favourable revenues while making use of the hydrogen buffer capacity. Results of the model-based controller using a heuristic strategy to steer the hydrogen production will be presented during the conference, as well as an outlook of using an adaptive, optimal control strategy that maximises revenues. Lastly, we will give insights into the realisation of the electrolyser and its control mechanism.

Keywords: hydrogen, electrolyser, control, flexibility

Enrico is an Industrial PhD fellow researching on data-driven optimization of smart building's energy systems operations.

Analysis of the impact of energy savings interventions on key performance indicators of a university campus

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The energy crisis of 2022, triggered by the war in Ukraine, caused the prices of energy to surge across Europe. As a response, the Danish government urged public institutions to reduce their energy consumption by decreasing the indoor temperature in their buildings to 19°C. The measure was implemented in the buildings belonging to the Technical University of Denmark by the facility manager, applying two interventions. In the first one, the weather compensation curves of the district heating-connected space heating systems of the buildings were lowered. In the second one, the ventilation supply air temperature was lowered to 19°C, while the running schedule of the ventilation comfort units was reduced from 7 to 17, to 8 to 16. Furthermore, the night set-back previously implemented in the heating system control strategy was modified or cancelled, supplying constant lower temperatures to the heat emitters. The measures were implemented within a few weeks after the governmental directive was implemented, assuming that they would reduce the indoor temperature of the buildings as required, without affecting the thermal environment of the occupants too negatively. In the presented study, the impacts of these adjustments on the energy consumptions, operations of the systems and indoor thermal environment are analyzed. Some key performance indicators are chosen for the analysis, including peak demand, supply and return temperatures and heat consumption. The latter is normalized to the weather conditions – such as outdoor temperature – and the electric consumption inside the buildings, to allow meaningful comparisons with previous years. The analysis is used to determine whether the measures implemented improve the key performance indicators for space heating while ensuring an acceptable level of indoor thermal comfort.

Furthermore, the analysis shows relevant insights related to the energy behavior and thermal dynamics of the buildings analyzed. The implemented improvements are expected to show potentials in enhancing the energy efficiency and reducing the cost of low-temperature district heating supply to the university campus.

Keywords: Energy savings, heating systems, low-temperature heating systems, key performance indicators, buildings technical systems' operations

Christopher Graf studied Renewable Energy and Energy Efficiency at the University of Kassel, Germany. After his master degree he started his PhD on building heating systems with a focus on domestic hot water systems, which are caught in a conflict between energy efficiency, hygiene, and comfort.

Domestic Hot Water Preparation in Residential Buildings: Comparison of Current Challenges and Future Solutions

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Domestic hot water is an essential part of daily life and therefore essential for the comfort and well-being of residents. However, the production of hot water can be energy-intensive, and a high temperature is usually required for hygienic purposes. Therefore, domestic hot water systems, specifically the preparation temperature, is caught in a conflict between energy efficiency, hygiene, and comfort.

Advances in insulation of the building envelope have led to a decrease in the overall heat demand for buildings, while the energy demand for domestic hot water remained relatively constant or even increased due to greater comfort requirements as well as higher consumption per capita. The decrease of space heating demand and supply temperature needed for such low-temperature heating systems presents great opportunity for renewable heat generators like heat pumps or solar thermal collectors or low-temperature district heating. However, large domestic hot water systems usually work with high supply temperature of at least 60°C and high return temperature due to circulation loops, resulting in a limitation for the efficient operation of renewable heat sources and district heating networks.

Therefore, it is crucial to develop more efficient and sustainable domestic hot water systems, which can meet the growing demand with a high energy efficiency as well as a high renewable energy share, while providing sufficient energy flexibility and ensuring impeccable hygienic conditions.

In this paper, we will give an overview of current challenges of existing DHW systems regarding energy efficiency and hygienic conditions. Based on the literature review and considering the characteristics of energy efficient DHW systems as well as risk factors of legionella contamination transformation measures are derived.

Further we analyse chosen measures to solve current challenges for future DHW systems with a focus on the total building heat demand and effects on heat generation and consumption. We will provide a comparison of simulation results of some solutions to underline the potential of transformation measures and new system architectures. The simulation results will provide insights into the potential energy savings as well as thermo-hydraulic properties of different solutions.

Keywords: energy efficiency, temperature and heat demand, renewable energy, low-temperature district heating, legionella contamination, transformation measures

Valentin Kaisermayer is currently a researcher in the area of Automation and Control at BEST - Bioenergy and Sustainable Technologies GmbH and a PhD student at Graz University of Technology. His research focus lies on optimization-based energy management systems.

Intelligent Building Control with User Feedback in the Loop

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Valentin *Kaiser*mayer & Martin Horn, Graz University of Technology - Institute of Automation and Control
Gerald Schweiger, Graz University of Technology - Institute of Software Technology
Thomas Schwengler, DiLT Analytics GmbH
Michael Mörth & Richard Heimrath & Thomas Mach, Graz University of Technology - Institute of Thermal Engineering
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Buildings use 30% of the globally consumed final energy, and air-conditioned office buildings have an especially high energy footprint. Retrofitting them with predictive control strategies can leverage flexibilities, reduce their energy demand and increase thermal comfort by considering future weather conditions. However, challenges include the required infrastructure and satisfying the comfort requirements of the users.

We propose a predictive control strategy, where an optimization-based energy management system (EMS) controls the thermal zones of such office buildings. The approach uses a mathematical model of the building within an optimization problem to predict and shift thermal demand. We use a grey-box models, the simultaneous state and parameter estimation is handled by an unscented Kalman filter (UKF). This minimizes the needed effort for deployment of the system, as the parameters are learned automatically from historical measurement data. The objective function ensures the users' comfort based on a comfort model, penalizes unwanted behaviour such as frequent valve position changes, and minimizes the costs for heating and cooling supply. The internal comfort model is calibrated based on the feedback of the users. Each feedback is viewed as a measurement from the internal comfort model, and an UKF updates the parameters of the model.

As a case study, an office building at the “Innovation District Inffeld” is considered. The proposed predictive control strategy, together with the user feedback, is implemented. A central information and communication technology (ICT) handles all communication with the building automation system. We developed a simple web-based feedback system with a five-point Likert scale for user feedback integration. The presented ideas are evaluated based on both a preliminary simulation study and a real-world implementation. A key requirement was to limit the number of new sensors and actuators, thus focusing on how much can be achieved with a retrofit measure with minimal hardware, but intelligent software.

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Keywords: energy management system, smart control, intelligent buildings, user integration

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.

The impact of energy efficiency, heat pumps and district heating on the future power demand in Norway

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The Norwegian energy system is facing enormous challenges in the transition to a fossil-free society. The on-going electrification of transport and industry, together with the establishment of new power-intensive industries, calls for rapid increase in both production of renewable electricity and the transmission grid capacity. This increase could partly be avoided through energy efficiency measures, heat pump adoption, and the use of alternative energy carriers for heating.

The aim of this study was to quantify the potential for increased use of district heating and heat pumps on reducing buildings' electricity demand in Norway. The energy demand of the Norwegian building stock, divided into three different groups with regards to population density, was first modelled in different scenarios with respect to energy efficiency and potential access to district heating network. The outcome was then applied in an energy system model to account for different energy sources and the flexibility available in the production of district heating.

The study shows that increased use of district heating reduces buildings' electricity consumption, and in particular the peak power demand. Comparing to 2020 level, continuing with business as usual is estimated to lead to +7% increase in buildings' total electricity demand and +5% increase in peak power demand by 2050. Preliminary results from the study show that maximizing the use of district heating will allow the buildings' electricity demand to remain at the 2020 level, while buildings' peak power demand could be reduced with -5% by 2050.

A net reduction in both electricity and peak power demand in buildings is achieved only when maximal use of district heating is combined with ambitious energy efficiency standards and maximising the use of heat pumps in rural areas where district heating is not feasible. Such a scenario could allow a reduction of -26% in buildings' electricity demand and up to -35% reduction in peak power demand by 2050, based on the preliminary results. Reduced energy delivered to buildings together with increased use of district heating have thus a great potential to reduce Norwegian electricity demand and contribute to increased energy system flexibility when the grid is under the highest load.

Keywords: District heating, Energy system modelling, Building stock modelling, Energy efficiency

Peter Lierhammer is a research associate at the Institute of Energy Economics and Rational Energy Use, University of Stuttgart. He received a M.Sc. in Sustainable Electrical Power Supply in 2022. His research interests include efficiency in building systems and optimal control.

Proposal of a Modular Management System to Quantify Suitable Smart Heating Approaches in Existing Buildings

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Pascal Häbig, Institute of Energy Economics and Rational Energy Use, University of Stuttgart;
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In the face of global developments in recent years consumers are confronted with increased unreliability of energy resources, leading to price increases in energy markets. Inevitably, this leads to the need to increase energy efficiency for both Germany and the University of Stuttgart. With space heating accounting for 40% of final energy consumption on the campus, this study investigates measures with direct impact leading to increased efficiency, applied to existing buildings.
While refurbishment and insulating can pose as long-term activities, the availability of hardware and human resources as well as the needed planning process can hinder a short-term realization of this steps. In contrast, the real-world laboratory "Campus hoch i" focuses on adapting low-threshold measures with immediate impact on increasing efficiency of space heating. This includes, for example, the use of smart hardware. Focusing on intelligent control of heating systems the objective of efficiency measures is approached from both the technical perspective as well as the user's perspective. This study presents the technical infrastructure and preliminary work.
In this conference paper, possible reference architectures and approaches for controlling the smart system of an existing building are presented. The focus is on the development and comparison of different approaches applied to an optimal single room control of heating thermostats such as predictive control or occupancy detection. The lack of reliable data for such building types poses an additional challenge for the

application of state of the art systems such as model predictive control. Therefore, a requirements analysis is carried out to classify both the data availability as well as the suitability of control approaches and optimization algorithms. Furthermore, a modular energy management system and communication infrastructure is designed to enable the real-world implementation of appropriate approaches.
In future works, the provided analysis and designed system can be used to implement and experimentally investigate different control approaches. Thereby, the potential to increase energy efficiency will be investigated as well as the effect on the users of the rooms will be evaluated form social science point of view.

Keywords: energy efficiency, consumption minimization, energy management system, existing buildings, optimal control

Pernille Seljom (PhD) is a senior research scientist at IFE since 2008 and an associate professor at UiO. Seljom is an experienced energy system modeller, and her current focus is on the future role flexibility and energy behaviour in the energy transition.

The value and impact of building mass upgrade on the Norwegian energy system transition

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Upgrading the building mass to a higher energy standard, also called building retrofit, is an energy efficiency measure that can significantly contribute to lower the energy demand. Although buildings mass upgrade is to a large extent cost-efficient from an energy system perspective, policies are required to ensure an implementation. Knowledge of the techno-economic potential, the economic gains, and the impacts on the energy system is a starting point for decision makers to facilitate for a larger implementation of energy efficiency measures.

This study analyses the role of building mass upgrade on the Norwegian energy transition, based on updated data on the potential and costs upgrade of Norwegian buildings from 2021. The analysis is done with the long-term energy system model, IFE-TIMES-Norway, that provides cost-optimal investments and operation of the Norwegian energy system towards 2050. To provide robust insights, the analyses is executed for two different transition scenarios, one scenario assuming incremental societal and technical change and one scenario assuming radical societal and technical change.

The results indicates that the final energy demand of existing buildings can be reduced to a third if all measures are implemented. Further, the results shows that the future electricity peak demand and energy costs of the building sector can lowered significantly if techno-economic building mass upgrades measures are deployed. When comparing building mass upgrade with flexible consumption and local PV at an end-use level, building mass upgrade is the measure that has the greatest impact on the future energy system costs and the future energy costs of the building sector. It is however not necessarily that investments in end-use solutions are done, although it is cost-optimal solution from an energy behaviour perspective. It is therefore necessary to better understand the barriers and drivers of these solutions, to facilitate for a cost-efficient energy system transition.

Keywords: Energy efficiency, energy transition, energy use, energy system model, TIMES, energy system analysis, building retrofit

Lucas Verleyen is a PhD student in the Thermal Systems Simulation research group led by Professor Lieve Helsen at the Department of Mechanical Engineering at KU Leuven. His research focuses on technically feasible and affordable collective energy systems in the built environment.

Positive energy districts – Performance assessment of different collective energy systems in a tiny residential cluster of buildings

Lucas Verleyen, KU Leuven / Javier Arroyo, KU Leuven / Lieve Helsen, KU Leuven & EnergyVille

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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. Having PEDs in mind, this work investigates different district energy system layouts for thermal and electrical energy services in a tiny residential cluster of three houses. The aim of this work is to analyse and assess the performance of different collective energy systems to identify solutions towards PEDs and to examine the benefits of having an electrical community when thermal services are electrified. The main layout consists of individual heat pumps, individual photovoltaic installations, and an electrical community in which the three houses can exchange electricity between each other and with the wider grid. This main layout is compared to a base case scenario consisting of individual gas boilers and individual photovoltaic installations, in the absence of an energy community. Furthermore, this work looks into the coupling of the tiny (heating-dominated) residential cluster with a cooling-dominated non-residential building such as a data centre, or a collective energy storage to examine potential synergies. 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 a smart controller as system integrator, i.e. model predictive control, are considered to have workable solutions and perform dynamic simulations. Relevant key performance indicators are calculated from the simulation results to quantify the benefits of system integration. Preliminary results show that the grid connection remains very important unless large (and expensive) seasonal thermal energy storage is present, and that it is difficult to obtain any energy surplus because of the limited available space for RES. However, it is expected that larger clusters with different building types connected through thermal networks and hybrid system layouts can (partially) solve these issues.

Keywords: Positive energy districts, thermal and electrical district energy systems, key performance indicators, model predictive control, system integration, tiny cluster

COMPONENTS AND SYSTEMS FOR DISTRICT HEATING, ENERGY EFFICIENCY, ELECTRIFICATION AND ELECTROFUELS

Martin Buitink is researcher in Sustainable Energy Systems at Saxion University of Applied Sciences, the Netherlands. His focus is on renewable energy systems for houses and the modelling of energy systems.

Effects of smart control of PVT heat pump systems on PV self-consumption

Martin Buitink, Johan Reurslag, Simon Hageman, Richard van Leeuwen, Sustainable Energy Systems, Saxion University of Applied Sciences, the Netherlands

Martin Buitink *(presenter)* m.n.buitink@saxion.nl

An increasing amount of houses in the Netherlands are being equipped with heat pumps. Mostly these are air source heat pumps. However, heat pumps in combination with PV-thermal (PVT) panels are also attracting attention. PVT panels are constructed from standard PV panels with a layer on the back to extract thermal energy from the panel and the surrounding air. When the sun is shining, more energy can be extracted from the PVT panels with a higher temperature, making the heat pump more efficient.

In this contribution a control system is investigated that improves the electrical and thermal efficiency of the PVT-heat pump system. Also the effects that a smart control system may have on self-consumption of PV energy are investigated.

Research is performed with a simulation case. A thermal RC model of a house validated with BESTEST is used. Thermal energy is buffered in a 200 L hot water boiler and in the house interior structure. In the reference strategy, the interior temperature is allowed to drop 1 °C below the set point and to rise 0.5 °C above the setpoint by heating. The rule-based strategy has the same boundaries for the temperature setpoints, but the interior temperature is allowed to rise 2 °C above the set point. As part of the rule-based strategy, this is only allowed when there is enough solar energy available. In addition, the buffer for hot water may be charged earlier if there is enough solar energy available.

We show that for the reference strategy, only 1% of the electrical consumption of the heat pump is supplied directly from the solar panels during a year. In this calculation the heat pump uses the remaining generated solar energy left over by the electric devices. For the rule-based control strategy, this is increased to 16%. In addition, the solar panels produce a small extra amount of electrical energy due to the cooling effect. The control strategy also slightly increases the COP of the heat pump. Although validation of the model and control results with practical data are needed, the outcomes show that smart control strategies for domestic heat pump systems with PVT panels as a heat source, can make a substantial difference in the self-consumption of generated electricity and may reduce stress on the grid during peak electricity hours.

Keywords: PVT panels, Rule-based control strategy, Smart control, System simulation

Stefan Hay is working in the R&D department of AGFW since 2014. Current R&D topics: Transformation & decarbonization of DH systems, aging & remaining service life of DH pipes, maintenance strategies in DH networks. He is the task manager of the ongoing IEA DHC TS 6 Project.

Sustainable Asset Management District Heating - a Future Perspective

Stefan Hay, AGFW | Der Energieeffizienzverband für Wärme, Kälte und KWK e.V.
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Market available asset management tools for district heating (DH) networks use inventory data, statistical ageing models and material-based service life models to generate maintenance strategies for heating networks. In utility companies, these strategies are evaluated under ecological, technical, and economic aspects. Up to now, maintenance measures were mostly used to maintain the security of supply and to reduce possible risks for the economic success of the company.
The implementation of the European climate targets is related to the transformation and expansion of existing DH systems. For this purpose, utilities have to develop suitable decarbonisation paths, transfer them into a transformation strategy and create acceptance for corresponding measures in the service area. In addition, technological developments and legal framework conditions will increase the number of remotely readable data points in DH networks. This will increase the demands on the asset management of DH networks, especially with regard to the forecasting accuracy of the remaining service life of the DH pipes, the processing of operating data and the expansion of existing evaluation criteria for the implementation of climate targets.
The main objective of the national research project "Sustainable Asset Management District Heating" will be the development of necessary enhancements of asset management tools for DH networks. For this purpose, among others, investigations of DH pipes aged

due to operation, installations of measurement technology to record operating parameters in DH networks of participating utility companies, software developments for predictive maintenance and the development of sustainability criteria are planned as part of the research project. At the same time, the results will be transferred into a marketable asset management software and validated through application at the utilities. Relevant results of previous research linked to the goals of the research project will be presented in the conference paper.

Keywords: District Heating pipes; asset management;decarbonisation; digitalisation

He is researcher at the Korea Institute of Civil Engineering and Building Technology and currently pursuing a doctoral course in geotechnical engineering at Hanyang University, Republic of Korea. His work focuses on maintenance of district heating network and water supply system.

Risk of pipe fault analysis process for safety diagnosis of district heating network pipe

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The district heating network pipes are generally selected for improvement based on the time used, like similar underground pipe such as water supply pipe in republic of Korea. However, it is necessary to predict the possibility of pipe fault considering various factors because the life time of the pipe affected by operating conditions and burial environment. DHN is operated and managed by 39 business operators in Korea. Depending on the operator's management capabilities, there is a large gap in the budget available for database construction and network improvement. It is recommended to perform a safety diagnosis on DHN pipe that have been used for more than 20 years and replace fault pipe in Korea. However, it is not possible to check the risk of pipe fault only with the time used. So, a standard is needed to determine the scope of safety diagnosis by quantitatively evaluating the risk of pipe fault. We propose statistical analysis model to estimate the pipe fault frequency based on the pipe construction and operation data and high-risk groups were selected. Prior to the estimating the pipe fault frequency, the pipe was divided according to main property information and type or location of connection. The fault frequency of each pipe was estimated by analyzing the GIS data, time used, pipe diameter, burial depth, and monitoring system data of the 11 years fault data (2,806 cases), construction and operation data (627,697 pipes) provided by Korea District Heating Corporation, a largest business operator in Korea. For business operators to easily understand, a regression analysis model based on the time used was first presented. After analyzing the independence of other evaluation factors such as pipe diameter and burial depth, the evaluation factors to be applied to the model were selected and integrated, and then the weighting factor was applied to a regression analysis model based on the time used. Business operator can conduct a safety diagnosis starting with the pipe with the highest rank considering the available budget if pipe is ranked according to the fault frequency.

Keywords: district heating network pipe, pipe fault frequency, safe diagnosis, time used, evaluation factor

Mao Ding, a Ph.D. student at Harbin Institute of Technology, focuses on vulnerability analysis and reliability optimization of district heating systems. Her research team specializes in high-performance buildings, district heating technologies, and urban energy planning.

Study on the identification of critical pipe segments and reliability design methods for district heating networks based on vulnerability

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District heating networks (DHNs) offer immense potential for efficiently, economically, and flexibly incorporating large-scale low-carbon energy sources into the heating energy mix. Designing a reliable DHN is of paramount importance for the establishment of smart and resilient energy systems. In this paper, we first analyze the structure, function, operation, and failure characteristics of DHNs. After that, we establish a vulnerability analyzing model for DHNs facing different failure scenarios and develop a multi-dimensional vulnerability evaluation system. Building on this foundation, we propose vulnerability-based critical pipe segments identification methods and pipeline design methods aimed at improving heating reliability. Moreover, we analyze the impact of heat source allocation, failure scenarios, and system controllability on the reliability design results of DHNs, and provide heating pipeline reliability design rules under different budget constraints. Lastly, we apply the research framework proposed in this paper to a DHN in a Chinese city. According to the simulation results, the vulnerability characteristics are effectively identified, and the results indicate the applicability of the proposed methods. Compared with conventional design methods that only consider functional satisfaction, our approach identifies critical pipe segments requiring reliability protection at different degrees, thereby providing better guidance for DHNs reliability design in practical engineering projects.

Keywords: district heating networks, reliability, vulnerability, design methods, failure scenarios

Jonas Ottosson is an Energy Engineer turned IT Product Owner with a passion for optimizing energy solutions.
He has a research background from IVL Swedish Environmental Research Institute and has vast experience in the opportunities and barriers for flexibility in heating and cooling networks.

Accelerate your growth of DHC with Demand Side Flexibility

Johan Kensby, Utilifeed

Jonas Ottosson *(presenter), jonas@utilifeed.com*

In most DHC systems, there is a large potential for demand side flexibility. The flexibility has many use cases such as: increase security of supply, reduce operational cost, reduce CO2 and other emissions, enable co-optimization with the electricity grid, substitute alternative investments in production and distribution capacity.
The impact and value of these use cases has been mapped for more than ten different DHC systems and they vary greatly between DHC systems with different prerequisites. Demand side flexibility has a potential to transform the DCH industry, not only it´s system design and operation, but also it´s business model.

Different types of demand flexibility have been tested in six DHC systems including:
- Utilizing thermal inertia of buildings as storage
- Emergency demand reduction
- Heat source shifting with DH and heat pump.
- Business models that share the created values between DHC companies and its customers have also been tested.

The presentation will present and draw conclusions from these studies and practical implementations as well as discussing how flexibility can be one component of managing the energy crisis and the energy system transition we are now facing.

Keywords: Demand Side Flexibility, Demand Side Management, Sector coupling, DHC, Electricity Grid, Heat source shifting, Flexibility, Demand Control

Constantin Völzel is a trained mechanical engineer with specilisations in thermodynamics and fluid machinery. Since his arrival at TH Mittelhessen he has been working on regenerative energy concepts for heat supply systems as well as on innovative heating networks.

Open source model of a shallow geothermal heat collector as a component for 5GDHC simulation frameworks

Constantin Völzel, Prof. Dr.-Ing. Stefan Lechner, TH Mittelhessen University of Applied Sciences

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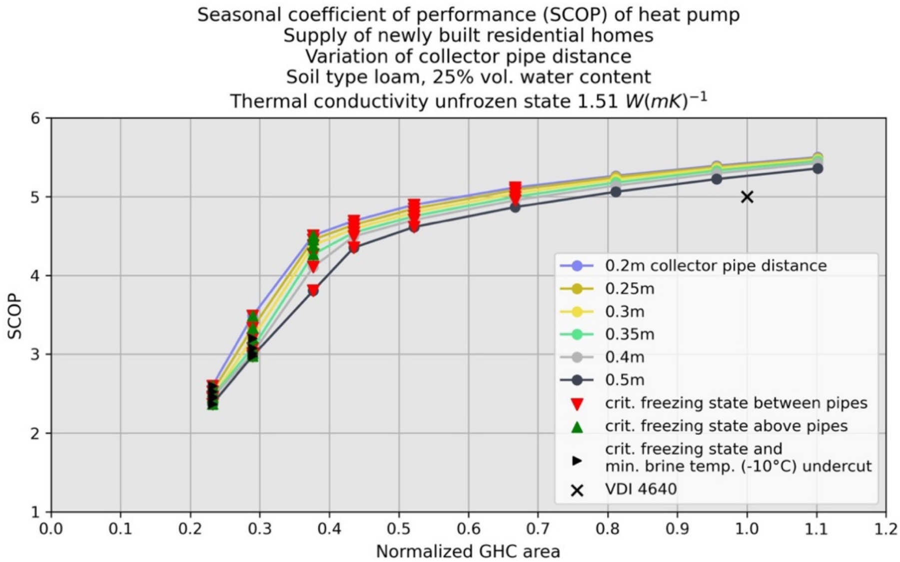
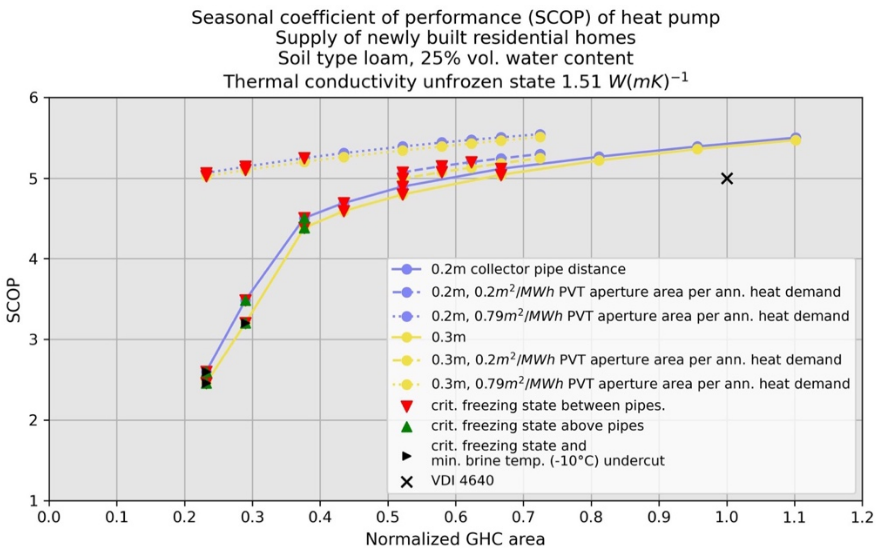
Savings of CO2-emissions and primary energy in the building sector are essential to the aims of the European Union as well as to national legislation when it comes to fulfilling the Paris Climate Accords.
5th generation district heating and cooling (5GDHC) networks are considered a key technology for attaining energy-efficient and carbon-free heat supply not only in new buildings but also in existing building stock.
In the present work an open-source model for shallow geothermal heat collectors (GHC) developed in Modelica is introduced.
Relevant parameters for the representation of locally varying weather conditions and soil properties can be adjusted easily.
Temporal evolutions of temperature and ice phase within the soil domain surrounding the collector pipes define the dimensioning limits for GHC.
This is due to restrictions of source-side temperatures of connected heat pumps and ecological aspects such as the infiltration of rain water in the soil.
The model is embedded in a broader library for heat sources, heat distribution and prosumers in 5GDHC networks.
This way, it allows for a more exact and individual dimensioning than standard procedures like VDI guidelines can provide by taking various other heat sources within the network into account.
Simulations for GHC as a single heat source show possible reductions of GHC area by approximately 30% compared to VDI guidelines before critical freezing states within the soil domain occur or the minimum source-side temperature of the heat pumps is undercut.

Freezing states between the collector pipes appear at bigger collector areas than those above the pipes where ice radii around the pipes can merge with surface frost. Feedbacks of excess heat yields by roof-mounted hybrid photovoltaic-thermal collectors into the GHC show potentials to further reduce the minimum necessary GHC area to as far as 38-63% of the value for GHC as a single heat source according to VDI guidelines.

Keywords: 5GDHC, cold district heating, shallow geothermal heat, Modelica





Gerald Zotter is an acknowledged expert in heat pumpt technologies and their innovative fields of application, in particular in the use of district heating networks and industrial applications. He has many years of experience in national and international research projects and industry.

Using of a special heat pump to lift the district heating supply temperature for an industrial facility

Gerald Zotter, AEE - Institute for Sustainable Technologies
Bernhard Adler, ECOP
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Globally, 75 % of industrial energy demand is for process heat, with 52 % of this energy being required at a temperature level up to 250 °C. However, at this temperature level, industrial facilities could not be supplied by most district heating (DH) networks, as the temperature levels are too low (around 95 °C supply temperature). From an economic point of view, industrial facilities are, very interesting consumer of DH, due to the fact they use a large amount of heat over the entire year (and constantly over the day). Therefore, industrial plants need a high constant heat capacity with high operating hours.
In this paper, an application for supplying an industrial facility via a district heating network with flow temperatures of 95 °C and the use of a special high-temperature heat pump to raise the district heating temperature to the required process heat of approx. 150 °C is discussed. The heat pump works with the reverse Joule/Brayton cycle using a non-flammable, non-toxic GWP-free working mixture. This paper shows the results from simulations that determine the electricity consumption for lifting heat from the DH grid (source) to the process heat (sink) of 150 °C using different refrigerants and electrically driven heat pump cycles. The focus of the simulation study lays on the required high target temperatures and the temperature lift, and on the available and required temperature spreads at the heat source and sink and their influence on the coefficient of performance. Furthermore, the saving of CO2 emissions and the economic benefits of supplying the industrial process heat with DH and heat pumps instead of natural gas up to 150°C are also discussed. Depending on the boundary conditions, such as inlet and outlet temperature of the industrial process heat and of the DH grid together with the

electricity mix required to run the heat pump, up to 90% CO2 emissions can be avoided compared to natural gas. Moreover, this work shows a control strategy for the heat pump that can handle a highly dynamic behaviour of the process heat at high COPs. The application demonstrated in this paper is a core way to extend the DH grid with new economic end consumers such as industrial plants and to make a big step towards reducing gas consumption in the industrial sector.

Keywords: GWP-free, CO2-reduction, temperature spread

4TH GENERATION DISTRICT HEATING CONCEPTS, FUTURE DISTRICT HEATING PRODUCTION AND SYSTEMS

After her master study in Sustainable Systems Engineering at University of Freiburg and thesis within the projects of Fraunhofer ISE, Şirin is now a fellow PhD student at Fraunhofer ISI, working on building stock modeling and investigating the role of heat pumps in decentral building heating.

Hybrid heat pump systems as bridging technology in the natural gas independence of Germany's residential buildings

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Over 40% of the natural gas consumed in Germany is used to heat the buildings and supply them with hot water (BMWK March 2022). Residential buildings of Germany are directly responsible for 16% of the total natural gas used in Germany, as around 250 TWh (38%) of the sectors' final energy demand is served by decentrally burned natural gas (BMWK 1/20/2022). Around 53% of all residential buildings in Germany has natural gas as the main heating energy carrier (Cischinsky and Diefenbach 2018). With this work, the aim is to reveal if hybrid-heat pump systems in residential buildings can be a bridging technology in the accelerated independence from natural gas in Germany.

15% of the residential building stock in Germany has a natural gas heating system that's between 8-14 years, either installed during modernization in an existing building, or installed as first installation in a new building. While, buildings that are built before 2010 and having a natural gas heating system that has not been modernized since 2010 make up ~38% of the building stock (Cischinsky and Diefenbach 2018). Taking into account the revision of the GEG in Germany, which stipulates that, as of 01.01.2024, minimum 65% of the annual heat delivered to a building from a newly installed heating system must come from renewable energy sources (BMWK March 2022), this study will investigate hybrid heat pump system investments in these buildings.

An own model-complex developed in Python programming language is used in the study. It calculates the heating demand and peak load of the investigated building. After assignment of heat system capacity, yearly simulations determine the heat pump/heat system efficiency, as well as the power/gas consumption of the system. Via a levelized cost of heat (LCOH) analysis, it shows how the hybrid heat pump systems can be a worthy investment. Monovalent systems having only heat pump or natural gas will also be analyzed, in order to compare and evaluate the cost-competitiveness of the systems. The contribution of hybrid heat pump systems to reduction of natural gas consumption, and consequently GHG emissions, will also be put into perspective in order to give the full picture.

Keywords: hybrid heat pumps, German residential buildings, levelized cost of heat, natural gas-independence

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 design engineer at Ramboll.

Operational Designs for District Heating and Cooling Networks with Decentralized Energy Substations: Development and Validation

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Daniel Zinsmeister, Technical University of Munich
Anastasia Ioannou, University of Glasgow
Daniel Friedrich, University of Edinburgh
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Decarbonising the thermal grid while addressing the energy trilemma of low cost, low environmental impact, and security of supply requires a holistic approach that integrates sector coupling and energy storage. District heating and cooling networks with decentralised energy substations, incorporating heat pumps and thermal energy storage can enable sector coupling and promote circular economy models. In this system, each connection point becomes a prosumer, consuming heat while producing coolth, or vice versa, interconnected by an ambient temperature bidirectional network.

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. Therefore, a comprehensive thermofluid simulation that accounts for both energy and hydraulic behaviour is necessary.

In this work, we present a set of Modelica models that capture the thermofluid behaviour of district heating and cooling systems with an ambient network and decentralised energy substations. These models have been experimentally validated in the CoSES lab of Technical University of Munich and are utilised to quantify the energy trading potential for different scenarios, analysing factors that affect energy trading potential.

The developed models provide a detailed simulation solution for holistic systems that incorporate heating, cooling, energy storage, consumer profiles, and environmental characteristics, offering a comprehensive and validated approach to studying complex district heating and cooling systems. All resources, including the models and associated data, are made open access to facilitate understanding of these systems and provide practical guidelines on energy trading potential.

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: 4th Generation District Heating and Cooling, 5th Generation District Heating and Cooling, Energy Trading, Sector Coupling, Smart Energy Systems, Modelica Simulation, Heat Decarbonisation

Isabelle Best is a postdoctoral researcher at the University of Kassel and a project manager at Qoncept Energy GmbH, where she focuses on heat master planning for cities. In her research, she was particularly involved in modelling and optimised design of low temperature distric heating systems.

System temperature reduction for new DH systems in low-energy residential areas: cost-effectiveness and eco-efficiency as a function of plot ratio

Isabelle Best; University of Kassel

Isabelle Best (presenter)

Renewable low-temperature district heating systems can make an important contribution to decarbonizing the heat supply of densely built-up residential areas. This is generally known so far. The analysis addresses the question of how the environmental and economic efficiency of new district heating systems for new residential areas is influenced by lowering the system temperature, considering the entire heat supply system: heat demand, heat distribution, and heat supply units. Three exemplary central heat supply systems based on central heat pump units are defined. The system temperature, the mean DH supply temperature, was varied from 75 °C to 40 °C for over 300 developments of different energy efficiency standards and plot ratios. The following research questions are of major interest:

- How does the heat supply system perform economically and environmentally depending on the system temperature?
- Is it possible to recommend a mean DH supply temperature that is adapted to the framework conditions of rural, suburban, and urban districts?

To evaluate the added value of system temperature reduction, the LCOH per heated gross living space, cost reduction gradients, and resulting greenhouse gas emissions are discussed. System temperatures have been found to have a significant impact on cost-effectiveness and environmental efficiency, even for new low-energy buildings and developments. Reducing system temperatures can save up to 20% on costs. In terms of environmental efficiency, system temperatures of 55 °C instead of 75 °C result in significantly lower greenhouse gas emissions (GHG) in the range of 30%. However, a further temperature reduction in urban residential areas does not result in a further significant reduction of GHG. The results confirm the importance of low system temperatures below 70 °C for temperature-sensitive heat supply technologies such as solar thermal and heat pumps.

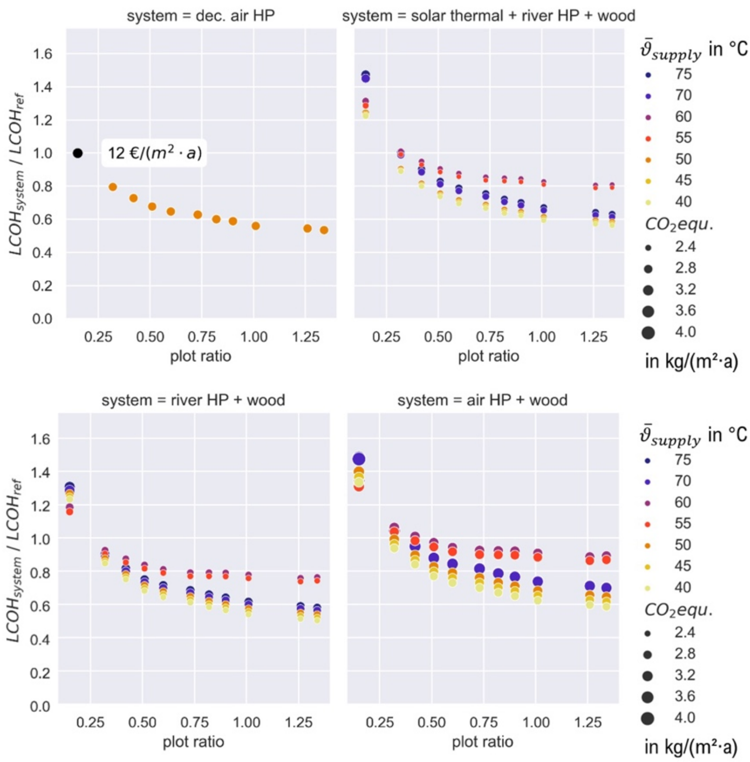

Figure 1: The LCOH per square metre of gross living space for the three exemplary central renewable DH systems along the plot ratio range from 0.1 to 1.3; the reference system is on the left, GHG emissions are given as CO2 equ. in kg/(m2 · a), the mean DH supply temperature is given in °C, and the LCOH is normalised to the black marked reference point

Keywords: Low-temperature district heating; cost reduction gradients; new district heating systems; low-energy buildings; fourth generation district heating; plot ratio;

Marek Brand works from 2013 as a senior application specialist in Danfoss Climate Solutions. His focus area is failure finding, optimization and performance documentation of thebuilding installations in residential and commercial buildings, mainly supplied by districtheating.

Economic comparison of 4GDH&C and 5GDH&C in Rome

Oddgeir Gudmundsson, Danfoss A/S. Irene Aiello, Danfoss A/S. Jan Eric Thorsen, Danfoss A/S.

Marek Brand (presenter)

As natural gas as an energy vector will be phased it is inevitable that heating demands will be electrified. In sparsely built areas, particularly rural areas, building level heat pumps will be the future heating and, if needed, cooling supply units. In urban areas a mix of different heat pump-based solutions can be applied, individual heat pumps, building level heat pumps, central heat pumps, or a mix of these. The physical location of the heat pump will not only impact the individual operation, e.g. cost and heat generation efficiency, but also the energy system, e.g. grid infrastructure and power generation capacity requirements. While a one-to-one change of an existing boiler to a heat pump is appealing there is a lot of benefits to couple the heat pump to a district energy system, especially in respect to having access to a suitable heat source temperature level for individual heat pumps as well as to avoid local noise levels. Another alternative is to avoid local heat pump operations to the extent possible and operate a central heat pump supplying immediately useful temperature levels to building heating systems. Research in heating dominated countries show that district heating systems using centralized heat pumps (4G) as more economical than systems with building located heat pumps (5G). The question however remains on which solution, central or building heat pumps, are more economical in locations where there are both heating and cooling demands. In this presentation the economics of a 4G system, with a local cooling option, will be compared to a 5G system using building heat pumps for fulfilling both heating and cooling demands of an area with a mix of new and existing single- and multi-family buildings in Rome, southern Italy.

Keywords: District Energy, 4GDH, 4GDH&C, 5GDHC, heating, cooling, economics

Alixe Degelin is a Phd Fellow under supervision of Prof. Michel De Paepe in the STFES research group of Ghent University. She is active in the field of district heating networks and thermal storage.

Influence of supply temperature and booster technology on the energetic performance of a district heating network

Alixe Degelin, Ghent University, Robin Tassenoy, Ghent University, Elias Vieren, Ghent University, Toon Demeester, Ghent University, Michel De Paepe, Ghent University

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In 2019, 70% of the households in Flanders still used natural gas as a fuel for space heating. To accelerate the decarbonisation of the building stock in urban areas, district heating networks supplied by a central heat pump in combination with geothermal energy, were suggested. While central heat pumps are more energy efficient at low condensing temperatures, existing buildings often require high supply temperatures for space heating and domestic hot water. In addition, heat losses decrease when lowering the supply temperature in the distribution network, while pumping losses can simultaneously increase due to increased mass flow rates.

This article investigates the influence of low and ultra-low supply temperatures on the primary energy demand and energy efficiency of a district heating network supplied by a central heat pump, taking into account the need for booster heat pumps or booster electric heaters. The simulations consider network temperatures ranging from 10°C to 75°C and distinguish between refurbished and non-refurbished buildings. The dynamic simulation of the network is performed using the IDEAS and Buildings libraries in Dymola (Modelica).

The results indicate that the most energy-efficient scenario is to keep the network at ground temperature and locally boost the water to the desired temperature. Booster heat pumps show a lower energy consumption compared to booster electric heaters, but have a higher investment cost. Refurbished buildings profit from the district heating network at ground temperature, reducing the primary energy consumption without the need for individual geothermal boreholes. For non-refurbished buildings, a higher

network temperature might be chosen over an ultra-low network temperature to avoid high investment costs for the end-user for refurbishment and booster heat pumps.

Keywords: District heating, space heating, domestic hot water, energy efficiency, energy system analysis, Modelica, booster heat pump

Jakub Garbacik is a PhD student, numerical simulation engineer and one of originator of heat pump powered heating plant – Euros HC Plant. His thesis is focused on optimization of control system for multi-source heat pump systems and managing seasonal thermal energy storages.

Heat pumps with thermal energy storage for district heating – standalone or integrated with fossil fuel heat plant

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Many Polish district heating systems, determined to low CO2 emissions, revise their strategy to replace coal with natural gas as a transition fuel. Instead, they look for technologies for deeper decarbonization.

In this paper, we present and investigate a demonstration district heating production plant, called Euros HC Plant 2.5 MW, build in northern Poland. This plant consists of a set of heat pumps integrated with two seasonal thermal energy storages – borehole (BTES) and pit (PTES), one short-term water storage tank, a PV farm, hybrid solar collectors (PVT) and air-water heat exchangers. Due to high RES autoconsumption the Euros HC Plant supplies local district heating systems for 27 multi-flat buildings with heat using at least 90% of energy coming from renewable sources.

Such infrastructure can be used differently, not only as a standalone heat source for relatively small district heating areas, but as a part of decarbonization for fossil fuel powered heating plants. In this paper, we investigate three scenarios of using the Euros HC Plant. All cases are computed using the numerical model implemented in TRNSYS 18. In the first scenario we determine the maximum heat demand, that would enable the Euros HC Plant to operate using 100% renewable energy sources. We show the capability of producing 100% RES heat and estimate the energy density of the plant.

In the second scenario we identify the effect of the cooperation of the Euros HC Plant (2.5 MW) with the existing conventional coal heating plant (24 MW). We analyze the possibility of combining two systems and show the way to maximize the efficiency of a heat pump-powered system and the RES share of the whole system.

In the third scenario we investigate the cooperation of the Euros HC Plant with CHP gas engine and conventional coal heating plant. Adding CHP benefits in obtaining greater energy density and possible reduction of capital investment costs by downsizing BTES/PTES or optimization of the operational costs. The combined systems aim to cover the demand for heat for presented DHN, while significantly reducing the amount of fossil fuels used in conventional heat plant. Possible modifications of the Euros HC Plant components allow us to further optimize the effectiveness of the whole system.

Keywords: heat pumps, district heating network, thermal energy storage, BTES, PTES, renewable energy sources

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Evaluating Germany's Ammonia Economy: A Comprehensive Analysis of Application-Specific Demands and Well-to-Tank Supply Costs

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This study addresses the knowledge gaps in potential ammonia demands and well-to-tank supply costs for various applications within the German energy landscape, essential for understanding ammonia's role in the energy transition. Green ammonia has emerged as a promising energy carrier due to its beneficial chemical characteristics, low supply costs for long-distance transport, and existing expertise in trading, technology, and regulations. However, the literature lacks comprehensive information on application-specific ammonia demands and well-to-tank supply costs for each application.

To bridge this gap, this study adopts a well-to-tank approach to analyze the ammonia supply chain components and develops a linear optimization model to minimize the levelized costs of ammonia production, transport, and distribution for each exemplary location. The study exclusively focuses on green ammonia, in alignment with ambitious climate goals, and considers greenfield transportation using renewable energy-sourced fuels.

For each application, demands and exemplary locations are determined as model input. Supply costs are computed from production costs in favorable locations worldwide, international transport costs, and distribution costs within Germany, allowing the model to endogenously decide between capacity investments along the supply chain for each location.

A sensitivity analysis, encompassing optimistic, baseline, and pessimistic scenarios, is conducted to explore the impacts of different input parameters and assess the

robustness of the findings. The study presents an in-depth analysis of estimated ammonia demands, and supply cost optimization, providing valuable insights for policymakers and stakeholders. This research enhances understanding of ammonia's potential in Germany's energy context, supporting climate goals and decision-making.

Keywords: Green Ammonia, Hydrogen Economy, Supply Costs, Levelized Costs, Ammonia Infrastructure

Elisa Guelpa is assistant professor at Politecnico di Torino. Her main research interests include District heating, Thermal energy storage, Multi Energy Systems, as well as Energy system optimization.

Solutions to reduce supply temperature in existing small-to-large scale DH networks: lesson learnt by the project "Leave 2nd generation behind"

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To meet long-term decarbonization targets require rapid pathways to transform existing networks into low-temperature systems in a cost-effective manner. Low temperature networks make it possible to efficiently exploit renewable energy sources and low-grade heat like industrial waste heat also lowering thermal losses. The existing infrastructure (e.g. network, substations, and building heating equipment) can represent a crucial obstacles that prevent the supply temperature lowering of second generation district heating. In this framework the project 1 Annex XIII IEA-DHC “Leve 2nd generation behind” (2020-2023) has been focused on the actions to overcome the obstacles in order to reach reduction of supply temperature reduction in existing. Specifically, the obstacles due to the characteristics of the existing network and substations are considered. Two case studies have been adopted for the analysis, a small-scale network, and a large-scale network, both characterized by temperatures larger than 100 °C. Different kind of actions have been considered for the two district heating, with a different approach. The degree of exploitation of the existing infrastructure with the aim of reducing the supply temperature has been maximised. Different levels of interventions have been considered, in order to quantify the supply temperature reduction that can be achieved with different expenditure. Results show that non negligible supply temperature reduction can be achieved by optimally exploiting the existing infrastructure and with minor intervention. Modification can provide significant increase in the penetration of renewable and waste heat in district heating.

Keywords: district heating, reduce supply temperature, existing networks, water congestions, substation efficiency

Aleksandr Hlebnikov is the researcher in the research group "Smart District Heating Systems and Integrated Assessment Analysis of Greenhouse Gases Emissions" with more than 30 years academic and practical experience in district heating field.

Evaluation of a Technical Solution for Seawater District Heating and Cooling Systems

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During the last few decades, seawater has been used as a low-grade heat source for heating. Finland, Denmark, and Latvia are among the countries where seawater heat has been used for district heating. The desired temperature is typically reached using large-scale heat pumps, which can also be used for district heating.
Other studies have discussed using sea water as free cooling for district cooling, or in conjunction with a large heat pump.
The aim of this study is to determine the best ways to use sea water as a low-grade heat source for heating and a cold source for district cooling in the summer.
A techno-economic analysis of a new residential district near the sea has been presented as part of the study. Three scenarios have been analysed and compared: a low-temperature district heating network operating at 60/40oC and a district cooling network; an ultra-low-temperature network operating at 45/35oC and a district cooling network; and a coupled two-pipe district heating and cooling network using individual heat pumps in each building.
The study examined the total electricity consumption of buildings, seawater heat pumps, district heating and district cooling network pumps, and seawater pipeline pumps for the three scenarios.
In a low-temperature network, the temperature of the heat carrier in buildings should not be increased; in an ultra-low-temperature network, individual heat pumps should be used in buildings to increase the temperature of domestic hot water up to 55oC; and in a coupled district heating and cooling network, the temperature of both heating and domestic hot water in buildings must be increased or decreased.
The purpose of the analysis is to examine these technical solutions for the comparison of the district’s energy consumption and select the best one. The main conclusion was that the ultra-low temperature network proved to be the most effective solution.

Keywords: seawater heat, free cooling, heat pumps, 5GDHC, power-to-heat

Rahul Mohandasan Karuvinga has been working as a research associate at the Institute for Energy Efficient Buildings and Indoor Climate in the team Urban Energy Systems since December 2021. His research interests are dynamic network simulations, advanced control algorithms, and operation optimization for cold DHC networks.

Analyzing Complex Network Hydraulics and Control Strategies in Cold District Heating Networks via Dynamic Thermo-Hydraulic Simulations

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A district investigated in this study is an example of a planned cold district heating network utilizing near CO2-free heat generation technologies such as geothermal and waste heat recovery from sewage systems. Such systems come with increasing hydraulic complexity leading to necessary improvements in the planning processes and the use of advanced control systems. Advanced control systems are used to efficiently manage the hydraulics in a cold district heating network by allowing real-time optimization of fluid flow and temperatures. It aims at improving the system's reliability by controlling the pumps and valves in a coordinated manner. For this purpose, sensors are placed throughout the system to measure parameters such as temperature, pressure, and flow rate. In this study, we use dynamic thermo-hydraulic simulations as a viable approach to explore the dynamics of such systems, evaluate the hydraulic interactions within the network, and locate monitoring equipment. We use a Modelica-based simulation framework with the well-tested AixLib building energy system library. The district's network supply temperature is 46 °C and the planned return temperature is 28 °C. There are three planned supply stations in the district. We develop two different simulation models of the district with centralized and decentralized network pumping strategies. The findings indicate that centralized pumps without coordinated control lead to over- or under-heating in certain buildings within the network, while decentralized pump systems effectively meet the demands. The results show that the scenario with

centralized supply stations yields higher or lower fluid flow and temperature at distinct points in the distribution network in comparison to the decentralized network. It is important to tackle fluid flow and temperature fluctuations to enhance the efficiency of the centralized supply station network. Further, we analyze our results to identify where fluid flow and temperature monitoring are necessary for a centralized pumping system. Evaluating hydraulic interactions, monitoring the data, and further developing advanced control strategies are necessary to efficiently operate centralized supply stations in cold district heating networks and achieve decarbonization goals.

Keywords: Cold heating networks, Simulation, Modelica, Dynamic thermo-hydraulic model, advanced control strategies

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 modelling to assess decarbonization pathways of the district heating sector.

Achieving Carbon Neutrality in District Heating: The Impact of Temperature Levels on the Supply Mix of EU-27 in 2050

Ali Kök, TU Wien. Anna Billerbeck, Fraunhofer ISI. Pia Manz, Fraunhofer ISI. Lukas Kranzl, TU Wien.

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Heating and cooling account for nearly half of the EU's final energy consumption, making them vital in reaching carbon neutrality by 2050[1]. District heating (DH) could be a key solution for integrating low-carbon energy sources into the heating energy mix on a large scale. However, currently, the DH supply of EU-27 highly relies on fossil fuels. We modelled the DH supply mix of EU-27 to reach carbon neutrality in 2050. In this study, we aim to answer the following research question: What is the impact of the temperature levels on the cost-minimal decarbonised DH supply mix of EU-27 in 2050, considering DH grid expansion and availability of renewable energy sources (RES) and excess heat potentials? The modelling chain consists of four main steps:

1. Building stock modelling
2. DH expansion modelling
3. Calculation of RES and excess heat potentials
4. DH Supply Dispatch

The focus of this study is on modelling the DH supply mix. The Hotmaps Dispatch model is used for this purpose. The model minimises the total cost of the DH heating supply using mixed-integer linear programming. Both investments and operation of heat generators and storage are optimised on an hourly basis. The two main scenarios are designed based on the system temperatures: high- and low-temperature DH systems, representing 3rd and 4th generations of DH. The system temperatures affect the dispatch model directly through the heat pumps and indirectly through the RES potentials. The initial results show the clear impact of the temperature levels on the DH supply mix. Heat pumps and geothermal are essential in decarbonising the European DH sector in both scenarios. The results also reveal that lower temperature levels do not necessarily lead to a higher share of heat pumps since lower temperatures imply a higher potential for low-temperature excess heat and geothermal. We will further analyse our results based on the levelized cost of heat levels, shares of exploited RES and excess heat potentials, operation of heating plants and full load hours. We will also investigate the sensitivities of energy carrier prices for hydrogen and biomass and the investment cost of geothermal plants.

References

[1] https://energy.ec.europa.eu/topics/energy-efficiency/heating-and-cooling_en [accessed at 18/11/2022]

Keywords: District Heating, supply mix, supply dispatch, temperature levels, decarbonisation, 3GDH, 4GDH

Niklas Kracht is a research associate at the Institute for Solar Energy Research Hamelin. His main field of work is the modelling and simulation of thermal energy systems, including solar and geothermal heat as well as district heating.

Feasibility study of an innovative drilling method for inclined medium-deep borehole heat exchangers in a 5th generation district heating concept

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Geothermal heat pumps show higher annual efficiencies than air source heat pumps, especially in the winter months. However, the available space for drilling especially in the urban building stock is limited. Connecting the buildings with the geothermal reservoir with cold thermal network solves that problem. These, also called 5th generation district heating networks, operate on temperatures close to ambient temperature, which allows collecting solar heat, air heat or waste heat efficiently. Decentralized heat pumps in the individual buildings raise the temperature to a usable level for space heating and domestic hot water. Almost no heat losses appear in the network and in the course of one year even a net heat gain from the surrounding soil is possible.

A lot of times shallow geothermal heat is extracted by the use of vertical borehole heat exchangers (BHE). In Germany BHEs are usually drilled to a depth of 75 m up to 150 m. To supply a district heating network a BHE-field is needed. Especially in densely populated urban areas this may lead to the problem, that there is not enough space to drill the necessary amount. An innovative drilling method, called 'steel-shot-drilling', allows for cost-efficient drilling of curved boreholes. BHEs with a depth of up to 400 m activate more subsurface volume and simultaneously reduce the necessary surface area.

This paper compares the 'steel-shot-drilling' method with traditional drilling methods. For this, a planned district for nearly 1000 residents in the city of Hanover, Germany is used as an exemplary case. A simulation study in TRNSYS is conducted, which is able to model the heat pumps, the district heating network with the necessary circulation pumps, the BHE field as well as the PVT-collectors to thermally regenerate the BHE field. The results show the same efficiency for a third of the BHE-field size and also less PVT area. Further evaluations on the aspects of efficiency, sustainability, construction and cost will be presented.

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Keywords: Borehole heat exchanger, PVT, 5GDH, heat pump, district heating, simulation, TRNSYS

Alessandro Maccarini is an Assistant Professor at Aalborg University – Department of the Built Environment. He completed his MSc degree in Aerospace Engineering at the University of Padova (Italy, 2010) and he holds a PhD degree in Civil Engineering from Aalborg University (Denmark, 2017). Alessandro's research focuses on advanced modeling and simulation of building and district energy systems. He also has experience in energy performance monitoring and thermal comfort in buildings. Alessandro was Co-PI of the national project KOHESYS (2020-2021) on the assessment of the technical and economic feasibility of 5GDHC systems in Denmark, and he is now involved in research projects related to geothermal-based energy systems, HVAC systems in buildings, and techno-economic tools for district heating and cooling networks. He has also worked in various large-scale collaborative international projects, including the IBPSA Project 1, and various Annexes under the IEA framework.

Techno-economic evaluation of 4th and 5th gen. DH networks and comparing to individual heat pumps: Idea and concept of a simple decision support tool

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The transformation of DHC systems has been conceptualized as the transition from the 1st to the 4th generation. In recent years, an often called "5th" generation of networks has been introduced, operating at ambient temperatures with consumer-side heat pumps, which enable heating and cooling to be supplied within one network. In fact, there are many different possible configurations; up to the point where individual heat pumps (HPs) become competitive. This led to a (fundamental) debate within the international DHC community regarding the benefits of both systems as well as some publications comparing them. Although there are some tools for evaluating the performance of the different systems available, they often require detailed data (e.g. hourly demand or supply profiles) and thus are not useful in very early planning stages. Other tools often don't consider all system properties (e.g. cooling or individual HPs) and therefore do not give a fair comparison.

This contribution introduces the idea and concept of a simple decision support tool for the economic evaluation of 4th and 5th generation DH networks and comparing both systems to individual HP solutions.

Keywords: District heating, Techno-economic Assessment, simple evaluation tool, 4th generation DHC, 5th generation DHC, Anergy Networks, cold district heating, comparison

Professor of heating and cooling and technical lead for UK Government

Energy Superhubs - the use of supermarkets as local energy centres

Phil Jones, Chris Dunham, Russell Fenner Henrique Lagoeiro Kristina Rozinski Catarina Marques Graeme Maidment

Graeme Maidment (presenter)

Smart local energy systems (SLES) have the opportunity to revolutionise how energy is used in urban areas for the provision of Mobility (EV), Power and Heat. Local SLES has potential to massively accelerate the decarbonisation of buildings and transport prioritisation of needs of individual places whilst delivering £ billions of growth and investment in businesses providing net zero solutions right across the UK.

GreenSCIES is a smart local energy concept that has been developed with the aims of reducing carbon emissions and tackle fuel poverty originally across the London Borough of Islington. The initial project aims to help Islington Council achieve its ambition of being a net zero carbon borough by 2030. The core concept is an ultra-low temperature 5th generation heat network enabling recovery of low-grade waste heat such as from data centres and the London Underground. It also includes distributed energy centres with low carbon heat pumps supplying heating/cooling from the ambient loop to local buildings. Each of the energy centres will provide hubs for photovoltaic (PV) electricity generation, electric vehicles and vehicle-to-grid charging/storage alongside large scale batteries. The hubs can then be used for Demand Side Response to flex with the electricity grid requirements/tariffs using a sophisticated artificial intelligence control system.

The GreenSCIES concept is potentially replicable in any urban area depending on the local characteristics. Critical to the success is having a potential accessible secondary waste heat source available to recover heat from whilst delivering cooling. We have investigated concept feasibility studies in 7 other locations across the UK. One of these applications involves the integration of a supermarket in an urban setting. By integrating supermarkets into local energy infrastructure they can share resources and provide local communities with low carbon, low cost decarbonised sources of energy. This paper

describes this investigation and explicitly describes the potential for supermarkets to become local energy hubs, including how a supermarket could be configured as part of the energy system, alongside the techno-economic model created to investigate potential performance with some provisional results.

Keywords: Heating and cooling, supermarkets, smart local energy

Aadit is a Ph.D. candidate at the Energy Economics Group (EEG), TU Wien. He has a master's degree in Energy and Environmental Management from the University of Flensburg. His research focuses is on strategic heating and cooling planning aimed at energy efficiency and sectoral decarbonization.

Modelling the potential for district cooling

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The rising European Cooling demand urges the need to plan and implement decarbonization pathways for the cooling sector. District cooling (DC), which until now has not been a common energy carrier in the cooling sector, unlike its counterpart in heating, could show potential for sustainable supply under increasing cooling demand and also provide a higher possibility for renewable energy integration. The study aims to develop a methodology to assess the potential for a district cooling network in a given area, focusing on techno-economic assessment for strategic planning for its implementation. In doing so, the research aims to answer the question: How sensitive is the economically feasible potential for the district cooling networks under long-term demand, climate change, and building connection uncertainties?
The methodology develops a geospatial optimization model that identifies potential areas for DC networks comparing the supply and network expansion costs against the operating costs of alternate decentral supply options. The network expansion is constrained by the technical parameters of the system which influences the overall system costs. The model also looks into potential free-cooling supply sources for an identified network area and recognizes the feasibility potential of its integration into the network. The model is able to identify sensitivity parameters and analyze their effect on the feasibility and coverage of the network.

The model, run for the test case of Vienna, shows potential for DC supply to about 1-20% of the theoretical cooling baseline demand under different electricity price sensitivity. The model identifies 13-170 multiple small DC networks around the city under different sensitivities. The average levelized cost of Cooling is observed in the range of 50-200 Euros/MWh in all feasible locations. Free-cooling supply for these

networks will further be assessed in addition to the size of networks under different demand uncertainty scenarios.

Keywords: District cooling, geospatial planning, free cooling sources, RE integration, decarbonization

Houssam Matbouli is a PhD student at the University of Antwerp, Belgium, working on facilitating the deployment of heat networks for local authorities. He obtained his master's in mechanical engineering at KU Leuven, which further grew his interest in heat networks, sustainable energy, CFD, etc..

Assessing the ability to reduce the supply temperature of a district heating network following the oversizing of diameters due to building renovations

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Climate change is a topic that led several EU countries to pledge to significantly reduce their greenhouse gases emissions by 2050. As a result, several cities are considering district heating networks as a solution to integrate more and more sustainable sources. However, the design of such systems is not straightforward, notably due to the constantly changing heat demand following building renovations. In fact, when the pipes are designed for non-renovated buildings, an excess of heat will be present if the system is to be operated optimally following the renovation of buildings. In this paper, the possibility of decreasing the supply temperature in order to avoid an excess of heat following building renovations, is studied. A fictional street with eight buildings, a building renovation rate and renovation heat demand reduction is considered in a case study. The time horizon of the simulation is divided into equal phases, during which the heat demand of the network decreases following the building renovations. The pipes are sized for the non-renovated buildings, and a simulation is then run to evaluate the excess of heat available at every phase, and the total costs, which are the sum of the investment and operational costs, minus the revenues of selling heat to buildings. For every phase, the supply temperature drop that can remove the excess of heat is calculated, and the buildings that cannot achieve comfort levels with the new supply temperature are identified. A higher connection cost is considered for those buildings, as booster heat pumps or boilers are required to reach comfort levels. Afterwards, different scenarios in which the supply temperature drop is performed at different phases, are defined, and for each scenario, a simulation is run to obtain the total costs of the network deployment. Subsequently, the heat network deployment scenario that achieves the lowest total costs is identified, and the phase during which it is optimal to reduce the supply temperature is finally deduced.

Keywords: district heating, building renovation, heat network, heat network deployment, supply temperature, heat network design

A chartered engineer with 15 years of experience in improving the performance of existing heat networks in the UK. His expertise in heat networks has helped to transform the industry and he is committed to advancing low-carbon heat networks, working closely with government, industry and academia.

Practical experience of converting a 1970s UK social housing block into a 4th generation heat network with independent quality assurance support

Tom Naughton, FairHeat

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The conversion of a 94 dwelling social housing block of flats in the UK into a 4th generation heat network has resulted in a significant reduction in carbon emissions, lower operational costs to the residents and improved thermal comfort. This project was funded by the UK government (DESNZ) as part of a demonstrator programme to help establish methodology for decarbonising the heat of UK's existing housing stock.

The buildings original heating and hot water system is very common and representative of the majority of existing UK social housing; including hot water storage in each dwelling, radiators with poor control and poor overall hydraulics. This resulted in higher energy costs and overheating in living spaces. The heat network was designed to operate at 80C flow temperatures and 60C return temperature although return temperatures were much higher at 75C due to performance issues with the system.

In order to operate at 4th generation temperatures, a new heat network was installed following best practice principles with instantaneous hot water and individual radiator controls. This was all undertaken while the building was fully occupied.
The project placed a strong emphasis on the importance of effective monitoring. This involved the use of smart metering that provides real-time performance data in every dwelling in addition to equipment in the energy centre. This helped evaluate the effectiveness of the work, supported commissioning and is used to maintain the high performance of the system.

Throughout the design, installation, and commissioning phases of the project, the importance of independent quality assurance processes was emphasized. This involved regular inspections and testing by independent experts to ensure that the system was being installed to the highest standards and that all components were working together effectively.

Overall, the retrofit works resulted in a reduction in flow temperatures to 55C flow and return temperatures of 35C. The success of this project demonstrates that existing housing stock in the UK can be converted into a 4th generation heat network and is a testament to the importance of independent quality assurance processes in ensuring that improvement works are installed and commissioned to the highest standards.

Keywords: Heat networks, 4th generation district heating, LTDH, Quality Assurance, retrofit

Henrik Pieper is senior consultant and researcher at the Hamburg Institut focusing on the integration of renewable energy sources in district heating using large-scale heat pumps. He has already gained several years of international experience through his PhD in Denmark and as a Postdoc in Estonia.

Heat pump configurations for aquifer thermal energy storage

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Aquifer thermal energy storage (ATES) provide an opportunity to integrate more renewable energy sources in district heating. In Germany are three large regions with suitable underground conditions for ATES. When ATES is fully charged at e.g. up to 90°C and then being discharged, the temperature in the storage drops below the one from the district heating supply temperature. Large-scale heat pumps (HPs) can be used to increase the exploitation of the storage by providing heat at required temperature level. Thereby, the ATES and large scale HPs act as a fully independent heating plant. During the discharge period, a large temperature drop of 30-40K is expected. Suitable HP configurations need to be identified.

The current research focuses on investigating large-scale HP configurations in order to identify suitable and efficient HP capacities, refrigerants and HP configurations for ATES applications. Engineering Equation Solver (EES) is used for representing HPs as thermodynamic models. Commonly used refrigerants for large-scale HPs, such as CO2, NH3 and R1234ze, are investigated among others. Transcritical CO2 HPs and multi-stage HPs are compared with each other in terms of the Coefficient of Performance (COP) considering the large change in temperature of the ATES. A comparison and future recommendations for suitable HP configurations for ATES are proposed.

Keywords: Large-scale heat pumps, Aquifer thermal energy Storage (ATES), Seasonal storage, Heat sources

Eftim Popovski works as a research associate at the Institute for Resource Efficiency and Energy Strategies (IREES). Since 2022, he has been working on his PhD on district heating networks and their role in the sustainable energy transition at the University of Freiburg.

The role of solar district heat in the energy transition of the German heating sector

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Most German municipalities and local utilities overlook the solar district heating (SDH) systems and its potentials most probably assuming that there is not enough land available, the technology is only suitable for individual households or have a lack of knowledge about the system costs and size. The focus of this study is on north German conditions which correspond to many northern European regions as well. The goal is to help policy/decision makers to get a first idea of the costs and size of an SDH system based on their heat demand and provide additional information's of the most influencing economic and technical factors. Hence, it aims to answer three central questions:

i. What is the influence of the design parameters (such as collector area and thermal storage size) on the cost-effectiveness of the SDH for a specific annual heat demand?
ii. What is the influence of the external factors such as price of land, investment costs, interest rate and supply temperatures on the cost-effectiveness of the SDH system?
iii. Is there suitable land for such projects and what is the current technical and techno-economic potential of SDH systems in Germany?

To answer the first two questions, we chose an approach of modelling 8 410 scenario variation by using the energyPRO software. The scenarios vary based on different collector areas (from 1 000 up to 200 000 m2), thermal storages (from 0 to 100 000 m3), diverse annual heat demand (from 10 up to 100 GWh) and supply/return temperature profile of 80/60 °C for climatic conditions in Northern Germany. To answer the third

question, a Geographic Information System (GIS) model was developed by using the QGIS software to identify the suitable solar areas that are within a range of 1 km of available heat demand with minimum heat density of 10 GWh/km2*a.

From the results, it is observed that the most cost-effective design of the solar district heating system is for solar fractions between 11 and 18% and collector area/storage ratio between 4 and 6.7. For these designs, the LCOH varies between 45 - 64 €/MWh. The spatial analysis shows that the techno-economic potential of solar district heat in Germany is around 17,6 TWh. Additionally, sensitivity analyses and equations for a preliminary design are presented.

Keywords: solar thermal, district heating, energy system analyses, energy system modelling, energy planning, levelized cost of heat (LCOH), spatial analysis

Els van der Roest is a researcher and part time PhD student in the field of energy and water. She has a background in chemistry and energy sciences, and is interested in the interface between energy and water that increasingly rely on each other in our future energy system.

Flexibility of a low temperature District Heating system with Power-to-Heat and ATES

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Aquifer Thermal Energy Storage (ATES) systems combined with a low temperature district heating network (LT-DHN/ 4th or 5th generation) have a high potential for delivering sustainable heating and cooling to groups of new buildings. The case using ATES and LT-DHN analyzed in this study is called 'De Binckhorst' and is located in the city of The Hague in the Netherlands. It is a combination of 3,000 new houses in apartment blocks and 50,000 m2 of utility buildings. In this system, a regeneration of 10,000 MWh/year of heat is necessary to ensure that the ATES wells have a yearly thermal balance. The company Dunea Warmte en Koude has proposed that the heat from this water storage could be used to regenerate the ATES system. As the water is a low temperature heat source (8-16°C), a centralized heat pump could be used to increase the temperature before heat is transferred to buildings or the ATES system, thus adding a power-to-heat facility to the system design.

In this study, it is investigated how this power-to-heat system with drinking water as a source compares to a similar system with surface water as source. Moreover, heat pump condenser temperatures ranging from 25 to 35°C are analyzed to see its effect on the ATES contribution to heat supply and thermal balance. Co-simulation of the different system components is done at an hourly basis for multiple years, including a dynamic hydro-thermal geological model of the ATES system, using current and future energy prices. The results show a clear effect on the ATES temperature, and a higher heat pump temperature leads to lower energy costs for the end user. On the electricity grid balancing markets, the potential of heat pumps is small due to their relative slow ramping-up rates. Despite this characteristic, the heat pump together with ATES could still offer flexibility to the electricity grid as a power-to-heat asset. An comparison between flexible and non-flexible heat pump operation for current and future energy prices showed that that between 14% (now) to almost 100% of the electricity costs of the heat pump could be saved. Overall, the results show different features of LT-DHN and how design choices and flexible deployment impact the energy balance and economics of the system.

Keywords: Power-to-heat, ATES, heat pumps, low temperature district heating, flexibility

Thomas Schmidt is scientist at Solites.

Emission-free heat supply for a large new residential area with a smart combination of natural heat sources

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A district heating system with a solar fraction of about 70% is currently being realised for the new residential area "Killberg IV" in Hechingen, Germany. An additional 15% of the heat demand of approximately 3.9 GWh/a will be provided by geothermal probes. To improve the system efficiency, a heat pump system that uses renewable electricity will be integrated, which contributes approximately 10% of the heat demand. The combination of solar and geothermal technologies with a pit thermal energy storage enables an almost fossil-free heat supply at affordable costs. In 2016, the city of Hechingen, located in the south of Germany, developed an urban plan for the new residential area "Killberg IV", which aims to provide housing for over 2,000 people. Due to the results of a citizen participation and the wish of the municipal utilities for an affordable, fossil-free heating system, a feasibility study was conducted. The winning concept is a district heating system which has now entered the realisation phase: A solar thermal system with a collector area of 7,000 m² and a pit thermal energy storage with 18,000 m³ water volume will be installed at a nearby earth landfill. Since 2021, the material delivered to this landfill has been arranged to create a pre-formed pit for the planned storage. Around 40 geothermal probes with a depth of 180 m will be realised to provide renewable heat. A smart combination of a low-temperature and a high-temperature heat pump will ensure a supply temperature of 68 °C. The peak heat demand will be covered by a biogas boiler. The system was developed and dimensioned by Solites using the simulation programme TRNSYS. The shallow geothermal system was developed by tewag GmbH. The "digital twin" of the system realised in TRNSYS made it possible to develop a control concept specifically for this application, which minimises the use of electrical power. According to the current plan, heat supply is expected to begin at the end of 2024. This concept is a best practice example for how to develop, design and realise the heat transition in practice using all synergies with local boundary conditions.

Keywords: emission-free district heating, realization phase, best practice, solar thermal energy, sesonal heat storage, geothermal energy

Martin Sollich is a PhD researcher 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.

Unlocking the energy efficiency potential of heating networks through low-temperature design and optimal retrofit

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Modern heating networks push to ever lower network operating temperatures, leading to increased efficiency in heat generation and easier integration of renewable and waste heat sources. To assist in the design of low-temperature networks, we extended our automated design tool for District Heating Networks (PATHOPT) to optimally select the producer supply temperature and to optimally retrofit an existing heating network. More precisely, the installation choice of a supplementary heat exchanger in the consumer substation is optimized to maximize the network temperature reduction, on the basis of a nonlinear heat transport model. For a realistic test case, we show that large economic benefits are obtained by optimally choosing the supply temperature set point. Moreover, it is shown how the investment for further lowering the network temperature via substation retrofitting is easily recovered through the cost decrease in heat generation. For a chosen use-case with 209 consumers, we show how the tool is able to decrease the operational temperature from an initial value of 90°C to 51.3°C without substation retrofitting and to 46.8°C with substation retrofitting.
To increase the capabilities of the tool towards low-temperature network designs and aiming at renewable-based heating networks, we also show first results on the extension of the framework to different low-temperature and renewable-based heat sources like solar thermal units and heat pumps. The production models include the physics, costs, and potential time-dependent availability. With these capabilities, the tool now

automatically decides on the operating temperature and the capacity of heat production units, while simultaneously optimizing the network layout and operation. This enables the optimization of renewable-based low-temperature heating networks and provides cost- and energy-efficient network designs. At the same time, network planners' flexibility and economic gains are increased due to the availability of different types of heat sources, as well as their design and operation optimization.

Keywords: District heating network, Optimal retrofit, Low-temperature heating, Renewable heat sources

Seyed Shahabaldin Tohidi is a postdoctoral researcher at the Applied Mathematics and Computer Science Department, DTU. His research background is modelling and control of dynamical systems. He is interested in the energy systems management to enhance stability and performance via controller design.

Optimal price signal generation for local energy management using flexibility function

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Renewable Energy Sources (RES) play a key role in smart energy systems. With more renewable energy resources, maintaining the balance between supply and demand by solely relying on the supply side is more challenging. Additionally, batteries and other storage capacities enhance the flexibility level in the energy management on the demand side.
However, it is not trivial to exploit these available flexibilities in a profitable manner. Aggregators must maintain an overview of their consumers' flexibility and determine appropriate price signals to balance consumers' load with the amount of purchased energy. Furthermore, for any given consumer, the amount of available flexibility is a complex and time-varying function of the price signal and weather forecasts.

In this work, we use a Flexibility Function (FF), identified from data, to represent the relationship between the price signal and the demand, and investigate optimization problems for the price signal computation. Consequently, this study considers the higher levels in the hierarchy from the appliances, households, districts to the markets. The flexibility function, which is a nonlinear stochastic differential equation, captures dynamic price-demand behaviors in price-responsive systems, and enables characterization of the energy flexibility by analyzing the transient demand response to electricity price variations.

This study considers a demand side flexibility managed by a Model Predictive Control (MPC) algorithm. Given a price signal, MPC repeatedly computes a control signal over prediction and control horizons to manage demand and minimize cost. Sequential and simultaneous approaches for computing price signal, along with various cost functions like quadratic, absolute value and economic costs, are analyzed and compared. Furthermore, secondary objectives to provide ancillary services and their effect on the price signal quality are studied. The flexibility obtained is characterized by the FF.

In summary, the overall framework contains models, forecasting, controllers and optimization within systems-of-systems organized as a hierarchical system that can exploit flexibility in a consumer-friendly and economically optimal manner. The entire framework is often called the Smart Energy Operating System.

Keywords: Price-demand relationship, Flexibility function, Optimal price signals, Model predictive control, Price-responsive systems, Aggregator, Electricity markets, Smart energy systems

Lei Wang works on the heat transfer, fluid mechanics, heat exchanger, and district heating.

Case study of a local district heating expansion scenario n scenario within the framework of EMB3Rs

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The EMB3Rs project is financed by Horizon 2020. It aims at developing a user-driven and open source modelling platform to simulate alternative supply-demand scenarios for the recovery and reuse of industrial excess heat and cold. The platform will allow industrial users and other relevant stakeholders to autonomously and intuitively explore and assess the feasibility of new technology and business scenarios. Within the framework of EMB3Rs, we conducted a case study by collaborating with industrial partner Landskrona Energy to investigate the potential expansion scenario of a local district heating grid expansion at the east side of Landskrona city. Grid simulations have been performed to study the detailed flow rates, pressure drop, as well as the heat losses in the pipelines, which are essential for the owner to operate the district heating network. We also identified the potential heat sources and heat sinks in the coming years and establish the model for them. By identifying the industrial partners with surplus heat supplies and demands, the cost-efficient and technically feasible solutions for the recovery, conversion and distribution of available surplus heat are explored.

Keywords: case study, heat sources and sinks, simulation, platform

Daniel Zinsmeister is a research associate at Technical University of Munich (TUM). His focus is the design of energy management systems and the simulative and experimental analysis of novel heating and cooling solutions.

Flow direction in district heating and cooling grids with booster heat pumps: Does it make sense to have unidirectional flow?

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Ultra-low temperature district heating and cooling grids with booster heat pumps are a promising option to reduce CO2 emissions for heating and cooling supply. Booster heat pumps extract heat or cold from the grid and provide it at the temperature level required in the building. They cool the grid during heat extraction and heat it during cold extraction. The waste cold from heating can be used for cooling and vice versa. Heat and cold extraction can be balanced on a daily or seasonal basis, making the system very efficient.
Current publications assume that booster heat pumps can reverse the flow on the grid side to feed waste heat from cooling into the supply line of the grid. To enable this, all booster heat pumps require a pump to reverse the flow, resulting in higher costs and a more complicated control. To the authors' knowledge, there are no publications that investigate whether and under what conditions a simpler ultra-low temperature district heating system with booster heat pumps and unidirectional flow performs similarly well. To address this research gap, we investigate which scenarios benefit from flow reversal and where unidirectional flow is sufficient.
We analyze a system, where all houses are equipped with a booster heat pump and a thermal storage. Different load patterns within the grid are studied by applying different profiles for heating and cooling consumption of the buildings. A seasonal storage or active balancing unit compensates daily and seasonal fluctuations. Furthermore, the temperature of the supply line can vary, depending on whether heat or cold consumption dominates. To compare the settings, we run various simulations in SimulationX, a Modelica based programming environment. We use detailed and validated simulation models for the components and vary the aspects mentioned above.

The results compare the annual auxiliary energy consumption to operate pumps and booster heat pumps and analyze the usage of the balancing unit.
The aim of this publication is to provide a guideline for researchers and developers to achieve the ideal solution for heating and cooling grids with booster heat pumps for their specifications.

Keywords: district heating and cooling, booster heat pumps, bidirectional flow, 4th generation district heating and cooling, 5th generation district heating and cooling

ELECTRIFICATION OF TRANSPORT, HEATING AND INDUSTRY

In 2013, Benjamin Blat-Belmonte began studying mechanical engineering at the Technical University of Darmstadt. While focusing on technical aspects, he also found an interest in business operations. Currently pursuing a PhD on electric mobility and vehicle-to-grid technology, his main focus is on electrifying society.

Smart Energy Systems and Electrified Transport: Analyzing the Flexibility Potential of Bus Fleet Operators in Germany

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The transition to smart energy systems is a crucial component for ensuring sustainability and reducing carbon emissions. Electrification is a key factor in achieving these goals, with the transport sector being an integral part of the equation. The integration of the transport sector with the electricity sector will facilitate a reduction in carbon emissions. This paper assesses the potential of electric bus depots to function as smart energy infrastructures. Analyzing the energetic system flexibility of the electrified public transport system is at the core. Previous studies emphasize the importance of identifying and managing the optimal operation strategies of electrified transport to achieve system flexibility. This work concentrates on Germany as a reference market for balancing and electricity markets at the center of the EU. It evaluates the development of balancing and electricity markets in facilitating the transition towards a smart energy system. The flexibility potential of a bus fleet with 80 electric buses is analyzed under optimal participation in the short-term electricity and balancing market. The bus fleet operator acts as a storage systems aggregator, which combines mobile and stationary storages to enhance energy flexibility. The study measures the potential contribution for the stability of the electricity grid in Germany. The additional battery degradation that arises with the provision of balancing services is part of the economic equation. The analysis is based on stochastic variations of the actual control energy activated in the balancing market using historical data based on the past three years. The exact activation of control energy is not registered in detail which motivates this sensitivity analysis. The paper concludes by demonstrating the feasibility of the electrified bus depot as an integral component of smart energy systems. These findings contribute to a better understanding of the electrification of transport, sector integration, and the role of infrastructures in achieving smart energy systems and showcases the attractiveness of this business model.

Keywords: electrification, sector integration, energy system flexibility, charging infrastructure, operation strategy, transport sector, battery storage system

She is PhD student at the EPFL laboratory of photovoltaics and thin-films electronics (PV-lab), where she is studying the potential of coupling photovoltaic power generation and electric vehicle charging.

From PV to EV: Mapping the Potential for Electric Vehicle Charging with Solar Energy in Europe

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The electrification of the transport sector is a key element in decarbonising our societies. However, energy systems will have to cope with additional electricity demand due to the charging needs of electric vehicles (EVs) together with the integration of renewable energy sources. Moreover, the environmental impact of electric vehicles depends on the energy mix, with lower emissions if the mix is more decarbonised.
In this context, smart electric vehicle charging can benefit a fluctuating energy system by increasing demand flexibility. Shifting EV charging during the day can absorb photovoltaic (PV) production peaks and limits the additional demand during peak periods. In addition, storing PV electricity in the EV batteries can help reduce the load on transformers during PV production peaks and the batteries can then be discharged into the grid or home during the evening or during other demand peaks.
The flexibility gained from EV-PV coupling is highly dependent on the local context of PV production and local mobility habits. Our approach first focuses on accurate geospatial modelling of mobility needs across Europe to quantify charging needs in terms of energy, power, and temporal distribution. Different scenarios are developed to distribute the charging demand between home, work and other points of interest (shopping, leisure, etc.). By comparing these scenarios with renewable energy production and future electricity demand curves, we can determine the best options for meeting demand while minimizing grid reinforcement and infrastructure costs. Policies influencing these scenarios are also considered.
Our model highlights that the electricity demand per square kilometre for commuters charging at home in 2050 is higher in urban areas than in rural areas, even though the distance travelled per vehicle is lower. We show, for example, a practical case in the Geneva Lake area illustrating when, where and how many public chargers should be installed during the next three decades.

Finally, we are working on the implementation of all scenarios and results in an open-source online geographic tool for energy transition planning based on the former "Hot-maps" platform.

Keywords: electric vehicule, photovoltaic, flexibility, mobility, electric vehicule charging, vehicule-to-grid,

Alaize is a PhD Student at University of Minho in the field of Industrial and Systems Engineering. Her research is focused on the whole-systems impacts of low-carbon technologies and their relationship with a just energy transition.

The systemic impacts of electric vehicles' uptake: A conceptual model

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Transport electrification is key to reduce emissions from fossil fuels. Together with renewable energy and storage technologies, electric vehicles (EVs) figure as mainstream technologies when it comes to the low-carbon energy transition. However, EVs uptake can have controversial impacts when a lifecycle perspective is employed. From mining to battery recycling, social, environmental, economic, and technical issues may threaten the achievement of a sustainable and just energy transition (JET). From this background, the present study employs systems thinking to build a conceptual model representing the systemic impacts of EVs uptake. Causal relationships are based on a prior literature review about the potential contribution or opposition of EVs to a just energy transition. Results highlight the several system's feedbacks and inherent complexity. Particularly, the effects of battery demand on mining and refining activities, community trust as a driver or obstacle for mining projects, the results of EVs deployment on the electricity grid, and the influence of battery recycling on resource extraction. The model can be used as a tool to inform stakeholders and policy-makers about the potential reach of their actions and contribute to the achievement of a JET. It also builds the conceptual ground for dynamic quantitative modelling and future simulations about the systemic impacts of EVs uptake.

Keywords: just energy transition, electric vehicles, system dynamics, systems thinking, life cycle, causal-loop diagram, energy justice

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Oliver Ruhnau is Assistant Professor of Energy Market Design at the University of Cologne since July 2023. Before that, he was Postdoctoral Researcher at the Hertie School in Berlin. His research interests lie in the field of energy economics and the sustainable transition of energy systems.

Representing electric vehicles in energy system models: an accurate and scalable aggregation approach

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Oliver Ruhnau (presenter)

The volatile consumption of a growing number of electric vehicles (EVs) may challenge the power system, but EVs may also have a balancing effect when following system-friendly charging strategies. Modeling the system-level impact of EVs while respecting computational constraints requires the aggregation of diverse individual charging profiles into one fleet profile. We show that previous studies typically rely on too few profiles to accurately model the system-level impact of EVs and that a naïve aggregation of individual profiles leads to an overestimation of the fleet's flexibility potential. To overcome this bias, we introduce a scalable and accurate aggregation approach based on the idea that the deviation from an uncontrolled charging strategy is modeled as a virtual storage. We apply this approach to a German scenario with 15 million EVs in 2030, estimating an average flexibility potential of 28 GWh (1.9 kWh/EV). This is much smaller than the assumed average physical size of car batteries (62 kWh) and much smaller than the result of a naïve aggregation. We conclude that the virtual storage approach enables a more realistic representation of EVs in energy system models and may be applied to other flexible assets.

Keywords: electric vehicles, demand-side flexibility, aggregation, representativity, energy system modeling, virtual storage

Studies of Renewable Energy Engineering (B. Sc.) and Electrical Engineering (M. Sc.). Currently research associate in the CC Integrated Energy Infrastructures at Fraunhofer IEG. Fields of research: dynamic electricity price components, distribution grid simulations, flexibility utilization.

How do dynamic electricity tariffs and dynamic grid charges interact?

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With the increasing electrification of heating and transport (i.e. heat pumps and electric vehicles) in the residential sector, the grid load in low-voltage grids is expected to rise sharply in the future. At the same time, electricity generation is becoming more volatile due to the expansion of renewable energy plants. Thus, the load will have to adapt more strongly to generation in the future. One possibility to leverage micro-flexibilities such as electric vehicles, heat pumps and home battery storage systems are dynamic electricity price components. There are different approaches to this: Energy utilities offer dynamic electricity tariffs (DETs), based on spot market prices. Dynamic grid charges (DGCs) are discussed in Germany and already implemented in other European countries such as Norway. Most studies in literature consider both aspects, though only separately. The questions arise:

- What happens if both concepts occur simultaneously?
- How does the financial incentive for household customers to use DETs change if DGCs are already introduced?
- What influence does the interaction of DGCs and DETs have on the grid load and the necessary grid expansion of low-voltage grids?

We answer these research questions by using a simulation model with embedded optimization, which minimizes the costs of the individual households in regard to the dynamic electricity price components by using their flexible technologies. In our analysis we assume that DGCs are mandatory. However, DETs are offered by utilities and residential consumers are free to choose their tariff. The decision behavior of customers regarding the choice of electricity tariff is also depicted in the model. Load flow calculations for a low-voltage grid are performed. The necessary grid expansion is determined using an expansion algorithm and associated costs are quantified. For comparison, a

fixed power rating for each grid connection point is investigated instead of DGCs. Results show that the financial attractiveness of a DET strongly depends on the design of the electricity tariff but also on the DGC and the available flexible technology. The study presents new insights on the potential and interaction of DETs and DGCs when considered in a more realistic setting.

Keywords: Dynamic tariffs, dynamic grid charges, heat pumps, electric vehicles, battery storage systems, flexibility, electricity grids, grid expansion

INSTITUTIONAL AND ORGANISATIONAL CHANGE FOR SMART ENERGY SYSTEMS AND RADICAL TECHNOLOGICAL CHANGE

Anders N. Andersen holds a PhD degree in Energy System Analysis from Aalborg University and a Master of Science in Mathematics and Physics from Aarhus University. He is a member of the research group Sustainable Energy Planning and Management at Aalborg University.

Major economic opportunities and challenges for Danish wind farms and district energy plants of German special regulation and netting

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The EU has comprehensive requirements for the capacity allocation and congestion management of electrical interconnectors between European price areas. The market coupling has allowed that, e.g., PV production in Spain may flow to Finland and wind production in Denmark may flow to Italy. To assist in the market coupling, Nominated Electricity Market Operators (NEMOs) have been designated to handle resulting flows while observing physical constraints in the interconnectors. The NEMOs must maximize the social welfare (SW) across Europe in the Day-Ahead (DA) auction using a single-price coupling algorithm.

The SW is computed as the sum of the consumer and supplier surplus and congestion rent. For the SW computation to work well, it is important that there are no bottlenecks inside price areas, however, in the German single-price area, such bottlenecks do exist, causing trade to be made in the DA market which cannot be executed physically. These non-executable trades affect DA prices in Denmark. In addition, afterwards the German TSO has to counteract the trades through Special Regulation delivered from, e.g., Denmark.

This presentation shows the results of a simplified SW model, calculating the prices in the price areas in and around Western Denmark. Results show that earnings of Danish wind farms and district energy plants delivering German Special Regulation in 2022 was ~ 70 M EUR – earnings that will be reduced if Germany is split into more areas.

A European platform for the imbalance netting process between TSOs has been implemented. As an example, if there is surplus production on a German offshore windfarm, this surplus production may be sold to the Scandinavian TSOs, in the hours they need upward regulation in the manual Frequency Restoration Reserve activation market (mFRR EAM). The German TSO earned ~ 70 M EUR in 2022 this way.
To avoid speculation in imbalances, it is not allowed in Scandinavia to offer e.g., upward regulation in mFRR EAM at a price less than the DA price. As the non-executable German trades affect the DA prices in neighbouring countries, this will also affect the German TSO earning in upward regulation. Our market simulation shows that this earning for the German TSO will be reduced when Germany is split into more price areas.

Keywords: Economic opportunities and challenges, Wind farms, District energy plants, Special regulation, Netting

Elisabeth Andreae is a second year PhD fellow at DTU Wind and Energy Systems researching the integration of electrolysers in designing future energy systems including green hydrogen.

The impact of offshore energy hub and hydrogen integration on the Faroe Island's energy system

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Background: Large-scale offshore energy hubs are being developed for expanding the future renewable energy systems. At small scale natural island systems can be deployed to serve as energy hubs. Island communities have a limited amount of land area to increase renewable capacity, thus offshore solutions are needed. Multiple green energy vectors can be combined to create a more robust green energy supply, including hydrogen (H2) production through electrolysis. Converting off-grid systems into fully renewable also provides higher self-sufficiency.

Objective and method: This work presents a feasibility study evaluating the transition of a small island system towards an offshore energy hub. The objective of this study is to use the EnergyPLAN tool to evaluate how different sensitivities impact the planning and decision-making of the Faroe Islands towards achieving their target of a fossil-free electricity system by 2030.

To evaluate the sensitivities of energy efficiency of electrolyzers and different investment levels, technical simulations are conducted, with and without H2 production for fuel.

Expected Results: A centralised and decentralised setup of an offshore wind hub with electrolyzers are tested, and the impact of using different electrolyser technologies (e.g., alkaline and PEM) is identified. The study aims to identify how to reflect on uncertainties associated with different energy sources for a small Energy Island with a closed grid system.

Expected conclusions: The overall question to be answered is whether an integration of an offshore wind farm, which can support both the green electricity demand and green hydrogen production, will be feasible? The research questions addressed are how to design and identify the most achievable and affordable strategy for a small offshore energy hub, and how the integration of green hydrogen impacts the whole energy system, also considering CO2 emission targets.
This feasibility study can provide a suggestion for the renewable-technology-mix to help reduce the carbon footprint of the transportation sector with green fuels.

Keywords: Hydrogen, EnergyPLAN, Faroe Islands, Offshore Energy Hubs, Offshore wind, feasibility study

Julia's doctoral research on modern multi-energy system design impact on energy markets started in 2020. Previously, she graduated in Electrical Engineering at the Polytechnic School of the University of Sao Paulo (Diploma) and the Technical University Darmstadt (master's degree).

Game-theoretic Analysis of Suppliers' Market Power in Local Multi-Energy Markets

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Local multi-energy markets (LMEMs) are a promising approach to fostering the integration of renewable energy sources. Different designs of thermal-electric LMEMs were already explored in the literature. Many of these works solve the market clearing by maximizing social welfare, thus assuming perfect competition. This assumption is debatable, as the limited capacity and number of participants in a LMEM can lead to oligopolies.

This work formulates a Nash-Cournot game in order to analyze the market power of local suppliers in a thermal-electric LMEM. We consider different types of suppliers, as illustrated in Figure 1. Each supplier agent seeks to maximize profits by adjusting its decision variables, while accounting for the decisions of all other market participants. A quadratic utility function describes the price-taker behavior of consumers. The Nash-equilibrium strategies are such that the optimality conditions of all agents' optimization problems are simultaneously satisfied, which constitutes a complementary problem.

Additionally, we propose and evaluate two strategies to mitigate excessive supplier market power. The first is the addition of a seller of last resort (SLR), which can place an unlimited supply bid at price πc, so local players have no incentive to bid at prices higher than πc in this case. The second, which we call diversification, consists of adding heat pumps and storage agents to the LMEM increasing competition and coupling between markets.

Simulations for a plausible LMEM setup show that the strategic behavior of suppliers can lead to prices up to 10 times higher than a perfectly competitive LMEM. The market power is especially high for CHPs, which can compensate for losses in the more competitive electricity market by forcing high prices in the heat market. Adding an SLR increases consumer surplus but reduces the total welfare. Diversification not only increases the consumer surplus and but also the social welfare. The energy arbitrage performed by storage agents reduces price peaks, while the thermal-electric coupling, as provided by heat pumps, effectively antagonizes the CHPs. In sum, a well-chosen mix of technologies in a LMEM is required to avoid abuse of market power by suppliers.

Keywords: Nash-Cournot, Local Energy Markets, Local multi-energy systems, Complementarity Modelling

Game-theoretic Analysis of Suppliers' Market Power in Local Multi-Energy Markets

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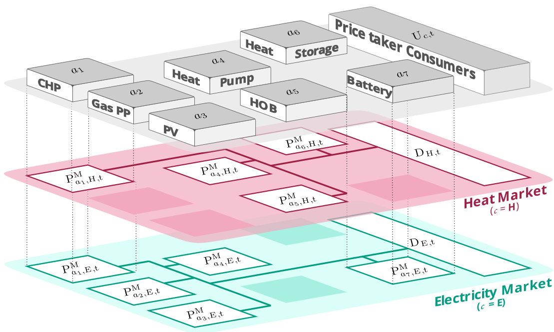

Figure 1: Agents of the thermal-electric LMEM. The consumers are modeled as price-takers with utility function $U_{c,t}(D_{c,t})$. Supplier agents a can influence prices $\pi_{c,t}$ by adjusting traded quantities $P^M_{a,c,t}$ and they play profit maximization strategies.

Anna Billerbeck is a researcher at Fraunhofer ISI in the unit focusing on energy policy and energy markets. She works in national and international research and consulting projects on renewable energies. Her research activities focus on the decarbonisation of district heating and cooling networks.

Is Germany on the right way for the market uptake of large-scale heat pumps in district heating? An analysis of the economic framework conditions

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Germany is aiming to become climate neutral by 2045. In line with these targets, Germany plans to phase out coal by 2038 at the latest. This has a direct impact on the district heating supply, as most coal-fired plants in Germany are used for electricity and heat co-generation. Large-scale heat pumps are a promising technology to replace coal in district heating as they can produce climate-neutral heat and increase the integration of renewables in the electricity sector. However, there are still barriers to the widespread use of large-scale heat pumps in Germany. This is the starting point of our research, which aims to answer the question: Are the economic framework condi-tions for large-scale heat pumps in Germany sufficient for the needed market uptake?

To answer our question, we set up a micro-simulation model for a scenario-based analysis of se-lected policy measures. This model is based on detailed cost calculations and considers the main cost drivers of different technologies. Hence, with the model we can examine the impact of dif-ferent economic framework conditions on the cost competitiveness of large-scale heat pumps in relation to competing gas-fired technologies. We model two scenarios: (1) CO2-Price-Scenario that looks at a low and a high CO2 price development until 2050 and (2) Support-Scenario that anal-yses the impact of the new German support scheme for large-scale heat pumps, i.e. the impact of financial investment and operating support.

The CO2-Price-Scenario shows that even with a high CO2 price, large-scale heat pumps will reach cost competitiveness only after 2030 and only if the conditions are in their favour (i.e. high costs for gas-fired technologies). The Support-Scenario shows that heat

pumps only reach cost competi-tiveness in 2025 when they receive the full support levels. Hence, we overall conclude that finan-cial support for large-scale heat pumps is needed for the market uptake of this technology. The success of the German support scheme should be closely monitored. Thereby, its 10-year funding duration and the restriction that only high-efficient systems (COP > 2.5) are eligible for funding should be evaluated, as our results show that both have a strong influence on the cost competitiveness of large-scale heat pumps.

Keywords: district heating, large-scale heat pumps, levelized cost of energy, CO2 price, support scheme

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.

District heating organizational models for a cost-effective energy transition

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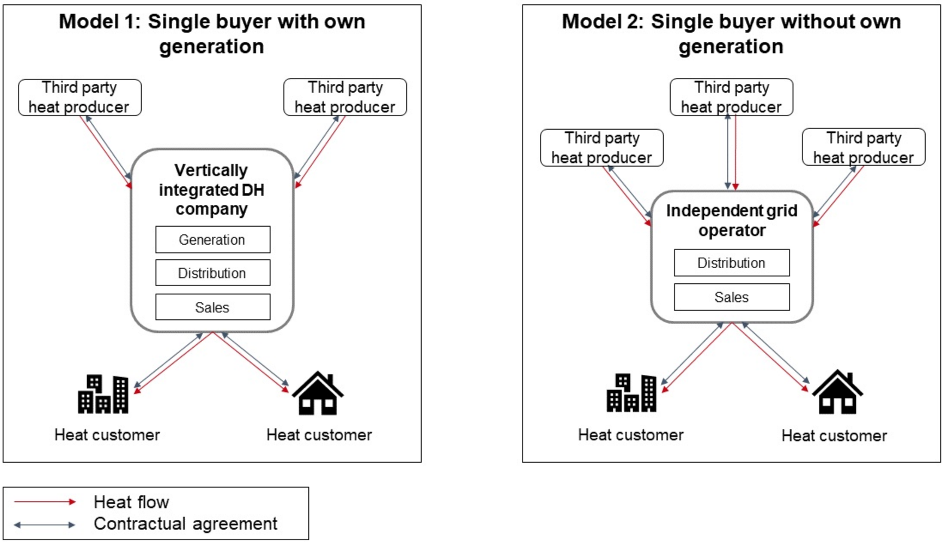
Enabling a cost-effective green transition is the central challenge in the district heating (DH) sector. Besides technical solutions, we must also find a suitable organizational model that is adaptive to the process of change. Previous studies lack a systemic evaluation of organizational concepts for district heating systems (DHSs) concerning their impact on a green transition and its cost-effectiveness. Therefore, an approach is presented which offers a global perspective on how different organizational models can impact the transition of DHSs.

The first step includes a systematic combination of possible elements for the organizational structure of DHSs such as third-party access or a liberalization on the customer side. This approach leads to five organizational models with different degrees of liberalization. A qualitative assessment discusses aspects and effects of their implementation, such as overall system costs, complexity, and feed-in conditions for third-party producers. Two models based on a single buyer (with or without own plants) are selected for further investigation that seem to be most promising to initiate and support the transition.

The two models allow a certain degree of competition and facilitate third-party access that could reduce the overall system cost and accelerate the investment in renewable heat generation. The aggregation of the heat distribution activities at the single buyer allows a system-wide optimization of the DHS. In both models, the chosen design has to secure a certain degree of transparency and fair access conditions for third-party producers to enhance the economic efficiency.

The research shows that new organizational models can accelerate the green transition in the DH sector by economy of scale and scope if certain conditions and processes are chosen accordingly. These processes must reduce the risk of market power, suboptimization, and investment risks. Therefore, the two chosen models will be investigated in more detail by implementing a digital marketplace which aims to reduce these risks. For a final evaluation of the benefits of economy of scale and scope, a macroeconomic evaluation should complement this investigation in the future.

Keywords: District heating systems, organizational models, green transition, third party access



Kristina Lygnerud works with district heating business modelling for low temperature applications. She is chair of the European knowledge hub of district energy, DHC+ and works as senior energy expert at IVL. Part of her time she is Adjunct Professor at Lund University.

Business models for low temperature district heating- 10 case studies

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Low temperature district heating (LTDH) has multiple benefits, such as low distribution losses, easier integration with waste heat and low-grade renewable energy to mention a few. Previous studies show that the added value of green DH, closer customer relationship and local heat supply; which are results of LTDH, tend to remain unexploited. Instead of developing a business model that is efficient for the LTDH solution the conventional, high temperature DH business model characterized by economy of scale and centralized production and distribution, is applied. Here, 10 implementations of LTDH innovations over a time horizon of 3 years have been studied.

Main results are (i) for all cases, the value of green has been important but only few cases capitalize on it, (ii) offering heat as a service is efficient in the LT context allowing the companies an increased control of customer assets allowing for optimization of the network and (iii) the business model for LT is characterized by increased interdependencies and shifting boundary conditions.

The LT heat source is either renewable or waste heat making such solutions inherently green. In the cases, the greenness of the installation was a main driver for undertaking the low temperature innovation. This is reflected in the value proposition of the business models. Service offers can have different extent. When they extend into the equipment of customers, the DH companies get the possibility to optimize equipment functionality allowing the removal of known errors and common malfunctions which benefits the overall operation of the system. LTDH installations often entail several low temperature

heat sources that are inserted into one network which necessitates an increased operational ability and a lower acceptance of system errors. Therefore, service alternatives appear to be particularly well suited for business models entailing LTDH. Services can also be challenging. One challenge is the additional complexity from new actions and interaction going beyond the traditional core business and by shifting the boundary condition to inside the customers building the amount of risk assumed by the district heating company increases: new risks in the business model appear and need to be managed between the parties.

Keywords: Business model, low temperature district heating, case studies

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.

Design of smart energy system for decarbonization leading areas in Japan

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While various measures are being implemented in Japan to decarbonise the country towards 2050 carbon neutrality, the national government (Ministry of the Environment) has selected the Leading Decarbonisation Regions as areas that will achieve decarbonisation by 2030, and has started implementing smart energy systems, mainly in the electricity sector. This section discusses the current status and efforts of regions to decarbonise in Japan, measures for realisation and future prospects, and examines the challenges they face. As specific target areas for decarbonisation and realisation of regional issues, the cases of Oogata Village, Akita Prefecture and Sosa City, Chiba Prefecture are taken up. In Oogata Village, the design of a district heating system that utilises agricultural residues, which are a local resource, as fuel, and a solar power generation system using on-site PPA(Power Purchase Agreement), etc., is being promoted for introduction by a local energy company. Furthermore, as a case study of Sosa City, Chiba Prefecture, the design of an off-site PPA using an Agrivoltaics technology that coexists with agriculture and contributes to regional revitalisation through community power is introduced, and the significance of the concept and issues are examined.

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.

Consumer empowerment in a time of change in the energy sector

Bent Ole Gram Mortensen, Professor, University of Southern Denmark and Lisa Hjerrild, Assistant Professor, University of Southern Denmark

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This abstract has a focus on consumer motivation, needs and challenges in the current energy market with the future transition uncertainties a head. In a time of energy transition and uncertainty consumer participation, acceptance and trust in the sector is more relevant than ever. It is stated that the most effective and least costly solutions are to be found when the energy sectors are combined, but it is also essential to put a light on the role of consumers and consumer empowerment as a relevant and powerful participant and stakeholder in the energy market.

The importance of the consumer role and their need to be able to control energy sources and prices was actualized in 2022, when consumer energy prices escalated dramatically. When it comes to renewable energy sources, consumers often have a dual role - as a consumer and as a citizen/neighbour. Regulation in the energy sector has a particular focus on regulating naturally monopolies and promoting investment in renewable energy sources. Only in recent years has there been a new focus on the role of the consumer in the development of energy systems. Focus on consumer wants and needs are starting to be reflected in the regulation. The challenge is the special requirements for the protection of consumers in consumer protection regulation and the fact that you want to liberalize and give consumers real free choice when choosing the family's energy supplier, whether it applies to electricity, natural gas/biogas, or district heating. Through an analysis of the current regulation of the consumer's role in energy regulation, requirements for the energy companies' communication to consumers, we will identify the challenges that the energy law regulation and the relevant institutions face in a future development and realization of a full sector integration based on 100 % renewable energy systems .

Keywords: Consumers, empowerment, regulation, challenges, institutions, energy, change

Dr. Christoph Neumann holds a Ph.D. in energy economics and a Master in business engineering. He was doing research in energy economics at the universities in Clausthal, Chicago and Sydney, worked as a research coordinator and at a DSO. Dr. Neumann is currently working as a senior advisor at TenneT.

Redispatch approaches in European power systems – towards harmonization or divergence?

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The need for redispatch in zonal systems is the consequence if the electricity transport requirement is not met with adequate grid expansion. The expansion and ongoing integration of RES is contributing to a rise in congestions in terms of volume as well as in terms of costs, as areas of high RES-potential are often far away from areas with high demand. Maintaining the zonal model in the EU's electricity markets means the use of redispatch measures to alleviate inner-zonal congestions and the associated question of an adequate remuneration for these services.

We conduct a survey on congestion management approaches across all transmission system operators which are part of ENTSO-E and summarize the so far non-public data in this paper. In particular we focus on four key aspects: (1) application of cost-and market-based redispatch in the different countries, also with regards to the integration of DSM and storage (2) core features of the redispatch product, e.g. minimum bid sizes (3) weather redispatch is a separated segment or combined with other market segments (4) what is remunerated if a market party is called for a redispatch measure, e.g. compensation for opportunity costs.

The analysis of the survey data serves as a basis to provide insights in best practices of redispatch approaches in European power systems. We answer where Europe is heading towards harmonization and if on certain areas individual approaches are dominating the practices of congestion management.

Keywords: Congestion Management, Redispatch, Transmission System Operator, Market Design

Marianne Petersen is an Industrial PhD fellow at Siemens Gamesa and the Technical University of Denmark. She is exploring different offshore hydrogen production pathways, cost optimization, revenue potential, time-varying uncertainties, and deliverability on large-scale offshore energy hubs.

Vision of Offshore Energy Hub at Faroe Islands: The Market Equilibrium Impact

First Author
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Background: With the climate crisis looming, it is crucial to accelerate the development of new technological pathways for sustainable energy production. Offshore Energy Hubs have been proposed as a potential solution to this issue, which could significantly shift offshore wind energy practices. For this analysis, the Faroe Islands will be used as a case study with the aim to assess the feasibility of incorporating offshore wind into the energy system and use electricity both for direct electrification and to produce hydrogen (H2). It is expected that the findings can be used to guide implementation of Offshore Energy Hub in the energy system for Denmark and potentially multiple countries.

Objective and method: The Faroe Islands heavily rely on fossil fuels for their energy needs today, leaving their energy system vulnerable to volatile oil prices, particularly for their marine industry. Therefore, this study aims to evaluate the feasibility of substituting fossil fuels with H2 production, where the Faroe Island can serve as a microcosm for larger regions. It is assumed that the H2 can be converted to ammonia or methanol for the transportation sector. The EnergyPLAN tool will be used to model three scenarios for the Faroe Islands' energy system:

1) 2020 reference scenario;
2) 2030 baseline scenario;
3) 2030 H2 scenario, using renewable energy for H2 production.

Market Economic Simulations are employed to assess the impact of different market mechanisms such as subsidies or economical support to the value chain of electrolyzer production.

Expected findings and conclusions: This feasibility study aims to answer the following research questions:
1) How will uncertainties in regulations impact decision making?
2) Under which market economic simulations can an offshore energy setup be feasible in an isolated island system?
3) Can the learnings be used to assess technology choices for larger regions considering hybrid offshore energy hubs?
The findings will provide insights into the potential of offshore wind becoming a key source of renewable energy for the Faroe Islands. This study will present policymakers and stakeholders with guidance on the need for support in the transition to a sustainable integrated energy system using energy from offshore wind.

Keywords: Offshore Energy Hubs, Faroe Islands, offshore wind, hydrogen, EnergyPLAN, renewable energy, feasibility study, market economic simulations, renewable energy subsidies, economical support

Lucy is a Consulting Engineer at FairHeat. Over the last 3 years her role has involved working on the design and operation of heat networks. She is currently working on the development a heat network technical quality assurance scheme that will form part of UK Government's regulatory requirements.

Development of a heat network typology for use within a heat network technical assurance scheme

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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 heat networks, leading to good consumer outcomes.

To enable certification through a regulatory HNTAS, heat networks need to be broken down into clearly defined elements. However, heat networks are complex systems, with multiple parts that are often designed, built, owned, and operated by different parties. The nature of how heat networks are designed, delivered, and operated often results in different parties involved at different stages and timeframes of the development of a heat network.

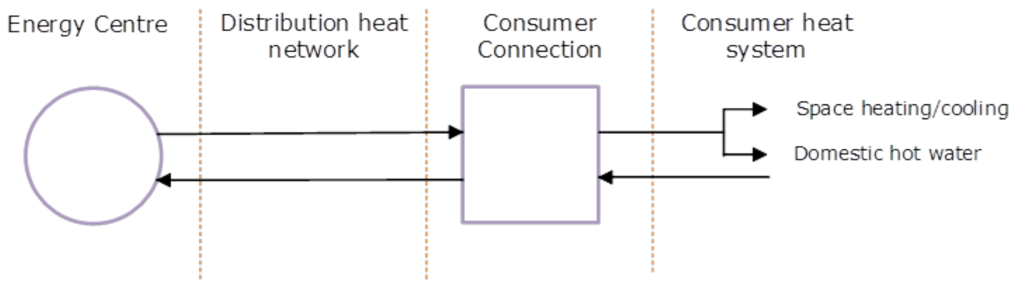
Whist developing clear definitions of heat network elements may seem a straight forward exercise on the face of it, the definitions within the Heat Networks: Code of Practice for the UK (CIBSE, 2020) does not provide granular enough definitions to allow clear delineation of responsible parties for each element across all heat network types. There is also some ambiguity in terminology used in the market within the UK and abroad.

Having reviewed industry standards, together with different case studies, it has been concluded that there are four constituent parts that are consistent across all heat networks – as shown in Figure 1.

These constituent parts of a heat network form the basis for the elements to be included within HNTAS. In total, six elements are defined: “Energy Centre”, “District Distribution Network”, “Communal Distribution Network”, “Thermal Substation”, “Consumer Connection”, and “Consumer Heat System”.

This work discusses how a heat network should be broken up into elements that can be checked and certified as part of a regulatory HNTAS. These technical minimum standards being introduced under HNTAS will underpin the forthcoming regulatory framework and will help take the heat network sector to the next level.

Keywords: Heat networks, district heating, certification, assurance scheme, regulation, industry standards, performance assessment, energy centre, thermal substation, distribution network, consumer



Former analyst in IEA, Green Energy and PlanEnergi. PhD from DTU Management where he is currently a postdoc. Focus is on economic and financial aspects of district heating. His research includes analyses of regulation of district energy in Nordics, Baltics and US.

End-users' up-front payments in district heating: Striking the balance between competitive price and long-term risk

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This study deals with the relation between the end-user and the district heating (DH) company: Striking the balance in designing an attractive up-front connection fee for the end-user, which maintains the project's feasibility from the company perspective.
We analyse this through interviews with DH plant managers and through economic modelling of key variables in a generic case.
In the modelling we explore a generic case, where a DH company would add up to 450 new households to its system. The below table shows part of the results: How the net-present value (NPV) of the project is impacted by the relation between connection fees and the share of end-users. Dotted and solid lines indicate relations between connection fee and share of connected end-users.

		Connection fee [kDKK/connection] incl. VAT, ex. substation										
	NPV [MDKK]	-	12.5	25	37.5	50	62.5	75	87.5	100	112.5	125
Share of end-users	30%	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-1
	40%	-9	-7	-6	-5	-3	-2	-1	1	2	4	5
	50%	-6	-4	-2	-1	1	3	4	6	8	10	11
	60%	-3	-1	1	3	5	7	9	12	14	16	18
	70%	0	2	5	7	10	12	14	17	19	22	24
	80%	3	6	8	11	14	17	20	22	25	28	31
	90%	6	9	12	15	18	21	25	28	31	34	37
	100%	9	12	16	19	23	26	30	33	36	40	43

The dotted line illustrates a project where a 40% connection rate yields a positive NPV, if the customers pay at least 87 500 DKK (11 700 EUR - 70% of the full connection fee's 125 000 DKK). At 70% connection rate, the project breaks even with DKK 0 in connection fee.

The red line shows a more direct relationship between connection fee and -rate. Assuming a willingness to pay at 50 000 DKK (40% of the full connection fee), the resulting -8 MDKK NPV makes the project infeasible. A reduction in the connection fee is thus a condition for the project to be implemented.
The lines are an indication of how good the financial buffer is in the project, and how much an effort for additional connection rate - and reduced connection contribution means for the company's finances.

Conclusions include:

- Relevant to explore end-users' willingness to pay regarding connection fee, as high willingness to pay decreases the needed connection rate
- End-users connecting to DH later in the project, e.g. increasing connection rate from 70% to 80% in year 15, cuts payback time from 17 to 15 years. The earlier "latecomers" arrive, the better for the project. This can be obtained through voluntary measures (campaigns and similar) or by mandatory connection (as seen in e.g. Denmark until the 2010s)
- The project is extremely sensitive to the cost of capital. A doubling of the borrowing rate more than doubles the project's cost, as rates have exponential cost impacts

Keywords: District heating, connection agreements, risk, finance, connection fees, end-users

Senior Engineer at FairHeat with 7 years' experience in the heat network sector. He has extensive experience in heat network QA with focus on new build heat networks. A Chartered Engineer with CIBSE, he is also Secretariat and Interim Technical Lead on the BESA HIU Test Standard Technical Committee.

Development of a new standardised testing regime to improve performance levels of residential heat interface units in the UK district heating market

Freddie Valletta, Senior Engineer at FairHeat, Secretariat and Interim Technical Lead on the BESA HIU Test Standard Technical Committee
Gareth Jones, Managing Director of FairHeat, Chair of BESA HIU Test Standard Steering Committee and Technical Committee
Phil Jones, Building Low Carbon Solutions, Member of BESA HIU Test Standard Steering Group Committee

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With 50,000+ Heat Interface Units (HIUs) being installed yearly in the UK, setting performance standards has become ever more important. A test standard for individual dwelling HIUs was launched in 2016, as part of UK government research into heat network efficiency. Following a round of initial testing, a steering group was formed that progressed the standard further to meet the needs of procurers. This steering group was (and still is) made up of representatives from all sides of the HIU testing process. It engages with stakeholders across the sector: developers, specifiers, procurers, manufacturers and installers to ultimately benefit the heat customer.

The Building Engineering Services Association (BESA) adopted the standard in 2017. It was revised in 2018 and a further update will be released in 2023. This new edition of the BESA UK HIU Test Regime has been created to assess the role and performance of HIUs in UK heat networks. It represents a major update to the standard and another crucial step forward for improving the overall performance of UK heat networks.

This consumer led initiative ensures that the HIU market is meeting the needs of stakeholders across the sector plus the heat customer. It aims to introduce a pragmatic and practical way of testing and comparing HIUs to provide a basis for assessing performance for those designing heat networks, whilst also raising the minimum performance of the HIU market.

The standard is now referenced within CIBSE CP1 (2020) UK Heat Networks Code of Practice and is widely accepted by manufacturers, with test results for 96 HIUs published from 31 manufacturers.

The standard is now being expanded to cover 7 HIU types and introduces minimum pass/fail performance requirements and further tests of operational performance. Considerable technical evidence has been developed in support of selected test parameters and conditions.

The standard has already driven significant industry R&D, with large performance improvements over the past 6 years, greatly on reducing carbon emissions and improving residential heat network services. It is expected that new edition's changes will take HIU performance to the next level. More importantly it demonstrates the positive impact that consumer led initiatives can have on the market.

Keywords: Heat interface units, district heating, low temperature district heating, 4th generation district heating, energy savings, industry standards, performance assessment, performance improvement

Zhe works at Aarhus University since 2022 as a project coordinator for the EU funded citizen science project AURORA, where she collaborates with various stakeholders to set up the solar energy community and crowdfund installation of solar panels on the rooftops of a few buildings at the university.

Challenges of setting up energy communities involving the Danish public sector: lessons learned

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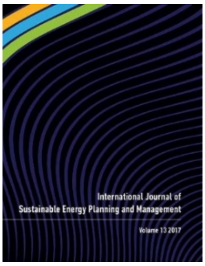
To achieve Europe's ambitious climate goals, energy communities (EC) are expected to play an important role. By providing opportunities for citizens, small businesses and municipalities to actively participate in the expansion of community-owned renewable energy infrastructures which provide the energy usage in the community, ECs differ from traditional energy suppliers and ensure economic, social and environmental benefits to citizens and their local area.

EU-funded citizen science project AURORA aims to set up 5 solar ECs located in Denmark, England, Portugal, Slovenia and Spain, respectively. In each case, a large public institution (a university or a district council) and the citizens who are associated with it aim to crowdfund a 200 kW rooftop photovoltaic installation (1MW in total). In particular, young citizens and marginalized groups who do not have enough financial means for their own rooftop photovoltaic installation are given the opportunity to co-own such installations through investments ranging from €20 to €1,000. As a result, the public institutions get access to locally produced clean energy while citizens get first-hand experience and knowledge with photovoltaic technology in addition to a small annual economic return.

In Denmark, a common form of EC is a cooperative. Wind and solar cooperatives existed in Denmark long before the concept of EC was introduced in EU legislation, setting good examples for developing future ECs. Despite this, we have faced both institutional and organizational challenges when setting up the solar energy community at Aarhus University. To name a few: legal barriers prevent the university from becoming an active EC member, the stakeholder matrix is complicated as a result of the ownership of buildings, and diluted responsibilities in a large institution lead to a less efficient decision-making process. In this presentation, we share the challenges of engaging public institutions in ECs in Denmark and the lessons learnt from the last one and a half years. We will also present the final legal framework for the energy community at Aarhus University, so that other public institutions can easily replicate the model and avoid unnecessary delays.Finally, initial learnings from the other AURORA communities are presented.

Keywords: energy community, community solar, solar cooperative, institutional change



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Comparison of Low-temperature District Heating Concepts in a Long-Term Energy System Perspective
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Flexible use of electricity in heat-only district heating plants
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Innovative Delivery of Low Temperature District Heating System
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Techno-Economic Assessment of Active Latent Heat Thermal Energy Storage Systems with Low-Temperature District Heating
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A spatial approach for future-oriented heat planning in urban areas
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Economic incentives for flexible district heating in the Nordic countries
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Economic comparison of low-temperature and ultra-low-temperature district heating for new building developments with low heat demand densities in Germany
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Development of an empirical method for determination of thermal conductivity and heat loss for pre-insulated plastic bonded twin pipe systems
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Developments in 4th generation district heating
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A multi-objective optimization analysis to assess the potential economic and environmental benefits of distributed storage in district heating networks: a case study
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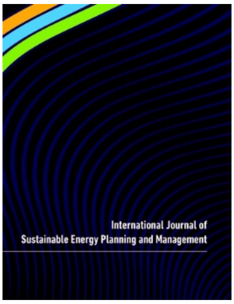
Modelling framework for integration of large-scale heat pumps in district heating using low-temperature heat sources
Henrik Pieper, Vladislav Mašatin, Anna Volkova, Torben Ommen, Brian Elmegaard, Wiebke Brix Markussen



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Energy system benefits of combined electricity and thermal storage integrated with district heating
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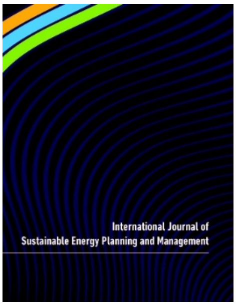

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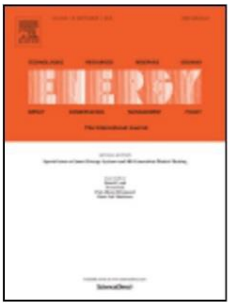

Energy, Volume 110 (1 September 2016)

Special issue on Smart Energy Systems and 4th Generation District Heating
Selected papers from the 1st International Conference on Smart Energy Systems and 4th Generation District Heating

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Low temperature district heating in Austria: Energetic, ecologic and economic comparison of four case studies
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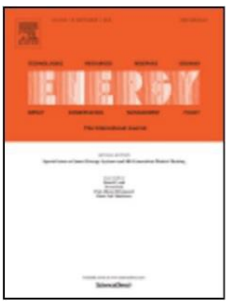

Energy (last update 21 September 2018)

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Dynamic modelling of local low-temperature heating grids: A case study for Norway
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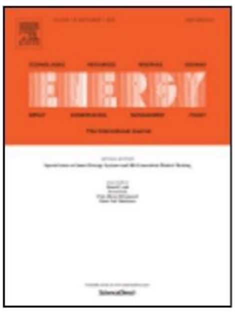

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Special issue on Smart Energy Systems and 4th Generation District Heating SES4DH 2017
Selected papers from the 3rd International Conference on Smart Energy Systems and 4th Generation District Heating

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Synthesis of recent Swedish district heating research
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Dynamic modeling of local district heating grids with prosumers: A case study for Norway
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Challenges and potentials for low-temperature district heating implementation in Norway
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Recycling construction and industrial landfill waste material for backfill in horizontal ground heat exchanger systems
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Pathway and restriction in district heating systems development towards 4th generation district heating
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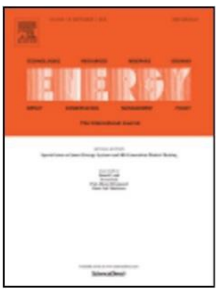

Energy (Last update 27 February 2020)

Special issue on Smart Energy Systems and 4th Generation District Heating
Selected papers from the 4th International Conference on Smart Energy Systems and 4th Generation District Heating

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Storage influence in a combined biomass and power-to-heat district heating production plant
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Trilemma of historic buildings: Smart district heating systems, bioeconomy and energy efficiency
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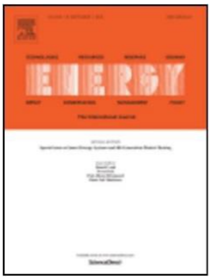

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Impact of network modelling in the analysis of district heating systems
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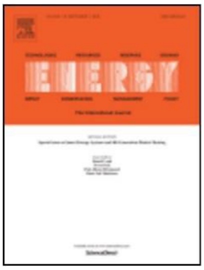

Energy (Last update 28 July 2021)

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Strategies for a transition towards a solar district heating grid with integrated seasonal geothermal energy storage
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Method of linear approximation of COP for heat pumps and chillers based on thermodynamic modelling and off-design operation
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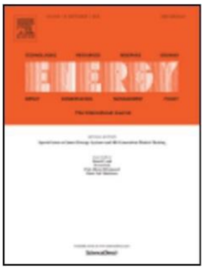

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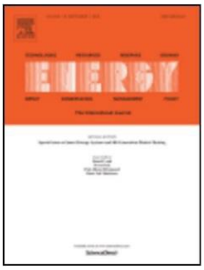

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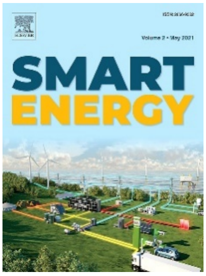

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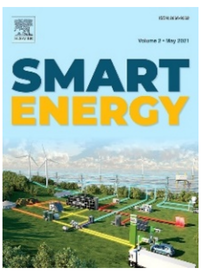

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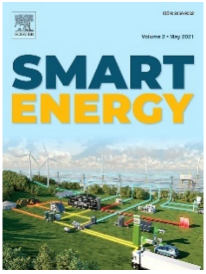

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