Summer School on
Communication Technology
and Data Analytics
for Future Energy Systems

11.-15. September 2017
Passau, Germany

Lectures
Workshops
Events

UNIVERSITÄT PASSAU

Gesellschaft für Informatik

DFG Research Training Group
ENERGY STATUS DATA
COLLECT · ANALYSE · UTILISE

KIT
Karlsruhe Institute of Technology

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Emergency Phone Numbers:
Police: 110
Fire: 112
Ambulance: 112
Non-Emergency Doctor on Call: 116 117

Overview

Arrival & Registration

MON, 11TH SEPT 12:00-13:30H

Arrival & Registration

University of Passau, IT-Zentrum (ITZ), Innstraße 43, 94030 Passau
Registration takes place at the same building as the following events. Storage for your luggage will be available on site on Monday (arrival) and Friday (departure).

Summer School Lectures

Location for all talks and lectures: University of Passau,
IT-Zentrum (ITZ), Innstraße 43, 94030 Passau

MON, 11TH SEPT 13:30-14:30H

Data Analytics in Practice - Tales from a Business Perspective

Keynote by Dr. C. Hinrichs
Doing data analytics for research on the one hand and for business needs on the other hand have a lot in common – but there are also differences. Coming from a former researcher who recently jumped ship, this talk gives some impressions from the business side of data analytics. In particular, key experiences from a handful of exemplary projects will be presented.

Dr. Christian Hinrichs (BTC Business Technology Consulting AG)

Christian Hinrichs graduated in computer sciences at the Carl von Ossietzky University of Oldenburg, Germany, before working as research associate in the Dept. of Environmental Informatics. His research focused on self-organized coordination and distributed heuristics in the domain of energy systems. After receiving his doctorate in 2014, he continued working in a postdoctoral position for another two years.

Since 2016, he is employed as Senior Consultant by BTC Business Technology Consulting AG, Germany, occupying the roles Data Scientist and Analytics Architect. A significant part of his work focuses on building cloud-based big data platforms for advanced analytics and smart data services.

MON 11TH SEPT 14:30-16:00H

Motivation and Need for Developing Energy Informatics

Lecture by Prof. H. Schmeck

The energy system is one of the critical infrastructures of our world. The reliable supply of energy is essential for the adequate operation of almost any process in our private and professional life, society and industry would suffer enormously, if the steady balance between demand and supply could not be guaranteed. The current transition towards energy from renewable sources is having tremendous effects on this well-established infrastructure. In particular, the restricted capabilities of controlling the supply of electricity from weather-dependent energy sources leads to the need for an essential change in one of the basic principles of the electric power system, which means that it will no longer be feasible to let the power supply follow the demand but there will be a strong need to let the demand follow the supply. This can only be achieved by discovering and exploiting the potential of flexibility of demand and supply in the best possible way.

The lecture will illustrate how the major challenges of the ongoing energy transition create the need for an adequately designed energy information and control network with distributed intelligence. A fundamental task in the design of this network consists of making the necessary information available to the locations where operating and control decisions have to be taken and to provide appropriate methodology for managing tomorrow's energy system in the most efficient and most reliable way. The appropriate design of information and communication technologies needs contributions from several areas of informatics, in close cooperation with control and power engineering as well as energy economics which is summarized under the name of Energy Informatics.

Prof. Hartmut Schmeck (Karlsruhe Institute of Technology)

Hartmut Schmeck studied at the Universities of Kiel (Germany) and Waterloo (Canada). He got his academic degrees (Dipl. Inform., Dr.rer.nat., Dr. habil) at Kiel. Since 1991 he is a Full Professor of Applied Informatics at the Karlsruhe Institute of Technology - KIT. He is (co-)author of more than 200 publications on advanced algorithms and architectures, in particular on nature-inspired methods in optimisation, algorithms for reconfigurable architectures, and, more recently, on self-organising, adaptive systems applied to energy and traffic systems.

He has been program and conference chair for numerous international workshops and conferences and coordinator of the German priority research program SPP 1183 on

"Organic Computing". As a principal investigator of several cooperative projects in various funding programmes he is pushing the development of intelligent systems in tomorrow's energy systems and for electric mobility, shaping the new discipline of "Energy Informatics", in particular as a director of the FZI Research Center for Information Technology.

MON, 11TH SEPT 16:30-18:00H (PART I)
TUE, 12TH SEPT 08:30-10:00H (PART II)

Communication Technologies for Energy Informatics

Lecture by Prof. S. Keshav

Future energy systems will be tightly coupled to communication and computation capabilities. The two lectures in this module will cover the following topics:

1) Communication requirements for energy systems
2) Communication architecture and its elements: LAN, gateway, backhaul, backbone
3) Local area communication technologies: WiFi, ZigBee/Z-Wave, Bluetooth, Wireless Mesh, IEC 61850, HomePlug
4) Backhaul communication technologies: PLC, WiMax, LTE, LoRa, SIGFOX

An overview of each of the technologies, along with its pros and cons compared to its competitors will be presented.

Prof. Srinivasan Keshav (University of Waterloo)

Professor S. Keshav received a B.Tech in Computer Science and Engineering from IIT Delhi in 1986 and a Ph.D. in Computer Science from the University of California, Berkeley in 1991.

He was subsequently a researcher at AT&T Bell Laboratories and, from 1996 to 1999, an Associate Professor at Cornell University. In 1999 he left academia to co-found Ensim Corporation and GreenBorder Technologies Inc. He was an Associate Professor at the University of Waterloo from 2003 to 2008 and has been a Professor since, holding a Canada Research Chair (2004-14) and the Cisco Chair in Smart Grid (2012-17).

An awardee of the Director's Gold Medal from IIT Delhi, the Sakrison Prize from UC Berkeley, two Test of Time awards from ACM SIGCOMM, and Best Paper awards at both ACM SIGCOMM and ACM MOBICOM, he is the co-director of the Information Systems and Science for Energy Laboratory, author of two graduate textbooks on computer networking, an Alfred P. Sloan Fellow, an ACM Fellow, and currently Chair of ACM SIGCOMM.

TUE 12TH SEPT 10:30-12:00H

Forecasts and Control for the Smart Grid

Lecture by Dr. S. Haben

The nature of our energy usage is changing with the increased uptake of low carbon technologies, more network visibility and ever reduced costs of storage technologies.

In order to create a true smart grid we must develop a network which can anticipate and plan rather than simply react when problems occur. Hence the future network must use accurate forecasting methodologies to facilitate the new technologies expected on the network. However, as we will show there are extra complications and surprises for modelling low voltage level demands.

In this talk we analyse low voltage network demand data to understand and identify the main features of such time series. We use this information to develop a range of transparent and accurate forecasting methodologies with the specific aim of using them to aid the control of storage devices. We will then demonstrate this with the control of storage devices, both in silico and real network trials. Finally we discuss the possibility and challenges of individual household level forecasts.

Dr. Stephen Haben (University of Oxford)

Stephen Haben is a post-doctoral research associate in the Mathematical Institute at the University of Oxford. He is also a member of the Oxford Centre for Industrial and Applied Mathematics (OCIAM). Since 2014 he has been an active member of the Industrially Focused Mathematical Modelling (InFoMM) CDT.

After completing his undergraduate mathematics degree at the University of Warwick in 2006 he completed a master in modern applications of mathematics at the University of Bath in 2007. In 2011 he achieved his PhD in the conditioning and preconditioning of variational data assimilation problem at the University of Reading before moving to the University of Oxford later in 2013.

His most recent work was as the academic project manager and lead researcher on the £30M low carbon network fund project the "Thames Valley Vision". On the project, Dr Haben investigated forecasting and mathematical analytical methods for low voltage network demand data for use in a number of applications including scenario forecasting, battery storage control and modelling with limited data.

Since 2012 he has been the co-organiser of 4 low voltage demand workshops which

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focus on forecasting, control and analytical methods applied to low voltage network demand data. In 2014 he was on a prize winning team for the Global Energy Forecasting Competition 2014. His interests include forecasting, clustering methods, optimization, data assimilation, kernel density estimation, quantile regression and error measures.

TUE 12TH SEPT 13:30-15:00H

Towards Better Privacy for Energy Status Data

Lecture by Prof. K. Böhm

Without adequate precautions, a lot of information can be inferred from energy-status data. This puts privacy at risk. Numerous approaches to shield from this unwanted effect have been proposed. In my presentation, I will give attention to approaches at the data level. In particular, I will focus on two approaches which have recently been developed at my chair. While in both cases data is perturbed in order to hide person-related information, the approaches are different: In the first case, energy-consumption data is perturbed with the help of an energy-storage device and proper charging strategies. In the second case in turn, perturbation is directly on the data, in order to meet individual privacy requirements in the best possible manner.

Prof. Klemens Böhm (Karlsruhe Institute of Technology)

Klemens Böhm is full professor (chair of databases and information systems) at the Karlsruhe Institute of Technology (KIT), Germany, since 2004. Prior to that, he has been professor of applied informatics/data and knowledge engineering at University of Magdeburg, Germany, senior research assistant at ETH Zürich, Switzerland, and research assistant at GMD – Forschungszentrum Informationstechnik GmbH, Darmstadt, Germany.

Current research topics at his chair are knowledge discovery and data mining in big data, data privacy and workflow management. Klemens gives much attention to collaborations with other scientific disciplines and with industry. He is the speaker of the DFG research training program 2153 "Energy Status Data – Informatics Methods for its Collection, Analysis, and Exploitation" at KIT.

OpenGridMap: Crowdsourcing Power Grid Data

Lecture by Prof. H-A. Jacobsen, Dipl. Ing. J. Rivera

The energy transition requires profound changes to the power grid, both on the transmission and distribution level. The ability to assess the impact of these changes, e.g., the integration of more solar power or electric mobility, requires data and tools that only exist partially today.

OpenGridMap is a project that crowdsources realistic power grid data to be used for research purposes. The goal is to create an open platform for inferring real power grids based on open data. Our vision is to provide a tool to researchers and practitioners that is able to produce realistic input data for simulation studies. OpenGridMap supports the entire process from data collection to formatting grid data for various purposes. We explore innovative ways to capture data and produce power grid approximations, e.g., using smartphone apps, expert classification, existing map APIs, and graph inference algorithms. The latest developments of the project can be found at opengridmap.com.

Prof. Hans-Arno Jacobsen (Technical University of Munich)

Hans-Arno Jacobsen is a professor of Computer Engineering and Computer Science and directs the activities of the Application and Middleware Systems Research Group. He conducts research at the intersection of distributed systems and data management, with a particular focus on middleware abstractions, (complex) event processing, and cyber-physical systems.

After studying and completing his Ph.D. in Germany, France, and the U.S., he engaged in post-doctoral research at INRIA near Paris, before moving to the University of Toronto in 2001. In 2011, he was awarded the Alexander von Humboldt-Professorship to engage in research at TUM in Germany on "Energy Informatics."

Dipl. Ing. Jose Adan Rivera Acevedo (Technical University of Munich)

José Rivera received the B. S. and the Dipl.-Ing. degree in electrical engineering and information technology with a specialization in control and power systems from the Technical University Munich (TUM), Germany, in 2010 and 2012 respectively. Until his graduation, he interned at Siemens Corporate Technologies in the area of peer-to-peer computing, grid technologies and control systems. He was also a visiting student at the Massachusetts Institute of Technology (MIT) in the Laboratory for Information and Decision Systems (LIDS). Currently, he is a pursuing his Ph.D. at TUM.

His research interests include distributed systems, stochastic optimal control, power systems management and renewable energy grid integration.

WED, 13TH SEPT 10:30-12:00H

Data Analytics for Smart Cities

Lecture by Prof. D. Neumann

The public value of information technology has received increasing attention in recent years. While most research focuses on mediating e-government technologies, we investigate potential benefits of Big Data and analytics in public sector decision-making. Specifically, we present a demonstration showcase of a spatial analytics application developed to optimize strategic investments into urban electric vehicle charging infrastructure. Based on data from Amsterdam, we quantify the benefits of data-driven decision support in the public sector. Our results show that analytics helps cities to manage the trade-off between economic and ecological value more efficiently. We also suggest that analytics may improve the legitimacy of public sector decision- making through objective, data-driven criteria. Furthermore, our study provides insights into potential benefits of open data platforms that are part of many smart city transformations.

Prof. Dirk Neumann (University of Freiburg)

Dirk Neumann (dirk.neumann@is.uni-freiburg.de) holds the Chair of Information Systems of the University of Freiburg, Germany. His research topics include business analytics, text mining and optimization. He studied information systems in Giessen (Diploma) and Economics in Milwaukee, U.S. (Master) and earned a Ph.D. from Karlsruhe Institute of Technology in 2004.

WED, 13TH SEPT 13:30-15:00H

Flexibility Modeling for Power Systems

Lecture by Prof. A. Weidlich

In addition to discussing what technical units in the power systems can deliver the flexibility to balance out fluctuations from renewable energy feed-in and what their technical constraints are, the different market roles in the energy systems and the information flow between these market roles will be discussed, to show the complexity of flexibility provision and accounting in an unbundled power system.

Prof. Anke Weidlich (University of Freiburg)

Anke Weidlich is a professor for Technologies of Energy Distribution at the University of Freiburg. Before, she was a professor for Energy Economics and Energy Systems Technology at the University of Applied Sciences in Offenburg from 2011 until 2017. Ms. Weidlich gained industry experience as a senior researcher and project leader in the domain of Smart Grids at SAP AG (today: SAP SE). Prof. Weidlich studied Industrial Engineering and Business and then pursued advanced studies in Energy Economics and Energy Policy in Paris. She pursued PhD studies at the University of Karlsruhe (today: Karlsruhe Institute for Technology KIT), with stays in the USA and in Mannheim.

THU, 14TH SEPT 08:30-10:00H

Requirements Engineering for Energy Information Systems

Lecture by Prof. S. Lehnhoff

Future energy systems will rely heavily on ICT- and automation systems. The scope of functions to be supported by these energy information systems is broad – ranging from mere billing purposes (e.g. by advanced metering infrastructures), the planning and optimization of a pool of decentralized energy sources (e.g. a virtual power plant made up of combined heat and power plants), to providing safety-critical ancillary services in (e.g. frequency response) by flexible power electronics. The non-functional requirements to be fulfilled by the ICT-system are equally diverse – data and information have to be exchanged e.g. in due time, with the necessary precision, while meeting certain service level agreements etc.

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With a vast variety of technical standards and solutions to choose from – at nearly arbitrary costs – a systematic approach is necessary to decide which particular energy information system realization is the ideal (e.g. cost efficient) one for a set of given Smart Grid use cases and when an ICT-based would not be feasible at all.

In this tutorial we will cover a use case-based requirements engineering methodology based on IEC PAS 62559, structurally mapping functions onto the European Smart Grid Architecture Model (SGAM) – with multiple practical examples.

Prof. Sebastian Lehnhoff (University of Oldenburg)

Sebastian Lehnhoff is a Full Professor for Energy Informatics at the University of Oldenburg. He received his doctorate at the TU Dortmund University in 2009. Prof. Lehnhoff is a member of the executive board of the OFFIS Institute for Information Technology and speaker of its Energy R&D division. He is speaker of the section "Energy Informatics" within the German Informatics Society (GI), assoc. editor of the IEEE Computer Society's Computing and Smart Grid Special Technical Community as well as an active member of numerous committees and working groups focusing on ICT in future Smart Grids. He is an honorary professor of the School of Information Technology and Electrical Engineering at the University of Queensland. Prof. Lehnhoff is elected chair of the of the IEEE CA4EPI Working Group P2030.4, and chairman of the architecture and quality committee of the openKONSEQUENZ industry consortium for the development of open source software in power system operation. Prof. Lehnhoff is author of over 100 refereed and peer-reviewed scientific publications.

His research interests focus on the large-scale integration of decentralized, renewable energy sources into the electricity supply system in combination with the politically motivated reorganization of corporate structures and business processes. The Energy Informatics group in Oldenburg develops ICT-technologies for a future reliable, robust, profitable electricity supply system based on renewable energies – the Smart Grid. Key issues are:

- Open communication standards and data models to ensure the interoperability of IT-architectures.

- Real-time methods for automating the distribution network to enable distributed plants at lower voltage levels to provide ancillary services.

- Distributed algorithms for decentralized resource planning within distribution networks to increase flexibility.

- Methods and tools to assess and support changing ICT-corporate architectures of energy supply protagonists.

- Methods for simulation and automated analysis of large-scale integrated multi-domain energy systems.

THU, 14TH SEPT 10:30-12:00H

Modelling the Electricity Transmission Network with High Shares of Renewable Energy

Lecture by Dr. T. Brown

In this talk we present the necessary background for modelling the flow of power in the electricity transmission network. We combine the equations for power flow in an optimisation model for expanding generation and transmission capacities at minimal cost, while reaching targets such as CO_2 reduction. We present datasets for the European power system as well as software tools for performing the optimisation. Results from simulations for Europe with a 95% reduction in CO_2 levels compared to 1990 are analysed with regard to investment decisions, dispatch, network flows, CO_2 prices and market prices.

Dr. Tom Brown (Frankfurt Institute for Advanced Studies)

Tom Brown completed his BA and MMath in mathematics at the University of Cambridge in 2004 and 2005 respectively. After a PhD in physics at Queen Mary, University of London in 2009, he continued his physics research as a Postdoctoral Researcher at DESY, Germany. In 2012 he switched fields to work on power systems at consultancy firm Energynautics GmbH, and since 2015 he has been working as a Postdoctoral Researcher on the grid integration of renewable energy at the Frankfurt Institute for Advanced Studies.

His research focuses on system planning for high shares of renewables, including the requirements for the expansion of the transmission grid, flexibility options and coupling to other energy sectors such as transport and heating. He is an advocate of open data and software in the energy modelling community and is one of the lead developers of the widely-used free software tool Python for Power System Analysis (PyPSA) (https://pypsa.org/).

FRI, 15TH SEPT 08:30-10:00H

Modelling Basics and Co-Simulation of Communication and Power Systems

Lecture by Dr. F. Kupzok

This lecture takes a closer look on typical modelling approaches for both electrical and ICT components in a digital power system. Practical and theoretical challenges in co-simulation of controls, communication and power system are discussed (models of computation, synchronization approaches, widely used co-simulators). An example use case (voltage control with a on-load tap changer transformer based on remote measurements) is discussed.

Dr. Friedrich Kupzog (Austrian Institute of Technology)

Dipl.-Ing. Dr.techn. Friederich Kupzog holds a Diploma Engineer degree of electrical engineering and information technology from RWTH Aachen. In 2006, he joined the Institute of Computer Technology at TU Wien, Austria, where he achieved his PhD Degree in 2008. Until 2012, he stayed at the university as Post-Doc and built up the research group "Energy & IT" at the Institute of Computer Technology.

Since 2012, Dr. Kupzog is Senior Scientist at the AIT Austrian Institute of Technology GmbH. His research interest lies in verification methods for networked Smart Grid systems. He coordinates the research field "Power System Digitalisation" within AIT, consisting of research projects together with industry, power grid operators and other partners.

Dr. Kupzog holds lectures in Smart Grid related topics at Vienna University of Technolgy and other universities and is active in national (ComForEn) and international (IEEE IECON, IEEE/CIGRE EDST, D-A-CH Energieinformatik) scientific conference organisation. He was awarded the Austrian Smart Grid Pioneer Award together with his colleagues in 2010 and 2012.

Summer School Workshops

Location for all Workshops: University of Passau, IT-Zentrum, Innstraße 43, 94030 Passau

TUE, 12TH SEPT 16:30-18:00H

Models and Ontologies for Energy Systems - CIM and Beyond

Workshop by Dominik Werle

In this workshop we will first look at the way ontologies are used in the context of future energy systems and different standards that are used for describing the information exchange in and the structure of those systems (Common Information Model, IEC-61968/61970, IEC-62056).

Furthermore, we will also touch on related standards (such as IEC-62559) and place them in the bigger picture. This will also encompass a short introduction into the underlying concepts such as OWL, UML, XML and RDF. In the second part, we investigate analyses based on these descriptions, methods for extracting information from models that use these formats, and on ways to create domain specific languages and tooling for own graphical or textual modeling languages that are interoperable with the standardized formats.

WED, 13TH SEPT 16:30-18:00H

Power Grid Quality Modeling

Workshop by Wolfgang Duschl

Increasing use of electronic devices in industry, household, distribution network, as well as changes in the supply structure (e.g., decentralized renewables) have a major impact on the power quality (PQ). Laws, directives and standards in the European internal market in the field of PQ and electromagnetic compatibility ensure a standardized character, where manufacturers and users of electrical devices benefits from.

Due to the huge relevance of the PQ for a stable power grid operation and the occurrence with the help of ICT infrastructures to carry out regulation measures, this workshop will provide an overview of the background, the challenges and the solutions Bayernwerk is currently using in his power grid. Electromobility is the new challenge for distribution networks. The Electrific project deals with the two main focus areas: providing customer services and a demand response systems within the framework of e-mobility. In the second half of this workshop, the project background as well as our solutions for the intelligent integration of electric vehicles will be presented.

THU, 14TH SEPT 13:30-15:00H (PART I)

Energy Time Series Storage and Analytics (I)

Workshop by Michael Vollmer, Holger Trittenbach

Energy status data, for example collected from smart meters, is often a time series of large volume and high velocity. It is a challenge to collect, process and store this data and make it efficiently retrievable for researchers.

In this workshop, we give an overview how to design an end-to-end system for this purpose with state-of-the-art technology such as time-series databases and distributed computing frameworks. We provide both conceptual considerations and practical insights based on a real world use case.

THU, 14TH SEPT 15:30-17:00H (PART II)

Energy Time Series Storage and Analytics (II)

Workshop by Adrian Englhardt, Edouard Fouché, Vadim Arzamasov

In the near future, wind and photovoltaic systems will have a large share in electricity production in Europe. Electricity production based on these technologies is weather dependent, which is a challenge for energy systems and markets. As a result, an accurate forecast of such energy production in the near future (1 day to 1 week) is crucial to control grid stability and ensure smooth operations on energy markets.

In this workshop, short- to middle-term weather and energy time series forecasting will be conducted on publicly available data. Several methods will be presented, ranging from ARIMA models to recurrent neural networks. Participants will get a practical introduction using Python and Jupyter Notebooks, and the code of the workshop will be made available to the participants.

FRI, 15TH SEPT 10:30-12:00H

Digital Approaches to Increase Renewable Hosting Capacity of Distribution Grids

Workshop by Dr. F. Kupzog

In the workshop, a simplified model of a distribution network is put together by the students, simulating the voltage control use case covered in the lecture. The power network model is based on the simplified assumption, that node currents do not change with the node voltage, allowing a non-iterative load flow calculation in Excel. Load profiles, line loading and node voltages are calculated based on different active control approaches. Students gain knowledge about typical dimensioning of power systems, ICT requirements of smart grid solutions and their comparison.

FRI, 15TH SEPT 13:30-15:00H

Smart Meter Privacy - Legal and Technical Aspects

Workshop by Rebecca Schwerdt and Jan Ullmer

The development towards a smart electricity grid and the necessary modernization of the metering infrastructure has led to increasing concerns regarding security and reliability of the intended system. Especially the protection of energy customers' personal data has been a source of reservations.

Germany therefore took a very thorough approach from a legal as well as technical perspective to ensure security and adequate protection of personal data in the energy sector. This led to a very detailed and complex legal and technical framework for the future smart metering infrastructure.

In this workshop we provide a comprehensive overview of the legal and technical requirements for smart metering in Germany focusing on data protection aspects.

Social Events and Meals

MON, 11TH SEPT 18:00-19:00H

Welcome Reception

University of Passau, IT-Zentrum, Innstraße 43, 94030 Passau

On the first evening of our summer school week a welcome reception will be held directly after the last lecture of the day (location in the same Building).

TUE, 12TH SEPT - FRI, 15TH SEPT 12:00-13:30H

Lunch

University of Passau, Mensa, Innstraße 29, 94030 Passau

All regular lunches during the Summer School week will take place at the Mensa (Canteen) of the University of Passau.

WED, 13TH SEPT 19:00H

Summer School Dinner

Restaurant „Das OBERHAUS" Passau, Oberhaus 1, 94034 Passau

Our Summer School Dinner will take place at the well-known Restaurant „Das OBERHAUS" in Passau where traditional Bavarian cooking meets modern cuisine.

Special bus shuttle available:

- From University of Passau to Oberhaus: Departure 18:30h

- From Oberhaus back to Central Bus Station Passau (ZOB Passau): Departure 23:30h

THU, 14TH SEPT 18:00H

Guided City Tour (Walk)

Meeting Point City Tour: Rathausplatz 2, 94032 Passau

The guided city tour will give you the opportunity to get to know the city of Passau. Also known as the „Three Rivers City" Passau has a rich history and tradition and a beautiful Old Town that we will dicover during our walk.

The City Tour is supported by:

fenecon
ENERGY ENGINEERING