Faszination **Forschung**

TUM Research Highlights
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Circular Economy: Too Good to Go

Earth System Modeling – Will Our Climate Suddenly Tip?
Artificial Intelligence – How Medical AI Can Become Trustworthy
Climate Neutrality – How Can We Achieve the Heat Transition?

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WE WALK THE TALK

TUM Sustainability Day
June 12, 2024

www.tum.de/sustainability

Through our **TUM Sustainable Futures Strategy 2030**, we are helping our university to shape and drive sustainable development – in scientific, economic, environmental and social terms. However, this endeavor can only succeed if we work together. We invite you to explore the range of sustainability activities underway at our university on TUM Sustainability Day: an opportunity to find inspiration, grow your network and get involved.

Garching research campus, Mechanical Engineering building, Boltzmannstrasse 15. Start: 12:00pm

Dear TUM friends and associates,

Are you familiar with William Anders' iconic image, 'Earthrise'? The astronaut took the photograph during the Apollo 8 mission in 1968: it shows our planet, illuminated by the Sun, floating in space. For me, this image also symbolizes just how fragile our planet is. The challenges posed by climate change and resource depletion continue to grow. If we are to maintain our economic prosperity while staying within environmental limits and upholding social justice, we need to find solutions.

We must preserve the very fundamentals of life for future generations – and that's precisely what numerous researchers at TUM are striving to do. This issue, which is in part devoted to topics such as the circular economy, details some of these researchers and their work. At present, our economy is based on a linear growth model of acquisition, production, consumption and disposal. The concept of the circular economy offers a resource-conserving alternative, replacing the end-of-life concept with reduction, reuse, recycling, recovery and returning materials to the production, distribution and consumption processes. The TUM Mission Network CirculaTUM concentrates our expertise on this topic across all disciplines and so, to my mind, represents a crucial part of our innovation agenda. Magnus Fröhling and Johannes Fottner have masterminded the foundation of CirculaTUM, and this issue introduces both of them. Fossil-free energy supplies are also vital to building a sustainable future. With Europe aspiring to become the first climate-neutral continent by 2050, this issue also features scientists' reports on how this target can be achieved. Kai Zosseder, for example, highlights the potential of geothermal energy. Thomas Hamacher examines energy systems as a whole and Christian Hepf investigates how digital solutions can contribute.

As a flagship university in Germany, we not only work to research sustainable innovations but also strive to undertake a sustainable transformation ourselves. With this in mind, I have appointed a Vice President for Sustainable Transformation: Werner Lang, an internationally recognized expert in sustainable construction. He is convinced that interdisciplinary research has a key role to play in promoting sustainability and, in this issue, explains how well positioned TUM is to achieve this through its School-based structure. Finally, Prof. Lang and I would like to invite everyone to TUM Sustainability Day on June 12, 2024. This is an opportunity for you to learn more about our TUM Sustainable Futures Strategy 2030 – and get involved yourself.

Now, dive into the world our scientists are building: I hope you enjoy reading this issue and find a wealth of new inspiration and insights!

Yours sincerely,

Thomas F. Hofmann
President

Picture credit: Astrid Eckert/TUM

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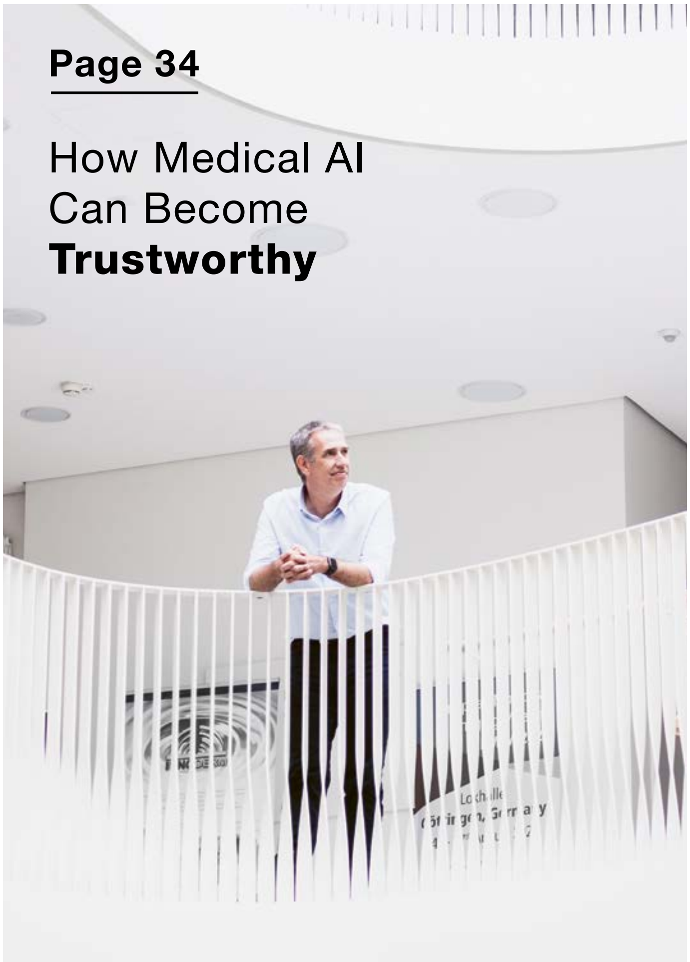

Picture credits: Magdalena Jooss, Juli Eberle

In every Issue

How Close is the **Point of No Return?**

Will our climate suddenly tip if we continue with business as usual? If so, how soon could it come? How fast would it happen? And what would the consequences be? Niklas Boers, Professor of Earth System Modeling at TUM, is working with his team to find answers, applying mathematical methods to describe how the Earth's climate works. The researchers use past climate data to test their models and try to produce forecasts. For his part, TUM mathematician Prof. Christian Kuehn makes sure that the entire project is on a sound theoretical footing.

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung

Wann gibt es keinen Weg mehr zurück?

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Auf der Suche nach Kipppunkten des Klimas: Im Rahmen des europäischen Programms TiPES beschreiben Niklas Boers, Professor für Erdsystemmodellierung an der TUM, und sein Team mit mathematischen Methoden, wie das Klima unserer Erde funktioniert. Sie testen ihre Modelle an Daten aus der Vergangenheit und versuchen, damit Prognosen zu erstellen. Dabei legen sie besonderes Gewicht auf Kipppunkte, die das Klimasystem abrupt verändern. Der TUM Mathematiker Prof. Christian Kuehn sorgt dafür, dass das Ganze auch theoretisch auf verlässlichen Beinen steht.

Das Klimasystem unserer Erde ist nicht das einzig mögliche stabile, sondern es kann unterschiedliche Varianten geben, zum Beispiel warme und kalte Zustände. Dazwischen gibt es Kipppunkte, an denen das Klima relativ schnell von einem in den anderen Zustand wechseln kann. Paläontologen fanden darauf Hinweise, zeigen doch geologische Befunde, dass sich früher warme Phasen und Eiszeiten mehrfach abwechselten.

Mathematisch gesprochen stellen Kipppunkte (englisch: Tipping Points) kritische Schwellenwerte dar, deren Überschreiten den Zustand oder die Entwicklung eines Systems abrupt und nachhaltig verändert. □

Picture credit: Magdalena Jooss

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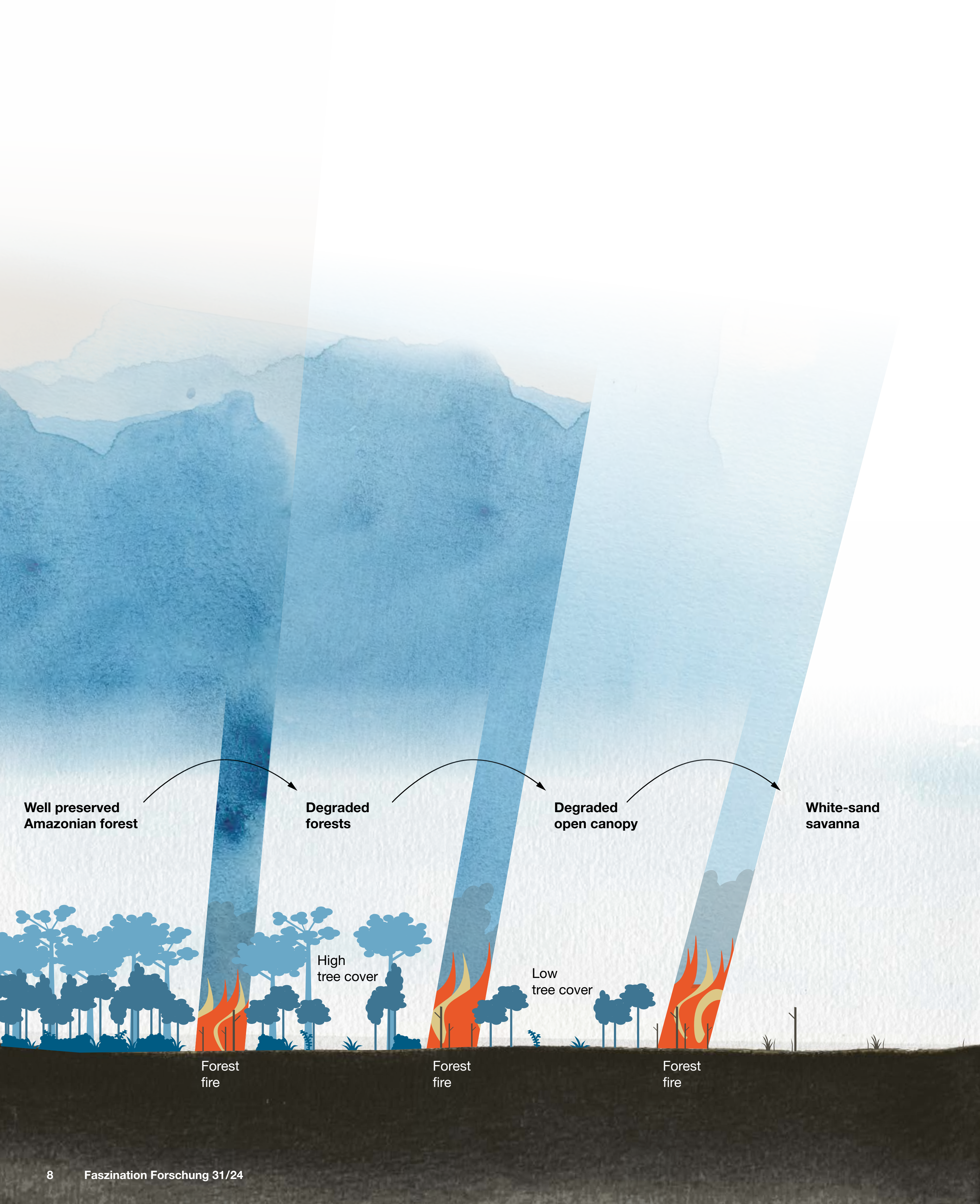
www.asg.ed.tum.de/esm

www.tipes.dk/

www.math.cit.tum.de/math/personen/professuren/kuehn-christian/


Well preserved
Amazonian forest
Degraded
forests
Degraded
open canopy
White-sand
savanna
High
tree cover
Low
tree cover
Forest
fire
Forest
fire
Forest
fire

If scientists are sometimes accused of sitting in ivory towers without any real connection to the real world, Niklas Boers is the perfect counterargument. He combines mathematics and theoretical physics with issues that could hardly be more pertinent at present: together with his team, Boers is investigating how the Earth's climate system will develop in the future.

Boers reached a point at which he no longer enjoyed working with pure theory, so looked for a practically relevant field for his doctoral thesis. "That's how I came across climate modeling," he recalls. Today, the 39-year-old mathematician and theoretical physicist is among the leading researchers in his field and has set his sights on an utterly fascinating topic with implications for the future of all humanity: tipping points in the climate system. His achievements to date include setting up the large-scale TiPES project in which 18 universities and research laboratories from ten European countries collaborate. Its successor project, ClimTip – which Boers will coordinate from TUM – started on March 1, 2024.

Graphics: ediundsepp (source: TUM)

The tipping of the rainforest into a savanna-like state is an iterative process associated with positive feedback. Deforestation and forest degradation reduce the moisture content in the system, increasing the probability of fires. Fires in turn thin out the undergrowth vegetation and the soil becomes drier, which favors the formation of new fires, clearing the vegetation further, and so on.

The rainforest is under threat

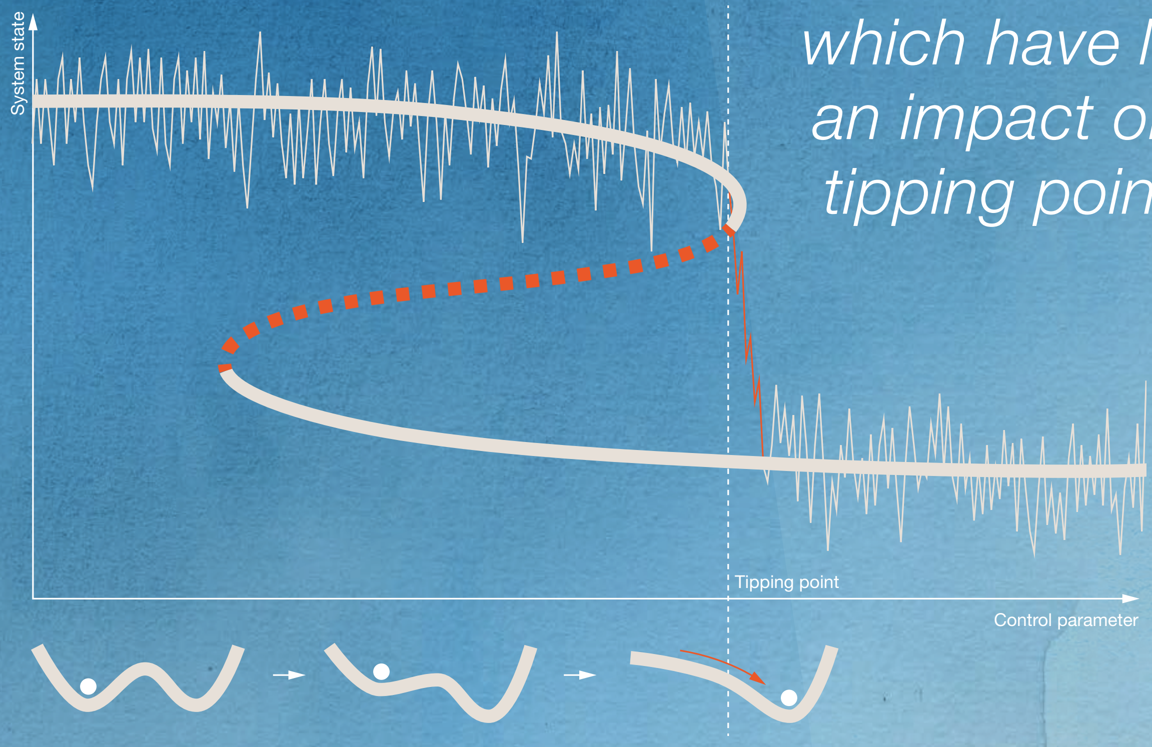
"The idea for TiPES came about in 2015 during my time as a postdoc with Michael Ghil at the École Normale Supérieure in Paris," says Boers. Ghil, an Israeli-American mathematician and physicist, is considered one of the founding fathers of theoretical climate dynamics. Even as early as the late 1970s, he understood how to develop mathematical models for air and water flows to describe key climate phenomena. He continued to refine these models over the years, applying state-of-the-art mathematical instruments. In his calculations, Ghil recognized that our Earth's climate system is not the only possible stable state: instead, there are different variants, such as warm and cold states. Between these states, there are tipping points at which the climate can shift relatively swiftly from one state to another. Paleontologists have long suspected as much, and geological findings indicate that the Earth has alternated between warm phases and ice ages many times. In mathematical terms, tipping points are critical thresholds; exceeding these thresholds triggers abrupt, lasting transformations in the state or development of a system.

One obvious example that is particularly relevant at present is the deforestation of the Amazon rainforest. Vast amounts of water circulate in this ecosystem and are exchanged between the atmosphere and rainforest, which leads to extensive rainfall. However, as people continue to clear the forest, the amount of water transported in the air decreases. Eventually, the situation will reach a tipping point at which the ecosystem as a whole dries out and irreversibly collapses – with grave consequences not only for its flora and fauna but also for the regional and global climate. This tipping process could happen within a few decades.

Researching these tipping points and, if possible, producing forecasts is the stated aim of two EU Horizon projects, TiPES and ClimTip. In an arduous process, Boers secured the cooperation of Europe's leading researchers in the field. "It's like a huge mosaic. Everyone knows what they can do best, so we exchange ideas intensively and bring everything together at the end," says Boers, who is Associate Coordinator of TiPES. The project received €8.5 million of funding and concluded on February 29, 2024, after a four-and-a-half year term. ClimTip is set to be even more extensive, with Niklas Boers coordinating the project. ▷

"We are researching which parameters should be given particular attention in simulations and which have less of an impact on such tipping points."

Christian Kuehn



A very simple example of a tipping point is how a ball behaves in a potential well. So long as the walls of this well remain relatively steep, after being deflected the ball will always roll back to its starting point. If a system parameter changes in such a way that these walls flatten, the probability increases that the ball will roll out of this potential well and fall into a neighboring well, from which it cannot return. Thus, it would have passed a tipping point. Even if the original well were restored by resetting the system parameter, the ball would remain in its new state. Mathematically, such behavior is called bifurcation, and the value of the control parameter at which the system jumps to another state, known as the bifurcation or tipping point. If the control parameter resumes its original values, the system remains in its new state. Climate modelers are now trying to find out whether such flattenings can already be observed in the climate measurements before a possible tipping point .

What data matters – and what doesn't?

Climate models are extremely complex constructs that push the limits of available computer power. Consequently, researchers rely on the most powerful supercomputers on the planet for their model calculations, some of which require months of computation time. The results can show how climatic changes, which often accumulate over many years, can suddenly escalate and reach a tipping point – from which there may be no return. In this context, physicists and mathematicians talk about feedback and non-linear dynamics, while the resulting "bifurcations" are a mathematical concept to describe abrupt transitions in the Earth system.

Probability calculus meets non-linear dynamics

Christian Kuehn uses theoretical methods to examine the reliability of climate models. "In principle, there are two different ways to look at the world in mathematical terms."

On the one hand, scientists can trace physical processes based on their deterministic laws. However, the resulting values can entail certain uncertainties due to perturbations caused by external influences (noise). These perturbations can amplify each other or cancel each other out. It is therefore important to consider the potential uncertainties involved in every result.

The alternative is to consider all processes as probabilities, like a die that randomly shows numbers. The interaction of these probabilities can be used to derive certain laws, and any result must be accompanied by the probability of its occurrence. So, while certain tipping points might be highly improbable, if they were to occur, the consequences would be catastrophic (high impact, low probability).

"The reality lies somewhere between the two," says Prof. Kuehn, who is therefore developing a combination of non-linear dynamics and probability theory to make his models more robust.

Being able to simulate such complex issues on computers at all requires many simplifications. At this point, a number of fundamental questions arise: "Can we even do that? Does that work? What impact will it have?" So, in order to ensure that such computer models are reliable from a mathematical perspective, and describe reality as accurately as possible rather than producing artificial effects, Niklas Boers collaborates with Christian Kuehn. The 41-year-old mathematician worked at various prestigious mathematical research institutes, including the University of Cambridge and Cornell University, before coming to TUM in 2016. Here, he holds the Professorship for Multiscale and Stochastic Dynamics. Kuehn applies his insights in numerous practical areas, such as neuroscience, epidemiology, opinion formation, fluid mechanics and medicine. In 2011 he first engaged with the topic of climate modeling and found the topic so fascinating that he examined it further.

Boers and Kuehn met at a conference in 2016 and have worked together closely since 2017. Kuehn and his team work on a purely theoretical level to develop rules and testing mechanisms that ensure such models do not deliver unreasonable results. "We are researching which parameters should be given particular attention in simulations and which have less of an impact on such tipping points," says Kuehn. "In sum, we are trying to create a sort of toolbox for climate modelers, so that they can choose the right techniques depending on their requirements and objectives." Ultimately, there is a whole array of different approaches – some of which are more suitable for tackling certain issues, while others are less so. ▷

Graphics: ediundsepp (source: TUM)

Climate systems at risk of tipping

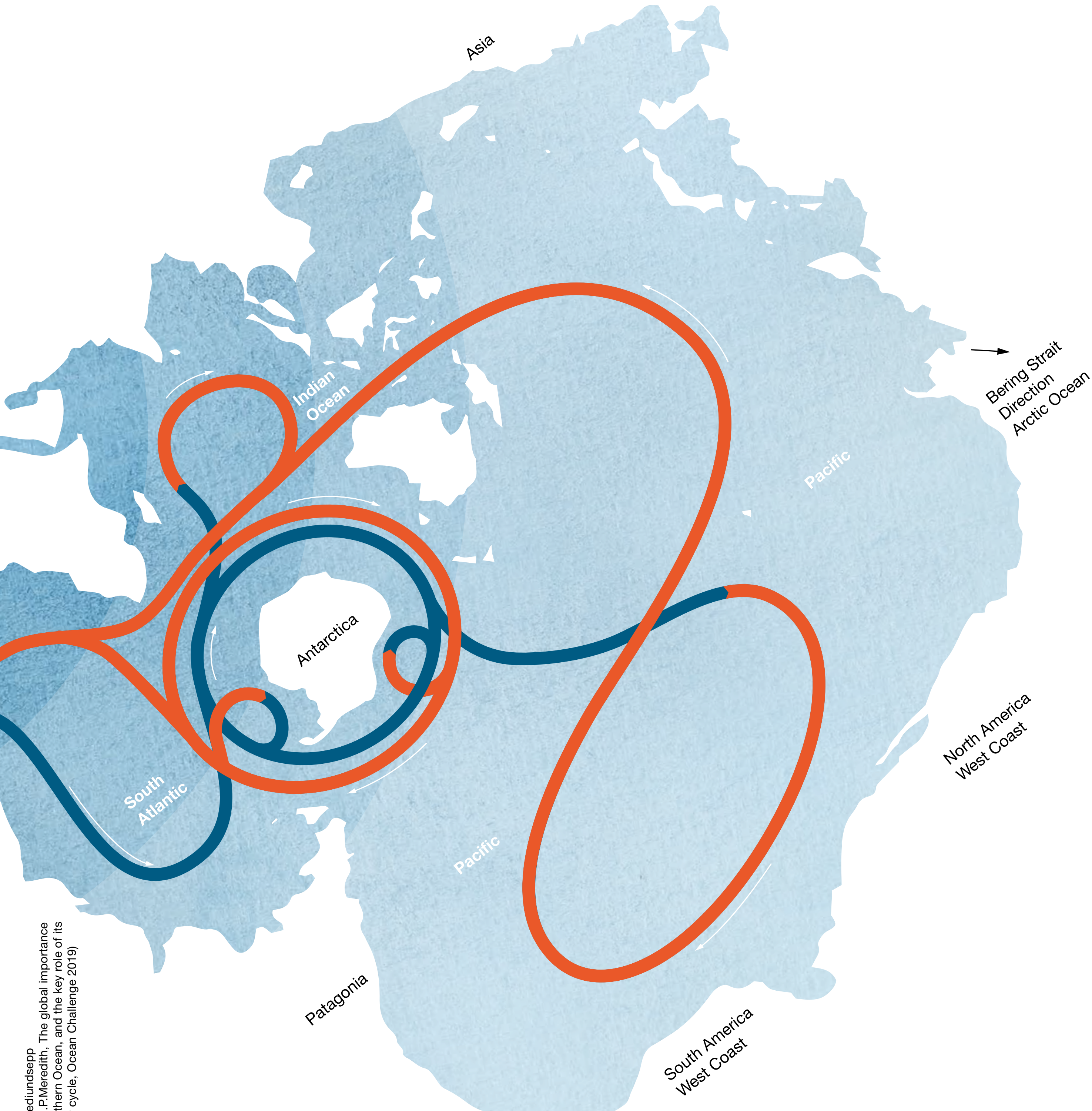
TiPES and ClimTip are researching a whole host of tipping points in the Earth's climate system. These tipping points are influenced by human actions and impacts, including global warming. Here are four examples:

1 If the uppermost, white layers of the **Greenland ice sheet** melt, darker ice will rise to the surface. This darker ice will absorb more and more solar heat; at the same time, the ice sheet will continue to shrink, with warmer temperatures at lower altitudes. Both factors will amplify the melting process; the effects will continue to accumulate until they can no longer be reversed. "In one study, I was able to show that part of the Greenland ice sheet has already become less stable over the last century," says Niklas Boers.

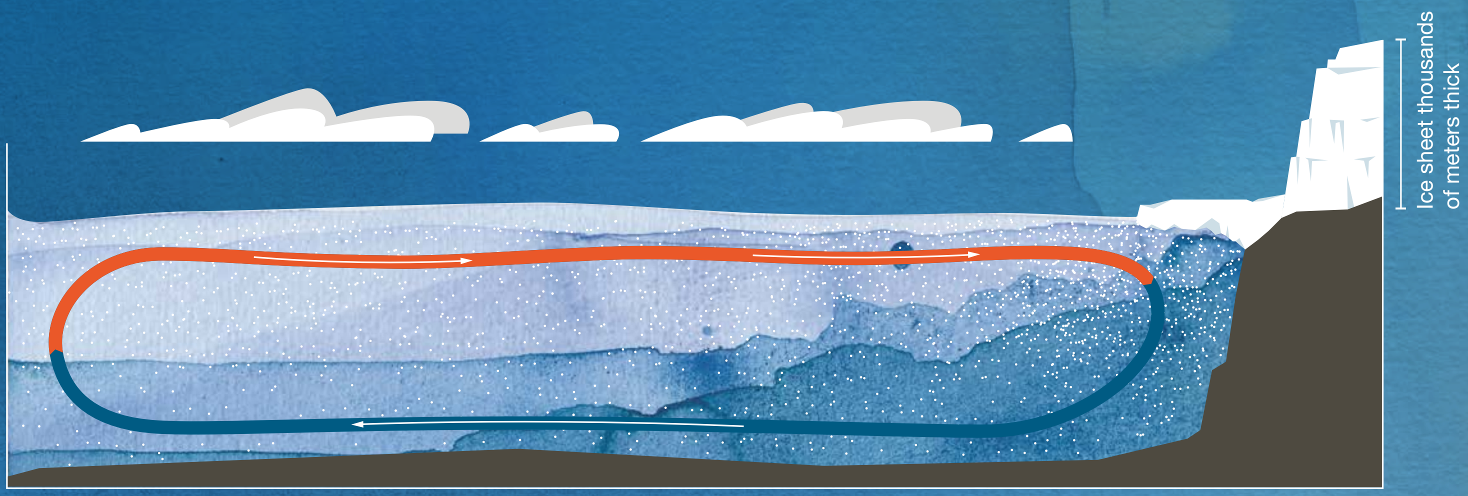
2 The **Atlantic Meridional Overturning Circulation** (AMOC), a large system of ocean currents in the Atlantic Ocean, circulates surface water from south to north, driven by differences in density. A proportion of the water is constantly evaporating as it circulates, so the water's salt content increases as it moves northwards. The warm, salty water eventually reaches the North Atlantic, where it cools down. This very cold, salty water is so heavy that it sinks deeper into the ocean. This process is the motor that drives oceanic circulation. The more salt it transports northwards, the stronger the motor becomes. Unfortunately, it is also the case that the more freshwater enters the North Atlantic – such as due to ice melting in Greenland – the weaker this circulation becomes. If the AMOC were to reach a tipping point, it would have far-reaching consequences for the global climate. In tangible terms, these consequences would include a significant reduction in average temperatures, especially in northern Europe.

3 Tipping of AMOC would also lead to fundamental changes to **tropical monsoon systems**. These could tip over quite rapidly following the collapse of the AMOC, leaving humanity very little time to adapt.

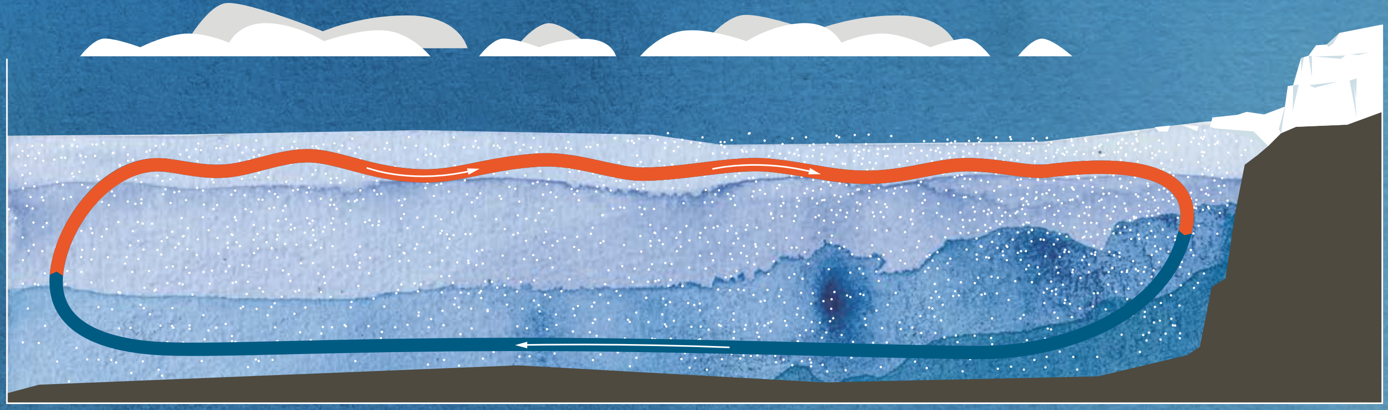
4 **Rainforest** clearing: Water circulates in this ecosystem, including in the form of extensive rainfall. As people continue to clear the rainforest, the water transported in the air decreases. Eventually, the situation will reach a tipping point at which the ecosystem dries out within a few years and therefore collapses completely – with grave consequences not only for its flora and fauna but also for the global climate.



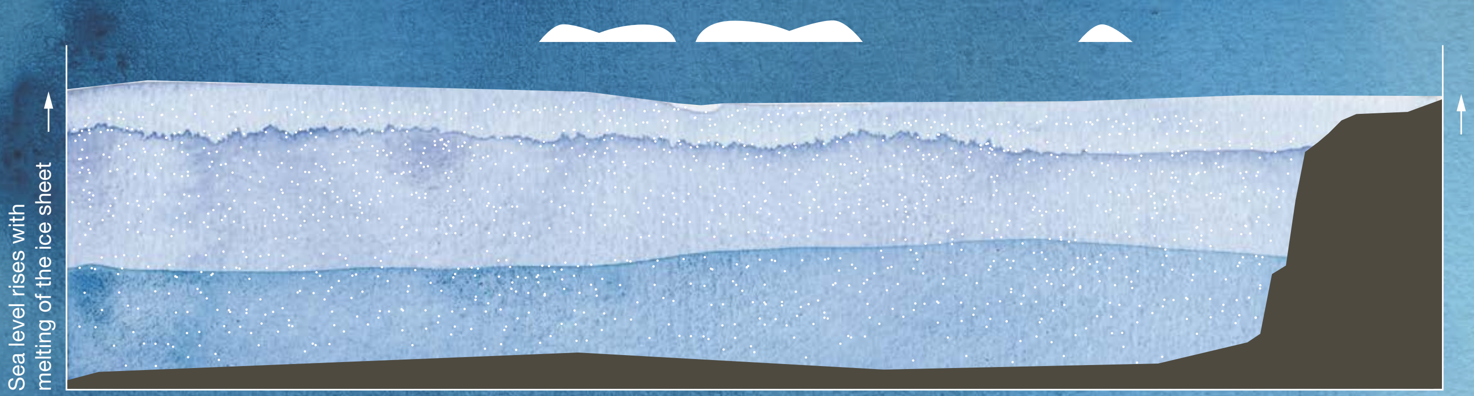
Graphics: ediundsepp
(source: M.P.Meredith, The global importance of the Southern Ocean, and the key role of its freshwater cycle, Ocean Challenge 2019)



Warm, salty water travels north and cools down near the ice shelves. The cold and salty (and thus heavy) water sinks down and travels south.



The melting ice sheet dilutes the salty surface water, it becomes less heavy and the circulation weakens.



Eventually, the thermohaline ocean circulation breaks down. The northern hemisphere cools off and gets drier.

The Greenland ice sheet is melting

Heat flows in the North Atlantic are one issue to which Niklas Boers and Christian Kuehn have devoted particular attention. These flows are the combined result of a number of factors: the winds, which drive vast masses of water; the temperature, because water masses moving north cool down and become heavier, and finally water salinity, because more salt makes the water even heavier. Once they arrive in the North Atlantic, these heavy water masses sink to deeper levels of the ocean. If we consider the interaction of these sometimes contradictory effects, it becomes clear that there is an enormous system of ocean currents in the Atlantic, which is known as the Atlantic Meridional Overturning Circulation (AMOC). It is primarily responsible for the moderate temperatures on the European continent.

If, however, the Greenland ice sheet continues to melt at accelerating rates – including due to global warming – more and more lightweight freshwater will enter the flow at its northern end, which will slow down the system as a whole. Boers and his team set about examining how long this can continue before it reaches a tipping point. "Studies have shown that current circulation levels are the weakest for at least 1,500 years," says Boers. "So, we wanted to find out whether this is a purely linear weakening or a destabilization towards a critical point. At the tipping point, the circulation would abruptly become significantly weaker. We found out that we are actually moving towards a potential tipping point." ▷

"Studies have shown that current circulation levels are the weakest for at least 1,500 years. So, we wanted to find out whether this is a purely linear weakening or a destabilization towards a critical point."

Niklas Boers

Graphics: ediundsepp (source: TUM)

If this tipping point is reached, it could have far-reaching implications for the global climate. In tangible terms, it would lead to a significant cooling and aridification of the northern hemisphere along with changes in the tropical monsoon systems and regional sea level rise. However, when exactly this point will come remains uncertain, with scientific opinion divided on the issue. Some think it could happen in the next few years; Niklas Boers, on the other hand, believes that the AMOC will remain stable for decades to come.

His priority is integrating these and other insights into current discussions surrounding the climate crisis. "I sometimes receive messages from people who are genuinely distressed because they believe we're facing a domino effect of tipping points and are racing inexorably into a climate catastrophe," he says. "I try to calm them down and explain to them that we definitely still have a chance to avoid the most dangerous consequences of anthropogenic climate changes." On a broader scale, he strives to share his insights with people as part of the TUM Sustainable Futures Strategy 2030.

At the same time, he is looking forward to tackling the scientific challenges ahead. "We have to get better, for example, at calculating how resilient a real-life system is, the extent to which it can withstand disruptions. This is another question we're researching and for which we hope to receive new mathematical insights from Christian Kuehn." ■ *Brigitte Röthlein*

Picture credit: Magdalena Jooss

Prof. Niklas Boers

Born in northern Germany in 1983, Boers moved to Munich to study physics and mathematics – and due to its proximity to the mountains. He earned his doctorate in Berlin and completed research stays at the Potsdam Institute for Climate Impact Research (PIK), the École Normale Supérieure in Paris and Imperial College London. In 2021, Boers was appointed to a professorship at TUM, and was particularly pleased to have the Alps close by again. He is very politically engaged, especially on climate-related issues. He is driven by a desire to leave behind a livable Earth for the next generation.

More about sustainability at TUM:
www.tum.de/en/about-tum/goals-and-values/sustainability

Picture credit: beresfotografie

Together in learning and growth.

As part of TUM Mentoring, alumni guide and support students or doctoral candidates in their personal development. A notable example is TUM Alumna Tsvetana Marinova, who serves as an inspiring mentor to her mentee, Samiddha Mukherjee.

Read their tandem story
www.community.tum.de/en/marinova-mukherjee

TUM. Your network.
For a lifetime.

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Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung

Bauen mit Hopfen

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HopfON möchte die Bauindustrie klimafreundlicher und ressourcenschonender machen und setzt dafür auf Baustoffe aus landwirtschaftlichen Abfällen und Rohstoffen. □

Building with **Hops**

The construction industry consumes enormous resources and is responsible for a large proportion of global CO_2 emissions. The HopfON team is seeking to address this situation. Their vision is to produce recyclable, climate-friendly building materials using agricultural waste and resources.

Link
www.hopfon.com

The idea came to them over a beer in their student accommodation. Thomas Rojas Sonderegger, a student in construction engineering back then, was telling architecture student Marlene Stechl about a talk he had attended: it was about a Colombian who was producing construction materials with banana fiber. “So we thought it would be great if we could make our own locally sourced building material. It could save greenhouse gas emissions,” says Marlene Stechl. “We thought about which solution might work in Bavaria. We were actually joking when we said it would be cool to use hops. The next day we actually started to do some research.”

A promising fiber-based material

They found a supporter in architecture and design professor Niklas Fanelsa. He not only contributes his scientific expertise but also gives the team access to the Bioregional Design Lab at TUM and thus enables further material tests. Because only a small percentage of the hop harvest is used for beer production, Stechl and Sonderegger came up with the idea of using waste from hop farmers. “Along with the ecological benefits, this also saves costs,” says Stechl. The fibrous structure of the hop plant lends tensile strength to the material, making it especially suitable for acoustic panels, insulation and structural boards. The woody cores of hops, known as shives, provide the material with additional compressive strength. Like hemp, which has become increasingly important as a building material in recent years, hops also have good heat insulation characteristics. To validate the team’s chosen material, Marlene Stechl tested the flammability of the hop plant as part of her master’s thesis and found no cause for concern.

Excellent idea

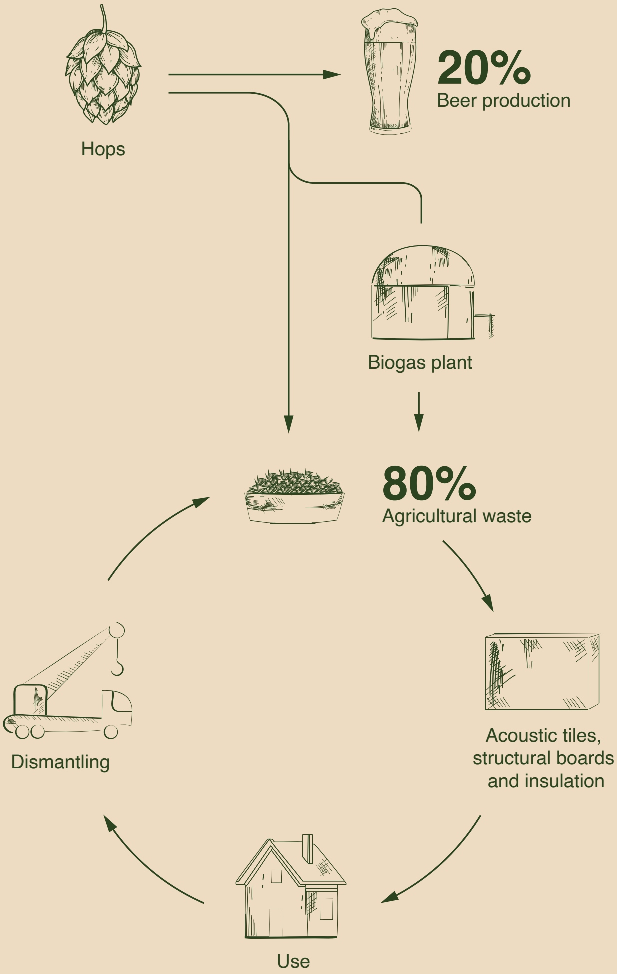
With their idea, Stechl and Sonderegger took part in the Urban Prototyping Lab run by the TUM Chair of Architectural Informatics. Participants were invited to propose solutions to problems from the construction industry. After submitting their detailed concept, they were invited to apply for the 2022 TUM IDEAward. They won first prize, which came with 15,000 euros in start-up capital.
The TUM IDEAward attracted the attention of former business student Mauricio Fleischer Acuña, who then joined the HopfON founding team. He was followed in 2023 by Matthias Steiger, a biochemist working on a doctorate at the Chair of Chemistry of Biogenic Resources, who is now developing further prototypes for HopfON. HopfON also received the TUM Booster Grant, which includes one year of funding worth 45,000 euros, and two prototyping grants from UnternehmerTUM, the Center for Innovation and Business Creation. The support from the business eco-

system of TUM is of such great help, especially when it comes to ramping up operations and founding the company in 2024, as Mauricio Fleischer Acuña explains. Another key pillar is the location: the world's largest hop growing region, Hallertau, is on Munich's doorstep.

A recyclable product

In their first harvest the founders got a lot of support from the farmers they worked with. As a result, the team was able to get a process up and running to secure enough raw material for production in the upcoming year. This was crucial, explains Mauricio Fleischer Acuña, as the hop harvest takes place only once a year. It is important to the founders to offer a recyclable product. For that reason, they completely avoid using artificial or non-soluble additives. That means that the hop-based construction materials can be broken down into their original components after use and reconstituted as new products. This is a key unique selling proposition as compared to other sustainable materials, says Mauricio Fleischer Acuña. It is also an essential prerequisite for the market launch, which is planned for 2024 with the rollout of acoustic panels for soundproofing applications. ■

Lisa Pietrzyk



Picture credit: ediundsepp, Astrid Eckert/TUM; Graphics: ediundsepp (source: TUM)

Link

www.mec.ed.tum.de/en/fml
www.cec.cs.tum.de/?langen

Too Good to Go

Picture credit: Astrid Eckert/TUM

Waste is a valuable source of raw materials, say Prof. Magnus Fröhling and Prof. Johannes Fottner. In joint projects with TUM colleagues, they are investigating what solutions for a circular economy might look like, for example in the automotive industry. Their credo: It will only work properly with a holistic perspective and a multidisciplinary approach.

"In truth, we have known for 50 years that we need to do something," says Johannes Fottner, referring to 'The Limits to Growth' – a world-renowned study published by the Club of Rome in 1972. Despite this, the UNEP International Resource Panel reported in 2019 that global consumption of natural resources has tripled since 1970. Sustainable stewardship of the Earth and its natural resources is imperative. Fottner, Professor of Materials Handling, Material Flow and Logistics at TUM, explains that this includes seeing waste not as rubbish but as a source of raw materials. "When we throw away products, we are wasting valuable resources," he says. "Mobile phones and used cars contain raw materials like metals and rare-earth elements, often in higher concentrations than found in natural deposits."

In addition to high extraction costs, the finite nature of resources, environmental pollution, increased CO_2 emissions and biodiversity loss, volatile commodity markets and fragile supply chains are further arguments for eschewing our current, linear economic system of "take, make, waste". Shifting to a circular economy is particularly important for Germany, which has few natural reserves of strategically important raw materials. ▷

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung

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Kreislaufwirtschaft: Ressourcen schonen, nachhaltig Werte schaffen

Um den Verbrauch von Ressourcen, Emissionen und das Abfallaufkommen zu reduzieren und die Umwelt zu schützen, setzen die Forscherinnen und Forscher der TUM auf die Kreislaufwirtschaft. Das Konzept zielt auf das Schließen von Stoff- und Produktkreisläufen und die Nutzung regenerativer Energieträger. Inzwischen existiert mit CirculaTUM eine interne Austausch- und Aktionsplattform, die an der TUM Kompetenzen sowie interdisziplinäre Forschungsvorhaben fördert.

Koordiniert wird die Initiative von den Professoren Johannes Fottner (Logistik) und Magnus Fröhling (Circular Economy): „Wir müssen dafür sorgen, dass Kreislaufwirtschaft vernünftig umgesetzt wird, und zeigen, dass es wirtschaftlich möglich ist." Im Rahmen von Projekten mit der Industrie erforschen sie, welche technischen Verfahren der Bereich Logistik für eine Kreislaufwirtschaft entwickeln bzw. wie eine Kombination aus Ökobilanzierung und techno-ökonomischer Analyse aus Systemperspektive aussehen kann, um unterschiedliche Technologien vergleichen zu können. □

Picture credit: Astrid Eckert

“If we want to sustain a long-term livelihood on this planet … we need a fundamental, sustainable transformation.”

Magnus Fröhling

Prof. Magnus Fröhling

studied industrial engineering and management at the University of Karlsruhe, where he later earned his doctorate and habilitation. In 2015, he was appointed Professor of Business Administration, esp. Resource Management, at TU Bergakademie Freiberg. Three years later, he was appointed to the Professorship of Circular Economy at TUM’s Straubing Campus. Fröhling and his team develop concepts and methods to analyze, evaluate and optimize circular economy systems, looking at technologies, networks and industrial sectors. His work focuses on industrial value creation, the built environment and bioeconomy.

Circular strategies aim at narrowing, (use less), slowing (use longer), closing (use again) and utilizing material and energy flows.

“We can only exploit the circular economy’s full potential if we have adequate logistics solutions.”

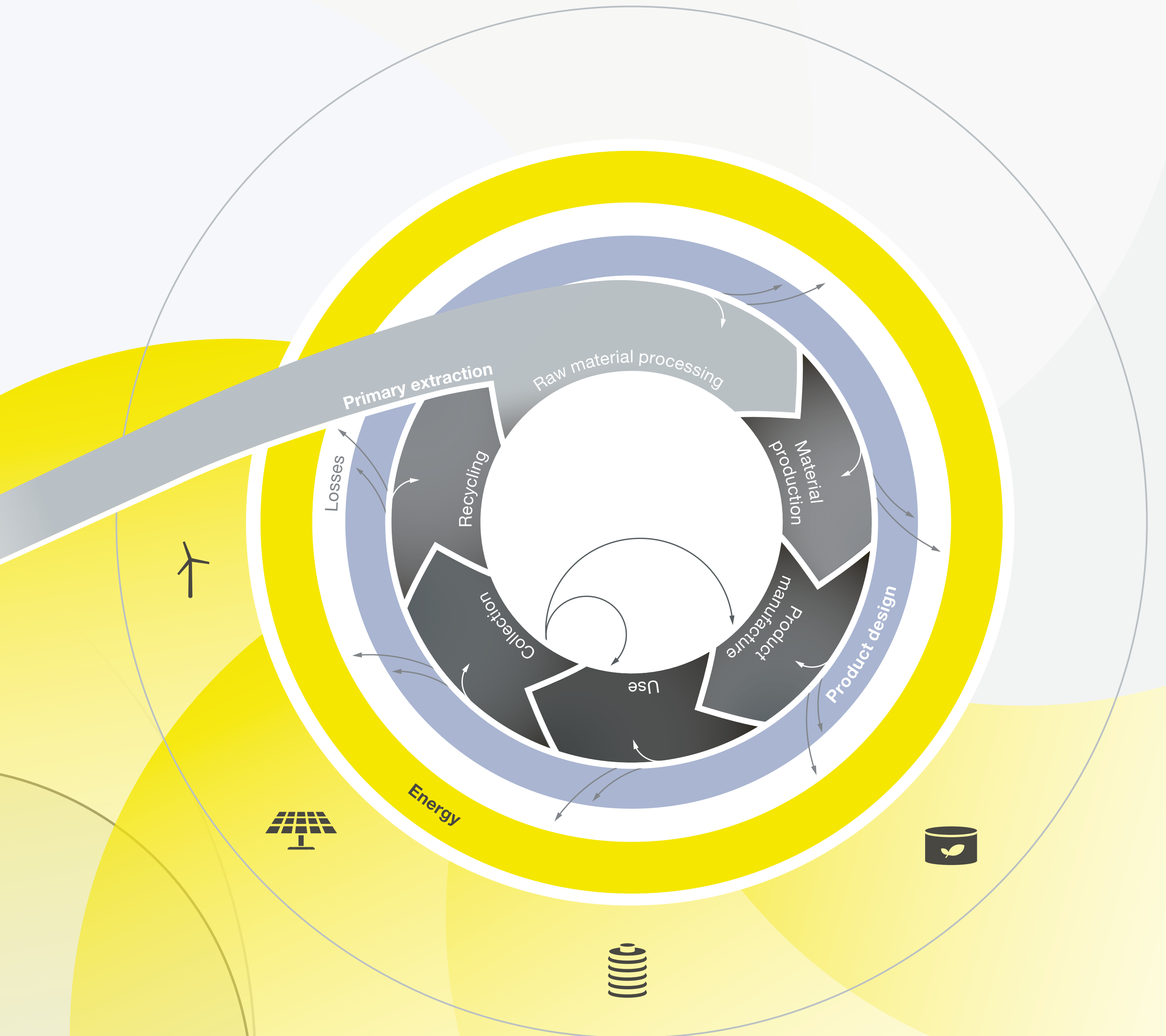
Johannes Fottner

“If we want to sustain a long-term livelihood on this planet against the backdrop of a growing global population, we need a fundamental, sustainable transformation,” argues Magnus Fröhling, Professor for Circular Economy. The two TUM professors perceive the circular economy as the antithesis of the prevailing linear system. The concept involves closing material, resource and product cycles in order to prevent waste, conserve resources and drive forward efforts to protect the environment. But that’s not all: like the EU, which has established the circular economy in its Green Deal, the two researchers expect it to generate positive economic and social effects.
Circular strategies are designed to create sustainable material and product cycles. The aim is to use less material, extend products’ useful life, close material cycles through reuse and recycling, and regenerate natural systems, such as by using renewable energy sources and biodegradable, non-toxic materials. ▷

Prof. Johannes Fottner

studied mechanical engineering at TUM and received his doctorate in 2002. He then held a range of management positions at a Swiss company from 2002 to 2008 and moved on to the position of Managing Director of the Munich branch in 2008. In 2016, he was appointed Professor of Logistics Engineering at TUM. He now holds the Chair of Materials Handling, Material Flow and Logistics, which focuses on technical and physical aspects of logistics, including methods of controlling and optimizing material flows with innovative RFID technologies, using digital tools to improve logistics planning and the role of human input in logistics.

Picture credit: Astrid Eckert, graphics: ediundsepp (source: TUM)


Primary extraction
Raw material processing
Material production
Product manufacture
Use
Collection
Recycling
Losses
Product design
Energy

TUM Mission Network Circular Economy (CirculaTUM)

The platform for exchange and action, CirculaTUM, brings together the collective expertise within TUM across all locations and disciplines to promote teaching, research and innovation on the circular economy. Over 30 chairs and professorships and more than 100 researchers from various schools and locations are actively involved in the platform at present. This network is well aligned with the TUM Sustainable Futures Strategy 2030, which establishes sustainability as a vital, guiding value for TUM.

www.mission-networks.tum.de/en/circular-economy/home

Circular economy loop of a product.
Product design, energy use and losses are relevant for all product stages.

Graphics: ediundsepp (source: TUM)

Transforming production processes

Achieving this, however, will require the transformation of production processes. Simultaneously, business models will have to be completely reimagined. This might include leasing systems and rental models in which providing a product is part of the service, pithily known as "product-as-a-service" or "PaaS" models. "In this way, we can broadly uncouple economic development from demand for natural raw materials," argue the two experts.

While potential solutions exist, Fottner and Fröhling believe that the problem lies in their implementation: the circular economy is highly complex and encompasses economic, environmental and social aspects. "At present, individual aspects are still considered in isolation. We need to instill a holistic, systematic mindset in decision-makers in business and politics. This starts with durable product design, continues through fabrication and use and then retaining products at the end of their useful life to collect their materials and return them to the product cycle. Consumers also need to change their thinking and believe that used, recycled products can have value," explains Fröhling.

So, can Germany play a leading role in tackling what is notoriously a global problem? "We can't always point the finger at others. Someone has to make a start. And, in the long term, it will yield economic benefits," assert the researchers. They have also founded CirculaTUM, a transdisciplinary, TUM-wide network dedicated to the circular economy, with the aim of actively shaping the transformation both within the university and beyond. ▷

Logistics as a key success factor

The automotive industry is one sector in which both academics are active. The joint Car2Car project, for example, aims to extract and reuse high-quality materials from used vehicle components. “Automotive manufacturers have been optimizing their assembly processes for 100 years. The task now is to give thought to disassembly – looking at the entire life cycle – and then record and automate the resulting logistics processes,” comments Johannes Fottner. His specialist field has a vital role to play in the envisaged transformation, as he points out: “We can only exploit the circular economy’s full potential if we have adequate logistics solutions.”

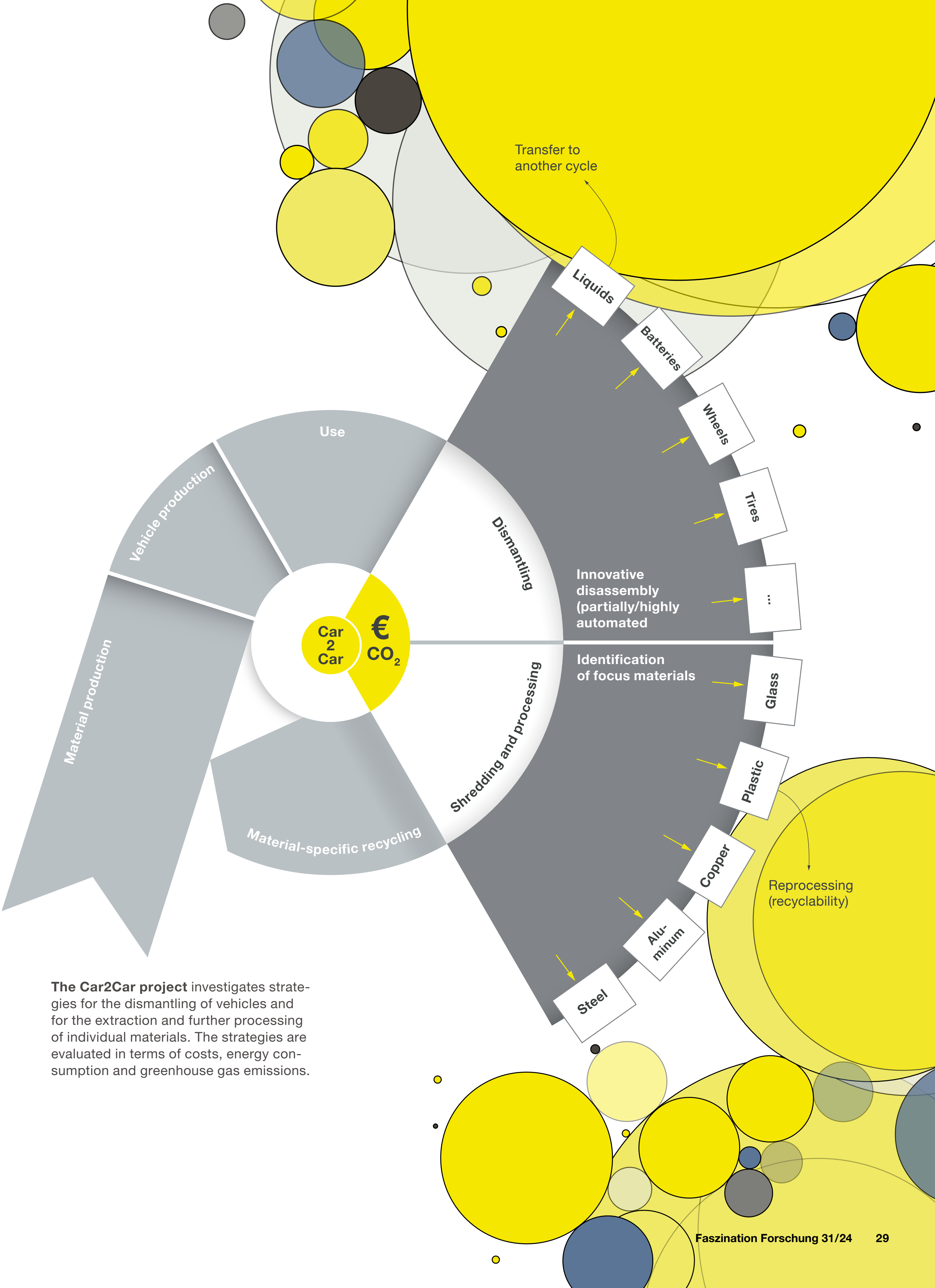
In essence, this will call for the end-to-end evaluation of supply chains, value chains and their associated processes. “This is where our professorship comes in. We’re developing methods to evaluate circular economy solutions,” says Fröhling. “This involves identifying and analyzing critical factors in their implementation. The question is: how and under what conditions can this succeed?” ▷

Car2Car: Innovative disassembly methods and automated sorting processes

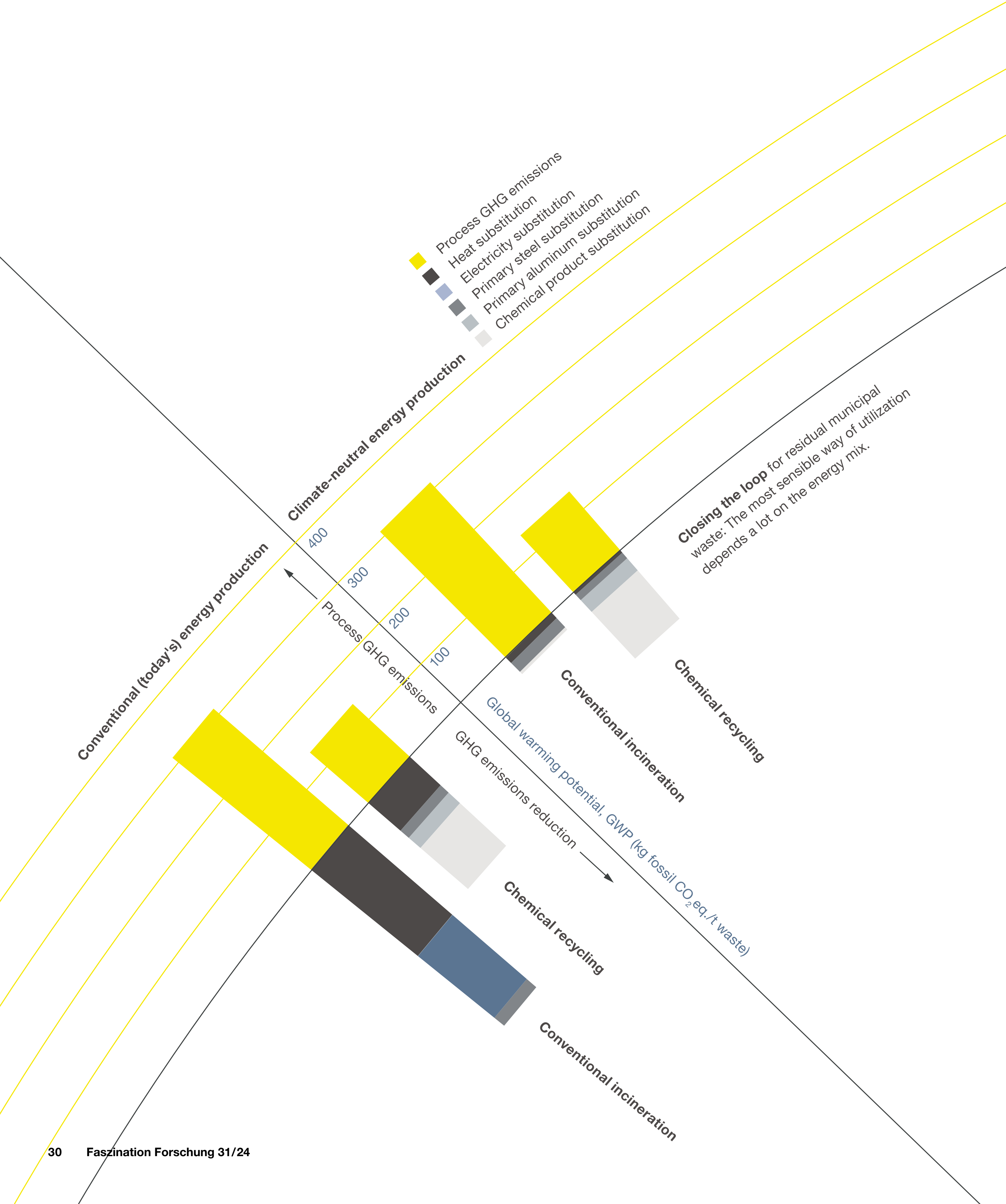
Launched in early 2023, the Car2Car project features a consortium of scientific institutions and industry partners – led by the automotive manufacturer BMW – working to close material cycles for automotive materials. The project participants are examining 500 used cars to find answers to questions about intelligent disassembly and methods of effectively and efficiently identifying, sorting and separating secondary materials (e.g. aluminum, copper and glass). This is because the components that can and should be disassembled depend on regulatory provisions, the materials’ structure and the amount of available materials. The aim is not only to improve the quality of secondary raw materials but also to increase the proportion of recycled materials in new cars. It also seeks to examine and evaluate the environmental and economic implications of closed material flows for selected groups of materials.

The task facing Johannes Fottner’s Chair of Materials Handling, Material Flow and Logistics and his colleague, Michael Zäh of the Institute for Machine Tools and Industrial Management, is to identify recyclable components and suitable technologies for dismantling them and sorting their materials. In addition to developing an optimized disassembly process, and after mapping the logistics processes involved, the success of the project depends on the researchers creating an economically viable and environmentally meaningful concept for recycling high-quality secondary materials. Magnus Fröhling and his team will assess the investigated processes and approaches. In addition, the researchers are investigating what the large-scale implementation of the solutions they find might look like, along with the potential positive environmental and economic effects. The German Federal Ministry for Economic Affairs has supported the research project with €6.4 million in funding.

Graphics: ediundsepp (source: TUM)



The Car2Car project investigates strategies for the dismantling of vehicles and for the extraction and further processing of individual materials. The strategies are evaluated in terms of costs, energy consumption and greenhouse gas emissions.



Process GHG emissions
Heat substitution
Electricity substitution
Primary steel substitution
Primary aluminum substitution
Chemical product substitution
Climate-neutral energy production
Conventional (today's) energy production
400
300
200
100
Process GHG emissions
GHG emissions reduction
Global warming potential, GWP (kg fossil CO_2 eq./t waste)
Conventional incineration
Chemical recycling
Chemical recycling
Conventional incineration
Closing the loop for residual municipal waste: The most sensible way of utilization depends a lot on the energy mix.

Chemical recycling as part of a circular economy

The Professorship of Circular Economy is examining the environmental and economic impacts of using solid waste to provide raw materials for the German and international chemical industry. In this context, the team combines approaches from life cycle assessment and technical, economic analyses to compare chemical recycling and conventional incineration systems for municipal waste in terms of their global warming potential and economic performance (capital investment, net present value, dynamic payback period and levelized cost of carbon abatement). The results show that, compared to conventional waste treatment methods, chemical recycling can contribute to reducing greenhouse gas emissions in low-emission energy systems and conserve natural resources. However, it is vital to create suitable framework conditions because the introduction of chemical recycling is associated with high initial system costs due to the capital-intensive nature of gasification technologies. This includes measures such as an obligation to trade CO_2 certificates for energy recovery as well as the introduction of a recycling quota to offset economic downsides.

Circular isn't necessarily sustainable

One of the focuses of Fröhling's research group is the role that chemical recycling can play in the circular economy: For example, they compare the global warming potential of domestic waste gasification with that of conventional waste incineration. Magnus Fröhling believes it is important to allocate the full costs of such processes to the relevant polluters. This also includes the external costs, which have primarily been borne by the community to date, rather than the polluters. “In relation to chemical recycling, we have also identified that fixed recycling quotas can be even more effective than tightening up emissions trading.”

Even though the circular economy is a powerful concept, it should not be viewed as a panacea for all sustainability-related problems. The reasons for this lie in physical and economic limitations as well as human behavior. If, for example, cost savings lead consumers to increase their consumption of other goods, the benefits of the circular economy could quickly be diminished or even reversed. However, Fottner and Fröhling are convinced that this does not change the importance of the circular economy as a vital, fundamental element of the sustainable transformation of our economies and societies. ■ *Eve Tsakiridou*

More about sustainability at TUM:
www.tum.de/en/about-tum/goals-and-values/sustainability

Graphics: ediundsepp (source: TUM)

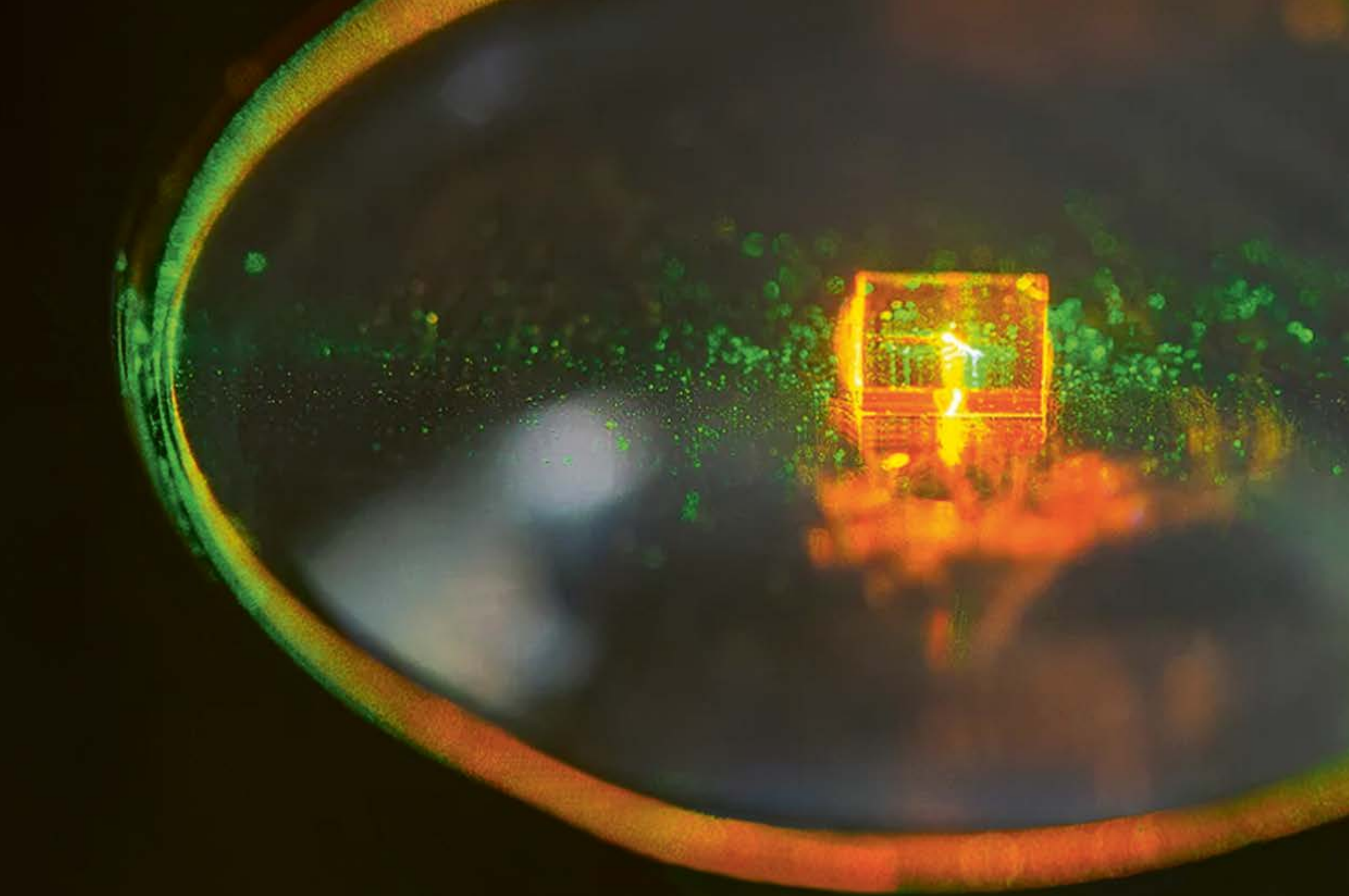
Link
www.ch.nat.tum.de/en/qsens/home

Quantum Sensors for Magnetic Resonance Imaging

A research team led by TUM has developed diamond quantum sensors that can be used to improve resolution in magnetic imaging.

Nuclear magnetic resonance (NMR) is an important imaging method in research that can be used to visualize tissue and structures without damaging them. The technique is better known from the medical field as magnetic resonance imaging (MRI), where the patient is moved into the bore of a large magnet on a table. The MRI device creates a very strong magnetic field that interacts with the tiny magnetic fields of the hydrogen nuclei in the body. Since the hydrogen atoms are distributed in a particular way among different types of tissues, it becomes possible to differentiate organs, joints, muscles and blood vessels.
NMR methods can also be used to visualize the diffusion of water and other elements. Research, for example, often involves observing the behavior of carbon or lithium in order to explore the structures of enzymes or processes in batteries. "Existing NMR methods provide good results, for example when it comes to recognizing abnormal processes in cell colonies," says Dominik Bucher, Professor of Quantum Sensing at TUM. "But we need new approaches if we want to explain what happens in the microstructures within the single cells."

Sensors made of diamond
The research team produced a quantum sensor made of synthetic diamond for this purpose. "We enrich the diamond layer, which we provide for the new NMR method, with special nitrogen and carbon atoms during its growth," explains Dr. Peter Knittel of the Fraunhofer Institute for Applied Solid State Physics (IAF).
After growth, electron irradiation detaches individual car-



The research team creates defects in an artificial diamond. This creates special quantum mechanical properties that can be used for sensor technology.

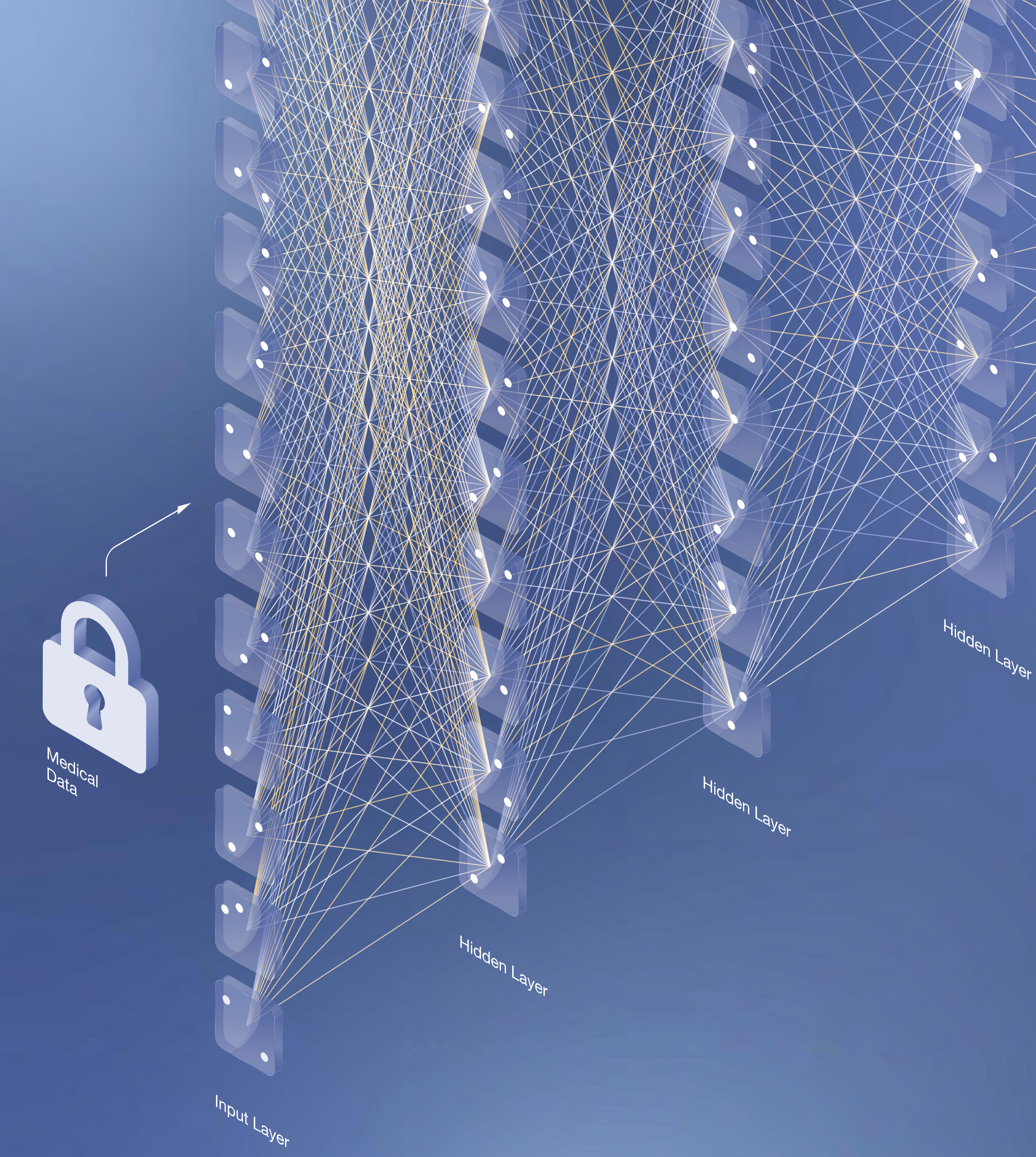
Picture credit: A. Heddergott / TUM

bon atoms from the diamond's perfect crystal lattice. The resulting defects arrange themselves next to the nitrogen atoms – a so-called nitrogen-vacancy center has been created. Such vacancies have special quantum mechanical properties needed for sensing. "Our processing of the material optimizes the duration of the quantum states, which allows the sensors to measure for longer," adds Knittel.

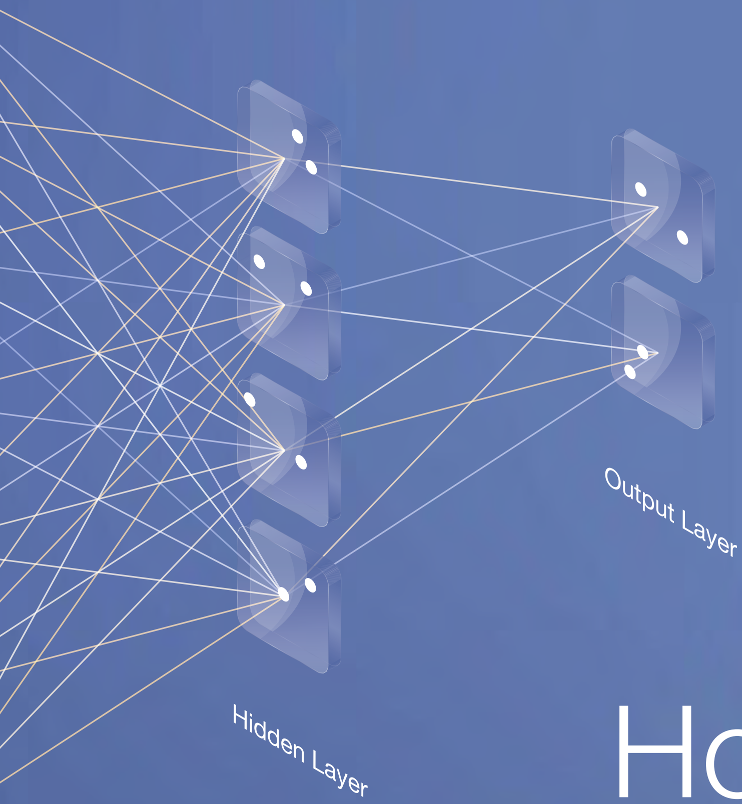
Quantum sensors pass the first test

The quantum state of the nitrogen-vacancy centers interacts with magnetic fields. "The MRI signal from the sample is then converted into an optical signal, which we can detect with a high degree of spatial resolution," Bucher explains.
In order to test the method, the TUM scientists placed a microchip with microscopic water-filled channels on the diamond quantum sensor. "This allows us to simulate microstructures of a cell," says Bucher. The researchers were able to successfully analyze the diffusion of water molecules within the microstructure.
In the next step, the researchers want to develop the method further to enable the investigation of microstructures in single living cells, tissue sections or the ion mobility of thin-film materials for battery applications. "The ability of NMR and MRI techniques to directly detect the mobility of atoms and molecules makes them absolutely unique compared to other imaging methods," says Prof. Maxim Zaitsev of the University of Freiburg. "We now have found a way how their spatial resolution, which is currently often deemed insufficient, can be significantly improved in future." ■

Stefanie Reiffert



Link
www.aim-lab.io



Graphics: ediundsepp

How Medical AI Can Become **Trustworthy**

AI systems in the health sector should be ethically above reproach and as trustworthy as possible. A research group working with computer scientist Prof. Daniel Rückert is developing methods by which privacy can be maintained with AI applications – with mathematical certainty.

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung

Wie medizinische KI vertrauenswürdig wird

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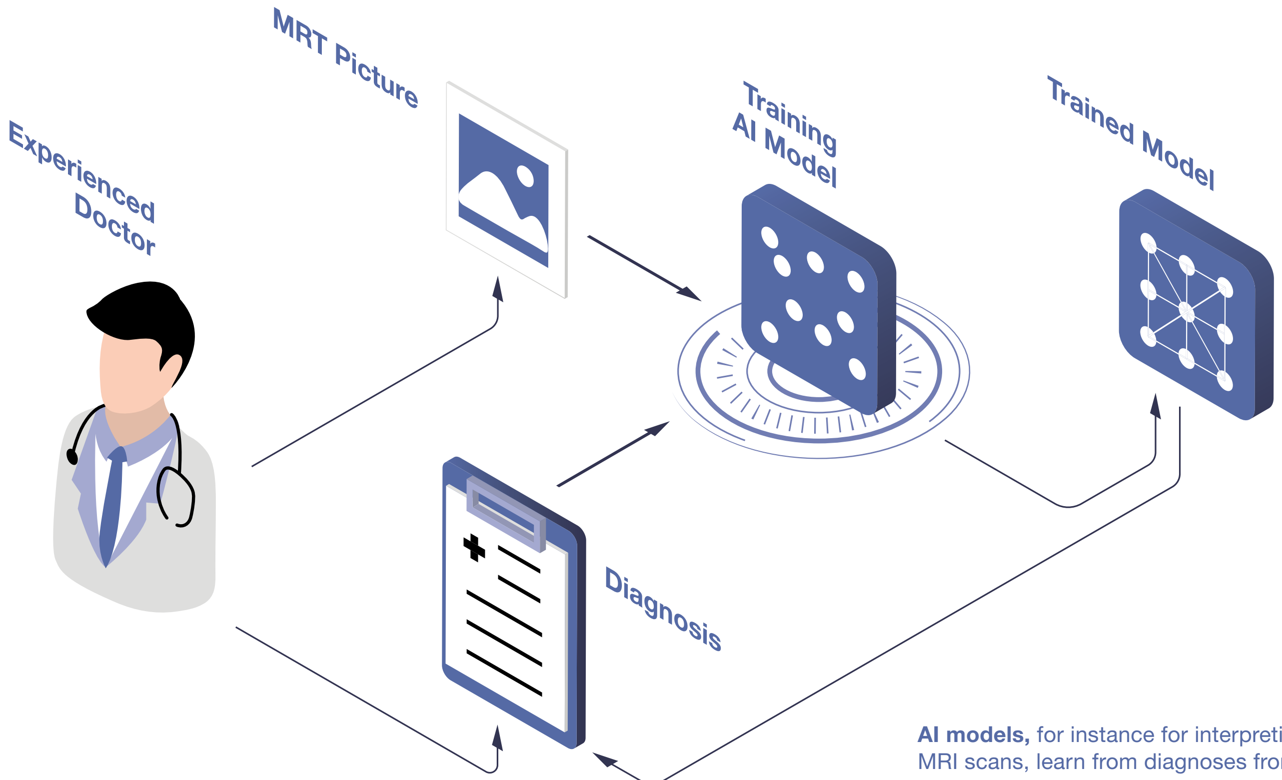
KI-Systeme in der Medizin müssen vertrauenswürdig sein. Sie sollten wie eine menschliche Ärztin zuverlässig und fair agieren und die Privatsphäre von Patienten achten. Das Forschungsteam um Prof. Daniel Rückert untersucht, wie die Trainingsdaten von Patientinnen sicher geschützt werden können und eine „Privatsphäre wahrende KI" möglich ist. Das Team hat gezeigt, dass Differential Privacy mathematische Garantien für die Privatsphäre gibt – und sie weder durch aktuelle noch durch zukünftige Angriffe unterminiert werden kann. Diese Garantien sind umfassend und unabhängig vom Stand der Technik. □

> "The requirements for AI systems are high. They should handle patients' personal data with care and not store any identifiable information."
>
> *Daniel Rückert*

Prof. Daniel Rückert

has been active as the Alexander von Humboldt Professor for AI in Medicine at TUM since 2020. He is also a professor at Imperial College London. Rückert studied computer science at TU Berlin (1993) and then earned his doctorate at Imperial College followed by a postdoc at King's College London. In 1999, he became Assistant Professor at Imperial College. He has held the Chair for Visual Information Processing at Imperial College since 2005 and was also the Dean there from 2016 to 2020.
At TUM, Prof. Rückert heads up the Center for Digital Medicine and Health. Daniel Rückert works in the field of artificial intelligence (AI) and machine learning and their applications in medicine. In his research, he focuses on the development of innovative algorithms for acquiring, analyzing and interpreting images and, with respect to AI, on the extraction of clinical information from medical images – particularly for computer-aided diagnosis and prognosis.

Artificial intelligence (AI) is in the process of changing medicine with intelligent systems. Most AI applications are based on models for machine learning. These models are trained to recognize certain patterns on the basis of patient data. The more data are incorporated into the training, the more accurate the diagnoses and prognoses become.
In medicine, such AI systems are now supporting doctors very successfully in the diagnosis and treatment of illnesses, the analysis of X-ray images and many other medical fields besides. But the rapid development in this area also raises questions of a fundamental nature: Are the AI systems as reliable as a human doctor? Can medical users trust them? And are the patient data used to train the model handled with care?



AI models, for instance for interpreting MRI scans, learn from diagnoses from experienced doctors until they are fit to detect diseases on their own.

Picture credit: Juli Eberle; Graphics: ediundsepp (source: D. Rückert)

Computer scientist Daniel Rückert from TUM is working on making automatic systems as trustworthy as a human doctor – an essential factor for the acceptance of such programs: “In medicine, we have two groups of people with whom an AI system interacts,” Daniel Rückert explains. “Doctors and clinicians make up one group, and patients the other. Both groups have very high requirements in terms of the quality of the decision-making processes.” AI systems also have to meet these requirements. For example, they need to handle patients’ personal data with care and not store any identifiable information – in other words, safeguard their privacy. They should be fair and treat men the same as women, for example. And they should state how certain their decisions are. Because, just like a human doctor, an AI system will be able to make some diagnoses with 99 percent certainty but others perhaps with only 80 percent. And the system has to communicate such figures as transparently as possible. “Generally speaking, there are many definitions and categorization approaches for trustworthy AI,” says Dr. Georgios Kaissis from Rückert’s team. The consensus is that intelligent systems in medicine should act in the same way, in the widest sense, as a responsible doctor. “Trustworthy AI must be compatible with human values,” says Kaissis. “The output from such systems should not conflict with basic human values such as fairness or the protection of data.” ▷

The data protection dilemma

Among other things, Daniel Rückert and his research groups are focusing on the topics of fairness and transparency – with the emphasis currently on privacy-preserving AI. Assistant Professor Georgios Kaissis is leading the research group on this topic. The question the radiologist and computer scientist is grappling with is this: How can you train AI models with patient data without enabling such data to be reconstructed from the models?

The relevance of this question must not be underestimated. Fundamentally, patient data such as MRI scans, for example, are essential for training AI models. However, these patient data are problematic for two reasons. Firstly, such data are not available in medicine in the same quantity as for non-medical AI applications – where millions if not billions of training datasets are often used. Here, one has to make do with fewer – which can limit the reliability of the models and diagnoses.

Secondly, the medical data used for training purposes are highly sensitive and very much in need of protection. After all, illness is a private affair – as a matter of principle, medical practitioners must not disclose such data without the consent of the data subjects, not even to train a computer system that may be able to save lives in the future.

Both challenges – not enough data and highly sensitive data – can be solved by reliable privacy protection. Anonymization and pseudonymization have largely established themselves as techniques for providing adequate protection for such data. In the case of anonymization, the names or identifying information are completely removed from the dataset. Bob Dylan's "Greatest Hits" album can be anonymized by deleting the name, with the result that the dataset now only contains the entry "Greatest Hits". With pseudonymization, the name "Bob Dylan" is replaced by a different name such as "Bob Marley".

The snag is that anonymization and pseudonymization are now no longer secure. The ways and means to attack AI models have become so powerful that even very well anonymized data can be re-identified with relative ease.

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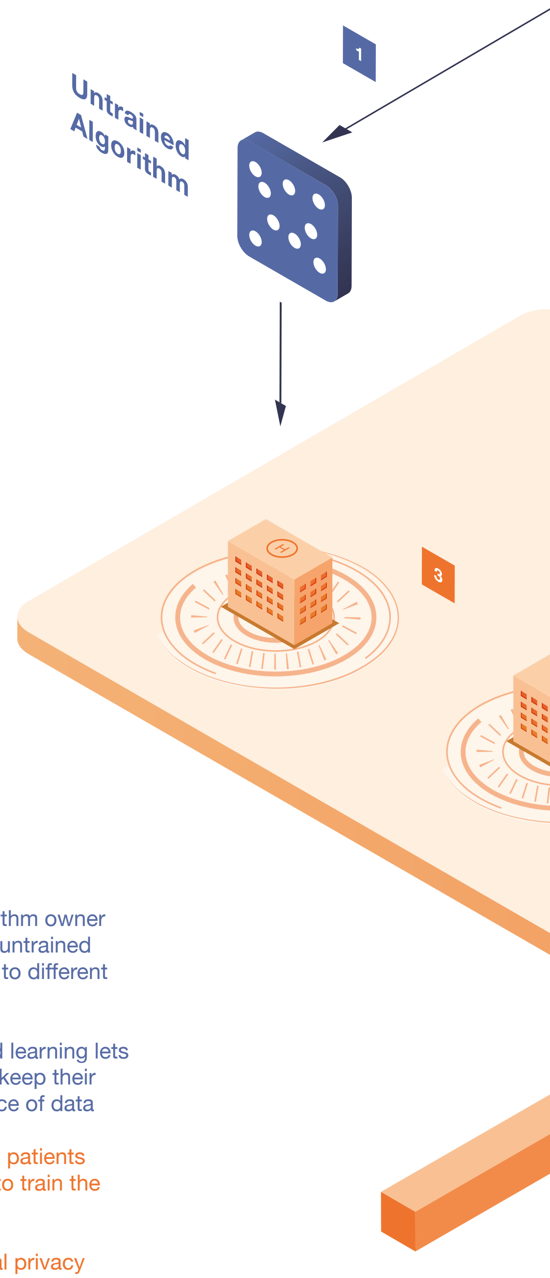


1 The algorithm owner sends an untrained algorithm to different hospitals

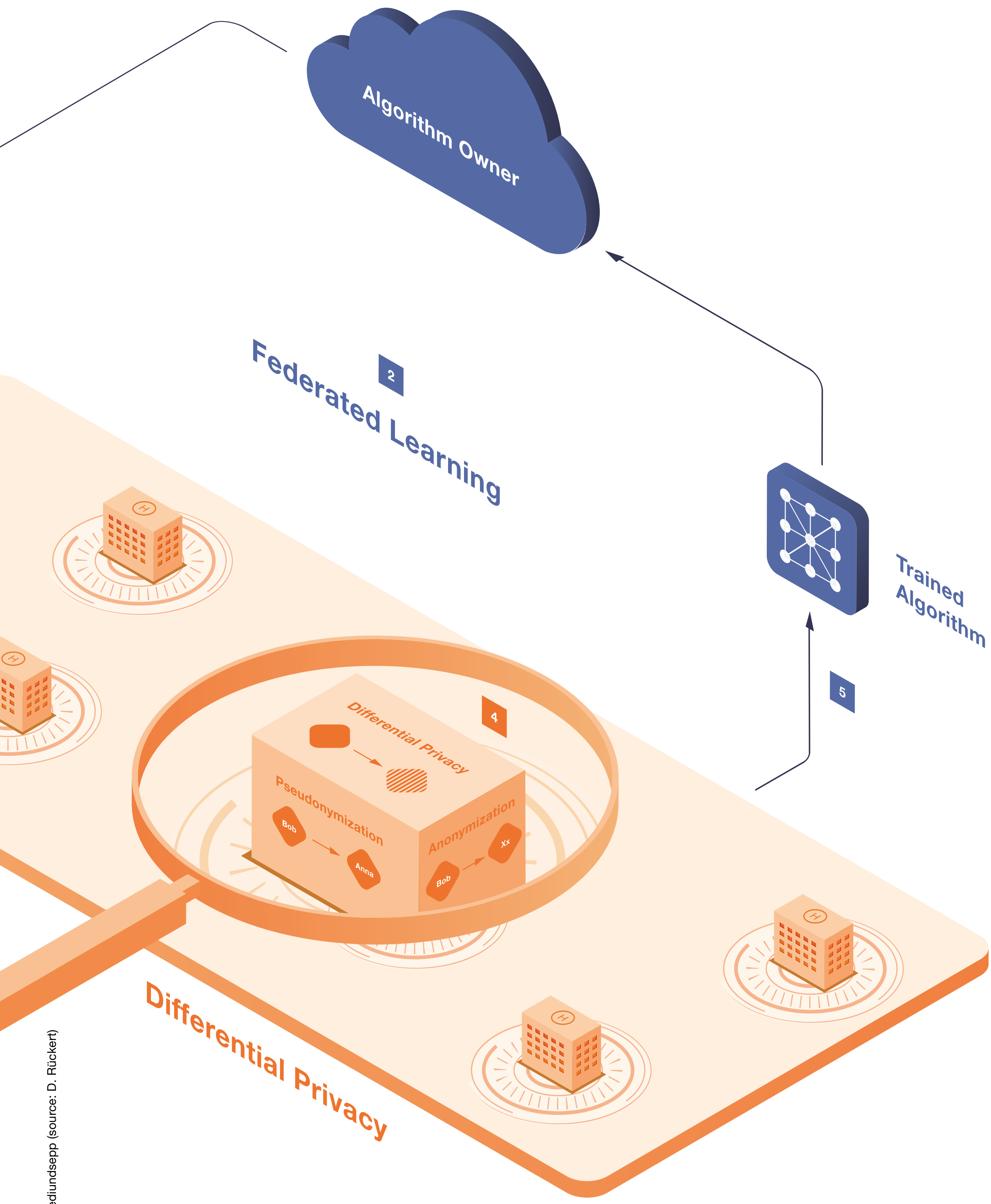
2 Federated learning lets hospitals keep their governance of data

3 Data from patients are used to train the algorithm

4 Differential privacy guarantees data security now and in the future, independent of the state of technology

5 The trained algorithm is then sent back to the algorithm owner

Rückert and his team rely on differential privacy and federated learning to keep health data used to train AI models private. Differential privacy adds a calibrated statistical noise to protect sensitive data. In federated learning, the AI model is successively sent to individual hospitals instead of sending sensitive data to a central server. This means that control of the data remains in the respective hospital.



Graphics: ediundsepp (source: D. Rückert)

Rückert and his team recently showed that data that flow into AI models are effectively protected by differential privacy.

“The mere removal of the name is completely meaningless for the latest hacking techniques,” Georgios Kaissis explains. “We were able to show multiple times in our work that patient data can be reconstructed from the models if you use them for training purposes without any additional protective measures.” For example, Kaissis and his staff succeeded in completely reconstructing patients’ X-rays from the models – a disaster for data protection.
Nevertheless, anonymization and pseudonymization continue to be used in practice. “That is down to the discrepancy between the state of research results and the legal framework,” Kaissis says. “Legally, anonymized data are still not considered personal data and are therefore legally permissible. However, research shows that anonymization is not secure.” The legal framework would therefore need to be amended.
Besides protecting sensitive data, any AI that safeguards privacy can also solve the problem of insufficient quantities of data – even if only indirectly. AI systems that preserve privacy are trustworthy for users and data providers alike and therefore have a highly motivating effect on patients, with the result that they approve the use of their data. More training data then become available, making the models more reliable and robust.

Interdisciplinary research: Center for Digital Medicine and Health (ZDMG)

Prof. Daniel Rückert heads up the Center for Digital Medicine and Health (ZDMG), for which TUM has received 43 million euros from the federal government and from the Free State of Bavaria. The intention is for researchers in medicine, computer science and mathematics to develop new approaches together in the fields of data science and artificial intelligence and drive their clinical application. Thanks to the targeted inclusion of expertise from the natural sciences and engineering disciplines, the development of innovative methods and technologies in the fields of AI and data science will be made usable for various medical applications at the new interdisciplinary research center.

Mathematical guarantees

Daniel Rückert and his team working with Georgios Kaissis are using a technique by the name of differential privacy that overcomes the limitations and lack of security of anonymization and pseudonymization. Differential privacy is essentially based on the fact that when training the AI systems, "calibrated statistical noise" – i.e. random noise – is added to the data. The whole method is mathematically complex but the result is that the privacy of individual patients is guaranteed.

The major benefit of differential privacy is that, in contrast to traditional techniques, this method offers a mathematical guarantee that it cannot be undermined by either current or future attacks. While an empirical guarantee only ensures that a current attack will be repelled, it cannot be ruled out that a future attack might evade this guarantee. A mathematical or formal guarantee, on the other hand, is a guarantee that privacy can never be circumvented, either now or in the future. This formal guarantee is significantly stronger than a merely empirical one – it is comprehensive and does not depend on the state of technology. "If I want to convince a data protection officer from Klinikum rechts der Isar to allow me to use such methods, it's naturally much more appealing to them if I can tell them that I can mathematically guarantee that it will never be possible to re-identify the patient from such data," says Rückert. ▷

PD Dr. med. Georgios Kaissis, MHBA

is the leader of a working group at the Institute of Artificial Intelligence and Computer Science in Medicine and Senior Physician at the Institute for Radiology at TUM as well as the leader of a working group at the Helmholtz Center in Munich. He researches in the field of privacy-preserving, trustworthy artificial intelligence, particularly on the subject of differential privacy as well as on applications in the fields of medicine and biomedical imaging.

Picture credit: Juli Eberle, Andreas Heddergott

The “holy trinity” – algorithmic privacy

Three methods have established themselves for the protection of sensitive data – under the heading of “algorithmic privacy”.

Federated learning

With federated learning, the data are not brought to the algorithms but the algorithms to the data. The model to be trained is moved to the hospital, trained in the hospital using the data available there and then returned to be further trained with data from a different hospital. The advantage here is that the data never have to be released from the custody of the hospital. The disadvantage is that hackers might be able to simply copy patient data from the training algorithm and smuggle them out.

Cryptographic methods

Cryptographic methods encrypt systems and primarily protect the algorithms – i.e. the model weights, for example. Model weights are the learnable parameters in a machine learning model that control its behavior and capabilities. Cryptographic methods are useful when sending out models. This means they cannot be used if they end up in the wrong hands.

Differential privacy

Differential privacy is seen as the gold standard of data protection and was developed at the start of the 2000s. With differential privacy, mathematical noise – i.e. false data – is added to the data. In this process, the characteristic features of individual datasets are changed as a result of the algorithm, or “spurious” datasets are added, which are included in the evaluation.

All three methods are used in AI. Prof. Rückert’s team is primarily backing differential privacy but also combining it with federated learning.

But differential privacy offers further benefits. For example, the method allows models to be trained with a “privacy budget”. This privacy budget works in a similar way to a purchase in which a certain amount of money can be spent. Applied to data protection, this means that if you have exhausted the privacy budget as a result of several iterations (computation sequences) with private data, the system will not permit any further interaction with this dataset – it is quite simply blocked.

“For example, with the privacy budget, every participating institution (or even every patient) can define a quantitative volume of privacy that they would like to expend for training this model,” Rückert explains. “This budget is correlated with the risk of datasets being re-identified. The higher the budget becomes, the higher the risk that my data can be reconstructed.”

Rückert’s team recently examined whether that can be put into practice. To do so, a dataset with patients’ X-ray images was used to train algorithms. The test was successful: The team succeeded in reliably analyzing X-rays with the algorithms trained in hospital, and in showing that they are protected from external attack. “We demonstrated in an article published in the journal ‘Nature Machine Intelligence’ that it can actually work in a case study,” the researcher stated. ■

Klaus Manhart

Picture credit: Juli Eberle

Proteins for **Singapore**

The Southeast Asian city-state of Singapore wants to produce one third of the food it needs locally by 2030. Sounds ambitious? Researchers at TUM are helping make the dream come true.

Link
www.tum-create.edu.sg/research/proteins4singapore www.lse.ls.tum.de/en/bgt/home

Oliver Watkins opens the door to the growth chamber, an enclosed plant cabinet as high as a full-sized refrigerator. Inside the chamber, soy plants are growing in orderly rows stacked on four levels, one on top of the other. “My colleagues can regulate the supply of light, water, and fertilizer independently and thus control how the plants grow. No additional pesticides are necessary,” the chemist says on his tour through the laboratory in the CREATE Tower, a high-rise research complex in the southwest of Singapore. “The decisive advantage is that vertical farming requires so little space.”

A high-tech metropolis short on resources

Singapore’s approximately 5.7 million residents live in an area roughly the size of the city of Hamburg. The Southeast Asian metropolis lacks farmland: Residential development and infrastructure projects have consumed all but one percent of the arable land. In response to this situation, Singapore’s government has announced the goal of locally producing one third of the food consumed here. In 2019, the figure was still less than 10 percent. The city-state hopes to cut down its dependence on imports and to soften the impact of supply bottlenecks and price fluctuations on the international food market. As part of its “30-by-30 initiative”, Singapore is heavily investing in research projects on sustainable aquaculture, urban farming and new food technologies.

A vision of the final food product

One of these projects is Proteins4Singapore. About 40 researchers from TUMCREATE, Nanyang Technological University and other academic and industrial partner institutions are working on protein-rich foods. “We’re not trying to optimize familiar foodstuffs, we’re starting at the finish line and asking ourselves: What do we want to produce, and what raw materials and processes can be used to achieve that best?” says Thomas Becker, program lead and Professor of Brewing and Beverage Technology. This approach is referred to as Reverse Food Engineering. “Our objective is healthy, high-protein food products, which taste good to the people here in Singapore and which can be produced right here as sustainably as possible. It should taste like chicken and when you bite into it, the texture and consistency should remind you of chicken,” Becker says. The researchers are evaluating the food production process from the beginning to the end, looking for suitable raw materials and cultivation technologies. They are experimenting with various processing methods, ranging from protein hydrolysis to fermentation and even to 3D printing. The special thing about the project is its comprehensive approach: The team covers the entire production process. The researchers can look at all the different perspectives.

Picture credit: Israel Tan Si Lie/TUMCREATE

Algae that taste like chicken

Nadyssa Willanda is one of the researchers responsible for the flavor of the target protein products. Based in Singapore, she is working on her doctorate with Prof. Corinna Dawid from the TUM School of Life Sciences, another investigator in the project. Nadyssa does research on algae, which is one of the most interesting resources for alternative protein products. The only nutrients they need are nitrogen, phosphorus and some micronutrients. "In the first step, we identify and quantify the components of the microalgae biomass which are active in taste and aroma," Nadyssa Willanda explains.

In a second step, the growth and extraction conditions are optimized to obtain algae proteins that resemble chicken meat in terms of the sensory perception of the product. "You have to know how taste perception works on the molecular level before you can specifically influence it," says Willanda. "For example, you can modify manufacturing conditions or add enzymes." The researcher can imagine that the finished protein product will be well-accepted later in Singapore: "Soy and algae products have long been a part of Southeast Asian cuisine." But people in Singapore are also very open to other cultures and their food. The best example of that are the hawker centers: These food courts are listed as UNESCO World Heritage Sites. It's easy to feel the influences of Chinese, Malay and Indian cuisine combined.

A small city-state with big ideas

High diversity in a small space – according to Michael Rychlik, that holds true for research in Singapore as well. "Singapore is an academic hub. Many international top universities maintain a presence here. The city-state knows how to attract cutting-edge level researchers from all over the world," says the TUM Professor of Analytical Food Chemistry, responsible for food safety aspects in the Proteins4Singapore project. In addition to his research, he has also taught at TUM Asia, the TUM teaching campus in Singapore. Modern classrooms, a high degree of digitalization and the enthusiastic participation of the students in this city have impressed him from the very start. "Singapore is highly competitive, but the fact that everything takes place within such a small space almost automatically results in collaboration and interdisciplinary approaches."

"Singapore is so tiny. You easily come into contact with other research topics and you turn into a real all-rounder," Oliver Watkins confirms. Together with colleagues from TUMCREATE, he's responsible for the analytical instruments like the high-resolution mass spectrometer. He appreciates the broad approach of the Proteins4Singapore project: "People from around the world work together, from widely differing disciplines – that's incredibly inspiring." ■

Christian Schnurr, Undine Ziller

Wrap Up **Warm**

How can we achieve the heat transition?

Germany aims to achieve climate neutrality by 2045. This means that greenhouse gas emissions must be reduced by over 88% compared to 1990 levels, with remaining emissions fully balanced by natural carbon sinks, such as forests, soils and seas. The country also aims to become carbon negative from 2050 onwards, meaning that the sum of emitted greenhouse gases must be lower than the absorption of these emissions by natural sinks. Germany's federal government has established these targets in the Federal Climate Change Act, the Bundesklimaschutzgesetz.

But how can this be achieved for buildings and cities? We spoke with TUM scientists who are researching strategies and technologies for the heat transition. While this article primarily casts light on the situation in Germany, these issues affect every country that aspires to achieve climate-neutral heating and energy supplies.

All texts by Gitta Rohling

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung

Warm anziehen

D

Ein warmes Zuhause gehört zu unseren Grundbedürfnissen. Wegen der steigenden globalen Temperaturen und der Notwendigkeit, den CO_2-Ausstoß zu reduzieren, muss sich allerdings die Art ändern, wie wir Wärme erzeugen und nutzen. Deswegen haben viele Länder die Ära der Wärmewende eingeläutet. Es ist ein komplexer Prozess, der viel technisches Wissen und eine komplette Transformation der Systeme und Energienetze erfordert. Erneuerbare Energiequellen wie Photovoltaik und Geothermie spielen eine wichtige Rolle, um einen bedeutend höheren Anteil unserer Strom- und Wärmeversorgung daraus zu beziehen. Zudem sollten wir einen ganzheitlichen Blick auf Gebäude, Quartiere und Städte werfen und uns auf die Kriterien fokussieren, nach denen wir Technologien sinnvoll auswählen. Wissenschaftler der TUM forschen an Strategien und Technologien, wie die Wärmewende gelingen kann – vom einzelnen Gebäude über die Zusammenarbeit mit Kommunen und den Ausbau von Geothermie bis zum Einsatz digitaler Lösungen. □

A warm, comfortable home is a basic human need. However, we need to change the way in which we generate and use heat. Rising global temperatures and the need to reduce our carbon emissions have ushered in a new age for energy supplies: the age of the heat transition. Following the established concept of the energy transition, which aims to effect a fundamental change in how we generate energy, the heat transition focuses on the urgent need to make our heating systems and heat generation processes greener and more sustainable.

The challenges we face are tremendous. At present, fossil fuels like oil and gas still account for the major share of heat generation. Not only are these resources finite, but burning them also emits vast amounts of greenhouse gases into the atmosphere. This contributes significantly to climate change and threatens the very foundations of life for future generations.

Yet, while the challenges ahead are certainly daunting, there is also good news. “We have the technical capabilities to make buildings climate neutral,” says Prof. Werner Lang, who holds the Chair of Energy Efficient and Sustainable Design and Building at TUM and is also Vice President for Sustainable Transformation. “We just need to use them,” agrees his colleague Thomas Hamacher, Professor of Renewable and Sustainable Energy Systems.

Many roads lead into the warmth

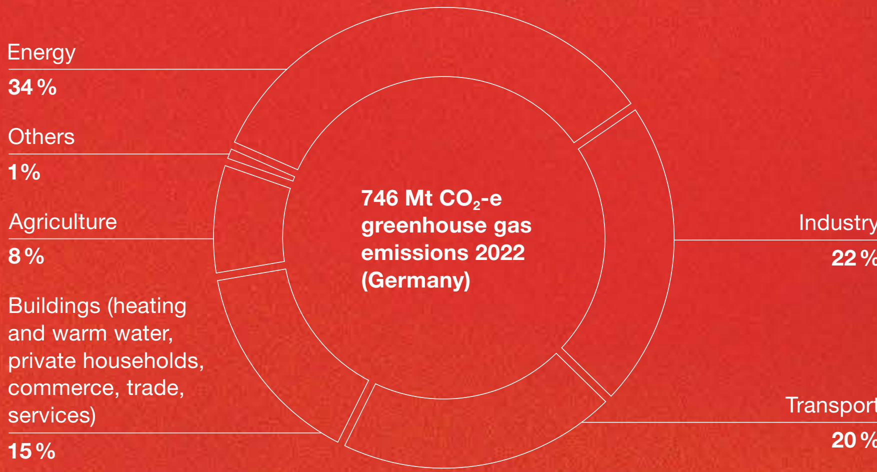
When it comes to the energy transition, there are two main levers we can pull. First, we need to reduce heat losses and energy demand by renovating buildings. Second, we need to restructure our electricity and heat supplies to rely more heavily on renewable energy sources. Digitalization also has an important role to play. “It enables us to significantly optimize or adjust our energy consumption more effectively to our actual needs,” says Christian Hepf, who is currently writing his doctoral dissertation at TUM’s Chair of Building Technology and Climate Responsive Design.

Far-sighted heating

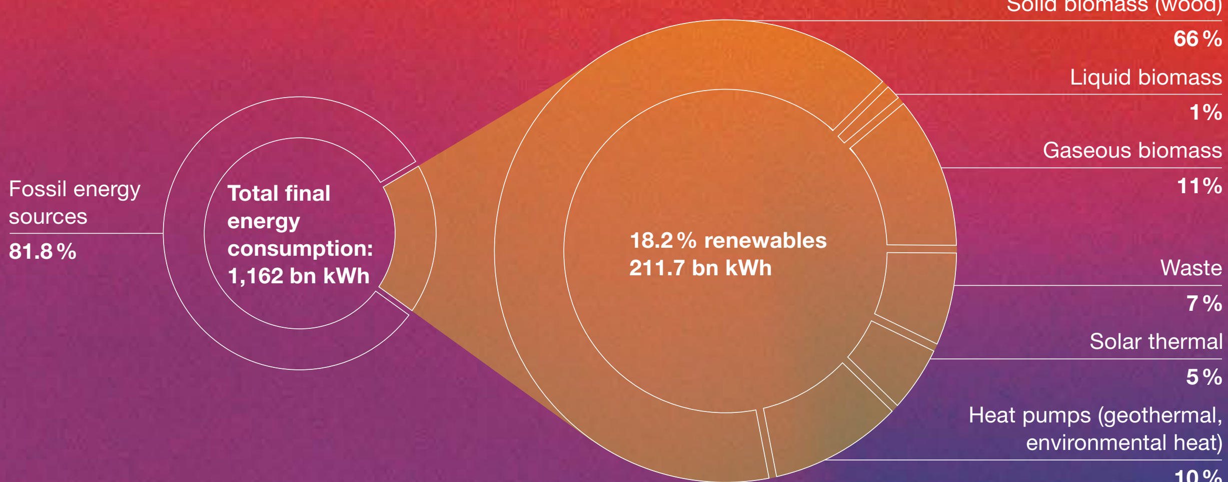
Above all, we need to take a more holistic view of buildings, districts and cities rather than discussing individual technologies in isolation. “It’s extremely important that we consider the entire life cycle of a building,” emphasizes Lang. Simply looking at the renovation costs is not enough. “The decisive question is this: How high will the operating costs be in the decades ahead if we continue to rely on fossil fuels rather than renewable energy? The difference in operating costs is far higher than the investment involved.” Hamacher adds that, when it comes to city and municipal authorities, “we need to consider the entire region with regard to potential for the heat supply system. We should spend less time discussing individual technologies and instead focus on the criteria we use to select appropriate technologies.

So, will we achieve the heat transition? “The answer to this question seems obvious to begin with because we could argue that, above all, it’s a question of attitude,” says Hepf. As the maxim goes, where there’s a will, there’s a way. Technologies drawing on different renewable energy sources already exist. And, as demand grows, these technologies will develop to become increasingly efficient and effective. “From another perspective, looking at the practicalities, this is a highly complex process that requires extensive technical expertise and a complete transformation of systems and energy grids,” explains Hepf. This means that, in addition to making greater use of renewable energy sources, we must also consider a range of other aspects, from energy storage and grid expansion to political and social aspects like subsidy programs and civic initiatives. All four TUM experts believe that the problem lies less in feasibility and more in our willingness to implement all aspects of this complex process. So, until this willingness becomes more widespread, there’s only one thing for it: wrap up warm. ■

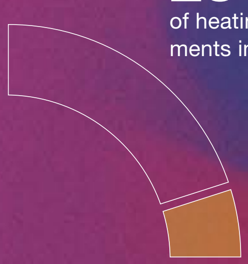
More about sustainability at TUM:
www.tum.de/en/about-tum/goals-and-values/sustainability



Shares of renewable energy sources in the heating sector (Germany, 2022)

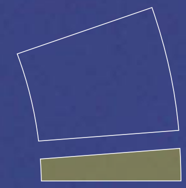


Deep geothermal energy can cover over
25 %
of heating require-ments in Germany



It currently accounts for
5 %

Achieving the targets in the European Green Deal will require us to renovate
4 %
of all buildings per year



The current rate is just
0.8 % per year

Graphics: ediundsepp (sources: UBA 2023: Treibhausgasemissionen in Deutschland; UBA 2023: Erneuerbare Energien in Zahlen; Beer et al., DIW aktuell, 87, 6 S., 2023; Bracke & Huenges, 2022, Roadmap Tiefe Geothermie für Deutschland)

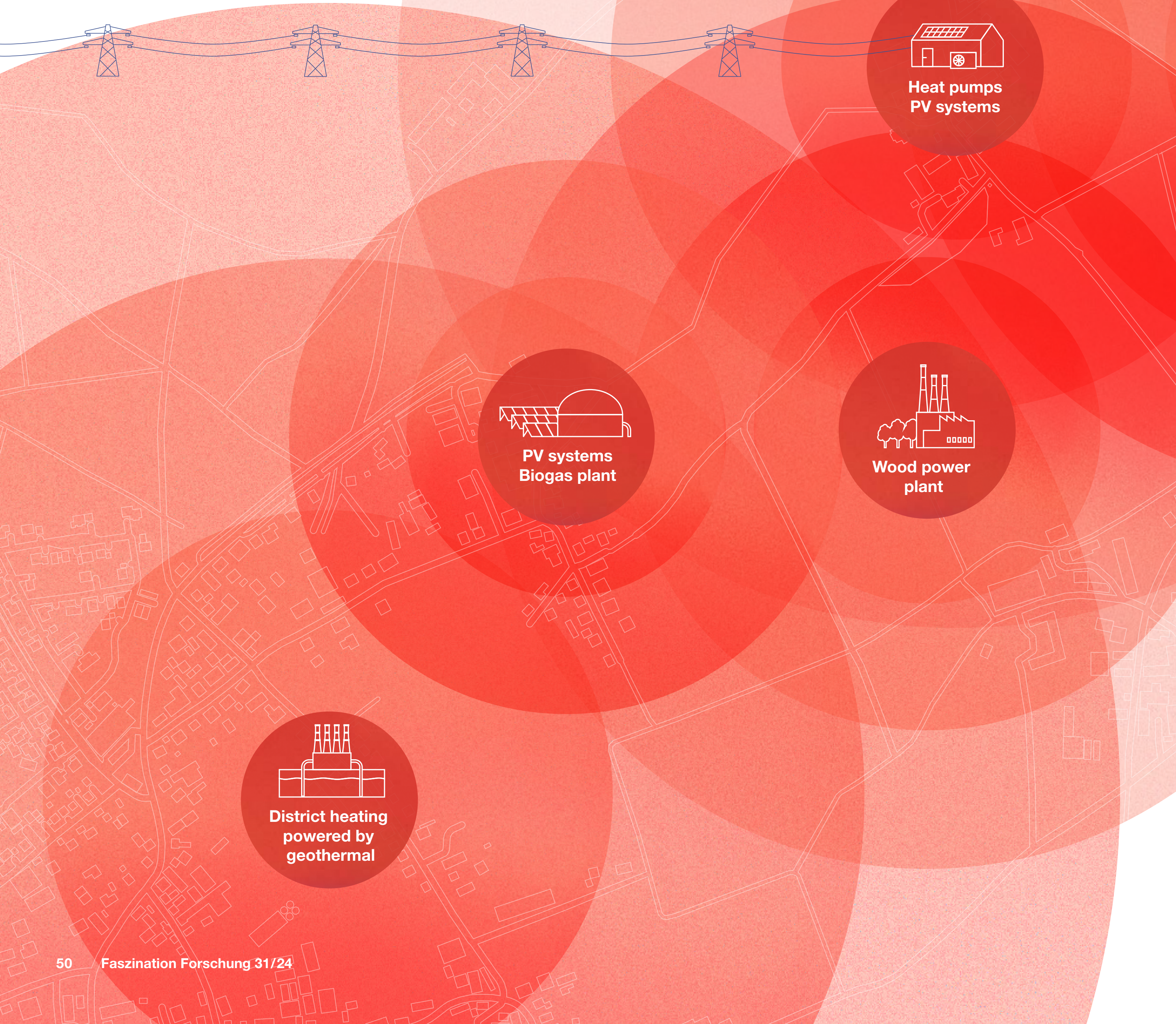
1

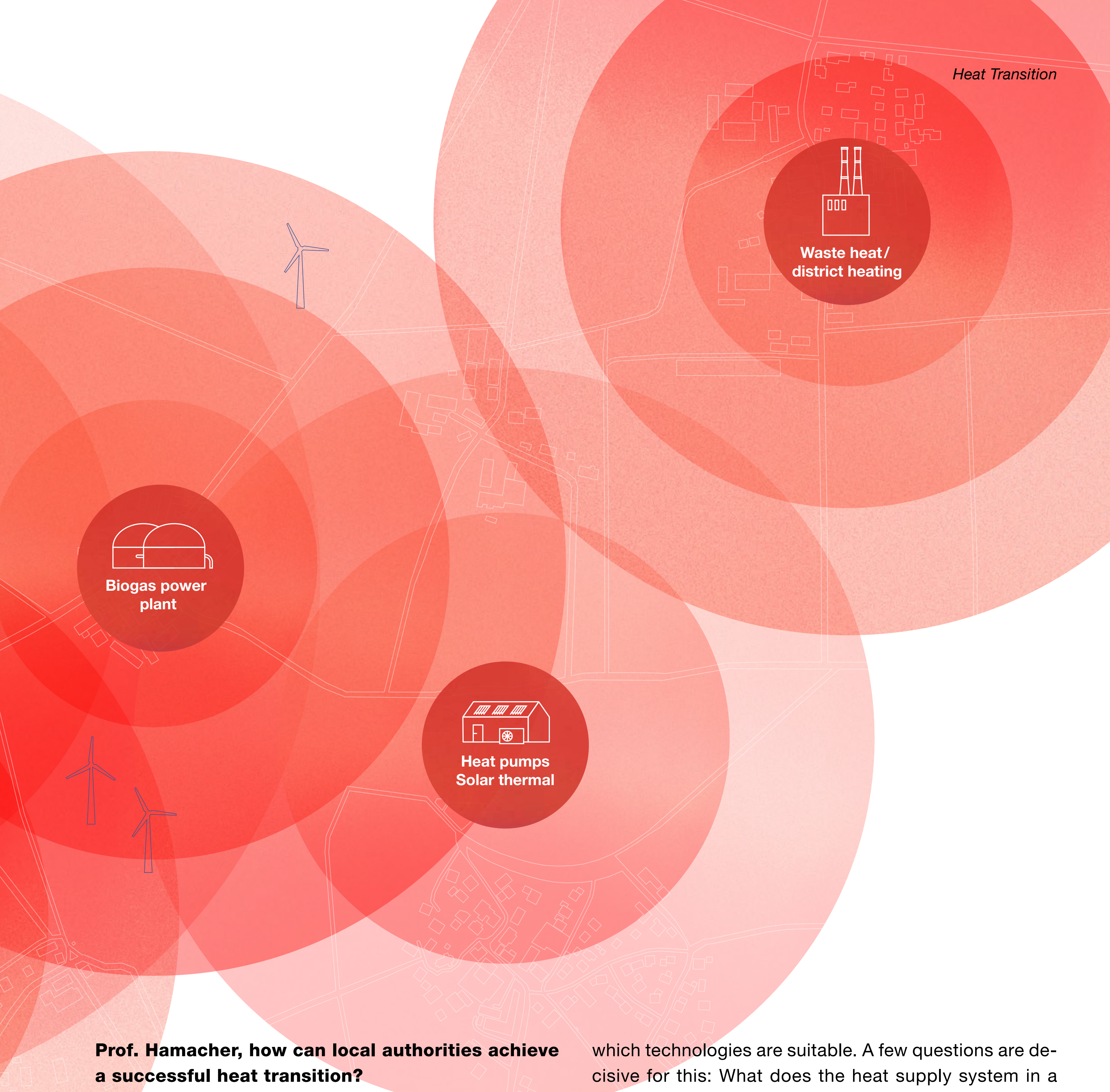
Heat up Together

How municipalities can spearhead the heat transition

Putting questions to Thomas Hamacher, Professor of Renewable and Sustainable Energy Systems

Link
www.epe.ed.tum.de/en/ens/homepage



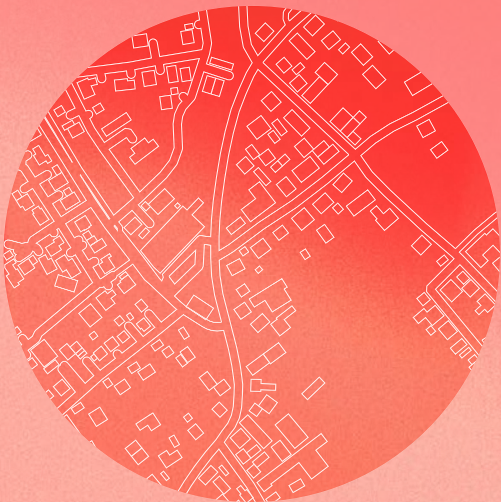


Graphics: ediundsepp

Prof. Hamacher, how can local authorities achieve a successful heat transition?

There are various technologies that have been discussed for years on end but are often not considered in strategic terms. For a while, people focused on solar thermal; this was followed by the Passive House and Zero-Energy Building concepts; today, it's heat pumps. Added to this is a cacophony of initiatives, some promoted by the state, which each have a different focus. What's missing from all of this, however, is a holistic view of energy and heat, a reasoned consideration of different measures. We should spend less time discussing individual technologies and instead focus on the criteria we use to select which technologies are suitable. A few questions are decisive for this: What does the heat supply system in a given region look like? Is there potential to use renewable energy sources? Would this region be suitable for geothermal or biomass? Where would district heating be worthwhile?

We explored these questions, for example, in the STROM research project, in which we identified heat supply areas for Bavaria and selected cities. It is about the integrated planning of the heat and energy supply and the question of how the additional electricity required for heat is delivered to consumers. Could our power grids cope with it? Or would we have to expand them? ▷



Exemplary decision criteria for technology selection:

- ? Which heat sources would be available?
- ? Could a district heating network be realized?
- ? Where are heat pumps a sensible solution?

If heat pumps are used:

- ? How will electricity consumption (incl. electromobility) develop?
- ? What contribution can PV roof systems deliver?
- ? Does the power grid need to be expanded?

What did you find out?
We need to expand local networks as well as the higher-level distribution grids. However, this always depends on the location. A place where there are many heat pumps at work will require more electricity than an area with district heating, so the distribution network will have to be expanded accordingly. In addition, energy management systems in buildings can make a significant contribution, limiting the maximum power drawn down from the power grid. These systems optimize aspects such as the interaction between a photovoltaic installation, an electric car and a heat pump, choosing the optimal time to feed power into the grid. We don't need sophisticated smart grids and we don't have to wait – we can start to expand power grids now.

But, as the owner of a house or an apartment, don't I need to wait for my local authority to do its homework before I make a decision?
Yes. The extent to which renovations make sense always depends on the supply side situation. Simply put, if a good renewable heating source is available, there is less need for renovation. Otherwise, extensive renovation is required first and the remaining heat demand has to be covered at greater expense. The responsibility for ensuring an effective link between the supply side and renovations lies with local authorities and their heat planning teams. However, we're already able to figure out very quickly which municipalities would benefit from district heating. This means we can lay the foundations for the heat transition without great effort or expenditure.

How do you support this as a researcher?
I see our role as providing the data and tools that municipal heat planning teams can rely on. That brings us to the topic of digitalization. There is a great deal of data about buildings – but we need to put it into formats that allow us to make up-to-date data available at any time. That is why we just launched the NEED research project, which aims to develop a platform that provides all the necessary data in the right form. At TUM, for instance, we're working with the local authorities in Garching to develop models for long-term heat planning, which will benefit local communities and our campus. ■

2 | Heat from **the Deep**

How we can utilize geothermal energy

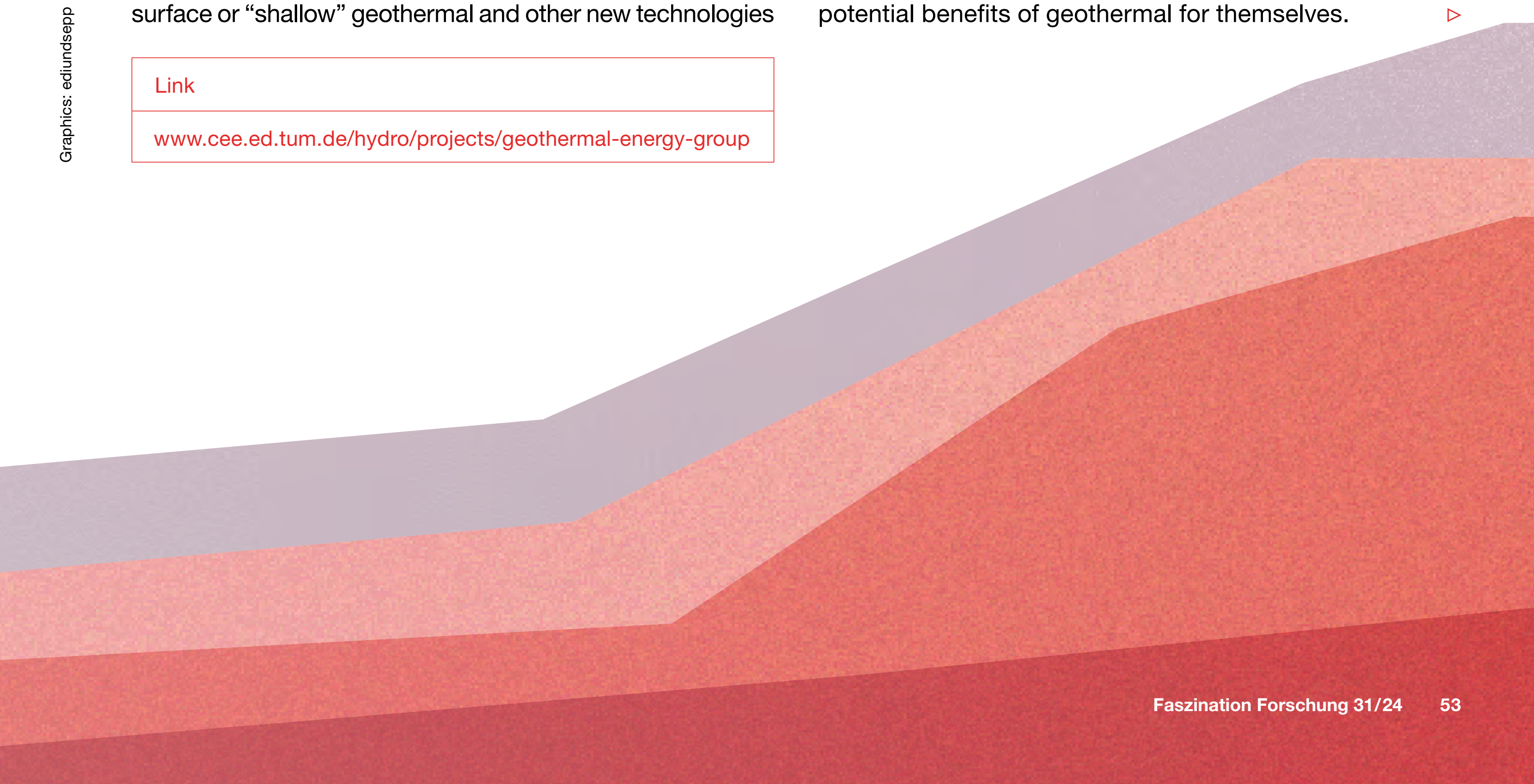
Bavaria is in an enviable position: its sits on top of the Molasse basin. Located between the Danube and the Alps, this geological formation offers favorable conditions for geothermal energy projects. At depths of up to 3,000 meters, one finds water hot enough to fulfill the conditions – at least 100 to 120°C – for cost-effective electricity generation and heat supply.

However, this isn't unique to Bavaria. Similar natural resources with vast quantities of water are widespread across Germany. "We could cover a quarter of our heating requirements with deep geothermal," says Dr. Kai Zosseder, a researcher at the Chair of Hydrogeology. Taking near-surface or "shallow" geothermal and other new technologies into account could boost this figure further. At present, however, geothermal accounts for a less than a 5% share and Zosseder is working to increase this.

Link
www.cee.ed.tum.de/hydro/projects/geothermal-energy-group

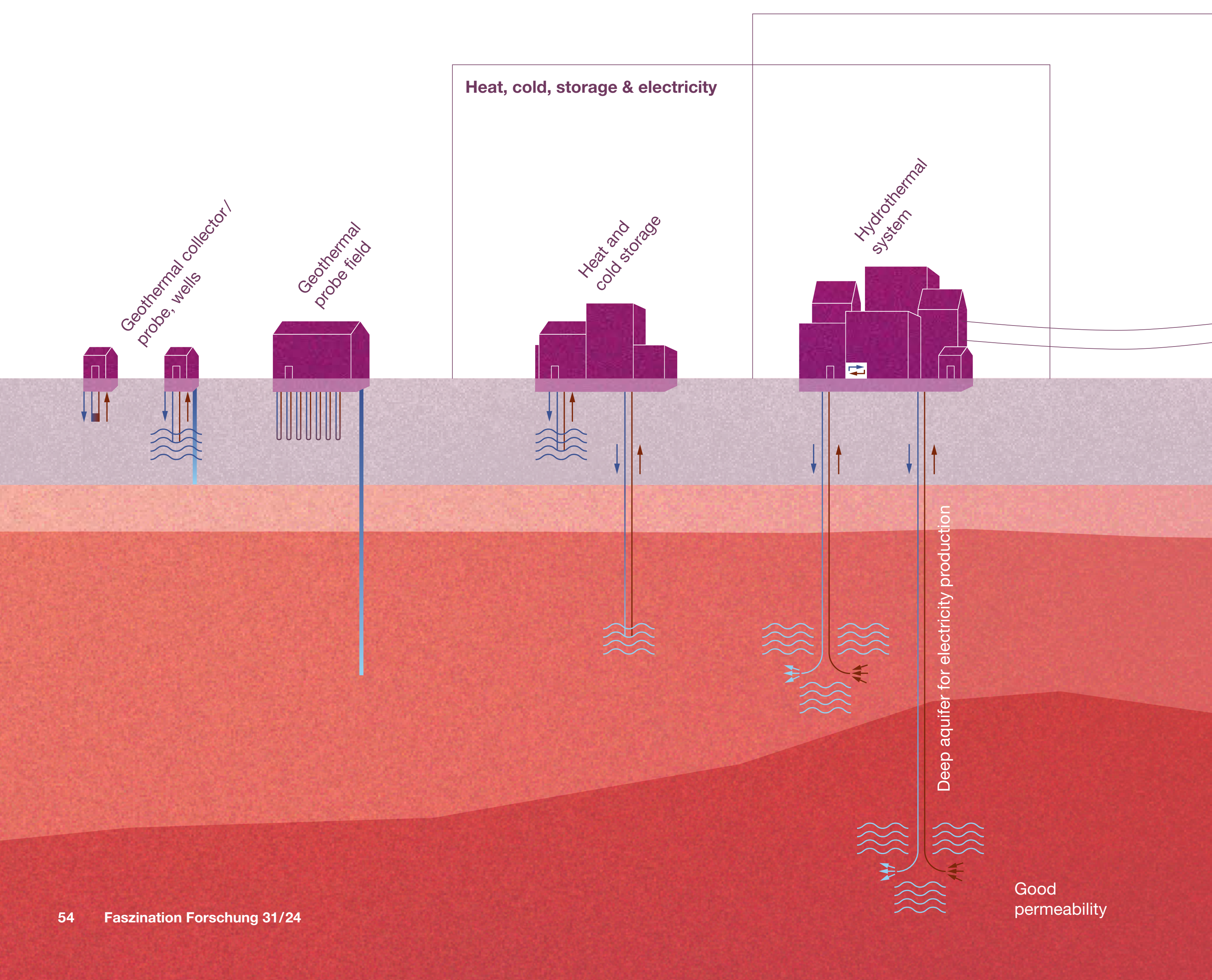
Platform promoting the exchange of data and knowledge between science, industry and politics

The Geothermal Alliance Bavaria (GAB) project, in which TUM collaborates with four other Bavarian universities, is part of this effort. It aims to advance geothermal energy systems, develop durable heating infrastructure, and thus build a bridge connecting research and practice. Zosseder primarily helps local authorities analyze and quantify the potential benefits of geothermal for themselves. ▷



Graphics: ediundsepp

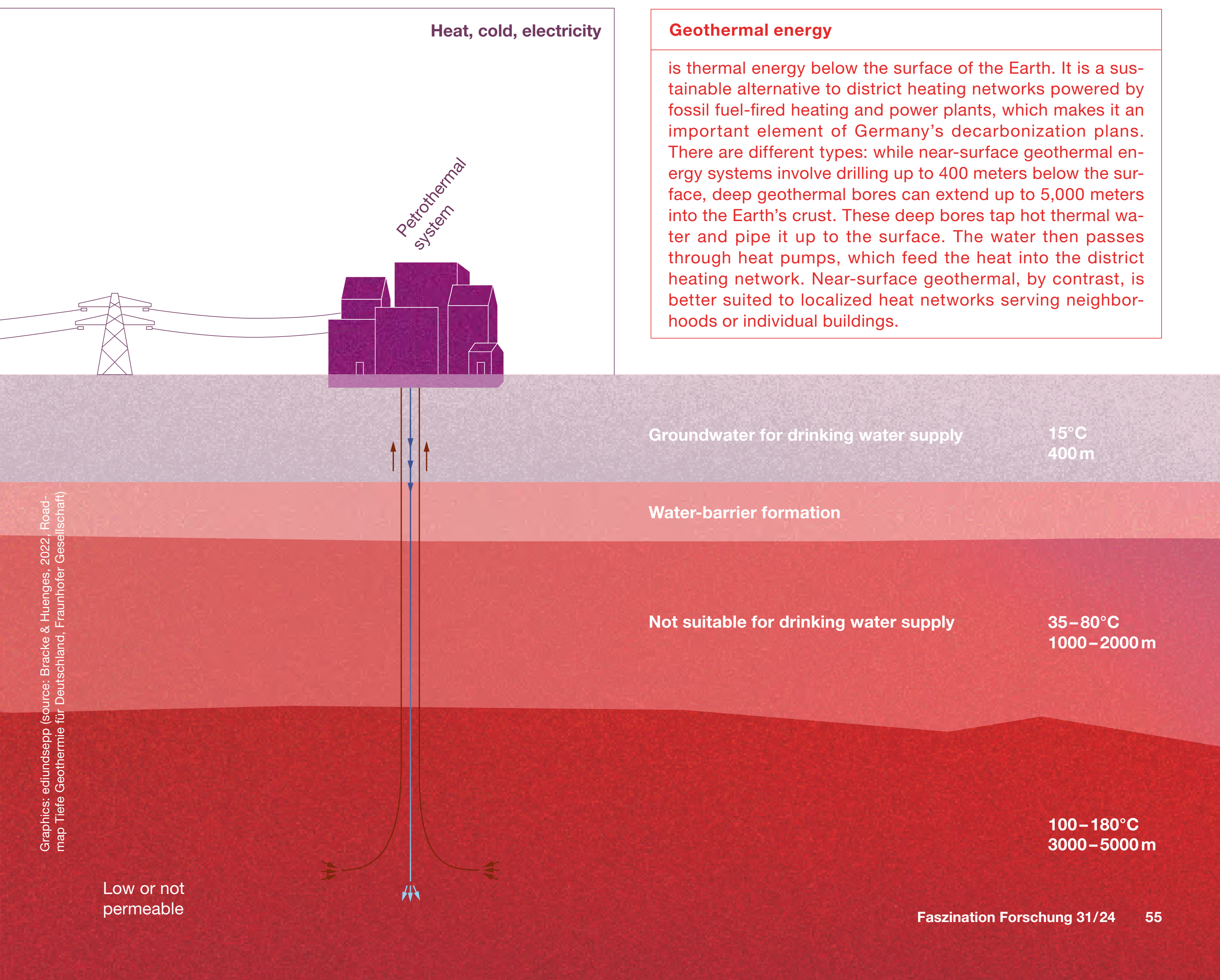
He and his team analyze data on underground conditions using bores, measurements and existing geothermal systems. They then develop methods and models to determine the spatial distribution of the potential along with new monitoring methods to ensure that these renewable resources are used sustainably. Zosseder and his team frequently receive inquiries from local authorities, especially since the German federal government introduced the Building Energy Act. “There are a few questions we focus on: Which areas would be suitable for geothermal? How should the systems be configured? But also: How can we improve the durability of the pumps, which are subject to harsh conditions with high pressures and high temperatures? In most cases, the pumps come from the oil and gas industry and have to be adapted for use in geothermal systems,” explains Zosseder.



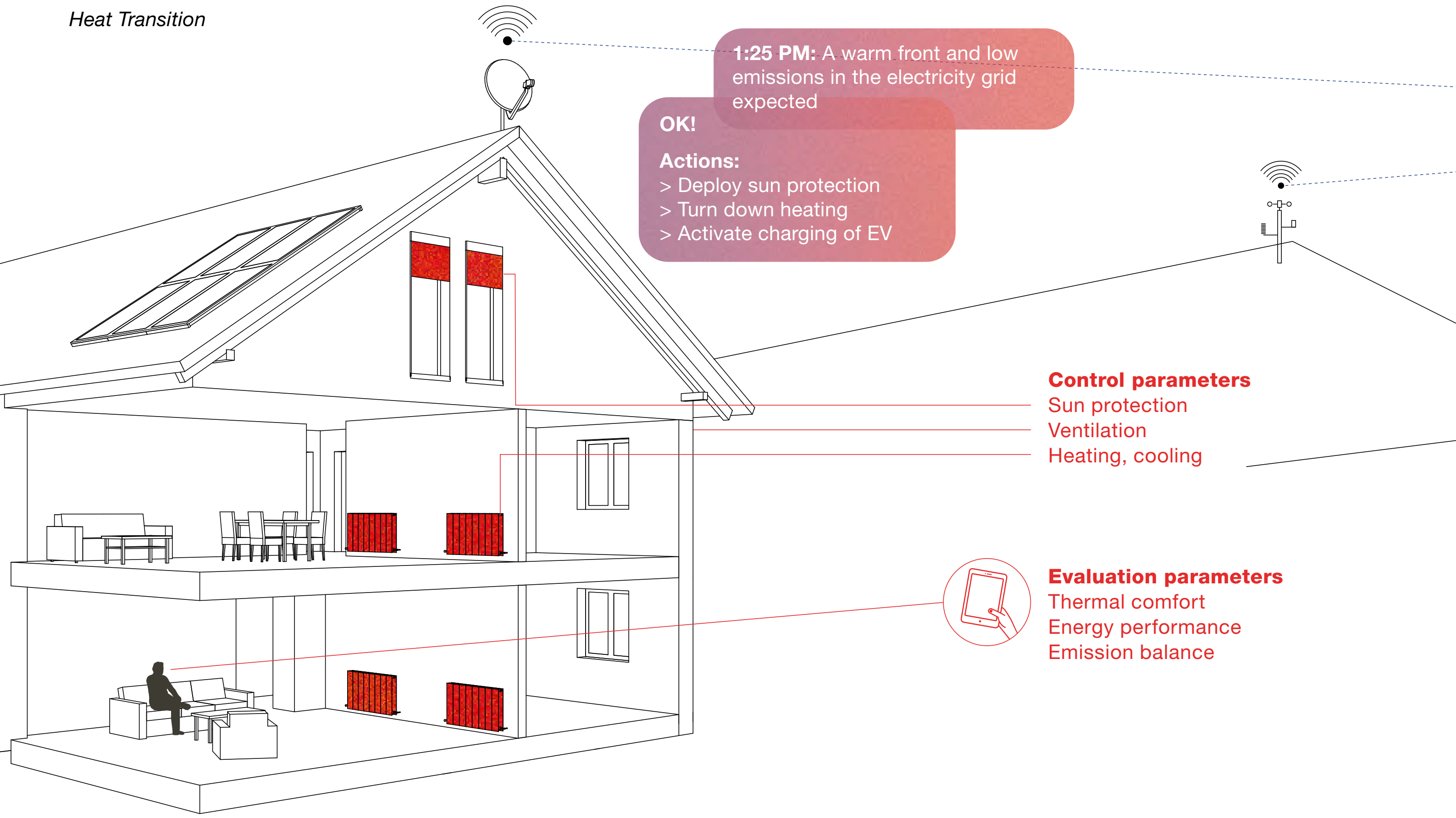
Zosseder applies his expertise to support individual local authorities. Above all, he strives to create associations that connect local authorities and make it possible to realize geothermal systems at scale. Pipelines can then send the heat where it is needed. He also conducts research into new technological developments, such as petrothermal geothermal energy systems, which is when no water is present but hot rock is available and potentially exploitable 2,000 to 6,000 meters below the ground. In truth, it is not just Bavaria and Germany, but Europe as a whole that is well positioned on geothermal. "A lot of countries have potential on this – such as Italy, where there are regions with active volcanoes," adds Zosseder. In addition to the Geothermal Alliance Bavaria, Zosseder is also involved in a range of EU research projects striving to tap the full potential of geothermal energy across Europe. ■

Geothermal energy

is thermal energy below the surface of the Earth. It is a sustainable alternative to district heating networks powered by fossil fuel-fired heating and power plants, which makes it an important element of Germany's decarbonization plans. There are different types: while near-surface geothermal energy systems involve drilling up to 400 meters below the surface, deep geothermal bores can extend up to 5,000 meters into the Earth's crust. These deep bores tap hot thermal water and pipe it up to the surface. The water then passes through heat pumps, which feed the heat into the district heating network. Near-surface geothermal, by contrast, is better suited to localized heat networks serving neighborhoods or individual buildings.



Graphics: ediundsepp (source: Bracke & Huenges, 2022, Roadmap Tiefe Geothermie für Deutschland, Fraunhofer Gesellschaft)



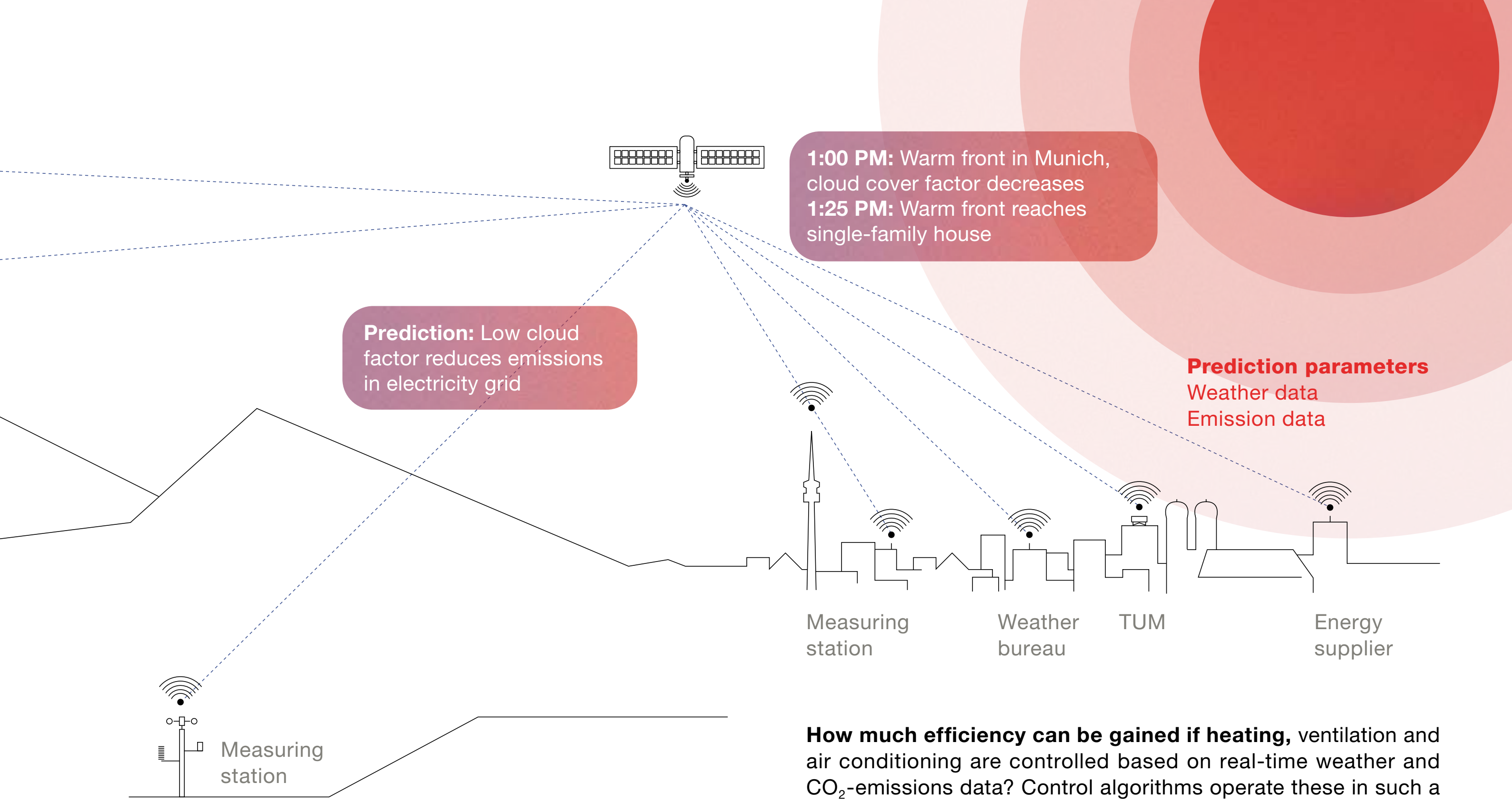
3 | Let the **Sunshine In**

How to make effective use of weather forecasts

Three questions for Christian Hepf, doctoral student at the Chair of Building Technology and Climate Responsive Design

Mr. Hepf, what role will digitalization play in the heat transition?
Digitalization makes it possible to tailor energy consumption in buildings and cities more effectively to actual needs, ideally with reductions in greenhouse emissions as the definitive control parameters and not financial savings. Real-time measurement and sensor data about energy and heat consumption, and the ability to forecast future consumption, open up enormous potential to optimize the efficiency of the heat and power network. Over the long term, this could lead to greater energy flexibility and, as a result, improved grid stability. Consumers can also use intelligent energy management systems to reduce their energy consumption and thereby cut their costs and CO_2 emissions.

Link
www.arc.ed.tum.de/en/klima/start



How much efficiency can be gained if heating, ventilation and air conditioning are controlled based on real-time weather and CO_2-emissions data? Control algorithms operate these in such a way that thermal comfort, energy consumption and CO_2 emissions are optimized.

You are currently writing a dissertation analyzing how weather and CO_2 data can be used to make a meaningful contribution to the heat transition. Could you tell us about it?

To be precise, my dissertation is about enabling building technology to operate more efficiently. The aim is to use control algorithms to optimize how these systems operate so that buildings consume as little energy as possible and generate as little CO_2 emissions as possible, all without compromising thermal comfort. I take advantage of current and future data about the weather and about CO_2 emissions from Germany's power grid. In the beginning, I tested the whole thing in the solar station, a measurement room on the roof of TUM's main building, at an altitude of almost 30 meters.

Drawing on this data, I test various scenarios in a thermodynamic simulation. So, for example, the heating system powers down when it knows – thanks to the forecast data – that the sun will come out soon. I can also operate electrical devices, like a heat pump, in phases when the emissions from the electricity grid are particularly low because renewable energy sources account for a high proportion of total generation. The simulation allows me to test the control algorithm under different conditions. This means, for example, that I can change the location of a proposed building and evaluate how its control system would behave in a different climate or in combination with a different electricity grid.

What insights have you gained?

I'm still in the final stages of my dissertation, so although I can't verify everything with 100 % certainty, I've been able to identify certain tendencies. One thing that has become clear is that a building's thermal mass has a significant influence on whether intelligent control systems are successful. So, the greater a building's thermal mass, the longer it takes to respond to temperature fluctuations, which results in greater energy savings and CO_2 reductions. We can see that this works better for cooling-related energy needs than for heating. And, fundamentally, I've determined that we can save a lot of CO_2 through distributed energy generation, such as using photovoltaics or solar thermal systems, as this eliminates the energy losses incurred during transport. ■

Graphics: ediundsepp (source: TUM)

4

That's on **the House**

How to heat buildings in a climate-neutral way

Research at the Institute of Energy Efficient and Sustainable Design

Link
www.cee.ed.tum.de/en/enpb/home

Do you dream of a house that produces more energy than it consumes? Almost ten years ago, Prof. Werner Lang and his team designed the energy concept for a house that does exactly that and built it in Hallbergmoos, a town north of Munich, with the help of a dedicated contractor. Its walls, floors and roof correspond to ambitious Effizienzhaus standards. Its photovoltaic system provides electricity and hot water – more than the building needs, in fact. The surplus electricity is either used for the EV charging point or fed into the power grid. "The important insight for us was that it is possible to build an energy-plus building. In fact, it is relatively simple. It wasn't particularly complicated or expensive to build," says Lang. The pioneering achievement of this project lay in producing the evidence, which was achieved by measuring the building's energy and heat consumption over a two-year period.

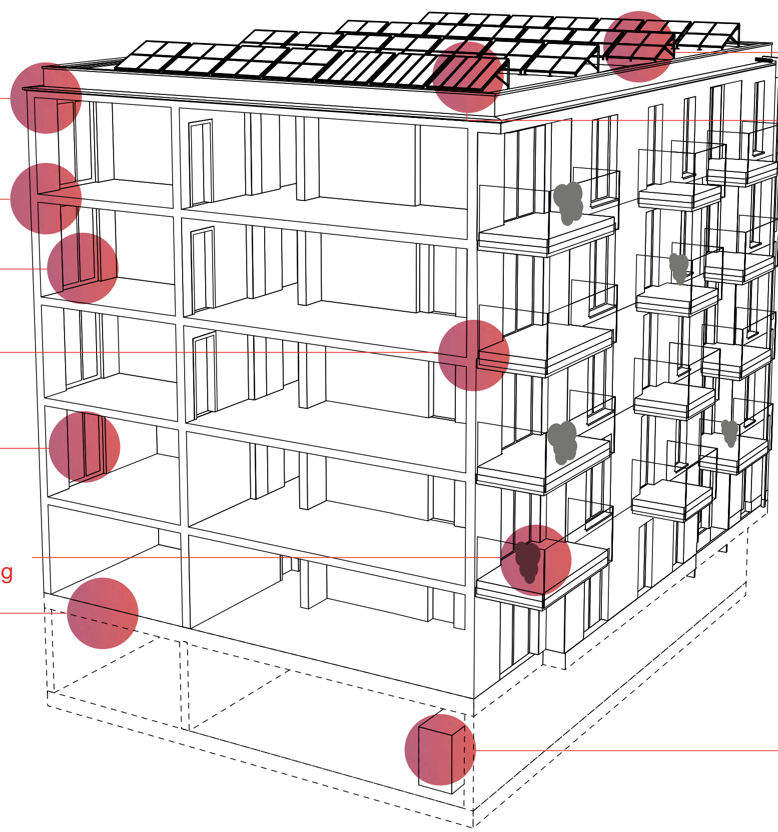
The Effizienzhaus

The Effizienzhaus (Efficiency House) standard provides a benchmark to guide the design and construction of energy-saving buildings in Germany. It indicates how energy-efficient a building is in comparison to a reference building. For example, an Efficiency House 40 only requires 40 % of the primary energy used compared to a reference building defined in the German Building Energy Act.

At the Solar Decathlon, an international collegiate challenge, students went even further than the energy-plus house in Hallbergmoos. They created an energy-plus house with an outstanding energy concept, building it almost exclusively out of sustainable materials and even implementing an efficient water treatment system. They also had a further challenge to overcome: with the house built in a hot Texan environment, it needs to be both heated and cooled efficiently. This is ensured by a heat pump that, in effect, works in reverse when appropriate. So, rather than removing heat from the air outside to heat the interior, it extracts heat from the interior and emits it outside.

What about an old house?

The building sector accounts for about 37 % of Germany's final energy consumption – 32 % for heat in buildings and 5 % for heating water. Three quarters of building-related emissions are generated through operation, with the rest caused by gray energy. This is the energy consumed in the building's construction as well as in manufacturing, transporting, installing and disposing of all the heating, ventilation and air-conditioning systems, sanitary systems, electrical systems, lighting systems and security technology.



The main challenge is existing buildings. “A total of 65% of today’s buildings were built before 1977, before the first legislation on heat insulation came into effect,” says Lang. Until then, Germany had no public regulations on the use of energy-saving heat insulation in buildings. A typical detached house built in the 1970s without further refurbishment uses around 250 kWh per square meter of heating energy per year. For context, the standard for low-energy buildings sets a maximum limit of 25 kWh per square meter per year.

Let’s get to it!

So, how can we change this? According to Lang, there are two main, interconnected levers we can pull. “First, we can drastically reduce heat losses – and, therefore, our energy needs – by carrying out renovations, such as installing façade insulation, roof insulation and triple-glazed windows. Second, we need to source significantly more power and heat from renewable energy, such as through photovoltaics and geothermal.” Lang and his team have demonstrated the positive impacts of such measures for new buildings in the BEWOOpt research project. The researchers examined how to make environmentally and economically optimized homes a reality. An environmentally sound building envelope and the use of photovoltaics makes it possible to reduce greenhouse gas emissions by more than 70% across a 50-year lifespan compared to a reference building.

In the European Green Deal, Europe has set itself the target of reducing its carbon emissions to zero by 2050, thereby becoming the first climate-neutral continent. If Germany is to reach this target, it will have to renovate buildings at a rate of 4% per year. At present, the renovation rate is just 0.8% per year.

“We can get down to business,” says Lang. “For new buildings, the KfW 40 standard has become common practice. It’s future-proof – and we can achieve it for existing buildings, too.” ■

Prof. Thomas Hamacher

is Professor of Renewable and Sustainable Energy Systems. He previously worked at the Max Planck Institute for Plasma Physics, most recently as Head of the Energy and System Studies Group.

Dr. Kai Zosseder

conducts research at the TUM Chair of Hydrogeology. He was previously a research assistant and risk analyst at the German Aerospace Center (DLR) and the Bavarian State Office for the Environment (LfU).

Christian Hepf

Since completing his Master's degree, Christian Hepf has conducted research as a doctoral student and Deputy Director of the Chair of Building Technology and Climate Responsive Design, currently held by Prof. Thomas Auer.

Prof. Werner Lang

holds the Chair of Energy Efficient and Sustainable Design and Building at TUM and is also Vice President for Sustainable Transformation. He was previously Professor of Sustainable Building and Director of the Center for Sustainable Development at the University of Texas School of Architecture in Austin, Texas.

Picture credit: Uli Benz, Astrid Eckert

How Can Research Advance **Sustainable Transformation?**

Prof. Werner Lang is TUM Vice President for Sustainable Transformation. We previously spoke with him and other colleagues about strategies for spearheading the heat transition. Time and again, we heard that the requisite technologies exist and the issues are with their implementation. So, in this article, we're asking what TUM can do to enable the solutions developed to date to contribute to greater sustainability in actual practice.

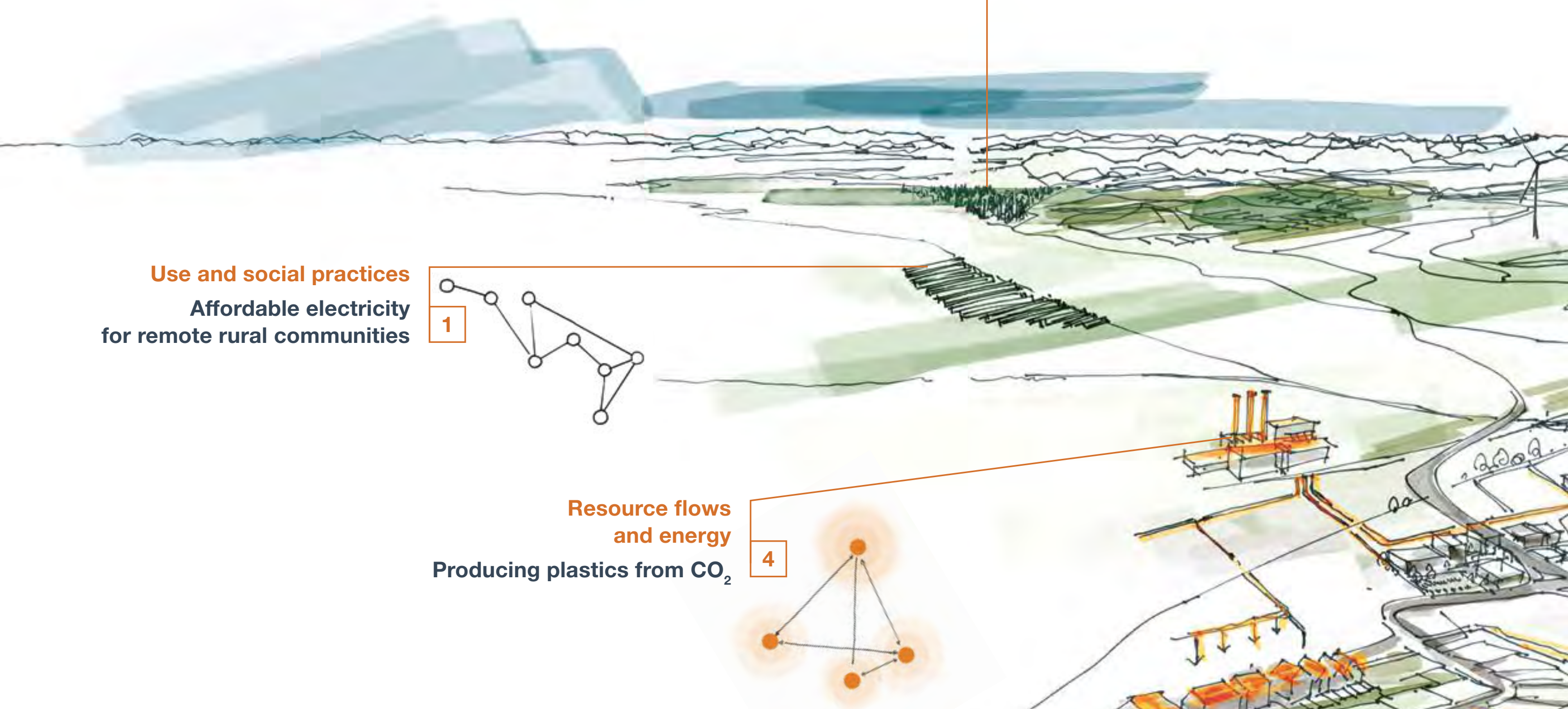
Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung

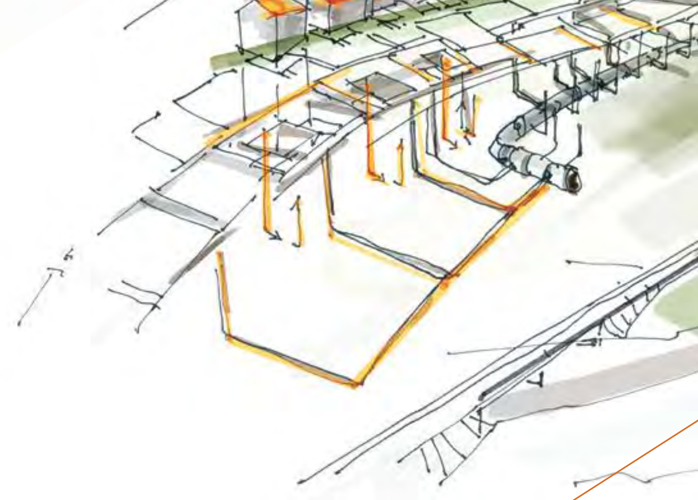
Wie kann Forschung die Transformation zur Nachhaltigkeit voranbringen?

D

Wir fragen Prof. Werner Lang, TUM Vizepräsident für Sustainable Transformation, was die TUM tun kann, um die Ergebnisse ihrer Forschung zu mehr Nachhaltigkeit in die Anwendung zu bringen. Seine Antwort: Interdisziplinäre Forschung, Einbindung der Gesellschaftswissenschaften, um abzusichern, dass die erarbeiteten Lösungen die Bedürfnisse der Menschen berücksichtigen, und Überführung von Forschung in marktfähige Produkte im Rahmen der UnternehmerTUM und der TUM Venture Labs. □

More about sustainability at TUM:
www.tum.de/en/about-tum/goals-and-values/sustainability



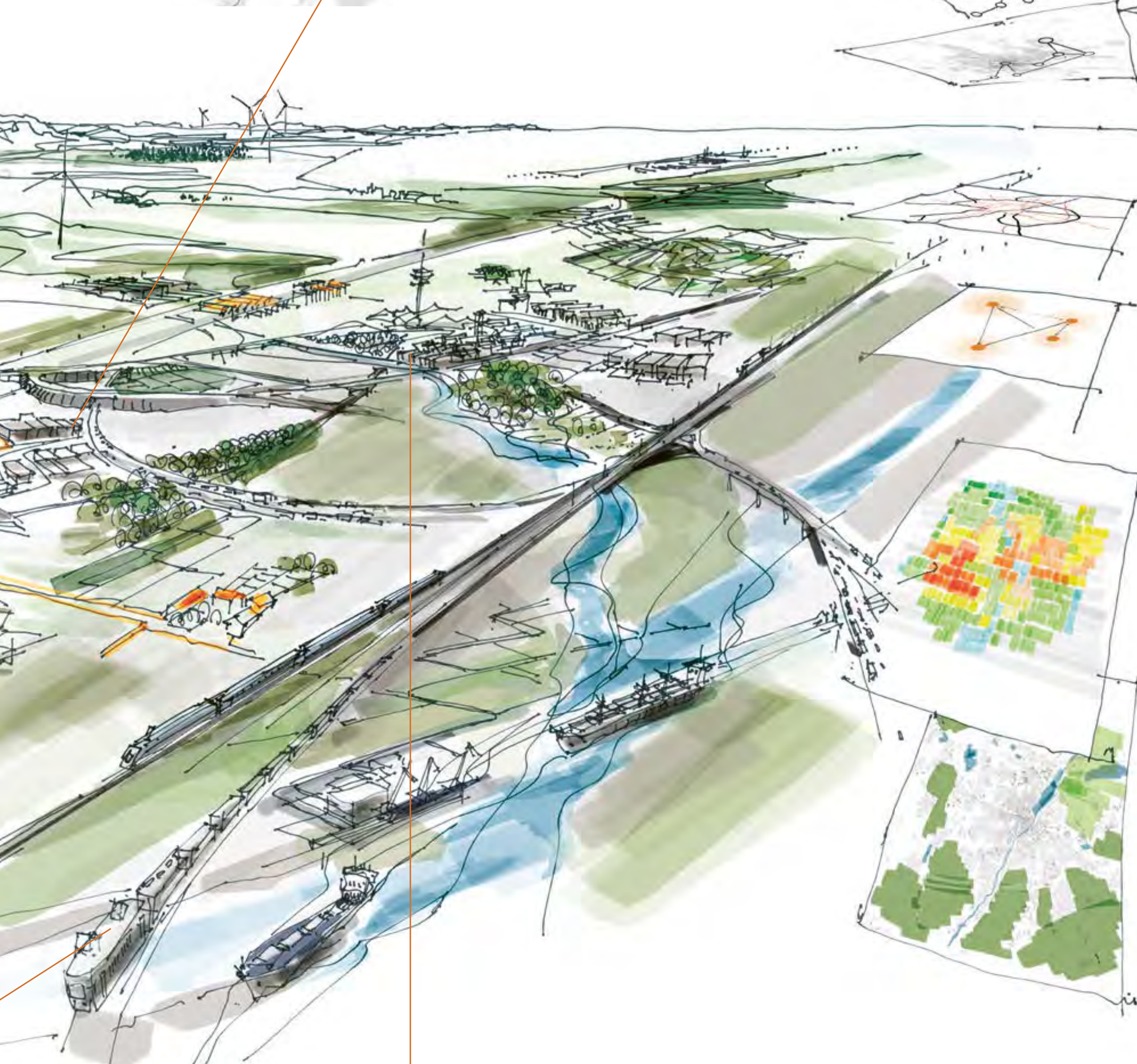


Prof. Lang, TUM adopted a sustainability strategy in 2022. How is the university's research promoting the transformation to sustainability?

In 2015, the United Nations adopted Agenda 2030, which contains 17 Sustainable Development Goals and serves as a global beacon, guiding the economic, social and environmental transformation of all member states. The objectives of Agenda 2030 are broadly reflected in our TUM Sustainable Futures Strategy 2030, which features a total of six action areas. Research – including both basic and applied research – has a central role to play in this. Against the backdrop of these 17 SDGs, research at TUM is making great strides in advancing the sustainability transformation in relation to many of these goals. 'Health and well-being', 'clean water', 'clean energy', 'industry, innovation and infrastructure', 'sustainable cities and communities', 'responsible consumption and production' and 'climate action' are just a few examples. For decades, many areas of our research have engaged with the topic of sustainability and it is on this foundation that we are driving our own transformation forward. ▷

2 Buildings and outdoor spaces

How the digital transformation is changing construction sites



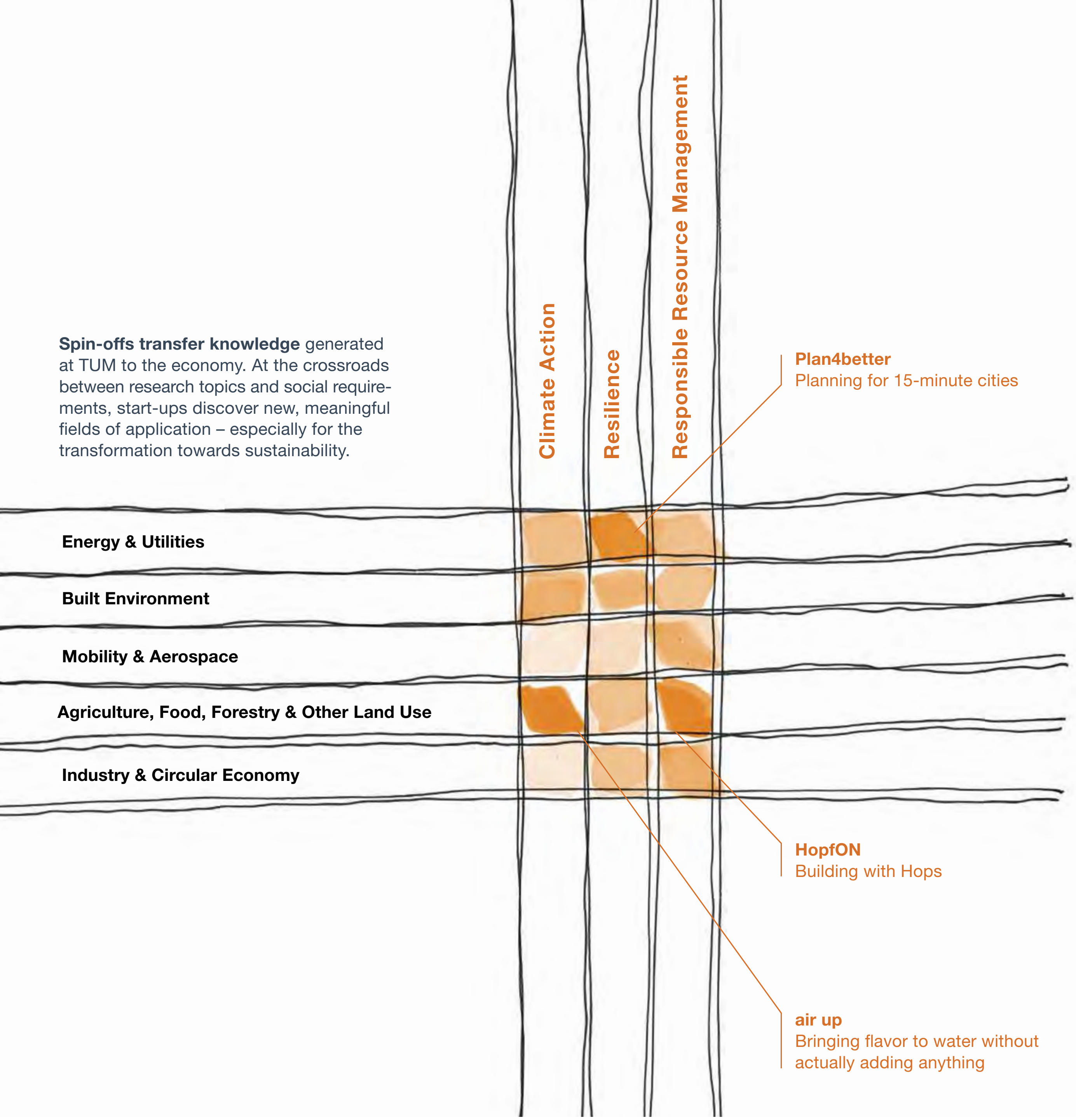
5 Climate and microclimate

Making satellite data available for visualizing changes in land use and climate change impact

Graphics: ediundsepp (source: TUM)

Our built environment can be depicted in a condensed form as an interlinked system of these interrelated topics: use and social practices, buildings and outdoor spaces, mobility, resource flows and energy, climate and microclimate, and green and blue infrastructure.
The transformation to sustainability must take an analytical approach to these fields so that they function as a system. TUM conducts research across all of these areas, shown with an example project each.

Spin-offs transfer knowledge generated at TUM to the economy. At the crossroads between research topics and social requirements, start-ups discover new, meaningful fields of application – especially for the transformation towards sustainability.



TUM Venture Labs

As a joint initiative by TUM and UnternehmerTUM, the TUM Venture Labs support talents and start-ups in successfully establishing their deep tech or life science ideas. Domain-specific expertise and continuous support enable scalable, sustainable and global impact.

On the one hand, we can identify a strong fixation on progress and technology in society, such as demand for the latest gadgets. By contrast, the implementation of technologies required to effect the change we need continues to lag behind. How are we, as TUM, dealing with this?

Above all, we have to recognize that the transition to sustainability can only succeed if it transcends disciplinary boundaries and integrates society in the process. With this in mind, TUM has made tremendous structural changes in recent years. Its faculties, which previously had a narrow disciplinary focus, have been restructured into seven schools that encompass major scientific domains and gear their research towards sustainable innovation for people, the environment and society. This means we are in an ideal position to address key contemporary issues with our interdisciplinary approach. Our Agenda 2030 explicitly puts people at the center of our work. After all, the preservation of our biosphere is a fundamental human need. If we develop solutions that people don't like, our efforts will come to nothing. But if our solutions exceed the limitations of our planet, they'll be equally worthless.

Let's take an example from our field of work: Green City of the Future is a joint project striving to develop concepts for climate-resilient neighborhoods in growing cities that can be applied in Munich. It integrated sociology right from the outset. The results of surveys and civil participation were also incorporated into competitive calls for tender. The first projects are now being implemented in Moosach, which is one of the six living labs. Here, the focus lies on creating additional housing in a way that doesn't exacerbate heat levels in the neighborhood, such as opting for green façades, for example.

UnternehmerTUM

UnternehmerTUM GmbH is an associated institute of TUM. Supporting more than 50 high-growth technology start-ups each year, it is the leading center for innovation and business creation in Europe. UnternehmerTUM offers support and services to start-ups at every stage in their development, from the initial idea through to IPO. UnternehmerTUM also offers established companies access to its ecosystem.

Let's turn to research outcomes that are not yet being implemented within living labs. How can TUM promote their adoption in future?

Our business creation center, UnternehmerTUM, and our entrepreneurial innovation centers, the TUM Venture Labs, have important roles to play in this. They transfer knowledge generated at TUM to the world of business. UnternehmerTUM is tasked with nurturing ideas through to their market launch as product-ready solutions. The European Commission's Green Deal opens up growing prospects for topics such as combating climate change, climate change adaptation and circular concepts with a view to conserving resources. This also helps to guide UnternehmerTUM and its activities, turning research at TUM into entrepreneurial activity in areas such as construction, energy, mobility, agriculture, food and the circular economy. HopfON – a start-up that develops construction materials from the waste produced in hop harvesting – is a relatively recent example of a spin-off supported by UnternehmerTUM. ■ *Christine Rüth*

Graphics: ediundsepp (source: UnternehmerTUM)

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The title image of this issue is an AI-generated, abstract representation of the circular economy. It shows fictitious components from industrial processes that have been photo-realistically implemented.

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Prompt: modern macro photography of circular economy that describes the use of recycled automotive materials for new products shown as a categorized diagram
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