In the political discussions about the energy transition, half-truths and untruths circulate – something that annoys Axel Kleidon. The physicist, who analyzes the Earth system from a thermodynamic perspective at the Max Planck Institute for Biogeochemistry, contributes to the debate with scientific facts in an effort to help the energy transition succeed.

TEXT: FINN BROCKERHOFF

Axel Kleidon reaches the small beach bar in Paradiespark on the Saale River on his bike: steel frame, unpainted. Emblazoned on the top tube is Boltzmann's entropy formula, a fundamental equation of thermodynamics – the first indication that physics is far more than just a tool for the Group Leader at the Max Planck Institute for Biogeochemistry in Jena. It sparks his curiosity, and also shapes his worldview. "I constantly strive to approach new situations as impartially as possible," Kleidon says. "After all, being a scientist doesn't mean knowing everything; rather, it means being open to new ideas, actively challenging them, and thinking things through."

In his research group "Biospheric Theory and Modeling," he uses the physical laws of thermodynamics to explore energy transformations in the Earth system: "When sunlight reaches the earth's surface, its radiative energy is converted into thermal energy," Kleidon explains. This causes air masses to rise in the atmosphere, which generates kinetic energy. Plants, meanwhile, use sunlight for photosynthesis, converting it into chemical energy in the form of carbohydrates. And when it hits a solar panel, it generates electricity. "These are examples of energy transformations that take place continuously on our planet. By considering them as a whole and figuring out their thermodynamic limits, we can model and predict many Earth system processes to a good approximation." Kleidon uses this method to try and gain a better understanding of the effects of climate change, for example, and to find out how much potential there is in renewable energies. "These topics are important beyond research for climate and energy policy and they also get me going on a personal level," says the physicist. You could almost take that last statement literally: to support the environment, the earth system scientist travels in Jena almost exclusively by bicycle. "Plus, it's faster than driving the route from my home to the Institute."

In keeping with his upbeat and talkative nature, Kleidon likes to occasionally move his work here to the beach bar in the summer, where he can talk to his coworkers in a casual setting. Nowadays Kleidon discusses specific issues in thermodynamics in these conversations, but there was only one significant issue at the start of his academic career: why does the world work the way it does? "And when you ask why, you quickly arrive at physics," the researcher says. And so, he began to study physics in his hometown of Hamburg in 1989. After completing his undergraduate degree, he went to the US in 1992 as an exchange scholar to pursue a master's degree at Purdue University in Indiana. There, some elective courses sparked his enthusiasm for climate modeling. "I was par-

→

VISIT TO

AXEL KLEIDON

PHOTO: ANNA SCHROLL FOR MPG

Axel Kleidon is a passionate cyclist. He almost always relies on his own muscle power to get to work.

PHOTO: ANNA SCHROLL FOR MPG

Sustainable power generation with a difference: With enough dynamos and sufficient training, Axel Kleidon can light up a lot of bulbs.

ticularly attracted to the fact that it allowed me to combine physics with programming," Kleidon says. He had already done a lot of programming alongside his studies – a passion he discovered in his youth and which had subsequently financed several vacations for him. So, Kleidon returned to Hamburg in 1994 to obtain his doctorate at the Max Planck Institute for Meteorology with Martin Heimann (who worked at the Max Planck Institute for Biogeochemistry from 1998) in the department of climate scientist Klaus Hasselmann, who later became a Nobel laureate. His topic was the influence of vegetation, and especially the root system, on climate in the Amazon. "What I found interesting here is that there is a biological component, but it's looked at in a physical way," Kleidon said. "Because people believed that the most important processes occurred within the atmosphere, vegetation was typically treated somewhat disparagingly as an insignificant boundary condition in the climate models of the time." In the end, however, Kleidon's model simulation showed that the Amazon is up to eight degrees cooler in the dry season than it would be without plants. The reason for this is the deep roots that take water from the soil; this water then evaporates through the leaves. "It was a very impressive result that made at least some colleagues aware of the importance of vegetation." After obtaining his doctorate, Kleidon went to Stanford University in California on a postdoctoral scholarship from the Alexander von Humboldt Foundation. There, in Silicon Valley, the center of the US computer industry, Kleidon almost gave up science. The search engine giant Google was still in its infancy at the time and was urgently looking for staff. "I could have gotten a job with them, and no doubt earned a lot more money than was to be made in science," Kleidon says. "But money isn't everything," he continues. "I think what ultimately kept me in research was again the question of why and my curiosity to get to the bottom of things."

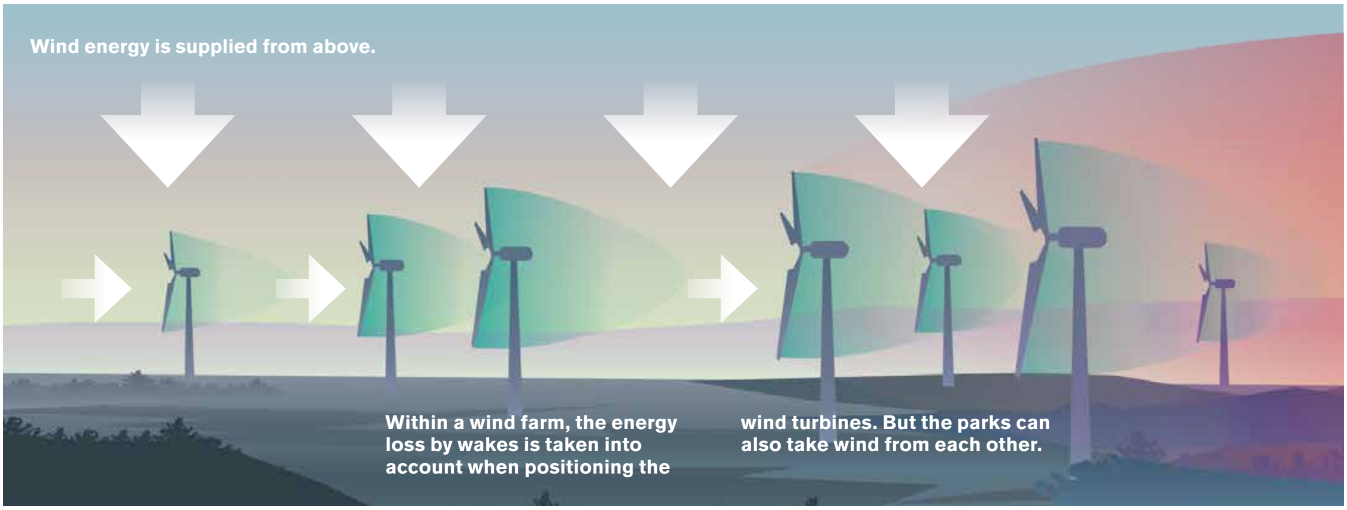
After two years at Stanford, Kleidon took a job as an assistant professor at the University of Maryland near Washington, D.C., in 2001, where he met Lee Miller, then a master's student. In the early 2000s, the two began thinking about how much energy could be generated by wind power. "During this time, I increasingly tried to incorporate concepts from thermodynamics and entropy into my thinking, laying the foundation for my later research," Kleidon says. Thanks to the tenure track, he says, he had good prospects for a tenured professorship at Maryland after his temporary appointment. In the US, you get nine-month contracts for the time you teach. The period in the summer with no lectures is then reserved for research. There are no official paid vacations. From time to time, Kleidon nevertheless took time off to visit relatives in Germany with his wife and children. “However, since I traveled a lot during college and really enjoyed it, I missed discovering the world.”

In the long term, he wanted to return to Germany. And, lo and behold: one day, his doctoral advisor Martin Heimann contacted him. There was a plan to start three new working groups at the Max Planck Institute for Biogeochemistry in Jena, and Heimann suggested that Kleidon apply. “I did, and pretty soon I got an offer. However, the position was initially limited to five years.” At that time, Kleidon was about to enter the tenure review process at Maryland, which would determine whether he would be offered a permanent professorship. “Since a secure position was more important for my family than paid vacation, I had to reject Jena with a heavy heart.” But just a few weeks later, he got another call: “They wanted to know if I would come if they guaranteed me a permanent position. So, of course, I accepted immediately and moved back to Germany with my family in 2006.”

As the head of an independent research group, he now had the freedom to decide on his own topics. “It’s a very free way of working,” Kleidon relates. For him, new research projects are largely the result of personal contacts. “Frequently, scientists from outside my community write to me to share ideas, which sometimes results in very stimulating discussions.” For instance, a study that was inspired by conversations with astrophysicist Adam Frank of the University of Rochester took a thermodynamic look at planets and categorized them based on whether and how energy is converted on them. They were particularly interested in celestial bodies on which life develops – which in all likelihood happens at various locations in the universe. In doing so, the scientists also analyzed – independently of the specific characteristics of humans and their culture – the transition to an age that corresponds to the terrestrial Anthropocene with its immense energy consumption and consequences such as climate change.

When Lee Miller came to Jena from Maryland a few years later for his doctorate, the two of them began to conduct specific research on the

Limited reservoir: The more wind turbines there are in a region, the weaker the wind becomes, because not enough energy can be supplied from above. This effect may reduce electricity output in some regions during the planned onshore expansion and will play an important role in the targeted expansion in the North Sea.



GRAPHIC: GCO BASED ON A TEMPLATE BY AXEL KLEIDON potential of wind energy. "With this subject, I think it was and is very important to establish facts," Kleidon says. This, he continues, is because the atmosphere is often regarded simply as an inexhaustible reservoir of energy. "But it isn't. Any energy taken from wind turbines is lost to the atmosphere. Then the wind speeds go down." However, because the pair's approach was so straightforward, they initially encountered challenges in getting their initial articles published in journals. "The trend in science is to make everything more and more complex and detailed, rather than striving for simple and more elegant approaches," says Kleidon. In the peer review process of high-ranking journals, the feedback was therefore sometimes quite harsh: "I can't imagine that the authors believe their own results. Reject!" Just one example of a review. But then, Albert Einstein had already stressed that one should make a theory as simple as possible, but no simpler. And the supervisor for Kleidon's master's thesis said that anyone who could not do that had simply not understood the topic well enough.

Only eight years ago, the two researchers finally published several papers in the esteemed journal *Proceedings of the National Academy of Sciences* using regional model simulations, and their efforts did not go unnoticed: wind energy researchers from the Danish research center Risø DTU reacted immediately with a critical comment. "We then published a response again, which eventually brought our discourse to the attention of Agora Energiewende, who invited us to a joint meeting," Kleidon recounts. The Berlin-based think tank looks for scientifically sound and politically feasible solutions for the energy transition in Germany. "As we were seated across from the Danish working group, things were a little tense at first," Kleidon recalls. "But we quickly found out that we were looking at the same thing from two different angles." While Kleidon was focused on showing the limits of wind energy, his Danish colleague Jake Badger was more interested in pointing out the potential within those limits.

"We quickly hit it off, and Agora Energiewende entrusted us with reassessing the potential of offshore wind energy in the German Bight." The two scientists each used their own methods. Badger developed a detailed model to simulate the German Bight at high resolution. Kleidon took a completely different approach: "I imagined putting the entire wind farm in a box and asking myself: How much kinetic energy goes through the front of the box? How much is lost in it due to friction? How much do the wind turbines take out to generate electricity? And how much energy is left in the system after that?" This allowed Kleidon to calculate how much wind speeds are reduced on average by wind turbines and how this affects electricity yields. To his delight, the results of his model were very similar to those of the highly complex simulation. "I was very satisfied with this. Because it seems to me that a lot of researchers don't want to hear that you can do things simply if you just do them right."

"Science has great potential to help improve decision-making in energy and climate policy."

After the results were published, Kleidon was surprised at the impact they had: "A couple of major energy companies and also the Federal Maritime and Hydrographic Agency changed their plans for offshore wind power as a result." Previously, it had been assumed that wind turbines would become more efficient over the years, which should enable ever higher energy yields. "But the opposite is true," Kleidon explains. "After all, when wind turbines become more efficient, it just means you're mining the resource more effectively and taking more energy out of the atmosphere. From my point of view, the work paid off because we managed to influence the energy transition."

But Kleidon's research on wind energy brought him to the attention of more than just wind energy companies and government agencies: "Agora Energiewende only learned about my research because wind energy opponents had previously frequently cited me to try and prove how absurd the expansion of wind power was," Kleidon says, looking downright amused. Proponents of nuclear power and coal-fired electricity also repeatedly referred to his work. Of course, it was never his intention to oppose the energy transition: "My only goal is to use physics to establish a foundation for discussion that is as impartial and rational as possible. Because I find it annoying when people talk 'scientific' nonsense in politics."

PHOTO: ANNA SCHROLL FOR MPG

Relaxed atmosphere: Axel Kleidon enjoys discussions with members of his group at the beach bar on the Saale River.

For him, one thing is clear: "Science has great potential to help improve decision-making in energy and climate policy." Particularly in these fields, he says, there are a lot of misconceptions and incomplete perceptions that lead to the creation of myths. This includes the view that using wind energy causes droughts. But the water cycle, and by extension rainfall, is driven almost exclusively by heating from the sun. Kleidon no longer only publishes the results of his research in scientific journals, but increasingly also writes articles for the popular-science magazine *Physik in unserer Zeit* to bring these discoveries to a wider audience. "I think it's important to consider the implications of your research for society, and use concrete examples from real-world situations to make your points so they stick in people's minds." In his latest article, for example, Kleidon used the actually planned expansion of wind energy in Germany as a hook. He demonstrated that with an installed capacity of 200 gigawatts, more than half of Germany's current electricity demand could be satisfied but for the atmosphere, this removal of energy is negligible.

Good ideas like these often come to Axel Kleidon while he is running. He has been jogging several times a week for 12 years, with his favorite area being the countryside around Jena, and he also likes to cover longer distances of around 20 kilometers. "It's a wonderful way for me to structure my thoughts. I frequently even plan out a few things in advance that I want to think about while running." After a long day at the computer, the exercise provides excellent balance for him. During the week there is usually no time for extended runs in nature, "but then I at least take a short detour to the running track at the University Sports Center of the Friedrich Schiller University." While running, he also keeps tweaking his lecture "Renewable Energies in the Earth System," which he has been holding as a private lecturer at the University of Jena since 2018. "It focuses more on the scientific principles required to describe the Earth as a whole system than it does on technology." A lecture on climate change will then be added for the 2023/24 winter semester.

Axel Kleidon certainly has no shortage of projects to ponder while running: "I keep toying with the idea of starting a YouTube channel for science communication. After all, not everyone likes to read pages-long magazine articles." However, his plans for this are not yet set in stone. "In any case, I intend to develop my popular science writing further and use that to dispel misconceptions about climate and energy research."

←