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FOR EARTH SYSTEM RESEARCH
AND SUSTAINABILITY (CEN)

HOW COMPANIES CAN MORE EFFECTIVELY PROTECT THE CLIMATE

TEN CLIMATE RESEARCHERS REPORT

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New Climate Stories from Hamburg

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NEW CLIMATE STORIES FROM HAMBURG

Business is one of the greatest sources of CO_2 emissions – and therefore an enormous burden on our climate and the environment. So, what do companies need to change in order to do business climate-neutrally? In this booklet, experts from Universität Hamburg's Center for Earth System Research and Sustainability (CEN) address this and other questions on climate change.

This issue, you'll also learn why wet moors are good for our climate, how rock powder can be used to remove CO_2 from the atmosphere, and why indigenous knowledge is essential for climate protection.

Once a month, our researchers discuss their work in the *Hamburger Abendblatt*. In the following pages, we've gathered ten of these articles.

Enjoy browsing!

IT'S WORTH REWETTING DRY PEATLAND!

Moors cover three percent of our planet's land surface, but they store twice as much carbon as all the world's forests. But if peat is extracted and the moorland soils are drained, they can become veritable carbon dioxide factories.

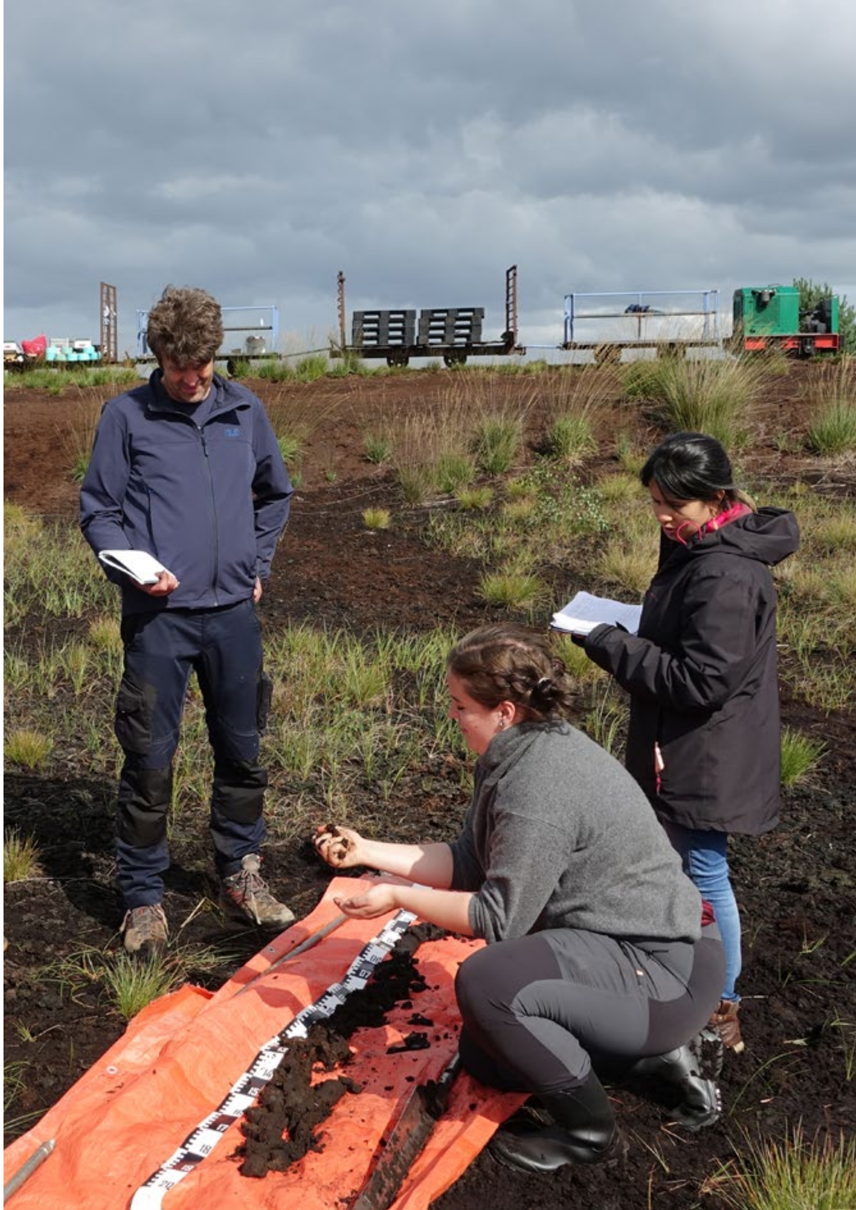
In Germany, natural moors once covered an area as large as Schleswig-Holstein and Hamburg. In many places, the peat has been excavated for heating, and entire moors have been drained to provide land for agriculture and forestry. Even today, peat is valued as a resource for horticulture; as a result, nationwide only roughly one percent of the original moors are still intact. Wouldn't it be a major step towards climate protection if we were to return moors to a near-natural state – in other words, restore them?

At Himmelmoor, north of Hamburg, I am investigating together with my colleagues how emissions of greenhouse gases from peat soils change when moors are restored. Parts of Himmelmoor have gradually been rewetted since the 1980s.

In these wet peat soils, plant matter remains largely intact, since decomposition by microorganisms is hindered. This means that most of the carbon stored in the soil is preserved. However, there are other microorganisms at work that produce the greenhouse gas methane. It's perfectly normal for natural moors to emit methane, but these emissions end once a moor is drained. Initially, in terms of the climate, that's very positive. However, once the soil is dry, oxygen can penetrate it, and the stored carbon is then converted into carbon dioxide (CO_2).

So, on the one hand, wet peat soil emits methane; on the other, drained and dry soil releases carbon dioxide. We're interested in what quantities of these gases are released in each scenario. In other words, is wet or dry peat soil climate friendlier?

Himmelmoor offers ideal conditions for comparing the two. For our investigations we selected a 1.4-square-kilometer area in the center of the moor, where half of the soil had already been rewetted. We built a six-meter-high tower with measuring equipment between the two areas, and over a two-year period recorded how much CO_2 and how much methane escaped into the air from the soil. This allowed us to directly compare the wetted and drained areas. The data clearly showed: as soon as the water level was raised, up to 40 per-



cent less CO_2 was released. At the same time, however, methane emissions increased – by up to 80 percent. Yet, even though methane is much more harmful for the climate than CO_2, by the second year, the restored area's greenhouse-gas balance was better than that of the untouched area – because CO_2 emissions continued to fall.

Admittedly, overall Himmelmoor continues to release large amounts of greenhouse gases. But my measurements confirm that restoring moorland results in a huge reduction in CO_2 emissions. Nevertheless, making these areas into effective carbon sinks could take several decades.

Dr. David Holl is a soil scientist and peatland expert at Universität Hamburg's Center for Earth System Research and Sustainability.

SCIENCE AND POLITICS IN CRISIS MODE

In the coronavirus pandemic, no political decision was made without input of epidemiologists and virologists. Why aren't scientists listened to when it comes to other topics?

Despite the fact that climate researchers have been saying for decades that anthropogenic greenhouse gases affect the existence of humans and the environment, to date there hasn't been any noticeable reduction in carbon dioxide emissions. Quite the opposite: in the past 25 years global emissions have increased significantly.

What does that tell us about the relationship between science and politics? As an expert on the sociology of science, I investigate, what role scientific knowledge plays in political decisions and public debates.

I do so with the help of a sociological model that divides society into different sectors according to their functions. One sector is politics, which has the task of making concrete decisions on behalf of the community. Another is the mass media, which provide a commonly shared background reality. The research community provides new information and is



acknowledged as the supplier of facts in today's world. This is true even though, when it comes to new or semi-political topics, researchers' knowledge is uncertain, and as in the case of corona, there were heated discussions among researchers concerning the current state of affairs.

All of these sectors are mutually dependent. Put simply, without money from business there wouldn't be any science or politics; without political decisions there would be no business or science; and without events in all areas of society, there would be no news for the media to report on. Added to that are the differences within the sectors: neither the business world nor the research community speaks with a single voice. Opinions differ, even within disciplines and business sectors.

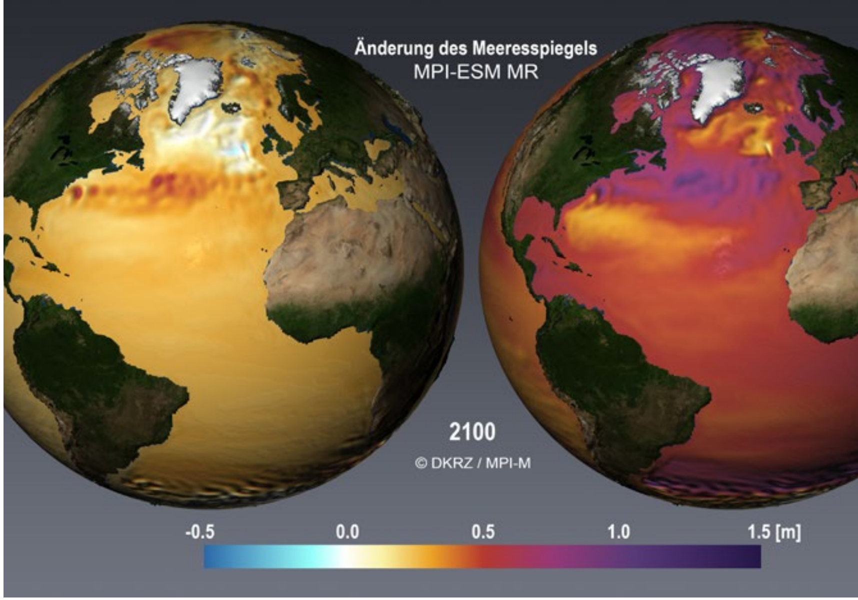
But what does that mean for climate protection measures like reducing CO_2? This could be achieved by expanding the use of renewable energy. Photovoltaic-system manufactures would probably welcome the move, while mining companies would of course oppose it. Physicists and geologists may favor the construction of wind turbines and dams, biologists warn of their negative impacts on the environment, while social scientists highlight the potential job losses. And some physicists question whether reductions in CO_2 might not be more easily achieved by reverting to nuclear power.

In other words, science provides arguments that compete with those from the other areas of society. Assessing these arguments and making decisions based on them is the task of politicians. Every political decision is the result of a process in which various arguments are weighed and compared.

There are a number of institutions that give certain sectors a voice. There are various lobby groups for business, and the Intergovernmental Panel on Climate Change, for example, lobbies on behalf of science. It publishes regular reports that summarize the current state of climate research, and, as such, offers governments a scientific basis for making informed decisions.

But during the corona pandemic scientists are being listened to without the need for lobbying. This was primarily due to the urgency. Unlike climate change, corona is perceived as an immediate and personal threat. What happened, happened directly – and in the middle of the decision-makers' terms of office. In contrast, most of the people making decisions on climate policy today won't be around to see their outcomes.

Prof. Simone Rödder is a researcher at the Department of Social Sciences at Universität Hamburg.



HOW COMPANIES CAN MORE EFFECTIVELY PROTECT THE CLIMATE

In the Paris Agreement, the international community committed to limit global warming to well below 2 degrees by the end of the century, preferably to 1.5 degrees. In order to achieve this goal, several countries have now introduced climate protection plans.

However, these plans will be nearly impossible to accomplish without corporations' involvement, as they are responsible for the lion's share of greenhouse gas emissions. Many companies are aware of this responsibility. Indeed, an increasing number of companies pledge to operate in a climate-neutral manner in the future – but how can they accomplish this in practice? This question is the focus of my doctoral research.

The first step toward a climate-neutral economy is setting effective climate targets. Relating to corporations, this requires managers to break down the global climate target to the corporate level. However, this is often a significant barrier for corporation managers because they do not possess the knowledge or expertise to develop suitable targets. As a result, most companies take their cue from what they think is feasible in emissions reductions. Whether these climate targets are ambitious enough to protect the climate, these remain unsubstantiated without a consistent approach.

So, how can science help companies to overcome this barrier? To answer this question, I have analyzed four prevailing methods based on scientifically sound climate scenarios. I have used these methods to calculate what each company would have to contribute to meet the global climate target. To do so, I have applied actual corporate data to run simulations and compared the methods. The analysis revealed that for companies with a broad product portfolio – including most economic sectors from chemicals to retail goods – three out of the four methods are unsuitable. The main reasons for unsuitability include that they are too inflexible and complex to implement. My conclusion: only one method is suitable for most companies. This method is comparatively simple to apply: a fixed reduction rate defines the extent and speed at which each company has to reduce its emissions.

More precisely, to achieve the target of well below 2 degrees, each company has to reduce its greenhouse gas emissions by 2.5 percent per year, starting from the time the company has set its target. In order to achieve the 1.5-degree target, emissions have to be cut more rapidly, namely by 4.2 percent annually. Importantly, this applies not only to emissions that occur within the company but to all emissions that occur in the upstream and downstream supply chains, including the products' use phase.

Of course, this method still offers room for improvement. For instance, it is hard to compare a retailer with a chemical company. Hence, our research recognizes that there is still a long way to go. Nevertheless, the one suitable method is a good starting point. The method makes it easy to develop effective climate targets for companies and thus, allows research and practitioners to classify whether a company's climate protection efforts have been ambitious enough so far.

Brigitte Frank is a doctoral researcher at the Cluster of Excellence for Climate Research CLICCS at Universität Hamburg. She is currently investigating strategies for a low-carbon economy.

CLIMATE, CRISIS AND CONFLICTS AT LAKE CHAD

In Nigeria, the terrorist organization Boko Haram is seeking to create an "Islamic state" in the north-eastern part of the country. Since 2009, there have been attacks on churches, mosques, public places and educational institutes. Violent clashes between these extremists and the military are common.

The conflict has spread to the neighboring countries Cameroon, Chad and Niger, forcing several million people to flee their homes. Many of them depend on food deliveries from humanitarian organizations, since local agriculture has virtually ground to a halt.

This already volatile situation is exacerbated by the fact that northeast Nigeria and its neighbors have been hard-hit by climate change. Prolonged droughts and heat waves have caused Lake Chad and the rivers connected to it – the most important sources of water in the region – to shrink by 90 percent.

To what extent is the ongoing drought, in addition to terror, also cause for migration and conflict? To investigate this,


UNHCR
The UN
Refugee Agency

I traveled to the capital of Borno State, in northeastern Nigeria, for three months in 2019. In the city of Maiduguri, the largest refugee camp in the region has been established there during this time. In 2019, an estimated 30,000 people were living there; I spoke to 300 of them at the time.

Most of the people I spoke with were landholder farmers and shepherds, who earlier travel with their livestock from pasture to pasture near their village. According to the interviewees, the water shortages and losses of arable land have caused additional conflicts. Shepherds are fighting amongst themselves over water for their animals. In addition, they have to compete with local farmers for land: one group needs it so their herds can graze, while the other needs it to grow fruits, vegetables and grains.

In the hopes of finding water or land, many people are now leaving their home villages. Some only move a few villages away; others abandon their lives as shepherds or farmers and go to one of the region's many refugee camps, where they hope to receive at least the bare minimum of food and water they need to get by. Here, they encounter people from other ethnic groups and religions, which also repeatedly leads to conflicts. According to the people I talked with, sometimes these are due to power struggles that took place thousands of years ago, but are often due to the growing competition for resources. After losing their livelihoods, some people choose to join Boko Haram. The extremists promise concrete aid, e.g. in the form of food and shelter.

The interviews show that the prolonged dryness has worsened conflicts and migration movements. My observations in Nigeria match research findings on other countries of the Global South: especially in regions already dominated by unrest or war, climate change multiplies the risk of conflict and strengthens terrorist organizations.

Studies show that climate change adaptation measures can improve both security and stability. For example, irrigation systems, boreholes and dams can be used to store rainwater and distribute it in times of drought, helping to stabilize the water supply.

But strong global climate protection remains indispensable. In this regard, the countries of the Global North are responsible for most of the damage to our climate, but have so far felt the consequences less than the Global South.

Frederic Kamta worked at the Center for Earth System Research and Sustainability (CEN) as a Geographer in the Research Group Climate Change and Security.

USING ROCK POWDER TO FIX ATMO-SPHERIC CO_2

In order to keep global warming well below two degrees Celsius, emissions of carbon dioxide (CO_2) have to be dramatically reduced. This is because the gas accumulates in and warms the atmosphere. Because politicians and society at large are achieving the "exit" from fossil fuels far too slowly, the likelihood of a climate catastrophe is on the rise.

Therefore, climate engineering methods to extract CO_2 from the atmosphere and store it permanently, must also be explored; one example is enhanced weathering.

Together with my colleagues, I am currently investigating this option. Certain types of soil are thereby sprinkled with rock powder. Once this has been done, rainfall sets certain chemical reactions in motion: the CO_2 in the air reacts with water to form carbonic acids. These acids dissolve minerals in the stone powder, and the CO_2, together with elements like calcium or magnesium, is absorbed by the solution. As a result, the CO_2 becomes fixed in the groundwater and, in the long term, makes its way through rivers out into the ocean.

Laboratory tests show that weathering can be highly efficient. We recently tested its effects in a greenhouse experiment involving ca. 90 rain barrels, each of which was filled with loamy soil and primarily planted. In order to intensify the weathering effect and fix more CO_2, we spread a powder chiefly consisting of olivine, characterized by high water solubility, on the soil in nearly all of the barrels. In addition, we used coarser powder in some, and finer powder in others. When the same quantity is used, the finer grains offer more surface area – ideally providing more rock for weathering.

The barrels were sprayed on a regular basis to simulate rainfall. Since the rock powder selected had a relatively simple chemical composition, we were able to clearly identify the chemical processes at work: we could gauge the weathering effect on the basis of the pH value, and on how much magnesium and silicon the water in the respective barrel contained. This approach also allowed us to compare the different variants used.

Our experiment shows that, although olivine fixes less CO_2 than theoretically projected, nonetheless an effect can be clearly observed. Due to their chemical compositions, other minerals (e.g. basalt) could yield an additional positive effect: the weathering process releases nutrients that are well suited as natural fertilizers. As a result, the crushed rock could be used to restore depleted soils and to complement industrial fertilizers. In turn, plants would grow better, allowing them to absorb more CO_2 from the atmosphere. However, depending on the minerals used, heavy metals like nickel and chromium can also be released and, if they accumulate in the soil and reach a certain concentration, can be harmful to human health. In the course of our experiment, however, we detected no harmful concentrations of trace elements in the plants.

Given the possible side effects, additional, thorough experiments are called for. Whether or not rock powder is a viable candidate for reducing global warming is something that only larger-scale field tests, for example on crop fields and forests, can tell us. In this regard, the characteristics of the soil need to be kept in mind. Ideally, the soil should be prepared so as to offer optimal conditions for weathering. Warm and humid regions in the tropics and subtropics are particularly well suited, since higher temperatures accelerate the CO_2 capture. The decisive factor is which rock types best combine sustainability and efficiency.

Dr. Thorben Amann is a geologist at Universität Hamburgs‘s CEN, where his research focuses on methods for removing CO_2 from the atmosphere.

HOW THE STONE SEDIMENT OF YESTERDAY IS SHAPING THE OCEAN OF TOMORROW

Some stones look as if they're striped. This "striped design" is produced by stacked layers of stone particles. If these particles are not compacted, they form what are referred to as loose sediments. Over time, these sediments are in turn eroded and transported by wind and water, sometimes over great distances.

For Earth system research, these are important processes – since the fine stone material can influence a range of ecosystems. For example, sediments can transport nutrients or determine how much water the soil can absorb. When this eroded stone reaches the ocean, it can influence the chemistry of the seawater. Until recently, however, researchers had no global map of loose sediment deposits.

In response, my colleagues and I set to work combining 126 maps, which represented the loose sediments in various regions of the planet, into a single global map: a true chal-

lenge. Many of the maps were provided to us by national geological services and were chiefly digital. But some still had to be digitalized. Another obstacle: many were in other languages – like Russian or Chinese. Thankfully, our international colleagues helped us translate them.

The resulting global map consisted of nearly a million different subareas and could be used to produce a grid of sorts. We then linked climate data to the grid – like the temperature and water run-off on the surface – and prepared a wide range of calculations, which can now be integrated e.g. into climate models.

The map was also the basis for my doctoral dissertation; I used it to calculate how the loose sediments transported by rivers affect the acidity of the ocean when they reach it. These calculations are extremely important for climate research, since in response to the rising carbon dioxide (CO_2) content in the atmosphere, the ocean is also absorbing more CO_2. In the water, the greenhouse gas dissolves and becomes carbonic acid.

So the water gradually becomes more acidic. This poses a threat to marine organisms like corals, mussels and snails, which create their shells using acid-sensitive calcium carbonate. Fish and fish larvae are also suffering from the increasing acidification.

However, some of the loose sediments that find their way to the ocean can also counteract the acidification process. Take loess, for example. The extremely fine yellow-gray material can help seawater absorb more CO_2. However, until my research, the effect of loess on ocean acidity had not been studied in more detail. My calculations show, for the first time, that loess can increase the pH level of seawater.

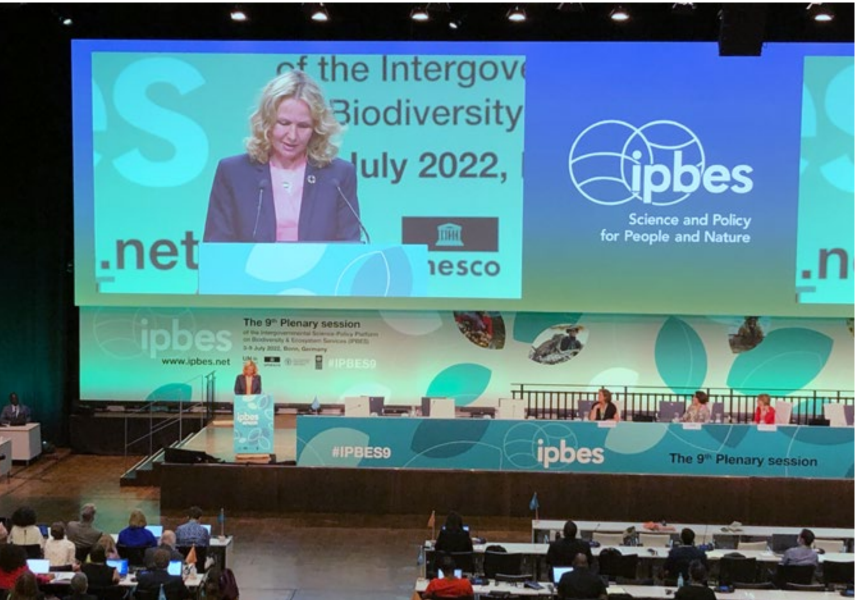
The pH value is a measure of an aqueous solution's acidity or basicity. The higher the value, the less acidic the fluid. Simply put: more loess means less acid. These processes should be kept in mind with regard to future calculations for ocean and climate models.

Dr. Janine Börker is a researcher at Universität Hamburg's Center for Earth System Research and Sustainability (CEN). She investigates global land-ocean material transport, as well as the role of chemical weathering in the Earth system.

OLD KNOWLEDGE FOR A NEW WORLD

As climate change progresses, living conditions are changing around the globe. Communities must learn to adapt. Accordingly, measures are now being developed and tested worldwide. At the same time, there is already a treasure trove of practices and strategies available, but to date it has been largely ignored.

How can less water be used on crop fields? Where is the best place for herds to graze during droughts? Herders and smallholder farmers not involved in industrial food production often know such things without following any written plan. Lessons learned are handed down from generation to generation – so-called indigenous knowledge, which includes knowing, for example, special cultivation methods and which rare plants are best adapted to specific local climates; which plants to cultivate as protection against flooding and erosion; and how to build houses on stilts or using sturdy types of wood. In addition, social concepts based on community and sharing, as well as early warning systems for climate risks, offer a wealth of insights into climate change adaptation.



This knowledge has also been recognized by the Intergovernmental Panel on Climate Change (IPCC). However, in the three years that I worked on IPCC Special Reports, starting in 2016, I realized that it had been barely taken into account so far. Were there perhaps too few studies on the topic? The IPCC's task is to assess all current research. In order to establish whether indigenous knowledge was sufficiently considered I collated the global research on the issue.

As a rule, IPCC reports are based solely on research findings that have been independently peer-reviewed prior to publication. These are stored in databases containing thousands of articles, which I systematically sifted through. I found a total of 236 articles that analyzed climate change adaptation based on indigenous knowledge. Of these, 68 should have been taken into consideration in the relevant part of the 5th Assessment Report, the IPPC Report of 2014. However, only 21 were included, and for the most part were only assessed superficially. Clearly, the topic was inadequately represented.

My study now provides the requisite data to allow research on indigenous knowledge to be extensively included in the Assessment Report. At the same time, I can highlight where there are geographical gaps – and which topics tend to dominate. For example, indigenous knowledge in rural areas and about changes in precipitation and droughts are most frequently addressed. Cities, on the other hand, are barely investigated, despite the fact that many members of indigenous groups also live in cities.

Nevertheless, there is still a dilemma: through its selection procedure alone, the IPCC excludes some of this knowledge, since as a rule it only accepts peer-reviewed, published articles. Those authors who, for financial or structural reasons, can't reach academic journals have no way to present their findings. Furthermore, oral traditions don't meet the IPCC criteria, even though they could be an important source of information, especially when it comes to indigenous knowledge.

But this doesn't have to remain the case: the international Global Assessment Report on Biodiversity and Ecosystem Services (IPBES Report) adopts a different strategy, and draws not only on the conventional sciences, but also on input from indigenous peoples and traditional communities.

Dr. Jan Petzold combined research from various disciplines as a geographer at the Cluster of Excellence CLICCS. Now he works at the Department of Geography at Ludwig-Maximilians-Universität München (LMU).

SMALL-SCALE TERRACED AGRICULTURE PROTECTS THE CLIMATE AND ENVIRONMENT

My gaze wanders down the valley. It comes to rest on a labyrinth of fruit trees, which, together with beds of vegetable and herbs, creates seemingly endless rows of green. That's how diverse some of the gardens on the hills of the Ricote valley in southeast Spain can be. For centuries, smallholders have cultivated terraced fields here, using sophisticated irrigation systems. The traditional fields are species-rich and resilient – and offer a climate-friendly alternative to industrial agriculture. However, in many abandoned gardens, the green has disappeared.

Why do people give up their land? I've investigated this question in detail and studied these terraced fields from 2016 to 2019. How many are still cultivated? What do the people living there have to say?

In the first step, I located the agricultural terraces using land-register data and a laser-based digital elevation model of the Earth's surface. Depending on how the surface behaves in the elevation model I was able to determine where there were terraces and where there were rocky areas.

In the second step, I used satellite images to determine how the terraces were used: I created a vegetation index that showed to what extent the areas were covered by plants and how healthy the latter appeared to be. By doing so, I was able to determine which fields were irrigated.

In the next step, I combined the terraces and their forms of use to calculate the total area of cultivated land. The result was surprising: the larger the plot of land, the less likely it was to be cultivated. In 2019, ca. 76 percent of the small fields on the terraces, but only 57 percent of the large ones, were cultivated. But there was also a promising trend: from 2016 to 2019, the proportion of uncultivated fields fell by roughly 16 percent. But that also means: In 2019 ca. 40 percent of the terraces weren't cultivated at all. Why not?

The final step in my study, in which I spoke with experts and locals, offered insights here: climate change, water shortages and soil degradation due to intensive farming were the main environmental factors when it came to land abandonment in the region. However, from the conversations, it soon became clear that social and economic factors were even more important. As a result, the steep slopes and the local

inheritance rules, which divide the land between siblings, have led to a fragmentation of the area. Furthermore, the locals claimed that farming was an unattractive option for young people, due to the amount of labor involved and low crop prices. Nevertheless, those in the next generation feel a strong connection to the land and don't want to sell, even if they don't farm it. Therefore, many areas are no longer cultivated.

However, my analysis also revealed that farming smaller fields appears to work well. I also found that families had other sources of income beyond farming, which allowed them to compensate for fluctuating prices. Despite this, the competition from industrial agriculture is omnipresent. Further, Ricote can't rely on farming subsidies, since small fields aren't eligible for support. But helping these smallholders would be an important contribution to preserving the variety and resilience of this landscape.

Dr. Katharina Heider is a geographer researching sustainable agriculture in the Mediterranean using satellite geographic information systems (GISs).

WHEN THE FISH IN THE PORT RUN OUT OF AIR

In Hamburg’s port, you can sometimes see fish gasping for air just below the water’s surface. A sign that there isn’t much oxygen in the water. This becomes life-threatening for them when the level falls below three milligrams of oxygen per liter.

In summer 2014, the level was below this value for several days. In the process, 100 metric tons of fish are said to have died. One reason for this are the high temperatures in summer, which are additionally intensified by climate change: the warmer a body of water is, the less oxygen dissolves in it. Furthermore, at warmer temperatures, more algae grow in the Middle Elbe. These are then transported downriver to the deeper Tidal Elbe. Whereas algae in shallow waters produce oxygen, at greater depths they don’t have enough light to do so. They die and are broken down, a process that removes substantial amounts of oxygen from the water.

The oxygen balance is upset when more oxygen is used as a result of breathing or the breakdown of organic substances than is supplied by the air or photosynthesis. To what extent

and in what proportions the sub-processes play a role here is still unclear. Likewise what influence the sediments in the riverbed have on the oxygen balance. I am investigating how much oxygen the sediments consume, and which factors determine oxygen consumption.

Sediments are made up of mineral particles and organic material such as decayed plants and algae. Their oxygen consumption is governed by chemical and biological processes. Microorganisms in the sediment consume oxygen when they break down organic components, or add oxygen-consuming substances to the pore water. When ships, excavators, or currents stir up the sediments, chemical compounds are released, which then cause oxygen consumption to rise dramatically.

In order to investigate this phenomenon more closely, I conducted various laboratory experiments using fresh sediment: I determined the oxygen consumption and the chemical and physical properties of the sediment in the port, and investigated how the concentration of various substances changed after seven days: based on the altered concentrations of ammonia, nitrite, nitrate, sulfate, iron and manganese in the water, I determined what effect individual processes had on oxygen consumption.

Over two years, I took monthly samples in the Port of Hamburg. My laboratory investigations showed that, under

certain conditions in summer, oxygen consumption is up to five times higher than in winter – especially at a depth of up to twenty centimeters. In addition, I also investigated the sediments from 21 different locations between Stover Strand in the east and Wedel in the west. The sediment in the port's shipping channel consumed the least oxygen. This is chiefly due to the large proportion of sand: hardly any organic material, which can consume oxygen, settles on the sand grains.

In my study I was able to identify the factors that control the sediments' oxygen consumption. Further, I determined the biochemical processes involved and how much they contributed to total oxygen consumption. Using this data, we have developed a predictive model with which we can model the oxygen consumption of sediments based on a given known parameter. This approach will help us to better understand the underlying processes and to improve current models.

Dr. Mathias Spieckermann conducted research at the CEN and completed his dissertation at Universität Hamburg's Institute of Soil Science.

A 25-EURO CO_2 TAX WON'T SAVE THE CLIMATE

By now, every country is being affected by climate change. Heat waves, storms and loss of biodiversity are changing our environment. And the social and economic damage is also enormous: crop failures, forest fires and health risks cost us dearly. How much money should we invest today, in order to mitigate the damage that will shape tomorrow?

The Paris Agreement set the goal of limiting the rise in temperature to below two degrees, or better still 1.5 degrees, and Germany plans to be climate neutral by 2050. How can this be achieved? In my work as an environmental economist I analyze various measures for reducing greenhouse-gas emissions. One key measure is, for example, levying a tax on greenhouse gases.

If a price is put on the greenhouse gas carbon dioxide (CO_2), production costs will increase, since the resulting emissions will have to be paid for. The outcome: CO_2-intensive products will become more expensive and consumers will have to dig deeper into their pockets. Accordingly, demand for

cheaper, low-CO_2 goods will increase. The same is true for the transport sector: if petrol prices rise, more will be invested in electric engines. This means climate protection will become more competitive.

Since 2021, in Germany 25 euros will have to be paid per metric ton of CO_2 produced by the combustion of heating or motor fuel, which is about seven cents more per liter of gasoline. This means that as of January, petrol will cost seven cents more per liter. The tax will gradually be increased to 55 Euros by 2025. But does the price make sense – and is it fair? One of the underlying questions is how much we're prepared to pay today in order to avoid climate damage in the future. To calculate this, together with an international team of researchers, I combined a climate model with an economic model. This allows us to link the emissions produced by our economy to the climate changes and damage they cause. We also incorporated a further component: the recommendations resulting from a questionnaire sent to 173 experts who are investigating how much we should invest today for future generations.

Our findings revealed the extent to which we need to reduce greenhouse gases in order to achieve optimal well-being for both current and future generations. This can be best expressed in terms of CO_2 prices: the higher today's CO_2 price, the greater the reduction in emissions, and therefore, the less harm done to the climate. One thing is certain: there is no single right price; rather, there are various climate paths open to us – depending on how much value we attach to the well-being of future generations.

If we set high ethical standards for safeguarding our children's and grandchildren's world, a metric ton of CO_2 should cost 200 euros. Or, put another way, a metric ton of CO_2 should be considered to cause 200 euros' worth of damage to humans and the climate. This is the amount recommended by the German Environment Agency (UBA), and also the price referred to by the Fridays-for-Future movement. If we take the model's middle path, a metric ton of CO_2 should be priced at good 100 euros.

Both sums are a far cry from the 25 to 55 euros now estimated in 2025. As such, the CO_2 price will have to be raised significantly in order to ensure that Earth remains habitable for future generations.

Prof. Moritz Drupp is an environmental economist at Universität Hamburg's Center for Earth System Research and Sustainability (CEN) and at the Cluster of Excellence Climate, Climatic Change, and Society (CLICCS).

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ABOUT THIS ISSUE

How is climate change affecting conflict areas in Nigeria? Why do the climate and environment benefit from traditional small-scale terraced farming? And how do seafloor sediments affect the oxygen concentration in water – and therefore, the survival of various marine fauna species?

In a series of articles in the *Hamburger Abendblatt*, experts from the CEN research center and Universität Hamburg's Cluster of Excellence CLICCS provide the answers to these questions – in plain terms, and 100% jargon-free. In our thirteenth booklet, we've gathered ten outstanding articles from the series.

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