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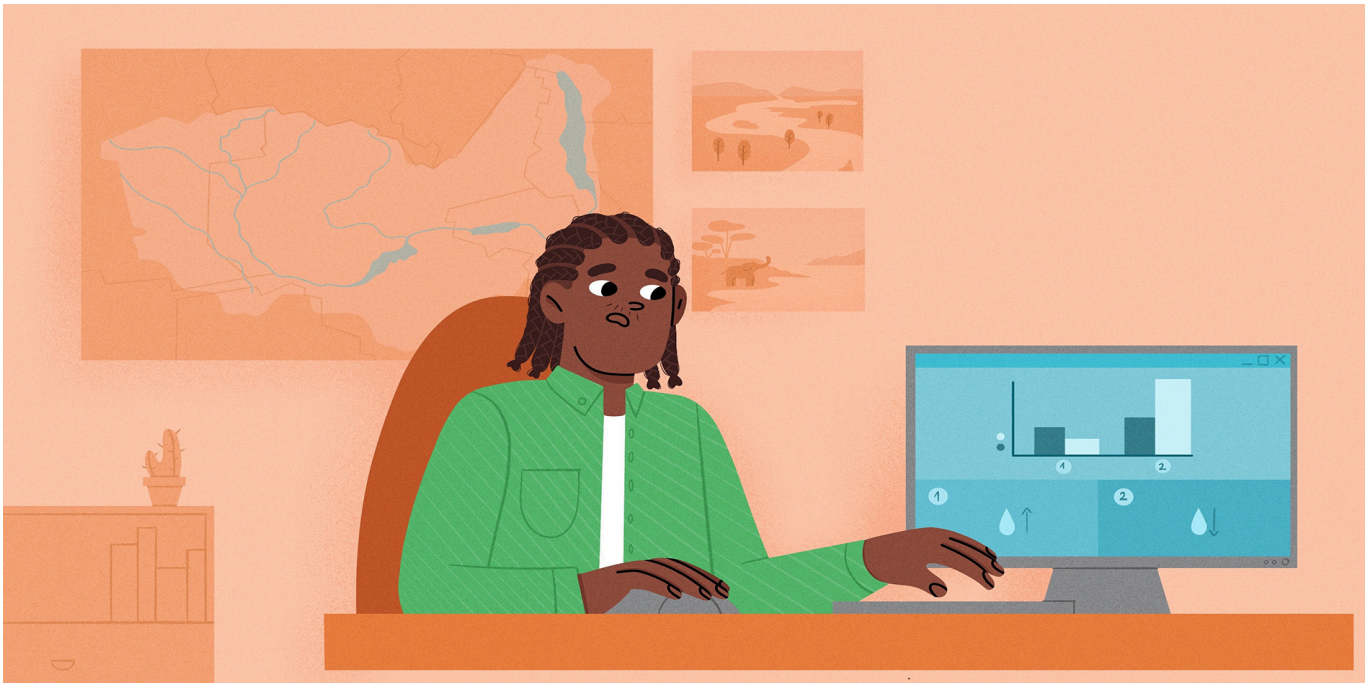

EXPLORING THE CLIMATE PUZZLE: A SURPRISING TWIST IN FIGHTING CLIMATE CHANGE

Matteo Giuliani* *and Andrea Castelletti*

Department of Electronics, Information and Bioengineering, Politecnico di Milano, Milano, Italy

YOUNG REVIEWERS:

ALAE
AGE: 13

HADIL
AGE: 13

Sometimes, when scientists try to help people, they can end up with a surprise ending in which things do not work out as expected. Their "help" might even accidentally make the situation worse for some people. We wanted to know if this could be true for a strategy to slow down climate change: charging countries a fee when they cut down forests to create farmland. We used computers to predict what might happen if countries were charged different fees, to keep things fair. Specifically, countries with less money would only have to pay low (or no) fees, while rich countries would pay higher fees. However, our computer model showed that this plan could have unexpected negative consequences for water availability in some places that pay low fees, like certain regions in Africa. This tells us that, as we fight climate change, we must keep our eyes open for unintended consequences that could result from our attempts to help the planet.

GOOD DEEDS CAN HAVE SURPRISE ENDINGS

Have you ever tried to do a good deed that did not turn out the way you planned? Maybe it had unintended consequences that were *not* so helpful for some people? Imagine a schoolyard so overgrown and messy that no one wants to play there. Weeds are popping up through the pavement, paint is peeling on the playground equipment, and kids have been carelessly throwing their trash on the ground. The principal decides to take action, so she assigns each grade a section of the schoolyard to tidy up and keep clean for the year. But wait—younger kids cannot do as much work as older kids, can they? To balance the workload, the principal assigns some of the teachers to help the younger grades, while the older students handle their areas without extra help. Sounds like a fair plan, right? A few weeks later, the schoolyard is much cleaner... but then something unexpected happens. The areas cleaned by the younger students end up looking really great because of the extra help they received. These areas become the most popular spots in the schoolyard, attracting lots of students during breaks. With more kids hanging around, these areas quickly get messy again. The younger students and their teacher helpers find themselves dealing with *even more* cleanup than before! Meanwhile, the areas cleaned by the older students remain less crowded and neater.

This situation, in which a well-meant plan has unexpected side effects for some groups, can happen in real life, too—with consequences more serious than just a messy schoolyard! In the rest of this article, we will explain how a similar situation might occur in our attempts to slow down **climate change**, if we are not careful.

CLIMATE CHANGE

Long-term changes in Earth's weather patterns, including rising temperatures, shifting rainfall, and more extreme weather events, affecting all life on our planet.

KEEPING EARTH'S ATMOSPHERE CLEAN

You probably already know that climate change is a huge problem facing the entire world [1]. Earth's climate has always been changing, but now it is happening really quickly because of things humans are doing, such as burning fossil fuels (coal, oil, and gas) to power our cars or to generate electricity. Burning fossil fuels adds a lot of carbon-containing **greenhouse gases** into the air—primarily carbon dioxide and methane. These gases act like a blanket, trapping heat close to Earth and warming up the planet. Global warming is causing serious problems for all of Earth's inhabitants, including humans. Seas are rising; heatwaves, storms, and other weather events are getting more extreme; and some animals and plants are struggling to survive because their ecosystems are changing. Humans struggle, too. For example, as the weather changes, it can become harder to grow crops in some places, leading to food shortages.

GREENHOUSE GASES

Gases in Earth's atmosphere, like carbon dioxide and methane, that help keep our planet warm. In excess, greenhouse gases make the planet too hot, causing problems with the weather and environment.

As the need to take action against climate change became more obvious, many countries decided to collaborate to try to limit

global warming. One big plan created in 2015, called the Paris Agreement, was supported by almost 200 countries. Supporting countries promised to work together toward a clear goal: to limit the global temperature increase in this century to 1.5–2°C above the temperatures that were present before the Industrial Revolution. Experts believe this target is critical if we want to avoid the most severe effects of climate change. Meeting this target will be very challenging, since the average global temperature increase recorded from 1991 to 2020 was 0.9°C.

PAYING THE PRICE FOR RELEASING CARBON

MITIGATION POLICIES

The actions that countries around the world are currently taking to combat climate change.

LAND USE CHANGE FEES

Fees charged by governments when land is altered from its natural state, like converting forests to farms or building areas, to manage environmental impacts from resulting greenhouse gas emissions.

Since the Paris Agreement was signed, many **mitigation** strategies have been proposed to decrease the amount of carbon released into Earth's atmosphere [2]. In addition to switching to energy sources like wind and solar power, one of the most discussed strategies for reducing carbon emissions involves charging a fee, kind of like a fine, when people or companies want to use land in a way that harms the environment. These are called **land use change (LUC) fees**. Some of the ways land is used can make climate change worse. For example, trees store a lot of carbon as they grow. So, when a forest is cleared to grow crops, less carbon can be stored on that land; and lots of carbon is released into the atmosphere when the trees are destroyed. LUC fees are meant to make people think more carefully about how they use land and discourage countries from contributing to climate change.

Some people think that charging the same LUC fees to everyone, all over the world, would be unfair. Think back to our schoolyard example, in which the younger kids needed more help to keep their section clean. Some countries have less money than others and might not be able to afford high LUC fees... but they might still need to convert land to farms to feed their growing populations. Maybe it would be better if these developing countries paid low (or no) LUC fees, right? After all, high fees might make things really tough for them. Or, as we saw in the schoolyard, might this good-hearted attempt to make things fair end up having unintended consequences?

RIVER BASIN

An area that collects all the rainwater and snowmelt from the surrounding land, which eventually flows toward a central river.

BIODIVERSITY

The quality of having a lot of different living things. "Bio" means life and "diversity" means variety.

ZAMBEZI WATERCOURSE—A DEVELOPING REGION

Our study focused on a **river basin** in southern Africa called the Zambezi Watercourse (ZW; Figure 1). The ZW is a good example of a developing region where LUC fees would be low or non-existent in some "fair" scenarios. The ZW is one of the largest river basins in the world [3]. It is shared by eight countries and contains 82 important **biodiversity** areas that provide homes for lots of wildlife, including migratory birds and threatened species like lions, hippos, and wild dogs. As you might expect in an area with so much water

available, the ZW is a good place for farming. Common crops include sugarcane, wheat, rice, and maize. Also, thanks to its rivers, the ZW gets much of the electricity it needs to power businesses and homes from **hydroelectric dams**, which is great because these dams do not burn fossil fuels.

HYDROELECTRIC DAM

A big wall that holds back a huge amount of water in a river, creating a reservoir. When water is released, it turns turbines to generate electricity.

Figure 1

Figure 1

(A) The ZW is the name for the area the Zambezi River flows through in southern Africa. **(B)** The Zambezi is one of Africa's longest and most important rivers. The ZW holds the entire Zambezi River and its tributaries, including the Kafue River and the Shire River. The ZW is shared by eight countries and contains 82 biodiversity areas, home to lots of wildlife.

Currently, about 40 million people live in the ZW, but the region's population is rapidly expanding—it is estimated that the ZW will be home to 70 million people by 2050! As the ZW's population grows, so will the demands for food and electricity—both of which require water. Right now, there is enough water for both of these critical purposes. But what will happen in the future? The ZW faces a double threat: rapid population growth *and* climate change. Climate change may lead to drier conditions in the region, which could decrease the amount of

water flowing through its rivers—at the same time that more water is needed for power and agriculture.

MODELING THE FUTURE OF THE ZW

COMPUTER MODELING

Creating virtual versions of a real system on a computer, to be used as a "laboratory" for experiments to explore and predict things that cannot be tested in the real world.

No one can see into the future to know exactly what will happen to the ZW, but scientists can use a technique called **computer modeling** to get a pretty good idea. Computer models are like virtual versions of the system scientists are studying, which allow scientists to experiment with various conditions to understand and predict how things might happen in the real world. Predictions generated using computer models can help policymakers make informed decisions to protect people and the environment, and they can also help to uncover any unintended consequences of human choices. Our group used a computer model to investigate what might happen to the ZW under many possible future conditions by integrating models simulating future climate conditions, models describing socio-economic development, and models showing the resulting impacts in the ZW [4]. We also compared three mitigation scenarios: no LUC fees at all; LUC fees that are the same all over the world; and LUC fees that differ from region to region, with lower fees in developing regions like the ZW.

When we used our computer model to look at the world as a whole, we found what we expected: LUC fees helped to decrease greenhouse gas emissions and limit global warming by the end of the century. At first glance, you might think that is good news for regions like the ZW—it might seem that the less the climate warms, the more water should be available in the ZW's rivers to irrigate crops and produce hydroelectric power for the growing population. But the story turned out to be more complicated.

When some regions of the world have very low or no LUC fees, these areas become attractive places for farming or other land uses. For example, a wealthy country that has a high LUC fee might have to pay a lot of money to change forest or grassland to farmland. But instead, if that country invests in farming in a developing region that has low or no LUC fees, clearing land to grow crops would be much less expensive. If this happens too frequently, the amount of land used for farming in developing regions could increase dramatically—and so would the amount of water needed to irrigate all the new crops. In fact, according to our computer model, the amount of water used in the ZW under varying LUC fees could increase by more than 400% by the end of the century. In contrast, under LUC fees that are the same across the world, that increase would only be about 100%—similar to the increase seen everywhere else in the world (Figure 2).

When too much water is removed from rivers and used for agriculture, less water flows downstream, which can harm the animals and

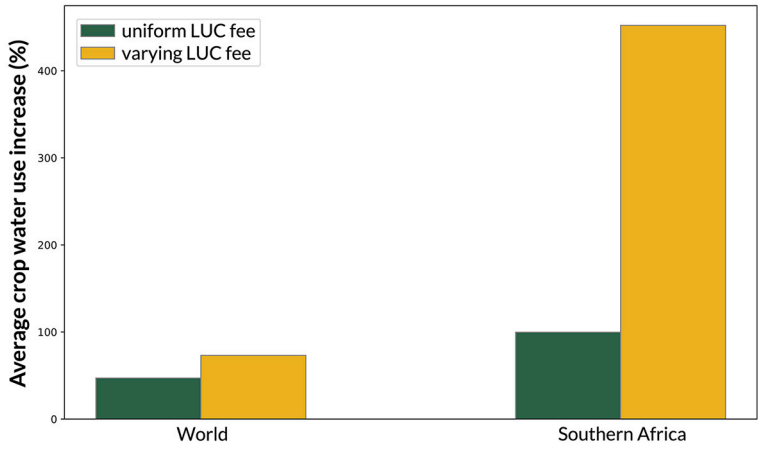

Figure 2

Giving the ZW a "break" on LUC fees might not be good for the ZW in the long term. This graph shows the average increase in future crop water use under two different scenarios, compared to 2015: globally uniform LUC fees (the same all over the world) and LUC fees that differ according to what regions can afford. When LUC fees are globally uniform, predicted water use in southern Africa is about the same as in the rest of the world (green bars). However, if regions like the ZW pay low or no LUC fees, water use in these regions may go up by 400%! This could have serious negative consequences for the region.

ecosystems that depend on that water to survive. Also, hydroelectric dams need a strong flow of water to produce electricity, so if water flow is reduced, some areas might not be able to produce enough power for the people who live there, or they might need to switch to less environmentally friendly methods that use fossil fuels.

THE IMPORTANCE OF LOOKING CLOSELY

Our research showed that, sometimes, what might seem like the "fair" way to address climate change might actually harm the very countries we are trying to help! At first glance, it might seem like we are helping developing countries by giving them a "break" on LUC fees. But when we look a little closer, we see that this strategy has unexpected side effects on water use, which could be really bad for the region overall.

The ZW is not an isolated situation—Africa alone has more than 60 international river basins and, in many of them, the population is expanding, and industries are growing. While expansion is good for the region's economy, more research is needed to find a fair way to balance global development with protecting the environment and limiting climate change for all. Along the way, researchers must keep their eyes open for unintended consequences that might do more harm than good for certain regions!

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ORIGINAL SOURCE ARTICLE

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

ALAE, AGE: 13

Hello, my name is Alae E, I am 13 years old, I love reading books, I read my first book when I was 8 and that is what helped me ameliorate my English, I love writing too, I write poems from time to time, and I also love drawing and painting, it is my way of expressing. My favorite color is green, because it reminds me of nature, grass, trees, flowers, and everything that is peaceful.

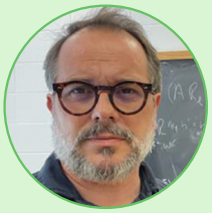
HADIL, AGE: 13

Hello everyone. I am Hadil, a Young Reviewer. I am very interested in natural and geological phenomena that happen and I am curious to know more while remaining with positive energy.

AUTHORS

MATTEO GIULIANI

I am an assistant professor in the Environmental Intelligence Lab at Politecnico di Milano, in Italy. I am an environmental engineer who uses computer models to study the management of natural resources under changing climate and societal demands. My work combines many fields, such as environmental, climate, and water sciences with machine learning and artificial intelligence. In my spare time, I enjoy watching several sports and taking outdoor excursions with my wife, our two kids, and our dog. *matteo.giuliani@polimi.it



ANDREA CASTELLETTI

I am a professor of natural resources management at Politecnico di Milano. I am the founder and head of the Environmental Intelligence Lab. My research interests include water systems planning and control under uncertainty and risk, decision making for complex engineering systems, and machine learning for environmental applications. In my spare time, I enjoy getting lost in the mountains while hiking or skiing.