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Modeling International Solutions for the Climate Crisis

Too often, discussions around climate change are centered either around the actions of single individuals or nations. In addition, climate policies are often affected by these same narrow-minded habits and individual countries improved at the expense of others. However, if the climate crisis is to be averted, international collaboration is necessary. This research presents a model based on the VIABLE Framework of agent-based models that predicts how the climate and international relations will develop together into the future based on the policies currently in place. Furthermore, it uses data capturing both of these two elements to train on the go, improving its predictions. This model allows for clear visualizations of the impact of climate change on the international landscape as well as the impact of proposed solutions. Such a model could be a powerful tool for climate advocates to analytically support their proposals and for short-sighted politicians to be held accountable.

This research takes inspiration from the life of Lewis Fry Richardson, a pioneer in the modeling of both weather and war whose pacifist ideals shaped his research. The model described here builds off of Richardson's research, with climate change a problem much more global than any Richardson faced. In analyzing the value of the model in providing transparency to the effects of climate policy on all different nations, it has a chance to drastically shape discussions around climate change for the better. As such, despite the model's risk of malicious use or flawed data, both problems Richardson faced, its myriad of benefits far outweigh these concerns. This research attempts to bridge this gap between policymakers and the public in creating international solutions for climate change.

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The Value of Cooperative Approaches to Climate Change

Climate change is a crisis unlike any we've faced before. It is an undeniable fact that our Earth's climate is changing for the worse at an unprecedented rate. Model after model showcases the damage that has been and will continue to be done to our planet over the coming decades unless we collectively change our actions radically. However, popular understanding of climate change is limited mostly to the severity of the problem (e.g. melting ice caps and rising temperatures) and to individual solutions (recycling and using electric cars to reduce one's carbon footprint, for example). When broader solutions are discussed, the focus is often on individual governments' abstract commitment to the future, like the US's 2050 deadline for carbon neutrality.[1] However, if climate change as a crisis is to be averted, it likely will not be through the action of individual people or even individual nations. Rather, a global problem like climate change requires a global solution built up by international collaboration. The purpose of this research is to present a model highlighting the risks and rewards of different policies toward encouraging an international solution for climate change.

The general purpose of this model is to allow nations to be held accountable, allowing both the general public and international organizations to understand the impact of climate change policies on our planet's well-being. It produces visualizations that demonstrate the impact of climate change on different countries, both at the moment and projected into the future.

[1] Matthew Daly, "Biden order would make US government carbon neutral by 2050," AP News, December 8, 2021

Furthermore, the model highlights the impact of different policies on these projections, showcasing their effects on climate across different nations as well as on international relations. Finally, the model takes in climate statistics as well as broader political data, including trade and warfare, to update its projections. With this data clearly interpretable, conversations about international approaches to climate policy, favoring no one nation over another, can more easily begin.

As a simple example of how such a model would be useful, it helps to look at one policy from the UK and its numerous unexpected consequences. Across the past several decades, the UK has greatly increased its use of wind farms for generating power.[2] While this renewable energy has helped to reduce the use of fossil fuels in the UK, wind turbines require the use of magnets, often made of neodymium. The mining of neodymium, which is also used in the production of electric cars, has become a booming but highly polluting industry in China. As a result, though this policy of increasing the use of wind turbines has helped wealthy countries like the UK, it comes at the expense of poorer countries like China. This sort of problem is common across climate policies, with third-world nations that bear the greatest brunt of climate change's devastation often receiving the least benefit from first-world initiatives. The purpose of this model is to reveal the global impact of these policies, making it clear when a nation's actions are meant solely to help themselves at the expense of others. In this sense, it's important to consider that extreme weather has the potential to risk societal instability and accelerating violence, but also greaten the chance for global collaboration amid a crisis. Understanding which path we may be headed on and how we can change our fate is critical to ensuring global well-being.

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[2] Andrew Montford, *Unintended Consequences of Climate Change Policy*, The Global Warming Policy Foundation, 2015

Lewis Fry Richardson's Vast Impact

To understand the utility and impact of this model, it helps to look towards the past, at a pioneer in understanding the social and ethical responsibilities of computing: Lewis Fry Richardson. Richardson, whose research and philosophy greatly inspired this research, began his career in Britain in the early 1900s by working in laboratories across the academic landscape, exploring mathematics, chemistry, physics, and botany before taking a post at the Meteorological Office in 1914.[3] However, when World War I broke out, Richardson's work was disrupted. Richardson was a Quaker and an ardent pacifist, and so declared himself a conscientious objector to avoid the military. He spent the rest of the war working in the Friends' Ambulance Unit, tending to injured soldiers before returning to the Meteorological Office. However, in 1920 his office was absorbed by the Air Ministry. Richardson refused to be a part of the military and immediately resigned from the Meteorological Office. Though his pacifism would make it difficult for Richardson to find career security, he firmly believed that "science ought to be subordinate to morals,"[4] a belief that he would hold to for the remainder of his life.

Richardson's most notable academic contribution came in the field of weather forecasting. From his research on meteorology, Richardson developed novel techniques for solving differential equations critical in understanding the changing of the weather. Without the existence of modern computers, Richardson worked through these calculations by hand to try to forecast the weather for a single day. Though his calculations were ultimately much too slow, taking six weeks to predict the next six hours, and his data was wildly inaccurate, resulting in unusable results,[5] Richardson's

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[3] J J O'Connor, E F Robertson, "Lewis Fry Richardson," University of St Andrew, Scotland, October 2003
[4] Nils Petter Gleditsch, "Lewis Fry Richardson – A Pioneer Not Forgotten," Springer, 2019
[5] Giancarlo Rinaldi, *Lewis Fry Richardson: The man who invented weather forecasting*, BBC, August 1, 2013

Weather Prediction by Numerical Process would ultimately be foundational to modern weather forecasting. In this book, Richardson imagined a factory of 64,000 human computers working through these computations together, able to predict the weather before it happened.[6] However, just a few decades later, a team of just 6 scientists led by meteorologist Jule Charney and mathematician John von Neumann would use Richardson's method on ENIAC, the first modern computer, to provide practical numerical weather prediction. But in the 1930s, researchers in chemical warfare became interested in Richardson's research on turbulence. Richardson was distraught, abandoning all of his research in this field and destroying all unpublished work, reinforcing his commitment to pacifism.[7]

Following this realization of the harm his work could do, Lewis Fry Richardson shifted his focus once again, working to apply mathematical analysis toward understanding the dynamics of war and peace. Applying his interest in psychology as well as his knowledge of mathematical modeling, Richardson developed systems of differential equations for understanding how conflicts may arise between nations. As presented in his *Arms and Insecurity*, these models look at how arms races may develop based on factors like international trade, shared borders, or military strength. Later, in *Statistics of Deadly Quarrels*, Richardson compiled a massive dataset on deadly quarrels, ranging in scale from single murders to world wars, to apply his models and demonstrate their ability to accurately model conflict[8]. Though the models Richardson developed were intentionally quite vague and simple, not accounting for the many complexities of global conflict,[9] their flexibility has allowed them to inspire much future research in mathematical modeling within the

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[6] Peter Lynch, *Richardson's Fantastic Forecast Factory*, European Meteorological Society, October 2015
[7] Nils Petter Gleditsch, "Lewis Fry Richardson – A Pioneer Not Forgotten," Springer, 2019
[8] Kristian Skrede Gleditsch, Nils B. Weidmann, "From Hand-Counting to GIS: Richardson in the Information Age", Springer, 2019
[9] Paul F. Diehl, "What Richardson Got Right (and Wrong) About Arms Races and War," Springer, 2019

social sciences. It is these models that also inspire this work. When Richardson was creating his models of war, he focused extensively on the lengths of borders between nations. However, he also noted that, with the increasing use of aircraft in warfare, land borders will likely decrease in importance, saying that "the trouble begins with the existence of a world-wide controversy."[10] This is especially true in the case of climate change which is, in all senses of the term, "a world-wide controversy." As such, this model expands on Richardson's geographic model for global conflict, combined with elements of his model for weather forecasting, to construct a model for international collaboration on climate change policy.

An Agent-Based Model with On-The-Go Training

The model is structured in such a way as to account for the unpredictability of climate and global politics, predicting potential future trajectories based upon data. The model proposed here is an agent-based model, in which nations are treated as agents capable of making decisions to interact with other agents as well as their environment. This model structure was chosen to allow countries to possibly collaborate to reach a global equilibrium, rather than simply acting in their own best interests. This model is based on the VIABLE Framework, a robust framework developed by Todd BenDor and Jürgen Scheffran for simulating complex interactions between agents under environmental constraints.[11] In this framework, agents have values and goals they wish to achieve. They can select action paths to better their value and investments to affect the state of their

[10] Jürgen Scheffran, "Weather, War, and Chaos: Richardson's Encounter with Molecules and Nations," Springer, 2019
[11] Todd BenDor, Jürgen Scheffran, "Agent-Based Modeling of Environmental Conflict and Cooperation," CRC Press, 2018

environment. Finally, linkages can be made between agents to represent their competitive or cooperative relationships. BenDor and Scheffran have developed a complex system of differential equations to predict how these different agents may act within this model, not too far in concept from those created by Richardson to understand arms races between nations. These researchers have already demonstrated the success of the VIABLE Framework in modeling conflict and cooperation between fisheries and the resulting "tragedy of the commons." They have also investigated how this framework could be utilized in the modeling of climate problems like emissions trading, a case where unexpected international downsides are common and collaboration is critical.[12] As such, building this model on top of the VIABLE Framework provides it with the strength to model complex international conflict and collaboration.

This model also builds upon the VIABLE Framework to allow it to function in its intended use case: providing transparency on the impact of global climate policy. The greatest adjustment comes in the data used to train and update the agents. Unlike in the traditional VIABLE Framework setup, in which data is received before the agents begin to act, this model is meant to be used in real-time. As such, it must adapt to changes in international relations, policies, or the environment. To achieve this goal, the model takes in data on factors that may affect the agents and their interactions, including emissions, trade, economic production, and conflicts with others, changing their values, goals, and linkages in response. As new national policies are implemented, they can be implemented into the model, which will be able to project their potential ramifications, with these predictions updated as new data is received. In this way, the model can be thought of like Richardson's imagined weather forecasting factory, with thousands of computers each solving

[12] Todd BenDor, Jürgen Scheffran, "Agent-Based Modeling of Environmental Conflict and Cooperation," CRC Press, 2018

calculations for their own small slice of the world, these calculations synthesized to provide a global forecast. As Richardson quickly realized, it is only when these calculations can be produced as rapidly as the data comes in that his models have value. As such, for such a model described in this paper to be useful, it needs to be able to adapt to climate data on the go to see how policy changes have effects on global wellbeing.

The Benefits and Dangers of this Approach

A model as described here could have dramatic positive effects on public understanding of climate change and policy. As mentioned earlier, too little attention is paid to international solutions to climate change, with the focus more often on national decisions. However, as cases like wind farms in the UK highlight, one country's policy has a global impact. Furthermore, globally or nationally aggregated statistics can be misleading for understanding overall trends. For example, though countries like the US and UK have cut their per capita CO_2 emissions dramatically over the past couple of decades, global emissions have continued to rise, in part because of the skyrocketing emissions of countries like China and India.[13] Outsourcing production does little to limit the global climate crisis, as this model will reveal. One can imagine the value of clear visualizations as produced by this model to, not only public understanding, but also environmental organizations looking to compile data supporting their initiatives. However, this model does not wish to recommend policies, with that work simply too complicated to account for in any such model. Rather, it will demonstrate how international relations and climate projections have changed and

[13] Hannah Ritchie, Max Roser, Pablo Rosado, "CO_2 and Greenhouse Gas Emissions," Our World in Data, May 2017

may continue to change given the policies currently in place. As Lewis Fry Richardson said in his study of the origins of war, "equations are merely a description of what people would do if they did not stop to think."[14] The hope for this model is that, with the right equations, it can encourage people to stop to think for the sake of our future.

However, it is important to understand that this model, despite its intentions, has the potential to harm. First of all, any such model would be trained in such a way to prioritize certain factors, either emissions, stability, or climate survivability, for example. Here, Goodhart's law that "When a measure becomes a target, it ceases to be a good measure"[15] can be applied. These metrics are the same ones countries are working to optimize, which can lead to a misleading view of the overall climate crisis. In this sense, a model will always be limited to the factors it optimizes, reinforcing its utility in visualizing impact and sparking discussions rather than presenting answers. Here, this problem can be partially addressed by allowing users flexibility in the heuristics used in the model. This ensures various factors can be accounted for depending on the circumstance and needs of a user. Another inherent flaw of such a model is its necessary uncertainty. Models based on the VIABLE Framework produce probabilistic, not deterministic outputs. This makes it more difficult for the actual impact to be observed from the data. Problems with accounting for uncertainty hampered public understanding of outbreak models during the COVID-19 pandemic and could plague this model as well.[16] Furthermore, as previous attempts to reduce uncertainty in climate models have demonstrated, it is nearly impossible to provide more definitive predictions without drastically reducing accuracy.[17]

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[14] Ron P. Smith, "The Influence of the Richardson Arms Race Model," Springer, 2019

[15] Michael F. Stumborg, et al., "Goodhart's Law: Recognizing and Mitigating the Manipulation of Measures in Analysis," CNA, September 2022

[16] Lyndon P. James, et al., "The Use and Misuse of Mathematical Modeling for Infectious Disease Policymaking: Lessons for the COVID-19 Pandemic," SAGE Journals, May 4, 2021

[17] Matthew Green, "Scientists warn over misuse of climate models in financial markets," Reuters, February 8, 2021

In addition, it is impossible to understand how such a model, which would be open-sourced for public use, would actually be used. As an example, Lewis Fry Richardson was not the only researcher looking into mathematical models of war. Around the same time, Frederick W. Lanchester developed Lanchester's laws which used differential equations to understand, not how arms races could be prevented, but rather how wars could be won.[18] The model described in this research, intended for use in encouraging international collaboration in averting the climate crisis, could just as easily be used by fossil fuel corporations to optimize emissions, and therefore profit, they could produce before complete disaster. Or, like Richardson's weather models being used for chemical warfare, these could be used by selfish nations seeking to help themselves no matter the cost. Another potential danger of the model could result if it is given too much power. If such a model is given the potential to directly impact global policy, any inaccurate projections could lead to poor policies or the destruction of international relations, devastating global stability. Similar issues have occurred in the past with overtrusted, poorly trained machine learning models placed in unfamiliar circumstances, like medical models trained on racially biased data struggling to account for different skin tones.[19] Within the climate crisis, data can shift rapidly and the model must be trained to adjust for these swings. As such, the model's outputs should be kept far separate from the actual policy-making process, with accuracy not yet sufficiently great. This problem can hopefully be addressed by social accountability. Because the model is public and open-source, these malicious choices can be visualized worldwide, allowing for those responsible to be held accountable.

[18] Niall MacKay, "When Lanchester Met Richardson: The Interaction of Warfare with Psychology," Springer, 2019
[19] Boris Babie, et al., "When Machine Learning Goes Off the Rails," Harvard Business Review, January-February 2021

Conclusions

Despite these risks, the net benefit of this model will almost certainly be positive. Put simply, it is difficult for a model like this to do much damage, poor results just sentencing the model to disregard. As long as the aforementioned excess of faith in the model is avoided, the maximum damage done is only so great. On the other hand, the potential for positive impact is significant. If this model can make accurate projections on the impact of climate policy, as supported by future data, it could become an invaluable tool for advocacy groups to hold governments and corporations accountable for their action or inaction towards the climate crisis. As the recent acceleration of machine learning and natural language models has demonstrated, a well-trained model can be accepted by the general public. As a result, this model could usher in a new, better-informed era of climate advocacy, driven by, not just local, but global projections. In noting this, though, it's important to remember that net social impact isn't the best way to assess technology. This was demonstrated by the numerous climate policies that had led to small change in the worldwide crisis at the expense of much-worsening conditions in certain countries. If this model is used in such a way to only better lives in wealthy countries, where this type of data and visualizations is much more accessible, it could still cause harm to those without access. This is why added focus is placed on the open-sourcing of this model, putting it in the hands of international organizations and underserved individuals. In this way, the hope is the model can provide a positive social impact, not just on balance across the world, but to everybody affected by the climate crisis.

The model described in this paper, combining the VIABLE Framework with on-the-go data processing and Lewis Fry Richardson's philosophy on technological impact will help to visualize the global impact of climate change and the way that international collaboration can limit its damage. By providing transparency to the effects of policy on all different nations, it can drive a better understanding of the risks we face and better advocacy towards global solutions. While this model is not perfect, with the risk of malicious use or flawed data, its myriad of benefits far outweigh these concerns. Through this framework, Richardson's dream of interpreting the chaos of the world, both in climate and in international conflict, can better be achieved. As Richardson acutely understood, all technology has the potential to kill, but it's difficult for technology alone to save. This research attempts to bridge this gap between policymakers and the public in creating international solutions for climate change.

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