Research Project #3

Regional Climate Risk, Carbon Budgets, and Carbon Removal under Uncertainty (ICE-2 & JSC)

Climate change poses not only gradual damage, but also abrupt, non-linear risks that may trigger irreversible shifts in natural and economic systems. Since Nordhaus' pioneering work on integrated assessment models, the economics profession has increasingly incorporated climate change into formal economic analysis [1]. A major insight from the natural sciences is that many ecological systems contain tipping points, where small additional pressures cause the system to move into an alternative, often much less desirable state [2]. Because the precise location of tipping points is uncertain, economic analysis must account for the possibility, rather than the certainty, of catastrophic transitions. This fundamentally alters the structure of the problem: stability may be lost, non-linearities arise in both constraints and damages, and optimal policy becomes sensitive to even small increases in the probability of tipping. Existing models have made important progress by showing how optimal carbon pricing and precautionary saving respond to these risks [3, 4]. However, they typically use highly aggregated representations of energy use and rarely incorporate mechanisms central to current climate policy debates, such as carbon dioxide removal (CDR) options or explicit carbon budget constraints reflecting the temperature targets of the Paris Agreement.

The PhD project will investigate how carbon budgets and CDR options influence optimal policy, economic resilience, and regional transition pathways under tipping uncertainty. Using a dynamic economic framework, where an economy chooses consumption, investment, energy use, and mitigation under a carbon budget and CDR, the project integrates theoretical modeling, numerical methods, and econometric calibration. By linking climate macroeconomics, applied mathematics, and regional economics, it provides both methodological and policy-relevant insights. The project has the scope to:

- Explore alternative functional forms for production, energy composition, and carbon removal
- Examine stochastic tipping risk representations using hazard rates, Value-at-Risk, or Expected Shortfall measures
- Implement and compare numerical solution methods (e.g., Hamilton-Jacobi-Bellman solvers, dynamic programming, or Monte Carlo simulation)
- Extend the model to multiple regional economies with differing technological and policy characteristics

The PhD project will benefit from the expertise of two complementary institutes: Jülich Systems Analysis (ICE-2) and the Jülich Supercomputing Centre (JSC). ICE-2, (specifically, the Spatial Economics Team) provides high expertise in regional energy transition analysis, applied econometrics, and policy-oriented economic modeling. With a strong foundation in empirical methods and regional economic assessment, the group develops tools to evaluate how technological shifts, decarbonization strategies, and climate policies affect economic structures across regions. This expertise ensures that the project remains anchored in real-world data, policy relevance, and the economic dimensions of energy system transformation. JSC (specifically, the group Algorithms, Tools and Methods Labs: Numerical and Statistical Methods) provides high expertise in both theoretical and numerical analysis as well as statistical methods, algorithm development and its implementation, and different high performance computing infrastructure tailored to the new developed solvers.

Combining both economic modeling and theoretical and practical mathematics, algorithm development and implementation in combination with high-performance computing, this project will generate a sound, theoretically founded modeling and analysis framework that integrates empirical regional analysis, policy evaluation, and advanced numerical methods. Together, the project partners provide the full spectrum of skills from data-driven economic interpretation to sophisticated mathematical modeling and implementation of efficient solvers required to deliver a rigorous and policy-relevant assessment of climate risks, carbon budgets, and regional energy transitions.

Work Packages:

WP1: Literature review and conceptual framework (Months 1-6)

- Survey the theoretical and empirical literature on stochastic climate tipping, carbon pricing, and carbon removal
- Define the analytical baseline model and identify data needs for calibration

WP2: Model development, regional extension, and calibration (Months 6-24)

- Formulate an extended dynamic model that incorporates a carbon budget and carbon removal
- Introduce regional differentiation in technology, energy mix, and adaptation capacity

WP3: Numerical implementation (Months 15-30)

- Develop numerical methods to solve the model under uncertainty and explore sensitivity to key parameters
- Calibrate selected scenarios using data for representative economies or world regions

WP4: Scenario and policy analysis (Months 24-36)

- Simulate policy experiments (e.g. tightening carbon budgets, introducing regional cooperation or fragmentation)
- Evaluate impacts on carbon prices, mitigation and removal efforts, and welfare

WP5: Synthesis and dissemination (Months 24-36)

- Integrate findings from previous work packages
- Summarize theoretical findings, discuss implications for climate policy design

Expected results:

- A flexible modeling framework that links stochastic climate risks, carbon budgets, and carbon removal into a coherent economic system
- Quantitative insights into how regional heterogeneity affects optimal carbon pricing and mitigation strategies
- Computational methods applicable to broader classes of stochastic dynamic climate-economy models
- Policy-relevant findings on how carbon budgets and removal options can stabilize economies facing tipping risks

This project helps bridge the gap between theoretical climate macroeconomics and empirical, region-specific policy design. It enables more realistic models that capture both economic behavior and physical climate constraints. For policy, it clarifies how global temperature goals translate into regional economic constraints and investment strategies. For academia, it shows how numerical and econometric methods can be combined to address dynamic uncertainty in climate policy. The interdisciplinary supervision from economics, applied mathematics, and numerical analysis, will equip the PhD student with strong quantitative skills applicable in academia, public policy, and international organizations. It will furthermore strengthen the competence and international scientific visibility of Forschungszentrum Jülich with regard to interdisciplinary climate policy research.

Location of the HITEC Fellow	Forschungszentrum Jülich, Institute of Climate and Energy Systems - Jülich Systems Analysis (ICE-2), Director: Prof. Dr.-Ing. Jochen Linßen https://www.fz-juelich.de/en/ice/ice-2
Partners of the HITEC Project	Forschungszentrum Jülich, Jülich Supercomputing Centre (JSC), Directors: Prof. Dr. Dr. Thomas Lippert and Prof. Dr. Kristel Michielsen https://www.fz-juelich.de/en/jsc
Specific **requirements**	Master's degree in econometrics, economics, applied mathematics, or a related field relevant to theoretical modeling of energy systems and economics Experience with or willingness to apply energy systems assessment and economic policy design, programming, and numerical simulation of economic systems
For **project specific** questions please **contact**	Dr. Imke Rhoden, ICE-2, i.rhoden@fz-juelich.de

[1] Nordhaus, W.D. *A Question of Balance*. Weighing the Options on Global Warming Policies. 2008: Yale University Press. ISBN: 9780300165982. DOI: https://doi.org/10.12987/9780300165982.

[2] Scheffer, M., S. Carpenter, J.A. Foley, C. Folke, and B. Walker. *Catastrophic shifts in ecosystems.* Nature, 2001. **413**(6856): p. 591-596, https://doi.org/10.1038/35098000.

[3] van der Ploeg, F. and A. de Zeeuw. *Pricing Carbon and Adjusting Capital to Fend Off Climate Catastrophes.* Environmental and Resource Economics, 2019. **72**(1): p. 29-50, https://doi.org/10.1007/s10640-018-0231-2.

[4] Pindyck, R.S. *The Climate Policy Dilemma.* Review of Environmental Economics and Policy, 2013. **7**(2): p. 219-237, https://doi.org/10.1093/reep/ret007.