Research Project #1

Modelling Water-Land-Energy Trade-offs and Synergies for Sustainable Energy Transitions (ICE-2 & IBG-3)

Growing pressures on water, land, and energy systems have made their integrated management a central challenge for sustainable development and climate resilience. In regions undergoing rapid demographic growth and energy transitions, such as Sub-Saharan Africa, the interplay between these resources is particularly pronounced. The deployment of renewable technologies often alters land use, affects water availability, and interacts with agricultural or ecological systems in complex ways. Yet, conventional modeling approaches tend to treat such interactions as static constraints rather than dynamic relationships shaped by local context. This has led to models that are robust to highly regulated settings but poorly transferable to areas where environmental governance and land-use negotiations are fluid.

Existing frameworks such as GLAES, developed at ICE-2, provide an excellent open-source basis for assessing spatial suitability and exclusion zones in renewable energy planning. However, such models typically apply binary exclusion logic defining areas as either feasible or not based on static thresholds (e.g., distance to airports, roads, or protected areas). While effective for European contexts with strong regulatory coherence, this approach overlooks the context-dependent trade-offs that characterize project planning in developing economies. For instance, as it is the case of Olkaria geothermal field in Kenya located within a natural reserve and on indigenous land, the coexistence of energy infrastructure, agricultural activity, and protected land often results from local agreements rather than rigid compliance. In such settings, purely rule-based exclusions risk obscuring viable development options and overlooking synergies.

This doctoral project addresses this gap by developing a flexible, spatially explicit modeling framework capable of representing water-land-energy (WLE) interactions through a spectrum of feasibility rather than exclusion. Building on the computational foundation of GLAES, the research aims to introduce graded feasibility layers that quantify trade-offs and co-benefits among resource uses. This approach combines optimization-based system analysis (ICE-2) with biophysical process modeling (IBG-3). The candidate will leverage existing modeling capacities at ICE-2 to represent energy transitions under multi-objective constraints, while drawing on IBG-3's expertise in hydrological modelling, land surface modelling and uncertainty analysis to implement environmental realism into system modeling.

The framework will be tested in a regional case study in Sub-Saharan Africa, Latin America, or comparable regions, chosen for their strong resource interdependencies and frequent negotiation between energy development, agricultural use, and ecological preservation. Using spatial and socio-economic data, the model will evaluate scenarios emphasizing different resource priorities and identify integrated strategies which can deliver maximal co-benefits. This will help informing development pathways that align with the Sustainable Development Goals (SDGs 6, 7, 13, and 15) and support just and context-sensitive transitions. Beyond its analytical innovations, the project reinforces Forschungszentrum Jülich's strategic objectives on sustainable bioeconomy, energy transition, and climate resilience by providing an open-source, transferable modeling instrument.

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, Institute of Bio- and Geosciences - Agrosphere (IBG-3), Directors: Prof. Dr. Jan Vanderborght and Prof. Dr. Wulf Amelung https://www.fz-juelich.de/en/ibg/ibg-3

Specific **requirements**	Master's degree in Energy Systems Analysis, Industrial Engineering, Energy Economics, or a related field with good grades. The candidate should demonstrate strong technical modeling skills and an interest in energy-related, economic, and environmental issues in developing economies. Prior experience in energy, hydrological or land surface modeling preferable.
For **project specific** questions please **contact**	**Dr. Amin Lahnaoui**, Christoph Winkler, Prof. Dr. Sandra Venghaus, ICE-2, a.lahnaoui@fz-juelich.de **Prof. Dr. Harrie-Jan Hendricks-Franssen**, IBG-3, h.hendricks-franssen@fz-juelich.de