Back to the Holocene

Modelling Detailed, Cost-Optimized, Realistic Regional and Global Technology Deployment Pathways to a Future of Abundant Renewable Energy and a Safe and Stable Climate

Research Proposal Outline

Note: This document is a summary explaining the research project and work packages. To view further information as a set of PowerPoint slides, visit our website. Available on request: A detailed version of this research proposal, comprehensively annotated with references to the peer-reviewed scientific literature.

Research Aims and Motivations

Our world has a problem: Policymakers have been focused, since the Paris Agreement of 2015, on trying to limit the increase in global average annual surface temperature well below 2.0°C and as close to 1.5°C as possible compared to the late 19th century average (right now we are already at 1.2°C). The implicit assumption has been that 1.5°C is "safe enough." Unfortunately, it turns out it's not safe enough:

- New evidence from climate science clearly shows that **stabilising even at 1.5°C would entail extremely disruptive consequences, including long-term loss of the world's coastal cities to >10 m sea level rise,** drowning London, New York, Shanghai, Mumbai, Jakarta, Hamburg, Amsterdam, and hundreds of other cities. The reason: Greenland and West Antarctic Ice Sheets (GrIS and WAIS) have both already shifted into physical dynamics of accelerating, self-reinforcing large-scale annual ice-mass loss.
- In addition, 1.5°C will entail more extreme heatwaves, droughts, and forest fires; heavy rains, floods, and typhoons; destabilisation of the jet stream; and the northward spread of insect vectors of tropical diseases, among other damages.
- The planetary boundary and therefore a safe climate is at **CO_2 levels around 350 ppm** (today it is ca. 420 ppm today), which corresponds to a temperature increase of about **1.0°C** relative to the pre-industrial age .Thus, CO_2 must be removed from the atmosphere, the energy needed to do so must be provided from renewable sources.

With the "Back to the Holocene" research project, we offer a **key piece of the solution:** an advanced tool for specifying realistically feasible, carefully calibrated technological pathways back to safety from the brink of disaster. The question we pose is: **Can the world simultaneously deliver sustainable energy abundance for everyone, leaving no-one behind, *and* regain climate safety by returning atmospheric CO_2 back down below today's levels?** If so, **how can this be achieved in infrastructure terms**, in well-calibrated technological detail? What equipment needs to be built, by when, in what quantities? What are the least-cost and best solutions?

- The purpose of LUT's new "Back to the Holocene" research project is to provide detailed, scientifically well-founded **calculations of cost-optimised technology pathways** for simultaneously achieving **renewable energy abundance** and **net negative annual CO_2 emissions in every world region**.
- These pathways would, if implemented, see the world exceed 1.5°C for as few years as possible, and restore a safer global climate by **returning atmospheric CO_2 concentrations to levels well below those of today** later this century, while **delivering energy prosperity in every region by drawing on abundant renewable energy resources.**
- Our research aims are guided by the **UN Sustainable Development Goals**, in particular SDG 7, access to modern sustainable energy for all, and SDG 13, urgent climate action.

Research Methods

This research project will further develop one of the world's most respected and **sophisticated Energy System Transition Modelling environments, LUT-ESTM,** which received the **highest rating from among ten globally leading energy systems models** from independent evaluators. This ESTM has already allowed us to calculate cost-optimised technology pathways to net zero emissions by 2050 or 2040 for individual countries, for Europe, and for the world as a whole. Our research based on LUT-ESTM is the basis of more than 60 peer-reviewed journal articles published since 2015, including in top journals such as *Nature, Joule,* and *Science*. See Google Scholar search results here. See Scopus search results here.

Our energy systems modelling research has found that because of steep unit price declines in solar PV, energy storage technologies, and electrolysers over the past decade – trends that are projected to continue – an **abundant renewable energy-based economy that leaves no-one behind** is coming into focus as a technologically and financially realistic mid-future prospect. In addition, IPCC Reports are in consensus that carbon dioxide removal technologies must soon be deployed at very large scale to restore a safe and stable climate.

The "Back to the Holocene" research project will explore these twin aims in detail. With LUT-ESTM 2.0, we will provide **least-cost technology pathways for simultaneously achieving sustainable energy abundance and net negative annual CO_2 emissions**, as follows:

- **Climate scientists will provide us with best estimates of "safe enough" atmospheric CO_2 targets** for 2050, 2100, and 2150 (e.g. 450 ppm CO_2 by 2050, 350 ppm by 2100, 300 ppm by 2150). These targets can be turned into aggregate CO_2 removal budgets (e.g. net removal of 1200 $GtCO_2$ over the years 2040-2100) and thence into net negative annual CO_2 emissions trajectories, set as boundary constraints on the cost-optimising LUT-ESTM 2.0 model's calculations.
- Global, regional, and local implementations of LUT-ESTM 2.0 will generate detailed quantitative estimates, calculated in five-year time-steps, of **cost-optimised combinations of more than 140 technologies** in **energy, energy storage, heating, transport, industry, seawater desalination, and carbon dioxide removal (CDR) sectors** that can achieve these climate-science-driven carbon targets.
- These combinations will identify pathways to future energy-industry-CDR infrastructure that deliver **sustainable energy abundance as well as net negative emissions** in **any given region.**
- LUT-ESTM features **hourly resolution** (hourly matching of energy supply and demand), **sector coupling** (energy flows between sectors), and **inclusion of Power-to-X technologies** that allow use of sustainable electricity to produce fossil-free e-fuels and e-chemicals.
- These features are necessary for an energy system model to generate technologically detailed, cost-optimised, realistic local, regional, or national technology pathways to a sustainable energy future.
- For technical reasons, none of these features are included in sufficient detail to enable their use for regional planning purposes in the simpler, coarser-resolution energy models embedded within Integrated Assessment Models (IAMs) used in the preparation of IPCC reports.
- IAMs, which include climate and land use as well as energy model components, are intended to give broad overviews of global climate risk and energy trends, not **specific regional or national energy systems planning guidance, while oversimplifying the energy system and largely ignoring Power-to-X technologies.** LUT-ESTM 2.0 can provide that guidance, and so has a different purpose that **complements rather than competes with the role of IAMs.**

LUT-ESTM already features by far the highest level of geographic resolution of any ESTM, featuring 9 major regions subdivided into 48 macro regions and 145 meso regions. LUT-ESTM 2.0 will further subdivide the world into **800+ regions corresponding to administrative units** such as **megacities, federal states or provinces**. This will make LUT-ESTM 2.0 directly useful to regional energy system planners and researchers.

- The model's detailed local and regional data sets (featuring infrastructure; renewable energy resources; carbon sequestration potential; demographics) will be nested and interconnected, allowing researchers and energy systems planners to zoom in and out of different levels, from local to regional to global – an unprecedented ability that no existing ESTM features.
- This **zoomable** high-resolution modelling environment will enable **researchers and energy systems planners** to **map out cost-optimised transition pathways** to prosperous, highly renewable energy systems futures, within their wider **regionally interconnected energy system context.** This is a major innovation in energy-industry-CDR systems research.

Implementation in LUT-ESTM 2.0 of carbon dioxide removal (CDR) technologies and estimates of their unit cost degressions, with the geographically specific potential of each technology quantified – and the CDR systems' energy and materials requirements specified – will allow us to provide **detailed regional pathways** beyond net-zero annual CO_2 emissions that will, if implemented, achieve net- negative annual emissions. **With this, we can chart a least-cost high-prosperity global pathway back down to 350 ppm and below.** This too is an unprecedented and very useful research innovation of the Back to the Holocene research project.

Research Impacts

We believe this project will have game-changing impact. Our research to date has shown that highly renewable energy based pathways to global or regional net-zero annual emissions can be achieved at cost parity or better, compared to business as usual. Our next research phase can show the least-cost path to climate safety even as it generates much more geographically detailed pathways to sustainable energy prosperity, region by region.

- LUT-ESTM 2.0 will be **very useful to national and regional energy system planners** because the development of **regional technology deployment scenarios** can help **improve the coordinated targeting of hundreds of billions of euros in spending** on clean electricity generation, heat, transport, industry, seawater desalination, and CDR infrastructures.
- This energy-industry-CDR infrastructure transition pathway optimisation tool and the information it generates will help shape international discourse on energy, climate, and industrial policy. Among other things, our research will **provide key input to future IPCC Reports** exploring pathways to climate safety. Ambitious climate goals become more feasible when decisionmakers know in advance, in detail, the dimensions and costs of the challenges before us – and see they are manageable.
- LUT-ESTM 2.0's **impact will be multiplied** by creating and disseminating a tutorials- and training-supported **Open Source version,** so that other research groups can join in implementing and refining the model for various countries and regions, in accordance with local priorities. Their results will contribute to building a highly detailed global dataset.

Research Work Packages and Funding Requirements

Funding is needed to carry out the next phase of research, including for:

- **Development of LUT-ESTM 2.0,** adding carbon dioxide removal technologies (CDR) and new energy storage technologies
- Increasing the model's geographic resolution from 145 meso-scale regions to 800+ local regions.
- Creation of several major energy and carbon **transition scenarios** for achieving both energy abundance and climate safety, covering the periods 2020s-2100 and 2100-2150.
- Covering the costs of preparing a tutorial-supported **freeware version** of LUT-ESTM 2.0 and all its datasets, which will be given as a gift to the global climate and energy research community, so that researchers and energy system planners around the world will be better equipped to chart a safe and prosperous path through the 21st century.

The standard all-in annual cost of a qualified researcher at LUT, including salary, social insurance, expenses, and some organisational overhead, is €100.000. To fully develop LUT-ESTM 2.0 and implement global models of "Back to the Holocene" technology pathways for a return to a $\Delta T<<1.5°C$ world, as per the details described in this document, we require **51 person-years** (PYs) of funding, totalling **€5.1 million**, distributed amongst five categories of key tasks or "work packages" (WPs).

- **WP1. New Technologies**. 8 PY (€800k) for **adding new technologies** to LUT-ESTM, including several carbon dioxide removal technologies (CDR) such as CO_2 direct air capture, carbon mineralisation, afforestation, soil sequestration, biochar carbon from sustainable biomass sources, bioenergy carbon capture and storage, and storage technologies such as underground hydrogen storage options, detailed pumped hydro energy storage potentials.
- **WP2. Nested Regional Datasets**. 6 PY (€600k) for further **refining the geographic resolution** of LUT-ESTM from 145 meso-scale regions to 800+ local regions, with nested datasets to enable zooming in and out between local- meso- macro- and major-scale regions.
- **WP3. Back to the Holocene Pathways**. 21 PY (€2100k) for **preparation of combined global net-zero-emissions energy technology transition pathways and net-negative-emissions carbon dioxide removal pathways** that, together, are consistent with returning atmospheric CO_2 concentrations to a non-dangerous target level before 2100 or 2150 (between 350 and 280 ppm CO_2, with a variety of target scenarios to be defined by collaborating climate scientists), **including regional technology pathway scenarios** developed for each of the following large regions: Europe, North America, South America, Africa, China, South Asia, and Southeast Asia, as well as a high-level model instantiation for the world. WP3 will include **5 PY for model intercomparisons**, because in complex systems modelling it is important to test model robustness and results plausibility by running different models from different

research groups with the same set of input data and system constraints, to see how the structures of the models influence results. Model intercomparisons for T<<1.5ºC scenarios will be organised with at least one other energy systems model: PyPSA (Tom Brown at Technical University of Berlin). Model intercomparison collaborations will also be sought with IAM modellers at PIK, IIASA and PBL, developers of three of the most important IAMs used by IPCC. In addition, collaboration on CDR technologies will be deepened with Felix Creutzig (MCC/Technical University of Berlin).

- **WP4. Open Science Freeware Preparation**. 6 PY (€600k) for preparing LUT-ESTM and related datasets for **Open Source/ Open Data/ Open Science release**, with tutorials (text and video) and workshop formats to lower barriers to entry and increase uptake.
- **WP5. Financing and Socio-political factors for implementation.** 4PY (€400k) for generating ideas for financing and considering socio-political factors analogous to the climate justice debate and to develop recommendations for action. Climate science teaches that knowledge does not necessarily lead to action.
- **WP6. Dissemination**. 6 PY (€600k) for **dissemination of LUT-ESTM 2.0** to external institutional users, and communication of scenario results to key stakeholders around the world. This will include many peer-reviewed scientific publications and corresponding media impact, as well as a free-to-download textbook hosted by a major scientific publisher, covering the LUT-ESTM methods and key findings.

Note that not complete funding of all WPs from one source can be considered. We could e. g. start with implementing CDR technologies (WP1) and continue simulations in nine major global regions with resulting scientific publications.

To learn more: visit our webpage and contact us

We are looking forward to finding funding partners who share our passion for and commitment to the **grand challenge** of **bringing into being a win-win pathway to both climate safety and energy prosperity.**

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