7. Public Summary

Strategy:

The Energy and Sustainability Research Institute Groningen (ESRIG) is a research institute (size: 20 scientific staff members and 80 PhD candidates) founded in 2009 to address the energy and sustainability challenges posed by the rapidly evolving world. ESRIG's strategy focusses on promoting interdisciplinary research among experts from key fields, including natural sciences, engineering, social sciences, and policy studies. By fostering a culture of innovation and knowledge exchange, ESRIG aims to advance cutting-edge research and develop practical solutions to global energy transition, sustainability, and climate issues. New generations are educated through the Energy and Environmental Sciences Master programme.

Research Quality:

ESRIG has a three-tiered strategy for maintaining a high standard of research quality. First, as part of the University of Groningen, we developed state-of-the-art facilities. Second, our multidisciplinarity researchers contribute to the vibrant academic community in the Faculty of Science and Engineering. Finally, by adhering to the highest scientific standards, ESRIG ensures that its research outcomes (expressed in terms of an average of 200 publications and 10 PhD defences per year) are reliable, relevant, and contribute significantly to the field of energy transitions and climate-related sustainability.

Viability:

ESRIG puts significant emphasis on the viability of its research. The institute recognises that sustainable solutions must be applicable, economically viable, and technologically feasible. ESRIG's research projects are designed with a focus on real-world viability, industry collaboration, and technology transfer. By conducting research with a keen eye on implementation, ESRIG aims to facilitate the transition towards sustainable energy systems and practices on a global scale. In the past 6 years, ESRIG has obtained an average of 4 million Euros per year from external sources to accomplish its research.

Societal Relevance:

ESRIG's research is inherently geared towards creating a positive impact on society. The institute actively engages with stakeholders, policymakers, citizens, NGOs, and industry to understand societal needs and challenges better. ESRIG's projects address critical sustainability issues, such as climate change mitigation, renewable energy integration, energy efficiency, and sustainable resource management. By aligning research outcomes with societal demands, ESRIG makes substantial contributions to building a sustainable and resilient future for generations to come. The staff members of ESRIG are frequently involved in various (inter)national advisory committees and make public appearances to raise general awareness for energy and sustainability challenges and solutions.

In conclusion, ESRIG is a forward-thinking research institute dedicated to advancing knowledge and solutions in the field of energy and sustainability. With a strategic focus on interdisciplinary collaboration, ESRIG plays a crucial role in shaping a more sustainable world. Visit our website to explore their cutting-edge research initiatives and learn more about the ongoing contributions to the global energy transition and sustainability landscape.

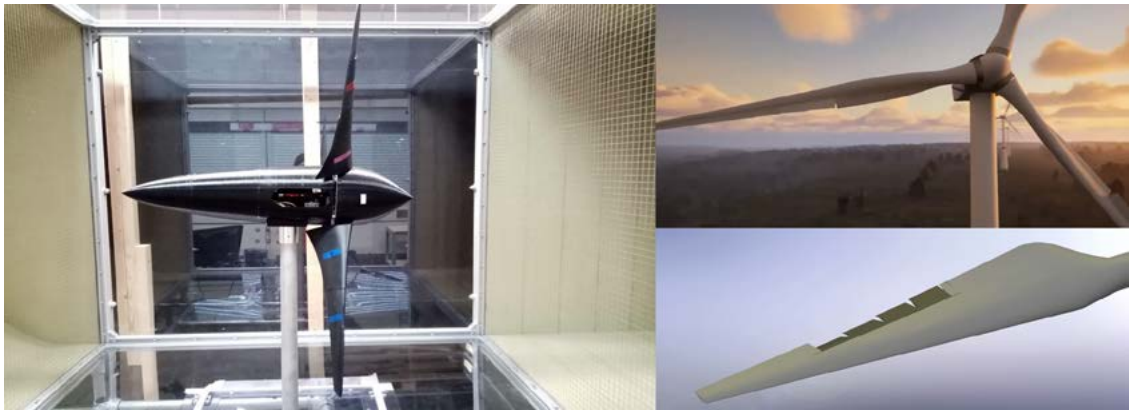
CASE STUDY 1

ALBATROZZ - Learning from birds to optimise wind turbines - Biomimetics group

Worldwide there is a growing demand for renewable energy. Next to solar energy and energy from biomass, wind energy is one of the biggest sources of renewable energy today. Wind turbine capacity has increased from 17 GW in 1997 to 600 GW in 2017, and is expected to reach 1000 GW in 2023. However, there is also a growing resistance to the installation of (large) wind turbines close to inhabited areas. It is therefore crucial to maximise the output of individual wind turbines, to get as much energy out of as few turbines as possible. This is particularly challenging when wind speeds are low. Currently, many wind turbines employed on land or at sea deliver their nominal/rated power at wind speeds of 12 m/s or higher. In practice, however, the prevailing wind speeds are much lower: 4-5 m/s on land and somewhat higher at sea. Wind turbines were simply not designed to perform well in those conditions.

To optimise the performance of wind turbines at low wind speeds, we have been inspired by how sea birds solve the puzzle of maintaining lift during low-speed flight. Albatrosses and Fulmars let their wings "wiggle" to prevent crashing (invoking a phenomenon called "delayed stall" in aerodynamics) while they slow down in order to land. Our research has shown that, by mimicking this oscillatory motion, the power output of wind turbines at low wind speeds can be increased significantly. Research in flow tanks and wind tunnels showed that lift forces of an oscillating wing profile temporarily rise to about 200% of the normal lift force. On average they are about 25% higher than normal lift forces. These increases are caused by very short periods of close-to-stall aerodynamics which appear to be reversible when the oscillation frequency is high enough. Tests on a relatively small wind turbine in the ESRIG wind tunnel (see figure) have shown even higher maximum outputs than expected. This principle of Lift-Enhancing Periodic Stall (LEPS) has now been studied in detail and patented[1], and forms the basis for research at a full-size wind turbine (see figure) to see if the same results can also be found at the full scale.

Large wind turbine companies such as Siemens-Gamesa, Vestas, Nordex and Enercon are following the developments closely. We founded a consortium with the companies RG-projecten & EmpowerMi, funded by an NWO Start-Up grant (40 k€) and an RVO grant (1.5 M€) to explore commercialisation. In cooperation with wind turbine modification companies (TopWind, Business In Wind & Rengineers), an 850 kW wind turbine of a large energy company (Pure Energie) is now being modified. Testing of this new turbine is foreseen for summer 2023.



Experimental turbine with partially oscillating blades in the ESRIG windtunnel (left), Artist impression of modified Vestas V-52 turbine (right).

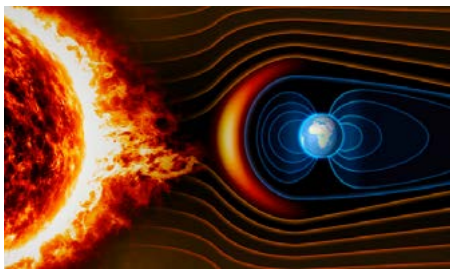
1 Patent application and registration 'Biomimetic Wind Turbine Design with Lift-Enhancing Periodic Stall' - WO2017/105244A1

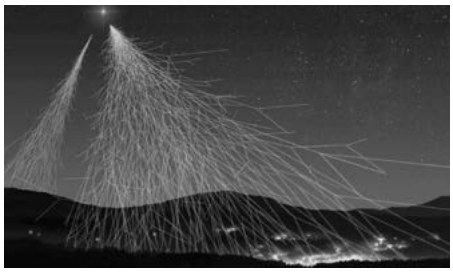
CASE STUDY 2

Extreme solar storms shine light on our past – Exact Chronology of Early Societies (ECHOES) project, ESRIG

Radiocarbon dating is used extensively in environmental and archaeological research. It uses the decay of the radioactive isotope of carbon (14C) to measure the age of objects containing organic material. However, the technique can typically only determine ages to within a century. We have pioneered a modified form of radiocarbon dating that is capable of achieving exact-year precision. The method uses the fact that some extreme solar storms leave distinct radiocarbon patterns in growing trees. Six such storms have now been detected in archives of tree rings of exact known age. As a result, if one of these signals is found in a piece of wood from an environmental or archaeological site, it may be datable to the exact year. We used this method to reveal the exact year the early medieval Siberian castle known as Por-Bajin was built. We were also able to show that Vikings were present in the Americas as early as 1021 AD, some five centuries before Columbus. This result garnered worldwide interest. The story was run on BBC World News as the second headline of the day, and covered by newspapers such as the New York Times and the Wall Street Journal, amongst many others. Ultimately, the article describing our findings obtained the highest Altmetric Attention Score of any study ever led by Groningen University. Most recently, our new approach to high-precision radiocarbon dating was singled out by the journal *Nature as one of the "Seven Technologies to Watch".*[1] A European follow-up grant of 2 M€ was awarded to investigate where, when and for how long Europeans went to the Americas prior to Columbus, who they may have encountered, and whether there were any lasting impacts of these first transatlantic connections.[2]

Our research also has a spin-off that focuses on the frequency and magnitude of the solar storms. If such an extreme storm were to take place now, it would likely have catastrophic impacts on modern civilisation. The accompanying radiation would decimate the observational, navigational and telecommunication satellite networks, with immense ramifications for our increasingly digitised society. It is, therefore, essential that we understand the scale and timing of these events in order to futureproof new technologies and infrastructure. As our systematic search for such events continues (by us and by others) for the purpose of better age determination, this understanding is also advanced.





Reconstructed Viking-Age building adjacent to the site of L'Anse aux Meadows.
Image credit: Russ Heinl aerial photography

1 Nature 613, 794-797 (2023), doi: https://doi.org/10.1038/d41586-023-00178-y

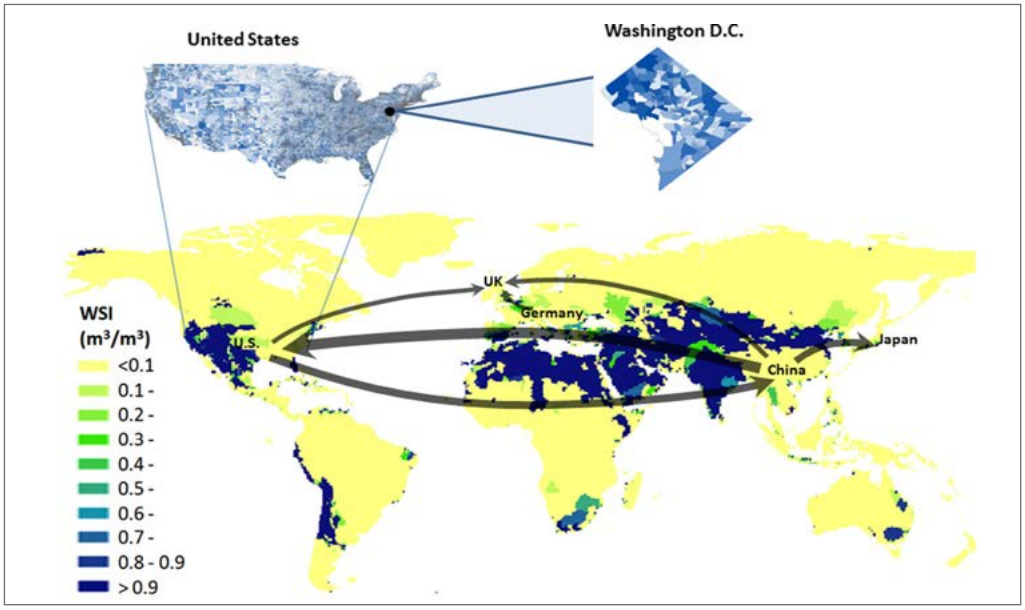
2 ERC Consolidator Grant, Michael Dee

CASE STUDY 3

Evaluating global value chains – Integrated Research on Energy, Environment and Society (IREES) group, ESRIG

New energy technologies and methods to produce energy in a sustainable way have a myriad of environmental impacts, and could even result in unwanted competition with food production for land and water. For decades, the Center for Energy and Environmental Sciences (IVEM, now part of IREES) has studied such impacts. We have now extended these analyses to evaluate the environmental, social and economic effects of the energy transition along global value chains (GVCs), and to look at climate change and poverty.

We made key contributions to the recent Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC; Working Group III[1]), using a unique global database developed in collaboration with the World Bank. The data and the model are also used in teaching and in the supervision of Master's students, whose results attracted much attention.[2] Applications of the GVC model include a recent project for Greenpeace Germany and Europe to investigate the environmental ramifications of Europe's Green Deal with energy and land-saving policies potentially leading to deforestation and other negative environmental impacts elsewhere around the globe. The model has also been used to investigate the impact of Covid-19 on the energy transition and reaching climate change targets, which has led to a number of highly influential publications in *Nature journals.*[3] Our publications on GVC interruptions due to Covid-19 have informed a bipartisan committee of the US Congress to lead the response and the subsequent "Build Back Better" initiative; it got an honorary mention in the final statement of the committee's chair person in the televised hearing. The most recent application of the framework and model was to analyse the global impact of the war in Ukraine on energy and food prices, highlighting its contribution to the current cost of living crisis, potentially throwing 140 million people into extreme poverty. This publication in *Nature Energy*[4] has been covered by media around the world, with a reach of more than 500 million people.



Teleconnecting consumption to environmental impacts at multiple spatial scales[5]

1 See https://www.ipcc.ch/report/ar6/wg3/

2 Two Master's theses were published in Nature Sustainability: Bruckner, B., Hubacek, K., Shan, Y. et al. Impacts of poverty alleviation on national and global carbon emissions. Nat Sustain 5, 311–320 (2022). https://doi.org/10.1038/s41893-021-00842-z; and Bruckner, B., Shan, Y., Prell, C. et al. Ecologically unequal exchanges driven by EU consumption. Nat Sustain (2023). https://doi.org/10.1038/s41893-022-01055-8

3 Such as: Shan, Y., Ou, J., Wang, D. et al. Impacts of COVID-19 and fiscal stimuli on global emissions and the Paris Agreement. Nat. Clim. Chang. 11, 200–206 (2021). https://doi.org/10.1038/s41558-020-00977-5;

4 Guan, Y., Yan, J., Shan, Y. et al. Burden of the global energy price crisis on households. Nat Energy (2023). https://doi.org/10.1038/s41560-023-01209-8

5 Hubacek et al., 2014. "Teleconnecting consumption to environmental impacts at multiple spatial scales – research frontiers in environmental foot-printing." Industrial Ecology. Vol. 18 (1), pages. 7 – 9.

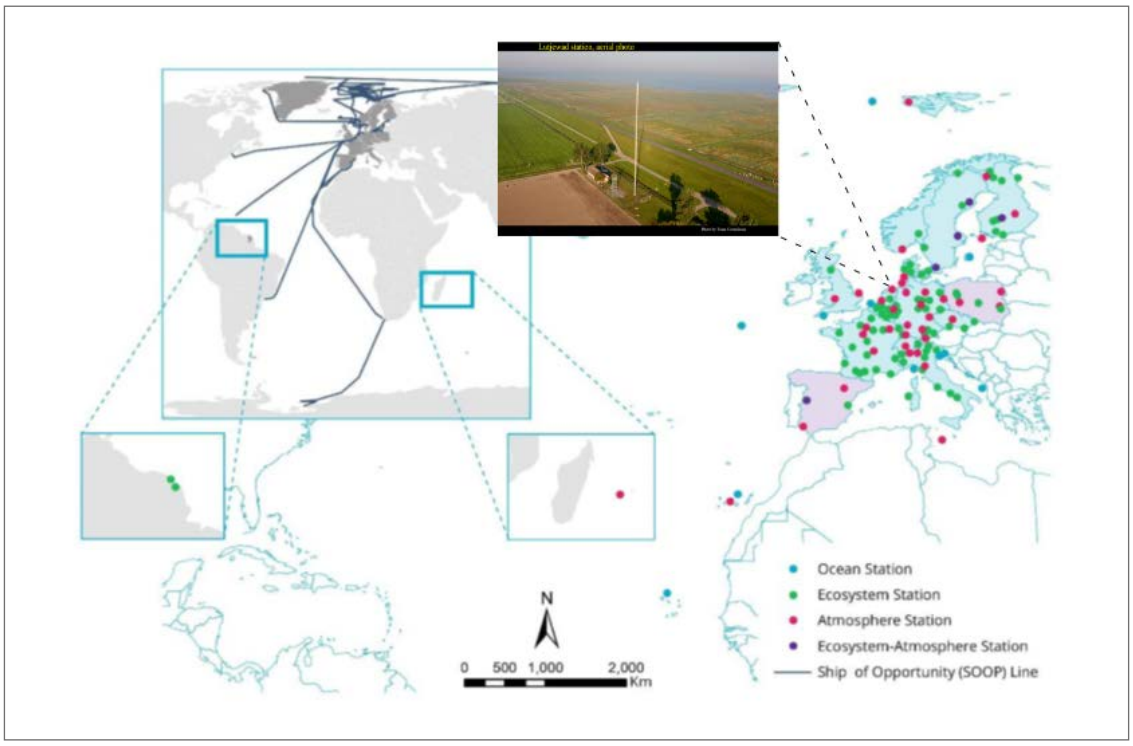
CASE STUDY 4

Studying greenhouse gases and aerosols at the Wadden Sea site Lutjewad - Centre for Isotope Research (CIO), ESRIG

Naturally occurring rare isotopes that are part of the major greenhouse gas CO_2, precisely tracked using sensitive instruments, act as tracers of the global carbon cycle. At the Centre for Isotope Research (CIO) we have a long-standing record in making observations of greenhouse gases and related tracers and using them to understand the influences of both natural and human carbon emissions on the global carbon cycle. Our Lutjewad measurement station (see photo) on the coast of the Wadden Sea was founded in 2001 and renovated in 2013. It consists of a 60m tall mast with air inlets and a laboratory building packed with measuring equipment.

Based on the opportunities the station offers, and its continuous record of observations, we have participated in a long series of national and EU projects, of which GHG Europe, InGOS, RINGO, ATMOS-ACCESS and Waterstof Werkt are among the latest. On 23 May 2019, the station officially became part of the European Integrated Carbon Observation System (ICOS). The data produced by Lutjewad is now made publicly available to everyone within 48 hours after gathering. Lutjewad is also an excellent testbed for innovations. It has a 20-year record of CO_2, O2/N2 and atmospheric potential oxygen (APO) observations that are available for analysis, and has fostered the adoption of two new tracers (carbonyl sulfide COS and triple oxygen isotope Δ17O in CO_2) to track gross primary production of CO_2, as well as the use of Δ14C in CO_2 as a tracer for fossil fuel CO_2. We also developed and field-tested an innovative system to use the atmospheric air sampling system called AirCore for high-precision observations of greenhouse gases, using an unmanned aerial vehicle (UAV).

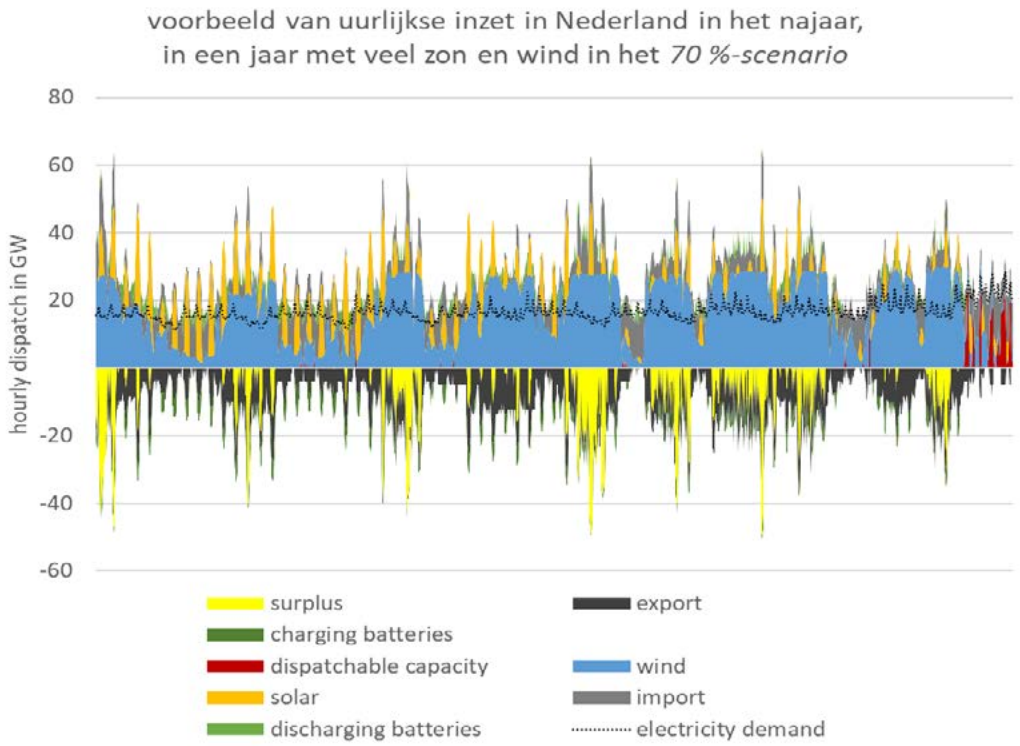
In addition to greenhouse gas infrastructure, the Lutjewad site has become a hub in the European network of measurements stations investigating aerosol, funded within the NWO Large-Scale Infrastructure "Ruisdael" project. Aerosol particles due to pollution can affect the Earth's climate by triggering or changing the formation of clouds, and by reflecting or absorbing sunlight. The Lutjewad site is ideally located to study the outflow of European pollution over the North Sea, as well as regional pollution sources of the marine area, such as shipping. Since July 2021, we have been providing a continuous measurement record of physical and chemical parameters of aerosols, together with cloud properties retrieved by a cloud radar. These measurements are crucial to study the effect of aerosol on cloud reflectance, which is responsible for the largest uncertainty in anthropogenic climate forcing.



CASE STUDY 5

Modelling the integration of renewable energy sources into power systems – Integrated Research on Energy, Environment and Society (IREES) group, ESRIG

The energy transition requires large-scale integration of weather-dependent renewable energy sources into the power systems. Due to daily, seasonal and yearly fluctuations in the weather, it is not easy to ensure the uninterrupted reliability of the power system. Energy and power system models can support stakeholders such as transmission system operators, energy companies, and governmental bodies in designing strategies to deal with these challenges.



An example of the output of our power system model with the dispatch of technologies including the use of batteries, demand response, and trade with other countries. This is the dispatch in the Netherlands in the usual windy autumn based on a scenario with 70% penetration of solar and wind power in the electricity mix (36 GW of wind capacity and 60 GW of solar capacity based on the ENTSO-E global climate action scenario). Even with high electricity exports to the other countries in Europe (that are also modelled), still part of the electricity has to be curtailed (i.e., the surplus). This is a simulation of the power system in a very sunny and windy year. The demand includes electricity for electric transport and heat pumps.

We develop and apply such models at national and European scales. We work in multi-disciplinary teams with expertise in energy and power system modelling, climate science and simulations, big data analytics, advanced algorithms, electricity markets, and grid planning and operation. Our partners in this research include European grid operator TenneT, the Royal Netherlands Meteorological Institute (KNMI), the Swedish Meteorological and Hydrological Institute (SMHI), the EU's Joint Research Centre (JRC), Utrecht University, and various energy companies. Example projects are the project Algorithmic Computing and Data-mining for Climate integrated Energy System Models (ACDC-ESM) funded by NWO, and the ERA-NET project DIRT-X, investigating the role of hydropower in Europe. We apply power-system models at high spatial and temporal resolutions based on new algorithms and model formulations, and insights from climate experts and big data analytics to capture the key patterns of weather-driven fluctuations in historical weather data and climate simulations. We are specifically successful in hourly modelling of future power system configurations in which all European countries and their interconnections are represented. We are able to assess their performance under many future weather years, also considering

the developments of the whole energy system by smartly soft-linking the hourly models to long term investment models. Finally, to bring this model integration to the next level, we developed a unique model at IREES with a built-in integration between long-term planning and hourly dispatch, and applied it to the Netherlands and other regions.

Based on this research, we advise on system adequacy in round-table discussions in Dutch parliament. Insights from the project are used in the formulation of the requirements for the European Network of Transmission System Operators for Electricity (ENTSO-E)'s new Pan-European Climate Database, the core of all European grid operator studies and their reliability indicators. In addition, they inform meteorological institutes on climate model requirements and improvements regarding their relevance for societal problems. Finally, this research has led to many highly cited papers. For an impression of relevant papers please see the following links in *Applied Energy*: "Cost-optimal reliable power generation in a deep decarbonisation future" and "Is a 100% renewable European power system feasible by 2050?".

CASE STUDY 6

Sharing insights into local renewable energy systems with citizens, companies and governments – Integrated Research on Energy, Environment and Society (IREES) group, ESRIG

IREES has a long tradition in working together with partners outside of academia, including civil society organisations, often in cooperation with the Science Shop of the university, which also has its office at the Energy Academy. Around 2014, we started a long-term interdisciplinary programme on local renewable energy, originally funded by the Responsible Innovation Programme of NWO and the Ministry of Economic Affairs, but later also financed by, among others, RVO, EU, governments and companies (in total 1.5 M€). The aim of these projects was to understand the characteristics, problems and possible improvement of local renewable energy systems in the Netherlands, Europe and developing countries. Within this programme, our researchers worked together with researchers at the Hanze university of applied sciences, TNO and other universities. Companies such as start-ups DrTen and Ecovat, distribution system operators (DSOs) such as Cogas, regional or local governments and citizens organisations were involved to guarantee political relevance and practical application. The programme resulted in suggestions for improvements of technological, social, environmental and economic aspects of local energy systems, for instance neighbourhood heating networks, local energy storage structures, off-grid hybrid systems and cooperative biogas installations, shared with both academic and non-academic audiences. In addition, several practical tailor-made reports and manuals were published for governmental organisations and energy cooperatives. At least one of our manuals is integrated in the planning and participation procedures of one of the largest Dutch energy cooperatives Grunneger Power. Another one is recommended by the largest umbrella organisation of energy cooperatives, Energie Samen, where our results are currently being implemented further.

Presentation mini turbine, result of co-creation

Hybrid conference with people from science, practice, companies and civil society

Design workshop Wageningen

Design for citizen driven district heating system

Practical suggestions for local energy systems were discussed with representatives of companies and governments, often during common design sessions, not just in the Netherlands, but also in Mozambique. There, we assessed existing hybrid systems and contributed to a better design of these types of systems. For the general public, we organised a national webinar, together with one of our partners, New Energy Coalitions (NEC), and we contributed to a policy brief for the European Commission to improve conditions for local energy initiatives.

We also investigated and quantified the aggregate contribution of Collective Action Initiatives (CAIs), which bring together economic, social and environmental needs at the scale of local communities. By empowering citizens in the incumbent energy system, CAIs are crucial in exploiting the potential and achieving EU clean energy goals. The Netherlands is an outstanding example of the transformational potential of CAIs. In a project funded by the EU, we tracked more than 400 CAIs in our country, showing that it is the country with the highest concentration by far in Europe. The project offered us a unique opportunity to capitalise on our multidisciplinary background and connect internally as the tasks involved different skills (scientific and social) and both English and Dutch languages (for the domestic studies). Most importantly, it enabled us to cooperate with the lively and diverse landscape of Dutch energy communities.