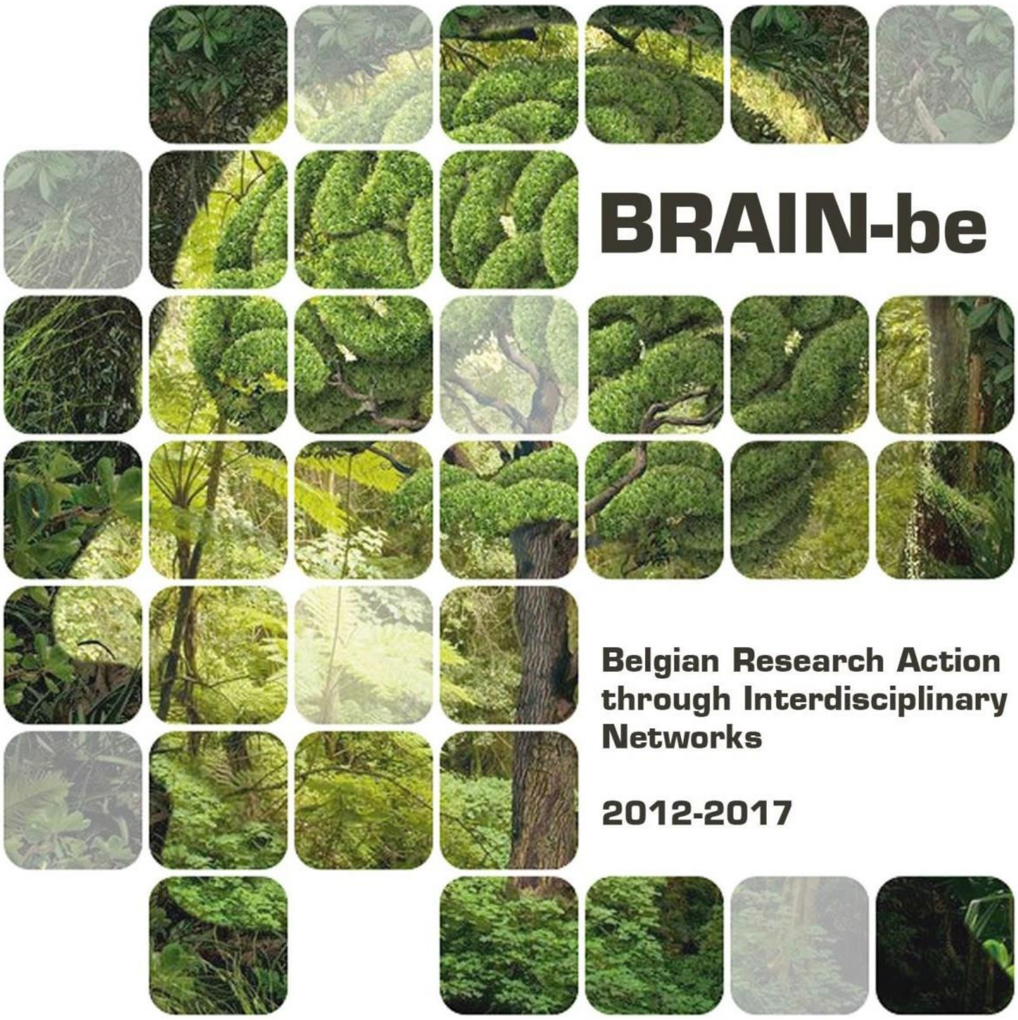

CIREG

Climate Information for Integrated Renewable Electricity Generation

Stefan Liersch (PIK) – Wim Thiery (VUB) – Sebastian Sterl (VUB) – Ann van Griensven (VUB)

Axis 2: Geosystems, univers and climate

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Belgian Research Action through Interdisciplinary Networks

2012-2017

NETWORK PROJECT

CIREG

Climate Information for Integrated Renewable Electricity Generation

Contract - BR/175/A2/CIREG

FINAL REPORT

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Contents

1. INTRODUCTION

Rural electrification is a crucial component of socio-economic development and is associated with higher youth literacy, enhanced employment, alternative income generation activities etc. In Sub-Saharan Africa rural electrification rates are with 14% extremely low, and even urban electrification rates are below rural electrification rates in other developing world regions. In the context of population development in West Africa, which is projected to double by 2050, the electricity demand is expected to increase fivefold.

2. STATE OF THE ART AND OBJECTIVES

A crucial goal of the CIREG project is to support and guide the decisions that are taken in the energy sector today, because they will have long-term impacts on greenhouse gas (GHG) emissions, energy prices, and sustainability goals. CIREG provides model-based support for decision-makers by establishing and providing necessary climate services to support sustainable and renewable electricity generation (REG) with a high share of renewables (hydro, solar, wind), electricity planning and implementation aligned with Sustainable Development Goals (SDGs) and Nationally Determined Contributions (NDCs). We assess temporal patterns of hybrid potentials including the complementarity of REG sources across space to aid in planning of the future West African (WA) electricity market. Long-term climate change projections and their risks and opportunities for REG systems are considered at the sub-continental and river basin scale (e.g. Niger, Volta, Mono). Three local case studies serve as demonstrators for the development of business models for off-grid REG solutions, which are representative for rural Africa. CIREG closely (net-)works with regional organizations and serves as knowledge hub and provider of climate services in the frame of renewable electricity generation. All knowledge, data and tools developed will be made publicly accessible in the future and promoted on a web platform.

3. METHODOLOGY

3.1 Stakeholder engagement and capacity building

The first period of the project was mainly devoted to establishing the stakeholder network, to elicit the demand for climate services in the context of renewable electricity generation, and to set up biophysical models to various model domains in West Africa.

The second phase (period concerned) of CIREG was more application-oriented focussing on co-development of strategies to increase the share of renewable sources in electricity mixes in West African countries and in the West African Power Pool under climate change and considering future developments of electricity demand and supply, aligned with sustainable development goals.

To achieve these goals, we have conducted a series of modelling workshops using the models WEAP (Water management), LEAP (Energy modelling), and the eco-hydrological model SWIM. Capacity building in terms of model training was a crucial demand of our stakeholders formulated in the first science-policy dialogue workshop in Niamey, Niger in October 2018. In the WEAP and LEAP model workshops (SEI), participants from various West African organizations worked on the setup and refinement of models for Burkina Faso and Ghana, basically covering the Volta River basin. Hydrological simulations of the SWIM model (PIK) under climate change and management scenarios served as input for the model WEAP. A four-week training for two West African scientists (Volta Basin Authority, WASCAL) was conducted by PIK in Germany. In these workshops, we jointly developed not only models but also scenarios of climate resilient future electricity mixes. Workshop results were communicated and discussed in science-policy dialogues with high-ranked staff members of institutions from the water and energy sector, with contributions of all CIREG consortium members.

In addition to the communication of CIREG results in science-policy dialogues, several policy briefs and scientific articles were published with contributions of all consortium partners, see Appendix.

3.2 Scientific analyses

To not only address renewable electricity generation at the country scale but at the sub-continental scale in the frame of the West African Power Pool, the model REVUB (Renewable Electricity Variability, Upscaling and Balancing) was developed and employed by VUB to investigate the complementarities of solar, wind, and hydro power.

Synergies and trade-offs between hydropower generation at existing and planned dams with agricultural developments, e.g., irrigation and flood protection were investigated using the SWIM model under two climate scenarios by PIK in a WEF nexus approach.

Ethnographic studies to investigate the socio-economic impact at decentralized and local demonstrator sites have been performed by WASCAL and ZEF. Willingness to pay studies were conducted by WASCAL in three demonstration sites for (1) an electrification system based on an off-grid solar park, (2) a solar PV-based water pumping system for micro-irrigation and electricity supply, and (3) hybrid system based on micro-hydropower and solar PV. WASCAL and ZEF have also contributed to the development of community-based business models for these demonstrators, an important component for uptake in other rural electrification projects.

3.3 Difficulties encountered and solutions

Almost the entire reporting period was impacted by the global COVID-19 pandemic. All planned workshops and project meetings in West Africa and Europe could not take place as planned. Nevertheless, we carried out all planned activities, including the final stakeholder event, and switched completely to online meetings. This allowed us to continue communicating with our stakeholders but on a limited level. The reasons for the limitation are on the one hand technical, e.g., poor internet connection, online fatigue, and on the other hand social, no face-to-face situations to build trust etc.

As the German project partner Smart Hydro Power (SHP) was excluded from the consortium by the German funding organisation shortly before the project was granted, some tasks, e.g., the identification of a suitable location, screening of use cases, had to be performed by the project partners PIK and ZEF with the support of WASCAL. Moreover, the process of publishing a tender to find an alternative enterprise for the technical implementation was delaying the Task 5.3 “Establishment of the REG demonstrator”, which was due in month 12.

The technical implementation of the demonstrator in Togo was not realized until the end of the project. The equipment, however, is ready for shipment from Germany to Lomé harbour. Reasons for the delay are: (1) very long tender process led to a delay of at least 15 months, (2) COVID-19 pandemic: due to the travel restrictions, the technical equipment was not shipped to Togo, because a transport from the harbour to the village as well as the installation would not have been possible, (3) rainy season. The solution was shipment after the rainy season 2021, transport from harbour to village in October, and installation in November.

The delay has the consequence that the post-installation studies (D5.4), to be performed by ZEF and WASCAL cannot be performed in the frame of CIREG. However, the demonstrator will be handed over into the responsibility of WASCAL after its implementation, thereby ensuring its operation and the continuation of social impact studies. If possible, ZEF may extend the field research on a cost-neutral basis.

4. SCIENTIFIC RESULTS AND RECOMMENDATIONS

4.1 Demonstrator installation

The CIREG project installed two demonstrators of renewable electricity generation to communities:

– An off-grid photo-voltaic (PV) power plant connecting 120 households (Sekoukou village, South-West Niamey, Niger), impacting the life of at least 840 people.
– A centralized PV-based borehole water pumping system providing access to clean water for consumption and micro-irrigation of the villagers involved in market gardening. At least 60 women are benefiting from the facility in the village of Jamih (East of Niamey, Niger).

A community management team at village level is responsible for the maintenance, security, and payments for the long-term sustainability of the demonstrators and their potential future extension. Additional research activities are conducted in these demonstrator sites to showcase local climate services provision through WASCAL, in partnership with the project partners Potsdam Institute for Climate Impact Research (PIK), Stockholm Environment Institute (SEI), Vrije Universiteit Brussel (VUB), Technical University of Denmark (DTU) and Center for Development Research (ZEF).

The project also concluded a number of demand-driven activities including:

– Training sessions of West African technicians (academic and non-academics, public/private institutions, research and development agencies of water and energy sectors of Burkina, Ghana, Niger, and Togo) on tools such as Long-range Energy Alternatives Planning system (LEAP), Water Evaluation And Planning (WEAP), Soil and Water Integrated Model (SWIM), REVUB (Renewable Electricity Variability, Upscaling and Balancing).
– Science-Policy dialogues on renewable electricity solutions that account for national and regional development policies under different climate scenarios in West Africa.
– Participative scenario building on energy management and planning in line with the SDGs in West Africa.

4.2 Streamlining strategies for renewable electricity generation from sun, wind, and water in sub-Saharan Africa

This project aims to advance our knowledge on transitioning towards modern, clean renewable electricity generation technologies in sub-Saharan Africa. Currently, the most promising technologies for renewable electricity generation appear to be solar PV and wind power, given their strongly decreasing costs. However, solar PV and wind power come with their own challenges, notably related to their spatiotemporal variability in function of weather and climate. Therefore, power grids with high shares of solar PV and wind power must be adapted to be able to withstand these challenges. For many countries in sub-Saharan Africa, this is not only a challenge but also an opportunity, namely to design power systems designed for a high integration of solar PV and wind power from the outset.

First, it is demonstrated that resource assessments for solar PV and wind power should consider their spatiotemporal variability and their complementarity patterns right from the outset. This is done through a case study for West Africa, where opportunities to leverage diurnal complementarities and synergies between solar PV and wind power are shown to be substantial. A new statistical metric is designed and applied to showcase the presence of these synergies not only from a mathematical point of view (how well do the profiles of solar PV and wind power match?), but also from an energy planners' point of view (is the resource strength sufficient for such complementarities to be interesting?).

Second, we show that hydropower may be a highly attractive complementary resource to solar PV and wind power in regions where rainfall exhibits opposite seasonalities to irradiation and wind speeds, such as West Africa. A new, high-fidelity dispatch model (REVUB) is developed to simulate the operation of hydropower plants alongside solar PV and wind power to meet target loads on hourly timescales while complying with downstream flow requirements and reservoir level safe ranges on multiannual time scales. It is found that West Africa could strongly diversify its electricity mixes towards higher shares of solar PV and wind power by leveraging the flexibility of existing and planned hydropower plants. It is shown that regional integration of power systems in the West African Power Pool would allow countries to harvest a cascade of spatiotemporal synergies (spatial, diurnal and seasonal) that would benefit the potential of solar-wind-hydro mixes to meet increasing shares of power demand. Such a scenario would allow to meet up to 60% of current West African electricity demand with these sources, of which roughly half would be solar PV and wind power. We also argue that synergetic hydro-solar-wind planning marks a strong opportunity for avoiding overexploitation of hydropower potential.

Third, we study the specific situation surrounding the Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile river, which, once completed, is to be Africa's largest hydropower plant, and whose reservoir will be capable of storing more than one full year of river flow. The GERD is currently the subject of a controversial geopolitical conflict around Ethiopia, Sudan, and Egypt, with Ethiopia insisting on its rights to develop river damming infrastructure on the Blue Nile, Egypt insisting that its self-proclaimed rights on Nile water not be infringed upon, and Sudan caught between both sides. We apply the REVUB model to showcase that many elements of controversy around the long-term operation of the GERD could be mitigated by explicitly coupling GERD operation to solar PV and wind power generation in Ethiopia, Sudan, and potentially other countries in the Eastern Africa Power Pool (EAPP). The core element of the proposed strategies is the fact that solar PV and wind power have opposite seasonal profiles to Blue Nile river discharge; a synergetic operation of GERD with solar PV and wind power would therefore re-introduce a seasonality in GERD outflow resembling the natural seasonality, thus making GERD appear (from the downstream point of view) like a relatively small hydropower plant, while retaining all power generation benefits for Ethiopia. Such strategies could further strongly support increased VRE grid integration across East Africa. We propose that harmonised hydro-solar-wind planning be incorporated into the ongoing diplomatic discussions related to GERD.

Fourth, we briefly cross the Atlantic for a dedicated case study on Suriname, which has a similar power mix composition and similar prevailing climate to many countries in tropical sub-Saharan Africa. The REVUB model is applied to Suriname's Afobaka hydropower plant, newly in the country's full possession, to investigate the potential for hydro-supported integration of wind power harvested along Suriname's shore. It is shown that this would allow to reach a wind power penetration of 20%-30% in Suriname's electricity mix while cost-effectively displacing diesel fuels used for power generation.

Fifth, we develop a new data atlas for hydropower on the African continent aimed at the energy modelling community. While atlases for solar PV and wind power, containing data on spatial resource availability and temporal resource profiles, are relatively widely available to the modelling community, this has hitherto not been the case for hydropower, thereby constraining modellers' options for accurately modelling synergies between solar PV and wind power on the one hand and hydropower on the other, especially on seasonal timescales. The newly developed data atlas provides seasonal availability profiles for a close-to-exhaustive list of existing and future hydropower plants in Africa.

Finally, we review the state-of-the-art literature from recent years that deals with on-grid integration of solar PV and wind power in electricity systems across Africa. We deal with generation-based, storage-based and demand-based flexibility, and position all conclusions from the previous chapters in the wider research efforts that are ongoing to support the clean energy transition in Africa.

5. DISSEMINATION AND VALORISATION

5.1 Engaging with Civil society and policy makers

The CIREG project has engaged with representatives from following institutions and organizations:

- Water and Energy sectors in West Africa
- Transboundary River Basin Agencies
- Ministries
- National Agencies and utilities
- Academia
- Civil society (demonstrators)

5.2 Stakeholder workshops (2019)

The Stockholm Environment Institute (SEI) and WASCAL co-organized two training workshops (March 11th - 15th in Accra, Ghana and March 18th - 22nd in Ouagadougou, Burkina Faso) for the benefit of renewable energy practitioners in West Africa. The two events were a follow-up to climate services demanded by the project beneficiaries during the first stakeholder workshop in Niamey-Niger (October 1st -4th 2018). Both workshops provided hands-on training using the Long-range Energy Alternatives Planning system (LEAP) and the Water Evaluation And Planning system (WEAP) tools. In Accra, the training targeted advanced users of the two software tools. The participants were chosen exclusively from various Ghanaian public institutions, research and development agencies and academia, oriented towards the water and energy sectors. Twenty-six participants have fully attended the training sessions. In Ouagadougou, the workshop was meant for beginners and new users of both models. The thirty-six participants came from various stakeholder institutions engaged in the field of energy and renewable electricity generation in Niger, Togo and Burkina Faso. During the workshop, the participants were engaged into dialogues to find alternative measures to various challenges such as data availability, sources and types, data access and sharing conditions including the continuous use of the models in their daily routine works of individual participants or institutions.

In October and November 2019, the CIREG consortium organized a second round of training workshops on Energy and Water modelling in Accra (October 28th – November 1st) and Ouagadougou (4th – 7th November), following up on the first round in March 2019. Both workshops were hosted by the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) and the Stockholm Environment Institute (SEI). The objectives of the training were to follow up on the previous WEAP/LEAP workshop held in March 2019, introduce the REVUB model, to link with the other models used in CIREG (SWIM and REVUB), to review and improve preliminary results of the models and to integrate the WEAP and LEAP models. In both Accra and Ouagadougou, a half-day science-policy dialogue was organized. The meeting concerned all stakeholder who are identified as policy makers, or decision makers in the various institutions. In parallel to the training workshops, additional door-to-door canvassing sessions were organized to meet and discuss CIREG results as well as user-needs. From the science-policy dialogue and the door-to-door canvassing, many stakeholders such as SONABEL, ANEREE, Ministry of Energy, ONEA in Burkina Faso, Water & Energy Commission in Ghana, and Volta Basin Authority have expressed some need of CIREG results and became aware of integrating climate information into their future planning. In Ghana and Burkina Faso, decision makers and many high-level staff of stakeholder institutions were interviewed in order to raise awareness to the integration of climate information into decision making.

The workshop provided hands-on training in using SEI's Long-range Energy Alternatives Planning system (LEAP) and the Water Evaluation and Planning system (WEAP) tools. In addition, this second workshop round also focused on the back-end models SWIM (for hydrological simulations) and the new REVUB model (for assessing the potential for hydropower-driven flexibility for grid integration of solar and wind power), both of which are used provide high-resolution input data for the WEAP-LEAP modelling.

The workshops were attended by high-level and technical staff from various governmental and research organisations in Ghana, Burkina Faso, Niger, and Togo.

The workshops in Accra were covered on Ghanaian news, including interviews with CIREG researchers Stefan Liersch (PIK) and Seyni Salack (WASCAL). CIREG researcher Sebastian Sterl (VUB), also wrote a blog piece for the World Energy Meteorology Council (WEMC) providing more details on the objectives and outcomes of this second workshop round.

– Blog piece: https://www.wemcouncil.org/wp/wemc-member-blog-climate-services-for-a-renewable-future-in-west-africa/
– Media coverage: https://www.youtube.com/watch?v=HL_AyUfxA2M&t=30s
– World Bank webinar on: sustainable hydropower (2020)

On behalf of the project consortium, Sebastian H. Sterl (VUB) presented the findings of the CIREG project for West Africa during the webinar series "Building back better and greener with sustainable hydropower" co-organized Wednesday and Thursday 24th -25th of June 2020 by "The World Bank Global Solutions Group on Hydropower" and the "ESMAP Hydropower Development Facility".

– The full programme of the webinar is available here: file:///tmp/mozilla_liersch0/WBG_hydropower_virtual_meeting_v11.pdf

5.3 Science-policy dialogue (2020)

– In December 2020, CIREG conducted an online decision-makers workshop with participants from various water and energy institutions in the Volta River basin. The purpose of the meeting was to:
– Share the results from CIREG models in terms of climate change impact on water resources, prospects for renewable electricity generation from hydro, solar and wind powers, and energy planning.
– Share results of energy demand and supply analysis in the near to long-term forecasting in respect to national plan, SDG, NDC and climate smart scenarios.
– Foster a discussion between CIREG scientists and senior managers of the water and energy sectors in Burkina Faso and Ghana.
– Identify potential follow-up activities and opportunities for fundraising.

5.4 Online seminars with WRC, DGRE, and SONABEL (2021)

In 2021, customized training sessions were organized with DGRE and SONABEL of Burkina Faso and the Water Resources Commission (WRC) of Ghana to present the results of the project and stock-take further needs of these institutions. At the end of the meeting, all institutions expressed the need for complementary training session for their staff in applying CIREG models (i.e., WEAP, LEAP, SWIM models).

5.5 CIREG final stakeholder event (2021)

In June 2021, CIREG conducted a final online stakeholder event with about 40 participants. The event was livestreamed on WASCAL's facebook channel with about another 40 visitors.

The CIREG project discussed its main achievements and highlights jointly with scientists, stakeholders, and other selected participants, e.g., National Funding Organizations, ERA4CS consortium. An important objective of the event is to enable the project stakeholders to discuss the usefulness of the results and identify possible follow up for an enhanced uptake and Operationalization of Climate Services (especially in the frame of the Operationalization of Climate Services initiative of JPI/ERA4CS).

There was a strong signal that a continuation of the project is desired. There is on the one hand the wish to continue capacity building and model training and on the other hand to continue working on very specific issues, like impact assessments of the construction of new and planned multi-purpose dams from a nexus perspective.

5.6 Hybrid REG demonstrator in Togo (2019)

Five CIREG scientists, supported by the GIZ and WASCAL Lomé, visited two villages and conducted interviews to identify potential electricity use cases, to understand the organisational and decision-making structure of the village communities, and to collect data to elicit the willingness and ability to pay and which serves to jointly develop a suitable business model. Furthermore, environment-specific characteristics were recorded, such as distance to the river, flow velocity, suitability of a site for the powerhouse. Based on a matrix of social and environmental indicators, one village was finally selected.

5.7 Willingness to pay studies, business model development in two demonstrator sites in Niger (2019-2020)

The CIREG project offered climate services to rural communities in Niger in the form of (i) an off-grid mini-park of photovoltaic (PV) panels for household electricity consumption in the village of Sekoukou; and (ii) a centralized PV-based water pumping system for small scale irrigation in Bonkoukou.

To self-sustain these two assets, WASCAL adopted a bottom up and participatory approach with local communities to establish the infrastructure and community business models for each. Expert interviews, focus group discussions with local communities, including management committee of existing services, young and women and household surveys have been conducted to discuss the business model.

5.8 Training and capacity building

- Water and energy planning workshops (Burkina Faso and Ghana):
  - 1st workshop in February 2019 (WEAP/LEAP)
  - 2nd workshop in October 2019 (WEAP/LEAP/REVUB)
  - 3rd workshop in June 2020 (WEAP / LEAP)
  - 4th workshop in December 2020 (WEAP / LEAP)
  - 5th workshop in May 2021 (WEAP) for DGRE
  - 6th workshop in June 2021 (WEAP) for SONABEL

- SWIM workshop (Burkina Faso, Ouagadougou), February 2019 for Volta Basin Authority and WASCAL staff
- SWIM training for 1 person from the Volta Basin Authority and 1 person from WASCAL for four 4 weeks at PIK in Potsdam, Germany in May / June 2019
- Sharing of research infrastructure

5.9 Project's impact on society: participation in other arenas; elaboration of policy briefs

As described in the section: Engaging with Civil society and policy makers above, the CIREG project had an impact on the civil society in two demonstrator case studies in Niger, by providing two villages with renewable solar PV electricity for different purposes.

Moreover, the hybrid REG demonstrator electrification system in the village of Gbandidi (Togo) will be installed after the official project lifetime and is guaranteed by the cost-neutral extension of the German part of the CIREG project. Once installed, the electrification system is expected to have a positive impact on the village community.

The PIK staff is co-supervising three PhD students of the WASCAL programme also after the CIREG-projects lifetime.

Please see the list of policy briefs in the Appendix.

CIREG provides its results on its website free of charge and relevant simulation results will be transferred to the WASCAL data infrastructure (WADI) to be available to the general public.

CIREG collaborated with:

- ERA4CS funded project ISIPedia (PIK)
- PAS-PNA (Climate Analytics)
- IRENA

5.10 Software and any other prototype

Development of the REVUB model (Renewable Electricity Variability, Upscaling and Balancing) by VUB. The main objective of REVUB is to model how flexible operation of hydropower plants can help renewable electricity mixes with variable solar and wind power to provide reliable electricity supply and load-following services. This model was first introduced in the paper "Smart renewable electricity portfolios in West Africa" by Sterl et al. (2020). A detailed description of all involved principles and equations can be found in the publication and its SI, as well as in the Manual on: https://github.com/VUB-HYDR/REVUB

5.11 Creation of a platform available to a community

The development of community-based business models facilitated knowledge sharing among stakeholders to sustainably manage the demonstrators. Women play an important role in finance management and selling tap water. This model was put in place and reinforced thanks to the frequent field schools implemented by WASCAL.

6. PUBLICATIONS

6.1 Policy briefs

- CIREG Policy brief: Power in Diversity – Climate Services for Renewable Energy in Ghana (2019).
- CIREG Policy brief: Power in Diversity – Climate Services for Renewable Energy in Burkina Faso (2019).
- CIREG Policy brief: Smart mixes of solar, wind and hydropower in West Africa.
- CIREG Policy brief: Mix énergétiques intelligents du solaire, de l'éolien, et de l'hydroélectricité en Afrique de l'Ouest (2020)
- Alongside solar and wind power, GERD is not a zero-sum game. Sterl, Sebastian Hendrik; Fadly, Dalia; Liersch, Stefan; Koch, Hagen; Thiery, Wim (2021).

6.2 Scientific papers published in the frame of CIREG

- Adamou, H., Ibrahim, B., Salack, S., Adamou, R. Sanfo, S. and S. Liersch (2020). Physico-chemical and bacteriological quality of groundwater in a rural area of Western Niger: a case study of Bonkoukou. Journal of Water and Health 18 (1), 70-99, https://doi.org/10.2166/wh.2020.082.
- Akinsanola, A. A.; Ogunjobi, K. O.; Abolude, A. T. & Salack, S. (2021). Projected changes in wind speed and wind energy potential over West Africa in CMIP6 models. Environmental Research Letters. https://doi.org/10.1088/1748-9326/abed7a
- Cantoni, R., Skræp Svenningsen, L. & Sanfo, S. (2021). Unattainable proximity: Solar power and peri-urbanity in central Burkina Faso. Energy Policy, 112127. https://doi.org/10.1016/j.enpol.2020.112127
- Liersch, S., Drews, M., Pilz, T., Salack, S., Sietz, D., Aich, V., Larsen, M. A. D., Gädeke, A., Halsnæs, K., Thiery, W., Huang, S., Lobanova, A., Koch, H. & Hattermann, F. (2020). One simulation, different conclusions - the baseline period makes the difference! Environmental Research Letters. https://doi.org/10.1088/1748-9326/aba3d7
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- Mutsindikwa, T. C.; Yira, Y.; Bossa, A. Y.; Hounkpè, J.; Salack, S.; Saley, I. A. & Rabani, A. (2020). Modeling climate change impact on the hydropower potential of the Bamboi catchment. Modeling Earth Systems and Environment, https://doi.org/10.1007/s40808-020-01052-w.
- Sterl, S., Fadly, D., Liersch, S., Koch, H. & Thiery, W. (2021). Linking solar and wind power in eastern Africa with operation of the Grand Ethiopian Renaissance Dam. Nature Energy. https://doi.org/10.1038/s41560-021-00799-5
- Sterl, S., A Grid for all Seasons: Enhancing the Integration of Variable Solar and Wind Power in Electricity Systems Across Africa, Current Sustainable/Renewable Energy Reports.

- Sterl, S., Vanderkelen, I., Chawanda, C. J., Russo, D., Brecha, R. J., van Griensven, A., van Lipzig, N. P. M. & Thiery, W. (2020). Smart renewable electricity portfolios in West Africa. Nature Sustainability. https://doi.org/10.1038/s41893-020-0539-0.
- Sterl, S., Donk, P., Willems, P., Thiery, W., (2020). Turbines of the Caribbean: Decarbonising Suriname's electricity mix through hydro-supported integration of wind power. Renewable & Sustainable Energy Reviews, 134, 110352, https://doi.org/10.1016/j.rser.2020.110352.
- Sterl, S., Liersch, S., Koch, H., Van Lipzig, N.P.M & Thiery, W. (2018). A new approach for assessing synergies of solar and wind power: implications for West Africa. Environmental Research Letters 13: 094009. https://doi.org/10.1088/1748-9326/aad8f6

6.3 Scientific papers under review

- Sterl, S., Devillers, A., Chawanda, C.J., van Griensven, A., Thiery, W., Russo, D. A spatiotemporal atlas of hydropower in Africa for energy modelling purposes. Submitted to Open Research Europe.
- Sanfo, S., Salack, S., Odou, T., Boubacar, T., Adamou, R., Saley, I., Skræp Svenningsen, L., Dahl Larsen, M.A., Liersch, S., Halsnæs, K., Ogunjobi, K., Implications of Bid Design in the Willingness to Pay for Centralised Solar Water Pumping Systems in Niger. Submitted to Energy Policy.

7. ANNEXES

Copy of scientific publications and policy briefs led by the CIREG partner VUB