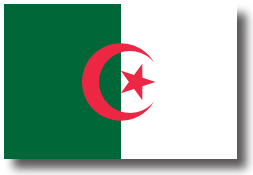
African Union

SPONSORED BY THE
Federal Ministry
of Education
and Research

DLR Projektträger



Pan African University
INSTITUTE OF WATER AND ENERGY SCIENCES (including Climate Change)

– PAUWES –

Pan African University Institute of Water and Energy Sciences

Recommendations for a Research Agenda at PAUWES:
Scientific Contribution to the Agenda 2063
of the African Union

PAU Nurturing Quality, Exemplifying Excellence
Pan African University
Institute of Water
and Energy Sciences

Table of Contents

Acronyms

ACMAD	African Centre of Meteorological Applications for Development
AfDB	African Development Bank
AFSEA	African Sustainable Energy Association
AIE	International Energy Agency
AMCOW	African Ministers' Council on Water
ARCT	African Regional Centre for Technology
AREA	African Renewable Energy Alliance
ATRST	Thematic Research on Science and Technology
AUC	African Union Commission
AUC-HRST	African Union Commission for Human Resources Science and Technology
BMZ	German Federal Ministry for Economic Cooperation and Development
CAADP	Comprehensive Africa Agriculture Development Programme
CAADP	The Comprehensive Africa Agriculture Development Programme
CC	Climate Change
CDER	Centre de Développement des Energies Renouvelables
CEEPA	Centre for Environmental Economics and Policy in Africa
CGIAR	Consultative Group for International Agricultural Research
CoP	Community of Practice
CORDEX	Coordinated Regional Downscaling Experiment
CRSES	Centre for Renewable and Sustainable Energy Studies, Stellenbosch University, South Africa
CV	Climate Variability
DFID	Department for International Development
DG-RSDT	Directorate General for Scientific Research and Technological Development
DIE	German Development Institute
DLR-PT	DLR Project Management Agency
EAC	East African Community
ECOWAS	Economic Community of West African States
EU	European Union
EUEI	European Union Energy Initiative
FAO	Food and Agriculture Organization
FEWSNET	Famine Early Warning Systems Network
FRIEND	Flow Regimes from International Experimental and Network Data
GEF	Global Environment Facility
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GWP	Global Water Partnership
HRST	Human Resources in Science and Technology
IAHS	International Association of Hydrological Sciences
ICPAC	Climate Prediction and Application Centre
IFPRI	International Food Policy Research Institute
IGAD	Intergovernmental Authority on Development
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	Information Communication Technology
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IRI	International Research Institute
IUWM	Integrated Urban Water Management
IWMI	International Water Management Institute
IWRM	Integrated Water Resource Management

MEDREC	Mediterranean Renewable Energy Center
NEPAD	New Partnership for Africa's Development
NGO	Non-Governmental Organisation
OECD	Organisation for Economic Co-operation and Development
OIC	Organisation of Islamic Cooperation
OUA	Organisation de l'Unité Africaine
PAUWES	Pan African University Institute of Water and Energy Sciences (including Climate Change)
PCA	Principal Components Analysis
EUEI PDF	EU Energy Initiative Partnership Dialogue Facility
USTDA	United States Trade and Development Agency
PIK	Potsdam Institute for Climate Impact Research
RCREEE	Regional Centre for Renewable Energy and Energy Efficiency
SADC	Southern African Development Community
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Management
SDGs	Sustainable Development Goals
SEI	Stockholm Environment Institute
SIWI	Stockholm International Water Institute
SWOT	Strengths, Weaknesses, Opportunities and Threats
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNISDR	United Nations Office for Disaster Risk Reduction
UNU	United Nations University
VA	Vulnerability Assessment
WAPP	West African Power Pool
WASCAL	West African Science Service Center on Climate Change and Adapted Land Use
WEF	World Economic Forum
WB	World Bank
WCRP	World Climate Research Programme
WPP	Water Partnership Programme

1. Introduction

1.1 About the Pan African University (PAU)

The Pan African University (PAU) is a flagship project of the African Union for the creation of African excellence in education and science. Initiated in 2008 by the Heads of State and Government of the African Union, PAU is a premier continental university network whose mission is to provide quality postgraduate education geared towards the achievement of a prosperous, integrated and peaceful Africa. The PAU is part of a continental initiative to revitalise higher education and research in Africa. It is aiming to exemplify excellence, enhance the attractiveness and global competitiveness of African higher education and research and establish African universities at the core of Africa's development. Listed below are the five thematic institutes within PAU which will establish Masters and PhD programmes and engage in collaborative and development-oriented research programmes.

1. Pan African University Institute for Basic Sciences, Technology and Innovation (PAUSTI) at Jomo Kenyatta University of Agriculture and Technology (JKUAT), Juja, Kenya.

2. Pan African University Institute for Life and Earth Sciences including Health and Agriculture (PAULESI) at the University of Ibadan (UI), Ibadan, Nigeria.

3. Pan African University Institute for Governance, Humanities and Social Sciences (PAUGHSS) at the University of Yaounde II, Soa, Cameroon.

4. Pan African University Institute of Water and Energy Sciences (including Climate Change) (PAUWES) at the University of Tlemcen, Tlemcen, Algeria.

5. Pan African University Institute of Space Sciences, Southern Africa, host country and host university still to be determined.

Picture 2: PAUWES Graduation 2017.
Source: Apo group

Picture 1: PAUWES Graduation 2017.
Source: Apo group

1.2 About the Pan African University Institute of Water and Energy Sciences (including Climate Change) (PAUWES)

The Pan African University Institute of Water and Energy Sciences (including Climate Change) (PAUWES) is one of the five hubs of the Pan African University (PAU) and is hosted at the University of Tlemcen in Algeria. PAUWES holds a unique position in understanding the Pan-African dimension of scientific problems and is especially suited to find solutions to the challenges faced in different African countries with regards to water, energy and climate change. Consequently, PAUWES is developing strategies for tapping into the advantage of its Pan-African perspective without losing focus of specific national and regional problems. This is particularly important at the interface between research and education as Master students are capable of finding innovative solutions to challenges in their home countries and local communities.

Germany supports the establishment of the PAU hub in Tlemcen, Algeria[1] as the *"Key Thematic Partner"* of the Pan African University Institute of Water and Energy Sciences (PAUWES). The support is based on a trilateral agreement between the African Union Commission (AUC), the Algerian Government and the Federal Republic of Germany. The German Federal Ministry of Education and Research (BMBF) is in particular supporting PAUWES in developing the research agenda for the institute.

1.3 The Research Agenda in the Context of African Union Strategies

Research is an important element in accelerating concrete actions to realise the African Union vision within its shared values. The African Union (AU) deems that research and innovation are key tools for leveraging its human capital in order to further benefit from the region's resources. Additionally, the vision for the region is to expand and strengthen access to post-graduate education, to ensure world-class infrastructure for learning and research, and to support scientific reforms that underpin the transformation of the continent[2]. The African Union's Agenda 2063 aims to create better synergies, collaboration and is expected to enhance impacts on the ground.

With regards to Water, the African Union Agenda 2063 aims to *"have equitable, sustainable use and management of water resources for socio-economic development, regional cooperation and the environment"* (African Union Commission 2016). Concomitantly, PAUWES has an opportunity to inform and support regional agencies such as the Intergovernmental Agency for Water and Sanitation for Africa (WSA) in achieving their goals for research and training whilst advising the Member States to promote appropriate technologies, participatory, operational and financial strategies in water access, hygiene and sanitation. Country specific vision documents identify water as an extremely vital component of development in developing countries.

In observance of the energy theme, the Call for Action of the Agenda 2063 with regard to energy refers to:

"harnessing all African energy resources to ensure modern, efficient, reliable, cost effective, renewable and environmentally friendly energy to all African households, businesses, industries and institutions, through building the national and regional energy pools and grids" (African Union Commission 2016).

The African Union has also identified low technical skills and capacity in energy as a barrier to modern and sustainable energy access in Africa. PAUWES therefore comes in to reduce this gap with scientific knowledge through research. The AU stresses the need to adopt Africa-led efforts that are able to accelerate and scale up the productivity of the continent's huge renewable energy potential by building integrated solutions to the challenge of widening access to clean energy services for improved human wellbeing. PAUWES plays a critical role in informing this process with updated data and technical expertise.

Reflective of the climate change theme, this research agenda complements Africa's priority to implement programmes geared towards mitigating the impact of climate change, alleviating poverty and attaining the Sustainable Development Goals, with emphasis on the most vulnerable communities in Africa. Aspiration 1, part 16 of the Agenda 2063 requires that:

"Africa shall address the global challenge of climate change by prioritizing adaptation in all our actions, drawing upon skills of diverse disciplines and with adequate support (affordable technology development and transfer, capacity building, financial and technical resources) to ensure implementation of actions for the survival of the most vulnerable populations, including islands states, and for sustainable development and shared prosperity." (African Union Commission2016).

Conjointly, this is in line with NEPAD's strategic focus for environment and climate to effectively address the environmental challenges facing the continent (NEPAD 2003). The African Common Position on Climate Change further emphasises sourcing, funding and technology to mitigate climate change, develop renewable energy resources and chart a course to a sustainable future while adapting to the impact of erratic weather patterns (African Union 2014). In this light, PAUWES can align its research to the goals of the African Union to complement the region's areas of focus.

The African Union Science, Technology and Innovation Strategy for Africa 2024 (STISA-2024) places science, technology and innovation at the epicentre of Africa's socio-economic development and growth. Research, particularly applied research, can be considered as a tool and an enabler for achieving continental socio-economic development goals in order to accelerate Africa's transition to an innovation-led, knowledge-based economy.

The recommendations of the research agenda are in line with efforts of the African Union to engage researchers within the region, bring together strategic partners, as well as public and private actors to carry out ground-breaking research while accruing fundamental data on water, energy and climate change, inform policy actors, support innovation and the implementation of projects.

Analogous to PAUWES goals, education, research, science, technology and innovation form the top priority of the AU strategic plan as established in the eight priority areas of the strategic plan namely *"Human capacity development focusing on health, education, science, research, technology and innovation"* (African Union Commission 2013). More specifically, the core agenda of PAUWES is to enhance development of programmes related to water, energy, climate change and cross-cutting issues within these areas of focus.

The development of the research agenda builds on the following strategic documents of the African Union and other Pan-African and international institutions. These are in particular

- African Union Agenda 2063 (African Union Commission 2016).

[1] http://pauwes.univ-tlemcen.dz/
[2] Agenda 2063 – http://archive.au.int/assets/images/agenda2063.pdf

- AU Science, Technology & Innovation Strategy for Africa 2024 (STISA 2014).
- Africa Water Vision 2025 (UNECA 2025).
- African Strategy on Climate Change (African Union 2014).
- United Nations Sustainable Development Goals (UN-SDGs) of 2030, UNECA (UNECA 2015).
- AU/NEPAD African Action Plan 2010–2015 (NEPAD 2011).
- The Grand Challenge of Water Security in Africa (NASAC 2014).
- African Development Bank – Policy for Integrated Water Resources Management (AfDB 2000).
- Continental Education Strategy for Africa 2016-2025 (CESA 2016-2025).

1.4 Vision and Focus of Research Activities at PAUWES

The mission of PAU and PAUWES is to serve Africa. It is clear that on the spectrum between pure science and application, research at PAUWES commits to having a strong application-oriented focus. PAUWES should define its role of being able to do qualitative and quantitative research which is not only demand-driven but also innovative and creative at the same time. A key role of PAUWES is seen in providing science-based advice to policy makers at a national, regional and Pan-African level. In addition to PAUWES providing scientific knowledge for existing strategies, it is also recommended that it positions itself as a think-tank and leader in shaping future strategies. Training scientists to answer societal questions and to communicate with other spheres should be an integral part in the education of students and scientists. In the current system of career advancement in academia, there are no academic rewards for scientists providing excellent advice to policy stakeholders. PAUWES could help in redefining the concept of academic excellence in Africa, at a time when the conventional concept of excellence in academia (publications, citations, etc.) is highly contested in the discourse of the global science community.

- PAUWES should focus on practice-oriented thematic research as well as research dealing with socio-economical, nexus and interdisciplinary issues in the field of water, energy and climate change.
- PAUWES should develop a framework incorporating innovative and creative mechanisms that link theory and practice to attract visiting scholars from around the globe.
- PAUWES should be positioned in such a way that it becomes the preferred partner of international and regional networks/institutions/funding organisations.
- PAUWES should establish platforms for research/stakeholder dialogues.
- PAUWES should develop new and strengthen already existing strategic networks and collaborations on the continent and beyond. This is of paramount importance for the future of PAUWES and PAU in general.
- PAUWES can capitalise on the youth dividend on the continent and foster research leading to entrepreneurship or creation of start-ups to generate employability and income in African countries.

In order for PAUWES to fulfil the mission of a network university, an adequate framework and instruments need to be developed to ensure that PAUWES graduates have the opportunity to live up to their full potential, to serve their local communities, home countries, the African region, and at the same time harness the potential of the African diaspora for the development of PAU respectively PAUWES. In the same breath, a strategic mission of PAUWES is seen in engaging in South-South co-operation and fostering intra-African mobility.

Picture 3: Africa-EU Symposium on Renewable Energy Research and Innovation 2016
Source: PAUWES

1.5 The Research Agenda Development Process

The research agenda development process is a corner stone of the support of the German Federal Ministry of Education and Research to the establishment of research at PAUWES. The aim of the research agenda development process was to:

- Identify relevant research areas and topics in the field of water, energy and climate change including their prioritisation for Africa.
- Identify needs regarding necessary infrastructural equipment as well as scientific and aso research management capacities.
- Identify relevant stakeholders in science and research, government and research policy, economy and industry, and non-governmental organisations (NGOs).
- Identify potential instruments and tools for implementation.
- Create a scenario for the integration of PAUWES into international and global networks.
- Contribute to the optimum integration of education and research at PAUWES.

Important milestones of this research agenda process were:

- The kick-off workshop held from 19th to 21st October 2015 in Tlemcen, Algeria.
- The consolidation workshop from 10th to 12th May 2016 in Bonn, Germany.
- The presentation and validation conference on 27th October 2017 in Addis Ababa, Ethiopia.

The development of recommendations for the PAUWES research agenda was organised in three working groups with more than 50 scientific experts from Africa and Germany in the areas of water, energy, and climate change. Each working group was co-chaired by two experts[3] from an African country and Germany. The role of the working groups was to:

- Initiate and follow-up the discussions on the scientific and political development of the scientific agenda.
- Propose and develop tools suitable for a sustainable implementation of the research agenda priorities.
- Provide scientific advice to PAUWES on the linkage between research, training and technical implementation requirements in order to guarantee a smoothly running interface between all components relevant for a university.
- Afford advice to the political partners regarding the legal framework necessary to implement PAUWES as one hub in a network of PAU hubs and allow for its interaction.

During the kick-off workshop, the experts first developed ideas on how PAUWES could build its research profile towards an African Centre of Excellence in education and research based on an assessment of scientific strengths and weaknesses, gaps and needs in the areas of water, energy and climate change in Africa. In conjunction, they discussed relevant topics and sub-topics in the respective scientific fields including their relevance for the implementation of Pan-African, regional and national policy strategies of the African Union in water, energy and climate change. They also reflected on the mission of PAUWES in research for the African continent.

After the workshop, the experts of the three working groups developed in a virtual workflow fact sheets of possible research priorities for PAUWES which were the basis for the experts' discussion of the consolidation workshop. The subsequent consolidation workshop in 2016 was geared towards the formulation of recommendations on the future research priorities of PAUWES. The workshop took into account the necessary coherence between these research priorities and the Pan-African regional and national policies in the respective areas. Recommendations were made with respect to the specific needs for infrastructural equipment, scientific and research management capacities, the overall set-up of research departments at PAUWES (and PAU) and the requirements for the profile of future PAUWES researchers. A pre-final draft of the *"Recommendations for a PAUWES Research Agenda"* was then prepared by the co-chairs of the working groups in close cooperation with the PAUWES director and supported by the PAUWES research coordinator and the DLR Project Management Agency. At a conference in Addis Ababa on 27th October 2017, the *"Recommendations"* were presented for discussion and validation to PAU and AUC representatives and other stakeholders from political, scientific and societal spheres.

[3] Appendix 1 presents the list of members who have contributed to the respective working groups of the research agenda.

2 Key Research Priorities for PAUWES

2.1 Water

The research priorities should be driven by the overarching theme of water security, incorporating both qualitative and quantitative issues for human and ecosystem demands. The wide range of issues and questions has been addressed in several policy documents including:

1. The African Union Commission Strategic Plan 2014–2017.
2. Africa Together through Shared Values.
3. Science, Technology and Innovation Strategy for Africa 2024 (STISA-2024).
4. AU Science, Technology & Innovation Strategy for Africa 2024 (AMCOST V).
5. African Development Bank – Policy for Integrated Water Resources Management.
6. African Development Bank – The future of water in African cities: Why waste water? Integrated Urban Water Management (Echart et al. 2012).

Furthermore, a useful account of the present research landscape is provided by the Joint Synthesis Report *"Water and Renewable Energy Stakeholder Analysis and Research Mapping Water and Renewable Energies in Africa"* (Maxime Souvignet et al. 2015)

The topics to be addressed on water are very diverse. It is therefore suggested that the topics are grouped in the following priority areas:

1. Water and food security: long-term food production and sustainable livelihoods.
2. Water management:
   a) Basin water management
   b) Urban water management
3. Water and environment: water-related hazards and health.
4. Water economy and governance.

Governance, socio-economic and cultural aspects should be considered as cross-cutting topics in all four priority areas. For all research priorities, core expertise in PAUWES should be developed with all stakeholders in the entire water value chains, from policy makers and producers to end users, considering the transdisciplinary nature of water-related issues.

Picture 4: Water Security in Africa.
Source: UNU-EHS/Yvonne Walz

2.1.1 Water and Food Security

a. Relevance for the African continent

Water and food security are impacted by changing climatic conditions as well as by increasing demands. Population growth and changing nutritional behaviour lead to an urgent need for increasing food production which mainly has to be achieved by raising productivity given the limited water resources. Irrigated agriculture is becoming increasingly important as an adaptation option; yet currently, low-use efficiency/water productivity needs improvement. Under these circumstances, water information systems and forecasts play a crucial role to avoid or mitigate loss in the food security sector during and prior to times of disasters such as droughts and floods.

b. State of the art and challenges

There is a wide range of expertise in agricultural sciences, irrigation and water management, but scattered in domains of climatic, bio-physical, socio-economic and institutional settings which limits wide-spread utilisation. Moreover, there is also limited exchange of knowledge between science, water administrations, commercial sectors and water end-users. A targeted cooperation between these sectors would unfold a huge potential for utilisation of findings (for example: information on rainfall forecasts and shifts in rainy seasons), particularly by the development of databases on meteorological and hydrological data in combination with agricultural responses in terms of yield and socio-economic drivers.

c. Recommendation for future research fields for PAUWES:

Based on the above analysis, future PAUWES research programmes can be grouped around the following research questions:

- How can the efficiency and productivity of irrigation be increased and impact on the environment be reduced, particularly under changing and variable environments?
- Water management lies at the heart of the sustainable use of water and its role in ecosystems services.
- How can remote sensing tools support water and food security?
- To what extent can imports of virtual water through food imports be utilised to conserve water domestically and achieve water and food security goals?
- Which valuation tools can be developed and utilised to inform the trade-offs among multiple uses of water?

2.1.2 Water Management

Water management lies at the heart of its sustainable use and its role in ecosystems services. Below, the area of water management is treated separately in view of basins and urban areas, but it should be kept in mind that there are strongly interdependent research programmes; if organised separately, it is advisable that they should have means for close collaboration.

Basin Water Management

a. Relevance for the African continent

Basin water management requires information about the entire water cycle including evapotranspiration, rainfall, storage, discharge, water demand for ecosystems, agriculture, energy and urban development. There is limited expertise in Africa on short, medium and longer-timescale hydrological forecasts, predictions and projections. There are many data gaps as well as lack of monitoring systems and inventory of water resources and water demands in Africa. Hence, the need for monitoring and data processing systems including quality control is huge.

b. State of the art and challenges

National instead of basin-wide perspectives still dominate. Therefore, research programmes should aim to strengthen basin-wide management plans. Data gaps, inadequate and declining data are also a considerable challenge. A limited number of universities, technical colleges, research institutions and regional organisations in Africa are already working on hydrological issues, including hydrological modelling. Moreover, the local capacities are financially limited as well as their expertise and infrastructure. There is need for PAUWES to identify and partner with these institutions and participate in international activities.

c. Recommendation for future research fields for PAUWES:

Based on the above, future research programmes at PAUWES and investigations can be grouped around the following research questions:

- How can basin-wide discharge forecasting systems in ungauged basins be developed and maintained?
- How can an inventory of ground water resources and aquifer characteristics be built up?
- Understanding the role of natural ecosystems (wetlands, rain forest, etc.) for regional water budgets.
- How can the negative impacts of hydropower plants on regional water budgets be limited and how can the positive aspects be utilised (e.g. for regulation purposes)?
- How can basin-wide (international) management legislation be developed and implemented?

Urban Water Management

a. Relevance for the African continent

Africa is the continent with the highest urbanisation rate. The rising population growth in urban areas, particularly in informal settlements, is a huge challenge to technology as well as legislation around urban water management. This has a detrimental effect on the health of the residents. There is little or no planning in the sections of the cities with the greatest need for water and sanitation services, the residents are poor and unable to afford the costs of conventional services, the electrical resources are insufficient for conventional sanitation techniques and there is insufficient water for conventional flush toilets. Consequently, there is an ever increasing need for affordable and environmentally acceptable water supply and sanitation systems. Thus, a holistic approach in the spirit of Integrated Urban Water Management (IUWM) and the Circular Economy is needed.

b. State of the art and challenges

Urban water management in Africa is facing a series of challenges, particularly the inadequate quality control of water treatment, water delivery and inappropriate waste water disposal approaches. Partly, inadequate legislation at the city level is at the root of these deficiencies, but furthermore often

insufficient data contributes to challenges in urban water management. The sanitation system contains all the nutrients ingested by the population and could be processed for recycling and reuse and associated economic activities

c. Recommendation for future research fields for PAUWES

Based on the above, future research programmes at PAUWES can be grouped around the following research questions, always in view of the IUWM framework and resource recovery in the Circular Economy:

- What are the constraints to urban water treatment and delivery, what new approaches are available, and how can they be implemented?
- How can sustainable affordable and acceptable sanitation systems be developed and maintained in fast growing urban areas? What are new approaches in waste water resource recovery and reuse?
- What appropriate legislative frameworks and institutional arrangements are necessary for IUWM and the Circular Economy?

2.1.3 Water and Environment

a. Relevance for the African continent

The water cycle connects rural and urban spaces in an intimate way. Food security for urban spaces is largely guaranteed by rural spaces. Therefore, healthy ecosystems are crucial for water and food security. This intimate interdependence will even grow in Africa in the presence of fast urbanisation, agricultural development, industrialisation, but also environmental changes, including climate change. Water quality issues are a significant threat to surface and ground waters with implications on health, water resources, and ecosystem functioning. Regional monitoring of water is increasingly an important research focus particularly looking at aspects such as algal blooms, land cover/land use dynamics on aquatic ecosystems which can be monitored using earth observation technology.

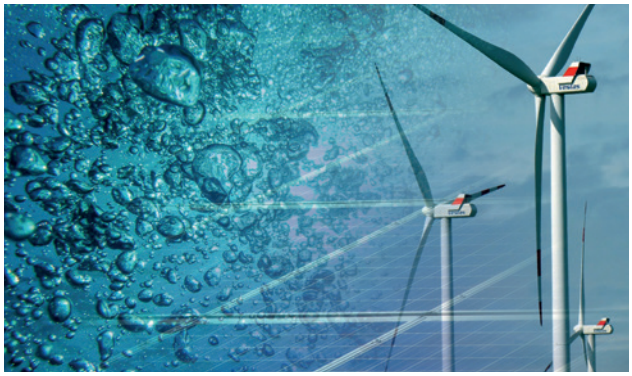
b. State of the art and challenges

There is a lack in knowledge about the regional pollution pattern as well as in the personal and infrastructural capacities to survey water quality. Key pollutants are: nutrients (eutrophication), pesticides, faecal pollution (human health). Moreover, there is significant urban pollution from various sources (leakage, contaminated sites, traffic) as well as from mining (acidity, metals). The need for monitoring systems as well as capacity building is huge. An efficient operation of such systems, as well as theory maintenance, needs a basin-wide cooperation. Hazards of inundation of coastal agricultural lowlands with seawater due to sea level rise as a result of climate change and global warming, also need to be researched.

c. Recommendation for future research fields for PAUWES

Based on the above, future research programmes at PAUWES can be grouped around the following research questions:

- How can monitoring systems (low-cost, where possible) using proxies for specific contamination (e. g. faecal, pesticides) be developed?
- How can inventories of contamination, including regional patterns, be developed and utilised?
- How can the results gained from monitoring systems and inventories be translated into guidelines and legislation?
- How to harness seawater desalination technologies considering seawater as resources



Picture 5: Renewable Energy
Source: Pixabay

2.1.4 Water Economics and Governance

Based on the previous sections, it becomes clear that economic and governance aspects, besides having their ramifications in different domains, are overarching and cross-cutting issues. These issues should be given particular attention in the PAUWES programmes and should not be separated, but be cross-cutting items to be addressed in all of the above research fields. PAUWES may decide to devote specialised long-term staff to economics and governance questions. However, individual projects should address the above questions in the planning phase, where appropriate, and seek support if the questions are not dealt with as a core activity in the project.

Besides the research questions addressed in the previous sections, attention might be directed to basic research areas such as:

- Water prizing: particularly with respect to situations where there is multiple use of water, in terms of prioritisation.
- Water efficiency: effective allocation and efficient management of water resources.

- Supply and demand analysis.
- Economics of institutions (property rights, water markets, market failure).
- Further empirical studies and evaluation of economic models and concepts with regard to water needed.
- Blue economy and the link to climate change particularly in coastal region represent a future interesting area for research.

2.2 Energy

Sustainable energy development is a key challenge for the African continent and globally. A key task in ensuring sustainable development of the region lies in an adequate development and management in the supply system of resources like water, energy and food. The vast majority of the rural population in developing countries has to depend on the traditional fuels to fulfil their daily energy needs. Expanding access to modern energy services for the poor is essential for achieving the Sustainable Development Goals (SDG7, SDG5 and SDG3) set by the United Nations. Renewable energy (RE) has great potential to address many of these challenges as well as to contribute to socio-economic development and poverty reduction. Energy use has a strong inter-relationship with agriculture (food security), water supply and climate change.

During the workshops for setting the PAUWES research agenda, a wide range of topics were discussed. Among many relevant topics, the following priorities were outlined as suggested PAUWES research priorities:

- Identifying and assessing the energy resources potential.
- Selecting, developing and implementing the applied technologies for conversion, transport, distribution and use of these resources to useful energy.
- Design and sizing of conversion systems (stand-alone or grid connected).
- Analysis of economic feasibility of such energy conversion and supply systems as well as policy schemes to promote renewables.
- Evaluation of the societal impacts of modern energy infrastructure reform.
- Study of sectorial interaction of modern energy use with other disciplines at PAUWES (i.e. in nexus context with water and climate change).
- Setting up standards and norms.

In the following, aggregated priority themes are described under four sub-sections.

Picture 6: Water and Environment
Source: Pixabay

2.2.1 Energy Resources Assessment

a. Relevance for the African continent

Reliable energy resource estimates are the foundation of energy planning – this includes conventional energy sources or fossil fuels as well as renewable sources. The assessment of current and future production of fossil fuels has been undertaken for many years on different scales by using elaborate methodologies. However, for all the African countries, comprehensive approaches for estimating national energy production potentials from renewable energy sources are still few and are often based on methods that lack rigor. Therefore, new measurements using advanced techniques are needed. No complete and rigorous account of renewable energy potentials of African countries is readily available (despite a number of country assessments and a large amount of available raw data).

b. State of the art and challenges

A limited number of universities, research institutions, regional organisations in Africa, and international organisations are already working on energy resources assessment. The main challenge in carrying out research in the area of energy resources potential assessment is the data gap. While the currently available data is inadequate, formats of data are often not very useful and there is untapped historical data that needs to be rescued (among others, through digitisation). In order to be statistically meaningful, the data should cover many years and many cases; this is not the case. In order to develop a renewable energy database for Africa, ground measurements are needed. There is hope that the data, together with the corresponding national energy models, will give governments and decision makers a basis to work on elaborating energy roadmaps for the future.

c. Recommendation for future research fields for PAUWES

PAUWES could set the following broad research questions for the moment and later make a specific list out of them based on

the available long-term staff's research field as well as societal needs for research on this theme.

- How to assess the geographical, technical and economic potential of renewable energy resources (solar, wind, geothermal, hydro and biomass) in each African country and within specific regions of the countries?
- How to ensure data quality (test stations, laboratories accreditation)?
- How to develop and analyse the energy resources and climate dataset and how to establish the linkages between climate change and the renewable energy potential?

2.2.2 Technological Development

a. Relevance for the African continent

Energy and its mastery are essential for any country, region or continent. For Africa, it is even more important because production facilities are few and do not cover all the needs. Continuous access to a vital energy source is not guaranteed. The industrial development and the services are largely based on the availability of electrical energy in terms of sufficiency and reliability. Electrical energy transport and distribution also differ from region to region, particularly in low-income countries. Grid extension might not always be the immediate solution. Isolated and decentralised power supplies also require specific technology and energy policy. A holistic approach in research and implementation is necessary to optimise the access to clean and reliable energy in all sectors of the society.

b. State of the art and challenges

At African universities and engineering schools, different academic programmes are dealing with renewable energy. However, most of them are doing academic research using simulations with a lack of experiments. There is a need for testing the developed concepts and experimental benches. However, research will highly depend on the field of interest and expertise of researchers recruited by PAUWES. Those experts can help, at least on a temporary basis, to develop the research infrastructure.

There are different challenges of carrying out research in the area of technological development. Besides the existing focus on simulations, it is important to set up experimental test benches, pilot plants as well as train technicians to operate them. Absence of industry cooperation with academics is another bottleneck. There is no accredited laboratory. There is lack of public/private investment in applied research projects. Societal actors, including policy makers, do not necessarily use research results in their programmes.

c. Recommendation for future research fields for PAUWES

- How to implement applied research addressing continental concerns and therefore inevitably contributing to the society through the access to clean and reliable energy?
- How to optimise the sectorial coupling of different energy generation and consumption sectors in a society (city or region)?
- How to increase the efficiency of different energy generation and consumption systems?
- How to design and implement grid interconnections and the decentralised energy supply systems (including rural electrification) for rural areas of the continent?
- How to choose the environmentally best energy generation mix by applying holistic analysis methods (e.g. environmental life cycle assessment)?
- How to choose the technically best technology mix (individual generation technologies, storage systems, transmission and distribution systems) for energy supply in a country or regions within the country?
- How to integrate ICT in energy systems management and control?
- How to promote the technological innovation and knowledge transfer in applied research in energy sector?

2.2.3 Energy Economics and Energy Policy

a. Relevance for the African continent

Africa is the least electrified continent. The reasons are partly rooted in policy and economics of electrification. Most poor communities in Africa rely on inefficient forms of energy that in many cases are harmful to human health and environmentally damaging. These forms of energy are mainly derived from traditional biomass exploitation (firewood and charcoal) leading to rapid deforestation. The replacement of these forms of energy with more sustainable forms is essential for sustainable development of these communities. To achieve this, coherent energy policies and cost reduction of modern forms of energy is required.

b. State of the art and challenges

There are several education programmes and some research laboratories on renewable energy across the African continent. Many tend to focus on technical aspects of renewable energy and its use. There are not many research programmes that

have a strong focus on energy economics and policy aspects of renewable energy. The issues of project financing and challenges associated with this are not well dealt with. There is a clear need to conduct research to explore alternative project development and economic models to accelerate electrification. Continuing with the status quo will not deliver the desired level of electrification to achieve significant and impactful change and will still leave many people on the continent without access to modern forms of energy in their homes.

There are some challenges in carrying out research in this thematic area. Lack of skills and experience in integrated development on the one hand and lack of well-organised and well-resourced research support systems in most African countries on the other hand are some of the main barriers. Apparent lack of belief amongst policy makers that research can indeed offer solutions to some intractable developmental challenges is another problem, sometimes also associated with the research culture.

c. Recommendation for future research fields for PAUWES

- How can the costs of different electricity generation technologies be reduced (solar photovoltaics and concentrated solar power, min/micro hydropower, bio energy, energy storage, etc.)?
- What is the impact of standards on costs of electrification and how can standards be relaxed to reduce costs?
- How can energy system analysis (technical, economic and environmental pillars) be performed and how can the question of sustainability be enshrined within a holistic energy delivery system?
- What policies would best support promotion of renewable energy and integrated development as a whole?
- How can policy tools and mechanisms for the implementation of energy projects and programmes be developed?
- How to properly carry out the energy need assessment today and in future (beyond electricity, also heating, cooling, cooking, transportation, etc.)?

2.2.4 Energy Stakeholders and Society

a. Relevance for the African continent

Energy influences every aspect of society. For stable and sustainable livelihoods, energy supply must be secure, accessible, affordable and environmentally sustainable. Numerous challenges such as limited resources, increased demand, skills shortages, economic hardships and climate-related constraints abound in Africa. The role of science and research is to offer solutions and interventions that will improve the quality of life. Public attitudes, perceptions, beliefs and knowledge have a profound effect on the success (or lack) of any interventions. Moreover, societal choices influence important aspects such as increase in demand that in turn affects security of supply as well as ease of access.

b. State of the art and challenges

Traditional top-down planning models generally do not involve the stakeholders in decision-making, projects implementation and use. Engagement of key stakeholders helps to identify and to understand the vital issues that need to be addressed during the successful implementation of energy projects. Identification of all relevant stakeholders is essential. Factors such as proximity, economics, social, gender or environmental issues and values often determine who may have a stake. Social factors and social impacts, including gender, culture, religion and race issues, among others, should be a central part of all development planning and action. This, however, bears its own challenges. It is therefore necessary to develop tools to tackle these challenges.

c. Recommendation for future research fields for PAUWES

- How to choose the appropriate participatory approach in the energy project planning and implementation phase?
- How to carry out the sustainability assessment of energy systems (e.g. indicator-based methods); including social life cycle assessment of energy systems?
- How can energy development contribute in the context of integrated development with provision of essential services including food, water, shelter, health care, education and sanitation?
- How to evaluate the externalities of energy supply systems in a society?
- How to design tools and mechanisms to use to involve stakeholders and the public?
- How to carry out socio-economic impact analysis of the energy projects?
- How to raise public awareness on clean energy use?

2.2.5 Energy, Water, Food Security and Climate Nexus

a. Relevance for the African continent

Many aspects show the importance of nexus research on the African continent. It is necessary to guarantee the

electrification of the continent, to ensure food security, and to address the scarcity of water. The heavy dependence of conventional energy generation on water and the similar dependence of water treatment and distribution on energy is a vital issue that requires coordinated planning. Limited access to clean and sufficient water in many regions both for drinking and irrigation needs scientific support in proper designing, implementing and operating such water, energy and irrigation schemes. Transition from the conventional polluting energy sources towards decentralised renewable water treatment and irrigation schemes can help to combat the adverse impacts of climate change on African countries.

b. State of the art and challenges

Despite the fact that nexus-based research is essential for achieving the sustainable energy supply goals, currently very few institutions are already working on nexus research in Africa. One of the main challenges is the lack of well-developed appropriate tools and instruments for conducting nexus research. Different stakeholders apply their own approach of nexus research and this sometimes causes chaos in coming up with a standard common approach that could be used. Additionally, there is a lack of networks between African universities and a lack of research platforms for sharing data.

c. Recommendation for future research fields for PAUWES

- How to develop a common approach (e.g. standard procedure) for energy-water-food security-climate change nexus analysis?
- How to interlink the dynamic relationships between energy, water, food security, agriculture, and climate change in modelling?
- How to design appropriate renewable energy-based irrigation schemes for agriculture?
- How to apply the results from nexus research in a selected region of a country in practice?
- How to develop the database appropriate for nexus research (data type, data format, etc.)?

2.3 Climate Change

Climate change and climate variability (CC & CV) are challenging Africa in particular due to a mix of reasons: high vulnerability, already existing severe problems in water and food security, uncertainty of CC predictions, particularly in terms of changes in rainfall pattern, shortcomings in governance capacities and limited economic resources. These reasons interact in a potentiating way leading to far reaching effects on the prevailing agricultural production systems, i.e. rain fed agriculture, the environment (ecosystem services) and in turn on the socio-economy, hence livelihoods and health of millions of people. In order to provide support to cope with these challenges, research-based knowledge on CC in the specific context of Africa is urgently needed. PAUWES' mandate and its embeddedness in an Africa-wide science as well as capacity building network of PAU create the need and at the same time offer the potential to effectively contribute to provide this knowledge.

A prerequisite for mobilising this potential consists in a research strategy considering the mix of the above mentioned reasons, and the interfaces to water-energy management. Sustainable development diplomacy and capacity building programs to strenghten skills for discussion and negotiation for climate policy represent also interesting area for PAUWES activities. Based on an assessment of their relevance for Africa and the state of the art, suggestions on research fields for PAUWES will be concluded for the thematic research fields of:

- Climate Modelling
- Vulnerability Assessment
- Adaptation, Mitigation
- Risk Assessment

Picture 7: Climate Change
Source: Pixabay

2.3.1 Climate Impact Modelling, Downscaling and Prediction of Climate Change

a. Relevance for the African continent

Design of infrastructure and its operational strategies in all major sectors (agriculture, water management, energy, traffic, health etc) are based on climate information using the assumption of stationarity in long-term series of climate variables. This assumption is no longer valid due to CC & CV.

Advanced information on future CC in Africa is an urgent need to support planning, especially for climate resilience and adaptation, in order to better conceive and adapt sustainable poverty alleviation strategies.

Key building blocks for adaptation are reliable projections of the climate over the coming decades, and across regional, national, and smaller scales. However, current global climate models have a modest ability to capture the processes driving the African climate. Slow progress in improving their performance over the past decades is limiting confidence in the usefulness of climate projections for supporting decision makers in Africa.

A limitation of Global Climate Models (GCMs) is the coarse horizontal resolution (150–300 km grids). Practical planning at a local scale such as water resources or flood management requires information with a resolution going by far beyond the capabilities of currently available GCMs. Regional Climate Models (RCMs) produce high-resolution climate variables in a range of 25–50 km while considering physical processes using high-resolution input (topography, land use).

b. State of the art and challenges

Dynamic downscaling of GCM scenarios to a regional scale using RCM requires high computational power, detailed input data, is very time-consuming and hence expensive. Lack of infrastructure is a major challenge for Africa.

Data gaps in Africa, restricted usage of data from many National Meteorological and Hydrological Services (NMHSs) and different formats of acquired data hinder the application of RCMs and CC analyses.

Only few universities, research institutions and regional organisations (e.g. ICPAC, ACMAD, SADC-CSC, AGRHYMET, WASCAL and SASSCAL) in Africa are already working on climate modelling, downscaling, climate predictions and information provision. Identifying these institutions facilitates collaboration, networking and enables to detect niches for PAUWES' own activities. The Africa Climate Policy Centre (ACPC) is a knowledge hub from which climate change information in Africa can be drawn from.

c. Recommendation for future research fields for PAUWES

- Data gaps can be closed through satellite remote sensing products (rainfall: GPM and TRMM, temperature: MODIS and MERRA, soil moisture: SMAP, and evapotranspiration: MODIS) in combination with the gridded re-analysis data. Strengthen PAUWES' connections with major research institutions and data providing agencies (NMHSs, WASCAL, SASSCAL, ICPAC, ACMAD, SADC-CSC, AGRHYMET, ACPC, etc.) and collaboration with global climate centres such as ECMWF, UK Met office etc. to develop regional downscaled climate models.
- Long-term development of high-tech laboratories with efficient computers for regional climate modelling including research and practical training of Master students.
- Linkages between CC, CV and land use dynamics in terms of a combined effect on water and food security and vice versa, mobilising synergisms in designing strategies to cope with impacts from climate and land use changes on hydrological cycle and food chains.
- Advanced Masters and PhD programmes on CC science as a contribution to develop highly trained climate scientists from Africa to foster high-quality research.

2.3.2 Vulnerability Assessment

a. Relevance for the African continent

According to the IPCC, Africa is one of the most vulnerable continents to CC & CV. In contrast, major parts of Africa are clearly under-represented in CC studies. This dilemma is further aggravated by the interaction of multiple factors (poverty, health status, rapid urbanisation) resulting in a low adaptive capacity. The trend in vulnerability and exposure due to CC (and human factors, e.g. urbanisation) has been increasing in Africa and hence calls for an urgent need for vulnerability assessments.

CC vulnerability assessments have a high potential to support stakeholders in reviewing, challenging, verifying and eventually refining existing assumptions about CC impacts at different scales. Yet, this tool is less applied and underutilised in Africa. Very few institutions in Africa are engaged in vulnerability assessment studies (e.g. University of Nairobi, Kenyatta University, and Makerere University; and research centres like ICPAC, ACMAD, AGRHYMET, CCAFS, USAID-ARCC, etc.).

b. State of the art and challenges

Clear definitions, allocable frameworks, concepts and methodologies of vulnerability assessment appropriate for Africa are missing and the importance of vulnerability assessment studies has not been sufficiently realised (especially regarding the ill impacts of CC on vulnerable communities). Integration of multi-/trans-disciplinary approaches considering the social-economical-environmental aspects into vulnerability assessment is insufficient.

c. Recommendation for future research fields for PAUWES

- Studies pertaining to spatial identification of hotspot areas vulnerable and exposed to CC.
- Few institutions/universities in Africa and international organisations working in Africa are engaged in vulnerability

assessment studies. This provides an opportunity for PAUWES to collaborate and contribute towards filling this lacuna in knowledge (i.e. getting the support on developing the Master and PhD curricula in PAUWES).

- Highly trained human resources in vulnerability assessments should be employed.
- Establishing state-of-the-art climate laboratories and enhancing training of human resources to conduct vulnerability mapping and modelling at PAUWES and forming multi-disciplinary and trans-disciplinary research groups at PAUWES.

2.3.3 Adaptation Research

a. Relevance for the African continent

To manage the inevitable impacts of CC that cannot be reduced through mitigation in short- and mid-term, adaptation is the current priority action in Africa. The IPCC emphasises that adaptation and development approaches can go hand in hand, and can in fact reinforce each other. Moreover, the predicted impacts of CC & CV in Africa underline food and water insecurity and negative impacts on ecosystems services (provision of clean water, soil health, carbon sequestration, biodiversity) that will certainly negatively affect livelihoods. Yet, climate predictions for Africa, compared to other regions worldwide, are highly uncertain, especially when it comes to rainfall predictions, which hinders subsequent decision-making at local, national or regional level. This creates an urgent need for enhancing research in adaptation to CC & CV which will provide policy and decision makers with sound information towards sustainable development.

b. State of the art and challenges

Available modelling tools are rather reliable in predicting temperature changes all over Africa, but are limited in terms of rainfall projections. Knowledge on interlinkages of climate and land use features is insufficient. Available models enable virtual experimentation in order to build scenarios on land and water management, but calibration is strongly limited by non-availability of datasets with appropriate quality. Reliable knowledge of uncertainties of CC scenarios and insufficient frameworks for impact assessment based on models at different scales are limiting the development of advanced adaptation strategies and policies (especially at the local level).

Despite the high practical need, testing of key crops and management options for adaptation over a range of agro-ecological zones under CC & CV conditions is underdeveloped. Unfolding existing knowledge on adaptation (gained empirically at the local level) has a high potential, but requires up-/outscaling and linking to conceptual approaches.

c. Recommendation for future research fields for PAUWES

- Impact assessment studies on CC & CV and land-use changes on the hydrological cycle as the basis for development of adaptation scenarios.
- Quantifying and reducing the uncertainties in CC scenarios, performing impact assessment from regional to local scales and providing service for large-scale decision-making also with local communities.
- Improving understanding of key processes, feedback and drivers relevant for CC in Africa (utilising the competitive advantage of PAUWES/PAU due to networks and links to policy institutions).
- Research on *"Policies and Institutions"* is needed for facilitating the implementation of adaptation strategies (creating an *"enabling environment"*); its internal structure (engineering and policy lines in water and energy) and the link to other PAU hubs put PAUWES in an advantageous position to refine this (inter-/transdisciplinary) research.
- Strengthen internal linkages with Masters and PhD programmes within PAUWES and intensifying external networking with national and international organisations on adaptation research.

2.3.4 Mitigation Research

a. Relevance for the African continent

Conceiving and implementing adaptation strategies are the most promising steps in order to achieve a considerable, effective and prompt effect towards coping with climate change in Africa. Consequently, adaptation strategies, and in turn research on refining these strategies, and especially on how to unfold available knowledge, currently deserve the highest priority. Yet, in the mid-term and long-term, and in order to sustain improved coping capacity to be achieved in the short-term by adaptation strategies, mitigation measures tackling directly the causes of climate change are becoming increasingly important. Furthermore, given the tendency towards expanding industry and intensifying agriculture in the coming decades in Africa, the potential impact of mitigation measures is rising and therefore research is needed now on how to mobilise that potential and how to link short-term adaptation and mid to long-term mitigation into the long-term effective overall coping strategies for the benefit of the environment, agriculture, industrial growth and livelihoods of coming generations.

b. State of the art and challenges

African countries face the key challenge that even with an increase in domestic revenue mobilisation, their available

resources will remain insufficient to tackle both climate mitigation and adaptation. Besides conceiving appropriate concepts combining adaptation and mitigation measures (considering the time-scale of implementation and achievable effects), international cooperation is crucially needed to help fill Africa's climate funding gap.

Africa's participation to date in the Clean Development Mechanism (CDM) and carbon trading arrangements under the Kyoto Protocol is rather small and needs to be increased in order to enhance financing for developing low-carbon and climate-resilient technologies utilising indigenous knowledge in Africa.

Africa's bargaining power in international negotiations is strongly limited and does by far not reflect the severity of impacts on a huge number of people in Africa. Hence, it is of utmost importance for the continent to strengthen options towards a participation in leadership roles in the governance of the *"global commons"*.

c. Recommendation for future research fields for PAUWES

- Deriving options to interlink adaptation and mitigation strategies in order to optimise short up to long-term effect on coping capacities based on an improved understanding of the impact and interplay of these strategies.
- As mitigation measures can especially achieve a high effect in the energy sector, PAUWES potentially is in an advantageous position by utilising the nexus approach in combination with its competitive structure dealing with water and energy themes and being embedded in PAU's continental network.
- As a consequence, research activities towards mitigation should be closely linked with research aiming at the introduction of renewable energy options and also utilising the network within the other PAU-hubs; in addition, enhancing networking with global partners can be used to explore experiences on mitigation gained elsewhere and research activities at PAUWES could focus on how to modify mitigation strategies based on these global experiences for use in the African context.
- PAUWES, in cooperation with other African research institutions like ICPAC, ACMAD, SADC-CSC, AGRHYMET, WASCAL, SASSCAL, ACPC, etc., can initiate research on developing indigenous low-carbon emission technologies for sustainable water and energy management in Africa.
- Advanced Masters and PhD programmes on climate politics and global negotiations should be introduced in PAUWES in order to facilitate strengthening capacities of African actors towards effectively participating in international climate debates.

2.3.5 Risk Assessment

a. Relevance for the African continent

Risks related to climate change arise from climate-related hazards (trends, extremes) and the vulnerability of exposed societies and systems (in terms of livelihoods, infrastructure, ecosystem services and governance). Effective measures to reduce the risks associated with climate change can address all three aspects of risk: hazard, vulnerability and exposure.
Climate change is expected to significantly impact the development of environmental risks. However, the attribution of changes in risk to CC in a specific context is difficult, partly due to insufficient understanding of processes/mechanisms and partly due to missing data. As a consequence, a twofold task is arising: on the one hand, it is important to improve the understanding of the specific impacts of climate change; on the other hand, an advanced understanding of the interplay between impacts and drivers of climate change, land use dynamics and demography based on appropriate data is a prerequisite to cope with the combined impacts and on the other hand pragmatic strategies to counterbalance the combined effect need to be conceived.

Communities in Africa are experiencing increasingly severe risks of extreme weather events, endangering human wellbeing and livelihood. This is enhanced by rather weak institutions and insufficient capacity to manage risks. Besides and in addition to the weather and climate-related factors, socio-economic components of risks are often related to the so-called *"root causes"* such as poverty and conflicts. Therefore, any risk assessment scheme needs to draw on natural as well as social sciences.

b. State of the art and challenges

Available databases are insufficient given the above-mentioned challenges.

Networks are not strong enough. By effectively utilising its structure, PAUWES (and PAU) can become key players to overcome current deficits. Available assessment schemes are not appropriately adapted to local and regional contexts, particularly for the application to nexus approaches and considering different data availability levels in Africa.

c. Recommendation for future research fields for PAUWES

- Risk assessment should be guided by and streamlined into the research strategies in the water and energy domains (see sections: 2.1.and 2.2); PAUWES has competitive advantages towards realising these links or nexus, respectively.
- Application of comprehensive risk assessment methodologies, i.e. integrating natural and social sciences considering

[4] Terms of Reference of the Scientific and Technical Partnership for the implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030

the root causes. Innovative tools (i.e. climate insurance schemes) could be elaborated and adapted to local and regional contexts.

- Developing methodologies to tackle situations with poor data base and to consider nexus contexts (case-by-case-based approach; refined tools and handbooks for risk assessment).
- Risk assessment research may have its home base at one of the PAU institutes, e.g. PAUWES, but should be considered as a cross-cutting activity relevant to the themes of all PAU institutes.
- High-quality research on risk assessment in collaboration with the international research community, particularly represented by the UNISDR Science and Technology Partnership (UNISDR 2015)[4] which hopefully will become a platform for application-oriented international risk research and national and regional stakeholders for risk assessment (i.e. water and energy in case of PAUWES).
- Potential instruments and tools for implementation: African Risk Capacity Programme (African Risk Capacity n.d.)[5]

2.4 Nexus Research

The PAUWES water, energy and climate nexus

Water, energy and climate change issues are interlinked; therefore it is proposed that PAUWES develops multi-disciplinary research projects whilst working directly with communities. Multi-disciplinary and trans-disciplinary approaches in research are currently being emphasised in research agendas. While multi-disciplinary research incorporates research from various disciplines, trans-disciplinary research cuts across and transcends the assigned themes of the research agenda, and interdisciplinary research relates to more than one branch of knowledge. PAUWES can embrace this trend and consider applied research when working with communities. There are opportunities in embedding multi-disciplinary thinking in the PAU community. Addressing the nexus, including aspects which could hinder the nexus between energy, water, climate change and food security in an integrated manner at the Pan-African level, presents a specificity which is hardly represented in the region. This represents a further unique selling point for PAUWES in comparison to other research centres or centres of excellence on the continent.

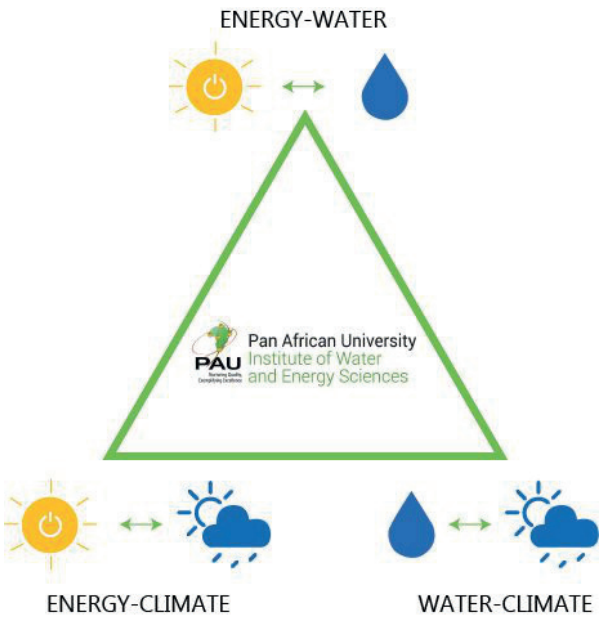
The research agenda recommends carrying out research geared towards the nexus between energy, water, climate change and cross-cutting themes in an inter-, multi- and trans-disciplinary manner, organised in three main pillars as illustrated in the picture 8 below and described in the subsequent subsections.

[5] African Risk Capacity Strategic Framework 2016–2020

2.4.1 Energy – Water Nexus

a. Relevance for the African continent

Although the Energy-Water nexus is one of the most commonly used terms in the nexus discussion, it is still not always used in a well-defined way. In the context of the continent of Africa this is a very important issue for researchers and academia; firstly to analyse the interdependencies and interlinks, and secondly to propose appropriate and practical solutions for stakeholders. Geographical, resource-wise, climatic and economic diversities in different countries make it essential to analyse the water-energy interrelations more precisely for efficient and economic use of both resources. The interdependence between energy and water in the context of hydroelectricity and the competition with agriculture, and the lack of appropriated data are amongst other relevant issues for the development of the continent requiring scientific analysis for appropriated solutions.



Picture 8: Energy – Water and Climate Nexus at PAUWES

b. State of the art and challenges

Even today, water and energy supply in Africa is a major challenge. Scarcity of water resources in some regions, and scarcity of clean and affordable energy for water purification and distribution in other regions pose a big threat to the sustainable development of the continent in the near future. The expansion of hydroelectric dams to address needs in growing cities exacerbated the situation. Some of these big problems could be eased with scientific solutions, if the policy

makers are convinced to implement such recommendations. Similar to other nexus topics (e.g. climate-energy), there are sporadic efforts from the scientific community to propose tools and methods for water-energy nexus analysis. Therefore, PAUWES could contribute towards scientific methods for this purpose.

The energy and technology nexus involves multidisciplinary research which can be conducted on different aspects. Data gathering, for example, is for climate change, water and energy groups. Whereas applied research on energy storage for small plants involves electrical technological aspects as well as fundamental and applied chemical research.

c. Recommendation for future research fields for PAUWES

- How to design new desalination technologies with larger capacities?
- How to integrate renewable energy systems in water pumping, desalination and purification plants?
- How to develop tools for appropriate selection and planning of potential sites for multipurpose dams (power production, irrigation, drinking water)?
- How to optimise cooling water demand in conventional energy plants?
- How to carry out water-efficient cleaning of dust deposited on solar modules and collectors?
- How to develop holistic water and energy management systems for larger basins?
- How to develop policies that support the access to sufficient, clean and affordable water energy resources to all people?

In addition to the aforementioned questions, PAUWES research in energy-water nexus in an inter- and trans-disciplinary manner may include areas such as social sciences principles in community engagements, cultural issues in electrification projects, the interplay between hydropower and utilisation of water for crop production in consideration of riparian rights and use of space for solar energy production versus use for crop production or both (agro-solarisation).

Interdisciplinary research encourages cross-sector planning to reduce water use conflicts, for instance incorporate IWRM, interact with mining, industrial and agricultural sectors to encourage integrated responsibility on water management, and interact with regional development initiatives that have cross-boundary implications. PAUWES research may also consider interaction with regional and catchment management agencies in some areas.

2.4.2. Energy-Climate Nexus

a. Relevance for the African continent

There is a common consensus that conventional fossil fuel burning has been the major cause of anthropogenic emissions of greenhouse gases to the atmosphere globally. The negative impacts of the global climate change are prominent also on the continent of Africa. The linkage between climate change and energy generation/consumption is quite complex. Climate change has impacts on different value chains of energy generation and supply. Examples include biomass use issues, vulnerability of future energy options, droughts or intensified rainfalls, water-cooling in thermal power plants, etc. There is a need to reduce these greenhouse gas emission induced impacts through proper selection of energy generation systems (bio-energy, renewables, decentralised power supply, energy from waste, synthetic fuels, user behaviour, energy efficiency and management issues, etc.). This is essential to combat climate change impacts from and in the energy infrastructure of the future for the continent and globally.

b. State of the art and challenges

The current energy supply system in Africa is dominated by fossil fuel and traditional biomass. However, there is enormous potential for modern renewable energy resources on the continent. So far, the systematic research is limited to few institutions on the topics of energy and climate change interrelations. It is necessary to develop and use scientific methods and tools for different aspects of energy and climate change.

c. Recommendation for future research fields for PAUWES

- How to define, collect and analyse the datasets necessary for quantification of bi-directional impacts on energy and climate change issues?
- How to use modern information and communication technologies on data collection, storage and analysis?
- How to assess the economic impacts of climate change-related uncertainties in energy generation and infrastructure (e.g. reduced water availability for hydropower, changes in wind and solar resources at specific sites, etc.)?
- How to assess the impact of population growth on the identified energy resources and climate change?
- How to establish a quantitative linkage between deforestation and climate change?
- How to assess the rebound effects (deforestation, soil erosion and their impacts on hydropower generation, etc.)?

Picture 9: Energy – Water Nexus
Source: Pixabay

- How to develop policies that support climate change-friendly energy resources and infrastructures?
- How to improve energy security at a national and local level with greenhouse gas mitigation strategies?

In addition to the aforementioned research questions, the energy-climate nexus should be addressed as a multidisciplinary field involving all aspects of society. PAUWES students focusing on energy research are likely to have an engineering background and advised to have some reasonable appreciation of how society issues such as economics, politics, culture and religion impact on the outcomes of technical interventions.

2.4.3 Water-Climate Nexus

Climate variables are impacting the water supply and water demand side. This combined effect is highly influential on water management which is basically a process of coordinating interventions via water infrastructure and its operation according to rules to be set by the stakeholders (equity, appropriateness), aiming at fulfilling the demand as far as possible under available supply and taking sustainability of water use into account in terms of quantities and qualities as well as surface and groundwater resources. The water systems provide the base for livelihoods, for example via provision of drinking water, enabling or enhancing agriculture by irrigation, managing water-related risks (floods, droughts) and supporting ecosystem functioning. As a consequence, the design and operation of water systems depend on hydro-meteorological variables (averages, extreme values with allocated probability).

a. Relevance for the African continent

CC & CV are altering the supply-demand relationships and shifting probabilities in flood and drought situations in a disadvantageous way. This creates the need to re-think design procedures and setting, as well as adapting operation of the water management systems in the light of alterations in major hydrological variables (rainfall, evapotranspiration, runoff) driven by dynamics of CC. Essential dependency of populations on rainfed-agriculture, critical situations in terms of food security, widespread occurrence of notably vulnerable communities, rather weak institutions and limited economic resources make Africa highly sensitive to water-climate interactions; yet, as a consequence, the application of the nexus approach has a high potential to utilise synergisms towards improving the current situation even under future challenges.

In order to unfold Africa's tremendous potential for food production (looking at currently low yield levels) under the actually complex and in future even more challenging situation (climate, water supply demand, land use changes, urbanisation), adapting the nexus approach for application under the African conditions is a must for sound decision-making in the future and therefore a priority area for research today. The nexus approach

has the potential to (i) consider interlinkages between relevant disciplines, and (ii) improve the coordination of management as well as policy interventions throughout the scales. Insufficient information on climate impacts at the local scale, missing assessment of limits (but rather high uncertainty) in climate model-based predictions, insecurities on the interplay between CC, land use dynamics and urbanisation enhance the need to consider the interlinkages between disciplines (part i). Non-transparency in decision-making processes, high share of transboundary hydrological basins, missing compatibility of current policies to accommodate the nexus (e.g. trade policies vs. agricultural policies) are relevant features in Africa to be overcome by improving the coordination throughout the scales and levels of decision-making via a nexus approach (part ii). To be promising, the nexus approach needs to be adapted to the African context and supported by science-based information. Refining operational rules of reservoirs designed in the past based on sector-thinking towards multi-purpose systems to adapt to climate and land use changes is a typical example of the nexus approach.

b. State of the art and challenges

The currently problematic situation (vulnerable communities, uncertainty on CC impacts, food insecurity, weak institutions, limited economic potential) is further complicated by a high share of transboundary river basins and linked groundwater aquifers, different climatic regions (from hyper-arid to full-humid), rain-fed as well as irrigation-based systems, land degradation and coastal regions endangered by salt water intrusion, and disparities between rural and urban areas (even mega cities). The latter disparities lead to rural-urban migration driven by climate stressors and create immense challenges in terms of providing/improving sanitation/health infrastructure, appropriate employment opportunities and avoiding conflicts. Reference areas of best practice are rather scarce and options for translating knowledge to other regions and settings need to be developed).

c. Future research fields for PAUWES

PAUWES should consider:

1. Relevance (and the potential) of the nexus approach for water and food security, sustainable development and livelihoods in Africa.

2. Current state of research.

3. Competitive structural advantages of PAUWES, major research direction consisting of further developing the approach, adapting to the African context and creating an enabling environment for its application.

More specifically, the following topics could be of interest to PAUWES:

- Enhance system understanding (linked water-land use – climate systems): how does CC affect these systems? What are the feedbacks? How are extreme situations altered?

- Assessing CC impacts on demand and feasibilities for irrigation under CC and how supplemental irrigation can support adaptation strategies (as irrigation often accounts for a high share of withdrawals and is severely impacting the quantity and quality of water resources and therefore important in nexus considerations).

- Options towards increasing efficiency, effectiveness and productivity of water use (and lowering of impacts) and their optimal combination (spatial and temporal conception of combined/integrated strategies for highest/cost-effective impact; i.e. irrigation: advanced facilities, re-arranged infrastructure & institutional settings, improved strategies, water re-use options).

- Establishing links between managing the water-climate nexus to energy systems, environmental and health context.

- Establishing links between water basin management because water quantity and quality are multidisciplinary issues which are strongly interrelated, e.g. water-energy-food nexus or IWRM.
- Improving/adapting management in case of water-related climate hazards (early warning systems).

- How to address the increase in water productivity and water footprint through wise use of water in agro-processing (reuse water for irrigation).

- Considering *"hotspot areas"*: how do urban/peri-urban areas in particular, behave and how to compensate disadvantageous impacts of urbanisation on the water cycle? How to avoid salt intrusion in coastal regions (high water withdrawals often from aquifers in intensively used coastal regions (deltas) and rising sea level may reverse groundwater slope and flow from the sea into the aquifers)? How to address the issue of urban water management intertwined with environmental legislation/regulation and governance?

- Considering the societal dimension of climate hazards (regional migration and marginalisation pushed by climate disasters, climate-driven stress caused by migratory pastoralists/future of pastoralism).

- Combining adaptation with mitigation research considering the timelines of effects and mobilising synergisms (i.e. water-efficient technologies incorporating low emissions; water saving is also energy saving in systems relying on water lifting; yet the impact on agricultural systems needs to be assessed).

Picture 10: Water – Climate Nexus
Source: pixabay

- How to bridge the science-policy interface (governance, law and policy, relevance, timeliness, non-linear process, language of dissemination) and proactive research on demand issues to address government priorities (always urgently required to make a decision: forward looking research, future water security issues, etc.).
- In terms of existing framework and policies: which of those discourage adoption of strategies to address the changing climate and resulting water scarcity?
- What policies serve as barriers to adopt water-climate interventions, e.g. climate smart agriculture?
- Political economy of water infrastructure (understand dynamics of transboundary basins).
- How to further develop the structure of PAUWES (water and energy; engineering and policy tracks) for a competitive advantage in trans-disciplinary and nexus-oriented approaches while adapting them to the requirements of water or land end-users.

Interdisciplinary research within the topic of water and climate change could be incorporated when undertaking climate impact modelling and analysing land use, human settlements, urbanisation, water and other indicators. Additionally, studies on the impacts of climate change and climate variability, land use, water resources and ecosystem services on the energy sector and impacts on sustainable development are highly recommended. The area of risk assessment research may have its home base at PAUWES, but can also be considered as a cross-cutting activity relevant to the themes of all PAU institutes. Trans-disciplinary approaches with relevant stakeholders from science, administration, industry, water and land users, e.g. basin administrations by Volta Basin Authority, are imperative.

3 Structural Measures for the Successful Implementation of Research at PAUWES

3.1 Research Departments/Units and Favourable Research Environment at PAUWES

For PAUWES to grow and realise its mandate, it could create relevant departments and units that have a combination of theoretical components and practical applied research in their respective field of activities. PAUWES should establish thematic research groups within departments that focus on specific areas.

Departments should be headed by a strong visionary leader, preferably an internationally renowned expert who will have the responsibility to develop the research group by bringing on board qualified researchers through third-party funding and manage research activities in the fields of specialisation identified in section 2 to research missions fitting in with research priorities. In parallel to the research departments with their respective leaders, PAUWES might establish a research (networking) manager/coordinator position in the transition phase for the development of research department/units and later for oversight, monitoring, coordination and evaluation of activities of the research units to ensure effective achievement of PAUWES' vision and scientific objectives. The research manager should establish collaboration and partnership with regional and international research institutions networks, NGOs, private sector and funding organisations, enabling PAUWES to drive the research agenda of the African Union in its respective field, to be competitive and well-positioned on the international research landscape. The leaders of research departments/units and the research manager are expected to identify research funding opportunities, write winning research proposals to implement research activities at PAUWES and contribute to the financial sustainability of the institute through third-party funding.

3.2 Partnerships, Collaboration and Networking Interaction with Other Research Fields Expecially with Other PAU Institutes

For the successful implementation of research at PAUWES, the research departments should consider during the early-stage planning the establishment of PAU satellites in other African countries and the repartition and coordination of research foci in the different satellites. The identification of satellites and research foci should be done according to experiences, resources, and further criteria in line with the vision and strategic development of PAU as network and PAUWES as institute.

Inter and intra-hub collaboration (satellites and other PAU institutes) and the connection with the host university should be at the centre of the collaboration strategy to address the nexus of water, energy, climate and food security. In order to strengthen connections with the host universities, it would be pragmatic to integrate professors and share resources both in infrastructure and other related resources between PAUWES and the satellites. The nexus approach specific to PAUWES should be driven in the PAU community and other centres of excellence and research institutions on the continent.

Consequential to the nexus approach, the collaborative/inter-, multi- and trans-disciplinary approaches to research and development must be considered by the respective research department/units.

According to the profile of research at PAUWES proposed in section 1.4 to focus on applied research, and therefore inevitably impact society through the economic interests of the social partners and the country in general, research activities at PAUWES should lead to the creation of new start-ups to generate employment and income in African countries. Based on its specific objective and comparative advantage, PAUWES could identify fields of specialisation, expertise and excellence in other universities, research institutes and networks such as the African Centers of Excellence initiated by the World Bank, ECOWAS Centre for Renewable Energy and Energy Efficiency

(ECREE), West African Service Centre on Climate Change and Adapted Land use (WASCAL) and South African Science Service Centre for Climate Change and Adaptive Land management (SASSCAL) and other relevant research institutes and networks on the continent and abroad. Consequentially, mapping studies on the scientific landscape in Africa will be important in order to find options for cooperation, usage of available findings, tools, software and defined research niches for PAUWES such as water-food-energy nexus and engineering-policy interface.

The following actions are recommended to set up a framework for collaboration and networking interaction with other research fields:

- Establish inter/multi-disciplinary research areas and support structures (research departments, units and groups, PAUWES satellites and PAU institutes).
- Map out research partners and find appropriate fields of specialisation/expertise/excellence amongst other universities, research institutes, networks and agree on modalities of engagements through drafting and signing of MOUs.
- Identify pilot research areas where PAUWES research departments, students and research partners can collaborate.
- Set up work plans and annual calendars of research activities within the different themes of PAUWES.
- Exchange of professors and organisation of special lectures and workshops within different PAUWES institutes to help the cooperation to be effective.
- Co-supervision of Master and doctoral students in inter-/multi-disciplinary research, e.g. agriculture, water, energy, economy, and sociology.
- Publish joint articles and scientific papers between PAUWES faculty and partner institutions.

Picture 11: PAUWES Research Agenda Kick-off Workshop 2015
Source: PAUWES

3.3 Profile of Researchers and Affiliated Experts and Interlinkage of Research Activities with Masters/PhD Programmes

Training PhD students at PAUWES can help reduce brain drain within the African continent by making it appealing to internationally renowned people. Below are some of the objectives for profiling researchers, to affiliate experts and interlinkage for Master and PhD programmes at PAUMES.

3.3.1 Profile of Researchers and Affiliated Experts

It is suggested that PAU and PAUWES reflect and decide on the future role of faculty staff in teaching and research at the PAU institutes, lecturers and researchers versus lecturer-researcher. Once the decision has been made, an adequate framework can be established for the staff to be able to fulfil their role according to the overarching concept. At a general level, PAUWES should strive for permanent researchers with outstanding track record and work experience in a relevant field, preferably in an international and multi-cultural environment in one or several PAUWES areas of specialisation. Experience in fundraising and writing of applications for research grants should be considered in recruiting senior researchers to ensure the financial sustainability of the institute. A critical amount of researchers should have experience in inter- and transdisciplinary research considering the nexus approach identified as a niche for PAUWES. Experience in climate-relevant research to address an area which is still underrepresented in current PAUWES activities should also be considered in the recruitment of researchers.

The following measures should accompany the recruitment of appropriate researchers at PAUWES:

- Set up a pool/college of research associates as a platform to involve African and international scientists in PAUWES research projects and activities.
- Set up a research network and database that identifies know-how, researchers, innovation hubs, funding institutions, etc.
- Invite experts from abroad for monthly conferences or seminars to present state-of-the-art cases of an emerging topic related to the sub-field.
- Exchange of professors and organisation of special lectures and workshops within different PAUWES institutes to help the cooperation to be vital for effective research.

3.3.2 Interlinkages of Research Activities with Masters and PhD Programmes

The interlinkages with Masters/PhD programmes are important for integrating their research capacities in the research mandate of PAUWES. The following measures are recommended:

- Conduct a critical review of existing Masters in order to identify areas that would warrant modifications to fulfil the close collaboration with the research agenda based on the feedback of lecturers during the first two years. The critical review of existing Masters should also contribute to the identification of areas for collaboration.
- In addition to the preparation of students for entrepreneurship or employment as engineers in Africa, the Master programme at PAUWES should additionally prepare students to apply for a PhD and research career.
- Introduce assistantship programmes in the departments where a Master degree student can work under a PhD student to support their research and familiarise them with research activities in order to decide whether or not to pursue a research career.
- The co-supervision of Master and Doctoral students in inter-/multi-disciplinary research context, jointly with African and internationally renowned institutes working on PAUWES priorities in Africa, is recommended to initiate or strengthen existing collaboration.
- Periodic evaluations of the curricula can be carried out in order to modify areas that require enhancement and incorporate studies that are relevant and on demand for the African continent and could be proposed as Master or PhD thesis.
- Participate in relevant fairs in Africa and Europe in relation to the sub-field to show the offers of PAUWES for benchmarking with the aim to improve Masters/PhD programmes.
- Support job placement assistance to graduates of PAUWES in key decision making position with high remuneration to curb brain drain after the completion of their programme.

With regards to specific area of energy, the following are recommended: a strong linkage between the engineering, the policy track on policy research and the engineering track on economics aspects; the linkage with water programmes to understand land water use for energy production and for other uses such as crop production. With regard to the area of water, the integration of water economics in the curriculum and research activities at PAUWES is recommended.
With regard to the area of water, the integration of water economics in the curriculum and research activities at PAUWES is recommended. The current structure of PAUWES (water and energy; engineering and policy tracks) is a competitive advantage in transdisciplinary and nexus-oriented approaches, which needs to be further developed and adapted to the requirements from practice and water/land end-users.

With regard to climate change, the existing MSc/PhD programmes at PAUWES need to be reviewed with a view to mainstreaming vulnerability aspects in the curriculum. Risk should be an important aspect of many PhD and Masters themes, but may be also a main theme. A new Masters programme led by PAUWES in collaboration with other PAU institutes on environment and climate change considering inter- and multi-disciplinarity of the topic may be envisaged.

3.4 Research Infrastructure, Potential Instruments and Tools for the Implementation of the Research Agenda

The aim of PAUWES is to have the latest technologies and systems to facilitate world-class quality of research. In a transition phase, PAUWES should make the best use of available facilities at the University of Tlemcen and set up its own infrastructure and facilities as soon as possible. The establishing of laboratories and equipment should follow a step-by-step procedure by focusing on a first phase of basic requirements (curricula, master theses) and specific equipment in line with needs, requirements and expertise of research departments/units and incoming long-term academic staff. PAUWES should seek ways for fast tracking facility procurement. The knowledge of how to utilise such tools should be a part of the PAUWES curricula.

The following are a few outlines of the objectives for setting up research infrastructure, instruments and tools for the implementation of the research agenda.

- Need for up-to-date offices, laboratories fitted out with modern computers with provision of excellent bandwidth, general and specific software for the different research areas (data acquisition, storage, analysis, modelling and treatment/processing, visualisation, etc.), GIS and remote sensing facilities.
- Set up a database that students and faculty can feed data into and extract data for both primary and secondary research.
- Strengthening the cooperation with administrations and industry (data provision for master theses and, at a later stage, for PhD theses; joint research) and exchange of students.

Picture 12: PAUWES Research Agenda Kick-off Workshop 2015
Source: PAUWES

- Set up innovation labs for finding sustainable solutions for specific problems in Africa or cross-continental challenges and to support the creation of start-ups and companies to bring the innovation into the market. Leverage entrepreneurship centre funded by the German Federal Ministry for Economic Cooperation and Development and planned by the GIZ.

The following measures are recommended to support the implementation of the research agenda:

- Leverage ICT tools such as the PAUWES Community of Practice platform to create a social and professional community of practice at PAUWES involving researchers, public-private institutions, and NGOs alumni around PAUWES' research priorities.

- Use classical media and printed materials for dissemination of research results and the improvement of the visibility of research activities (advertisements – press releases – newspaper inserts – newsletters – bill stuffers – public displays – information repositories).

- Use traditional analogue (print media) and digital channels for the dissemination of research results and the improvement of the visibility of research activities (public meetings – public hearings – the Internet – response sheets – postal/telephone/web surveys – polling – teleconferencing – presentations to community groups).

- Establishment of a platform for exchange in scientific and academic research programmes.

- Development of a series of conferences and symposia on PAUWES research priorities and establishment of credible journals for publication of research results.

- Participation in international organisations and exposure of students to (practical) research problems of different countries and developing solutions thereof.

- Collaboration with private sector and industry (refer to section 6).

4. Interaction with Regional and International Research Institutions and Networks in Research

Picture 13: PAUWES Graduation 2016
Source: PAUWES

In order to develop sustainable partnerships, some of the guiding principles could include stakeholder identification, strengths, weaknesses, opportunities and threats (SWOT) analysis of the participating institution and evaluation of the geographical proximity, economic, social, gender or environmental values of the potential partners in order to determine who may have a stake. To exhibit commitment of partners and to work in close collaboration with them, PAUWES should join networks of excellence in Africa and further strengthen the partnerships by following partnership guidelines stipulated in MoUs or other agreements. These partners could range from individuals to organisations in Africa and other regions. It is vital that PAUWES interacts with organisations such as the African Academy of Sciences and the Association of African Universities.

4.1 Water-Specific Partners

The Comprehensive Africa Agriculture Development Programme (CAADP), endorsed at the African Union Heads of State Summit as a New Partnership for Africa's Development (NEPAD) programme is an example of a key partner for water-specific research within the African region. The importance of CAADP is that it aims to help African countries reach a higher path of economic growth through agriculture-led development, which eliminates hunger, reduces poverty and food insecurity, and enables expansion of exports.

It is important to identify a number of water basins with the pertinent host country of the basin facilitating the research

[6] Science, Technology and Innovation Strategy for Africa 2024 (STISA-2024).

in order to make this approach a reality. A potential proposal for the research will be: firstly, identify all the elements such as physical elements and processes, secondly, identify all the attributes of the elements, and finally, the most important part of the research, make interlinkages between all elements.
Some potential national, regional and international stakeholders that PAUWES can collaborate with within the specific areas of water have been listed in the tables illustrated in the fact sheets in the appendix section of this document. Furthermore, a useful account of the present research landscape is provided by the Joint Synthesis Report *"Water and Renewable Energy Stakeholder Analysis and Research Mapping Water and Renewable Energies in Africa"* by Maxime Souvignet et al. 2015.

4.2 Energy-Specific Partners

The Energy Sector Report of the African Development Bank Group (AfDB 2012) clearly stipulates that partnerships for energy should collaborate with regional member countries and work together with other stakeholders who play a pivotal role in the identification, development, financing and implementation of energy initiatives (African Union Commission 2014). Within the same scope, for PAUWES, partnerships with a broad group of entities are vital in developing synergies and pooling together knowledge and resources. As in the AfDB Energy Sector Report, the areas of collaboration may include knowledge generation and dissemination, co-sponsoring projects and programmes, development of joint strategies as well as capacity building. PAUWES could sign agreements with national and regional energy regulatory bodies, government ministries, funding organisations, European universities and research centres to enhance the exchange of scientific information between both staff and students.

A Useful account of the present research landscape is provided by the Joint Synthesis Report *"Water and Renewable Energy Stakeholder Analysis and Research Mapping Water and Renewable Energies in Africa"* by Maxime Souvignet et al. 2015.

4.3 Climate Change-Specific Partners

Partnerships for climate change are essential in driving research for information, innovation and policy. For instance, the African Union Agenda 2063 supports the policy debate of the Science, Technology and Innovative Strategy for Africa 2024 including biosafety, climate change, biodiversity and environment regulation and ICT, however, most contributions are not supported by evidence.[6] PAUWES can play a strategic role through outlined partnerships in order to present evidence-based research and innovation for climate change. Alluding to the experience of the conglomerate of scientific organisations, Consultative Group for International Agricultural Research (CGIAR), they point out that their most successful areas of research and practice have been built around partnerships with the clear need to develop, test and release new varieties of methods of agriculture that would be adapted to changing climatic and ecological conditions within the contexts in which they work (UNEP & ICRAF 2006). PAUWES can join or create such partnerships to address issues in the dynamic challenges resulting from climate change.

Picture 14: PAUWES research agenda Kick-off workshop 2015
Source: PAUWES

5. Interaction with Transnational Organisations, Institutional (Policy) and Societal Players

Institutional stakeholders play a pertinent role in influencing policy across the region. PAUWES should integrate social sciences and humanities to develop policy frameworks for communicating climate change, economy, politics and governance to decision makers and other stakeholders. On this fabric, economic tools can be embedded for comprehensive policy approaches and governance practices. The stakeholders within this research agenda may include transnational organisations, policy institutions, policy stakeholders and civil society institutions such as:

- The African Union Commission for Human Resources Science and Technology (AUC- HRST).
- The African Union Commission for Infrastructure and Energy.
- NEPAD and their subsidiary bodies.
- African Development Bank and their subsidiary bodies.
- Regional integration institutions, economic and political institutions, e.g. ECOWAS, EAC, SADC.
- United Nation agencies and programmes related to water, energy and climate, e.g. UNECA, World Bank, United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), Food and Agriculture Organization (FAO), Intergovernmental Panel on Climate Change (IPCC), United Nations University (UNU) and Global Environment Facility (GEF).
- Development agencies: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), European Union (EU), Department for International Development (DFID), etc..

Furthermore, strategic documents of the African Union and other Pan-African and international institutions used to develop the research agenda mentioned in section 1.5 and the Joint Synthesis Report on *"Water and Renewable Energy Stakeholder Analysis and Research Mapping Water and Renewable Energies in Africa"* by Maxime Souvignet et al. 2015 present further transnational and Pan-African organisations, policy institutions and societal players.

Picture 15: PAUWES International Symposium 2015
Source: UNU-EHS

6. Interaction with the Private Sector

African Union's report on Competitiveness of the African Private Sector has established the private sector as an essential component of the continental effort towards achieving more inclusive and sustainable growth over the next decade and beyond. The African Union further acknowledges the private sector as the largest employer, however, its leading role is hindered by institutional, regulatory and legal constraints, infrastructural deficiencies, inadequate professional skills and limited access to financing, which have favoured the development of a sprawling informal sector with insecure employment for Africa's youth (AU 2017). Additionally, research and development of technological innovations can have a positive impact on private sector operations and vice versa. However, there are limited to non-existent research and development platforms by the public and private sector in the African region.

PAUWES in collaboration with the private sector can play a critical role in contributing: knowledge and skills to serve African economies research and development of innovations and strategies to increase the region's competitive advantage. These private sector institutions can come from various backgrounds of practice, e.g. finance, consulting, manufacturing, small and medium enterprises. Depending on the topic, stakeholders from the public sector such as national authorities, policy making and administrative bodies should also be considered in the context of public private sector partnership.

The industrial Advisory Panel (IAP) already developed and proposed to the PAUWES board can build a good framework to assist PAUWES in achieving its mission to promote and harness productive linkages with the public and private sector for innovation as well as knowledge and technology transfer in the fields of water and (renewable) energy. The IAP would strive to enhance applied research, employability and entrepreneurship at PAUWES. PAUWES can also reap the following opportunities identified in the concept note of the industrial Advisory Panel by collaborating with the private sector:

- Receive advice on potential growth areas, technological trends and the needs of industry, which helps the institute's leadership in the strategic long-term planning.
- Gain access to internship placements, Master and PhD thesis assignments that create opportunities for students to be trained on the job, work on practical research challenges and acquire important generic skills.
- Expand its network and is supported in interdisciplinary (applied) research projects and entrepreneurship education.
- The private sector could also get the following benefits by interaction with PAUWES.
- Benefit from further collaboration opportunities in joint research projects, shared facilities or public private partnerships.
- Benefit from the co-supervising of Master and PhD theses on relevant topics for industry and take part in patents, publications and other projects.
- Benefit from *"externships"* where members of staff bring projects to the institute for students to work on.

Guided by MoUs and other forms of agreements, joint initiatives to equip PAUWES with research tools, data sets, research reports and research laboratories, can empower PAUWES to position itself to be a leading hub for local knowledge, documentation and development of technological innovations. This type of collaboration could motivate the development of research topics that can lead to establishing start-ups which, in turn, create employment and growth economies in African countries. Furthermore, the research agenda can explore collaboration with the private sector to share lessons learned and attract further financing for Research and Development.

7. References

- AfDB 2000 *"Policy for Integrated Water Resources Management"*. African Development Bank | African Development Fund. 2000 AfDB. URL https://www.afdb.org/fileadmin/uploads/afdb/Documents/Policy-Documents/IWRM%20Policy-%20Integrated%20Water%20Resources%20Management%20-%20FINAL%20version%20%28highlights%20removed%29_April%2026%202000.pdf (Accessed 09.2017).
- AfDB 2012. *"Energy Sector Policy of the AfDB Group"*. AfDB. URL https://www.afdb.org/fileadmin/uploads/afdb/Documents/Policy-Documents/Energy_Sector_Policy_of_the_AfDB_Group.pdf (Accessed 09.2017) (African Union Commission 2016).
- African Risk Capacity. n.d. African Risk Capacity Strategic Framework 2016–2020. Strategic Report, URL: http://www.africanriskcapacity.org/wp-content/uploads/2017/01/PI_Strategic-Framework-2016-2020_20161207_EN_TA.pdf. (Accessed 09.2017).
- African Union 2014. *"Draft African Union Strategy on Climate Change"*. AU, Addis Ababa http://www.un.org/en/africa/osaa/pdf/au/cap_draft_auclimatestrategy_2015.pdf (Accessed 09.2017).
- African Union Commission 2013. *"The African Union Commission Strategic Plan 2014–2017"*. AU. URL https://au.int/sites/default/files/pages/32028-file-the_au_commission_strategic_plan_2014-2017.pdf (Accessed 09.2017).
- African Union Commission 2014. *"Science, Technology and Innovation Strategy for Africa 2024 (STISA-2024)"*. Strategy Document, African Union. URL http://www.hsrc.ac.za/uploads/pageContent/5481/Science,%20Technology%20and%20Innovation%20Strategy%20for%20Africa%20-%20Document.pdf (Accessed 09.2017).
- African Union Commission 2015. *"The 2014 Africa Water and Sanitation Sector Report, Securing Sanitation in Africa"*. Conference Report, Addis Ababa: African Union Department of Rural Economy and Agriculture. URL- http://www.amcow-online.org/images/Resources/2014%20african%20water%20and%20sanitation%20report.pdf (Accessed 09.2017).
- African Union Commission 2016. Agenda 2063 | The Africa We Want. Addis Ababa: African Union. URL: http://archive.au.int/assets/images/agenda2063.pdf (Accessed 09.2017).
- CAADP "Comprehensive Africa Agriculture Development Programme (CAADP") NEPAD. URL: http://www.nepad.org/download/file/fid/3606%20 (Accessed 09.2017)
- CESA 2016-2025. "Continental Education Strategy for Africa 2016-2025" African Union Commission. URL: https://au.int/en/documents/29958/continental-education-strategy-africa-2016-2025 (Accessed 09.2017)
- Echart et al. 2012. *"The Future of Water in African Cities : Why Waste Water? Integrated Urban Water Management"*. Echart, J.; Ghebremichael, K.; Khatri, K.; Mutikanga, H.; Sempewo, J.; Tsegaye, S.; Vairavamoorthy, K., Background Report. Worldbank URL- https://openknowledge.worldbank.org/handle/10986/12275 (Accessed 09.2017).
- Lundvall, Bengt-Åke 2016. The Learning Economy and the Economics of Hope. London: Anthem Press. URL- http://oapen.org/download?type=document&docid=626406 (Accessed 09.2017).
- Maxime Souvignet et al. 2015. *""Water and Renewable Energy: Stakeholder Analysis and Research Mapping Water and Renewable Energy in Africa""*. Joint Synthesis Report Maxime Souvignet; Tareq Zahw and Martin Kaltschmitt. Addis Abbaba: GIZ African Union Support to the Pan-African University.
- NASAC 2014. *"The Grand Challenge of Water Security in Africa, Recommendations to policy makers"*. Network of African Science Academies URL-http://www.interacademies.net/File.aspx?id=25143. (Accessed 09.2017).
- NEPAD 2011. *"Revision of the AU/NEPAD African Action Plan 2010_2015"*. NEPAD URL http://www.oecd.org/investment/investmentfordevelopment/47693615.pdf.
- NEPAD 2013. Introducing the Comprehensive Africa Agriculture Development Programme (CAADP). URL: http://www.nepad.org/download/file/fid/3606%20. (Accessed 09.2017).
- NEPAD 2003b. New Partnership for Africa's Development (NEPAD): Action Plan for the Environment Initiative. Midrand: NEPAD. URL- http://www.nepad.org/download/file/fid/3072%20 (Accessed 09.2017).
- UNECA 2015. *"Africa Regional Report on the Sustainable Development Goals"*. United Nations Economic Commission for Africa, Addis Ababa URL-https://www.uneca.org/sites/default/files/uploaded-documents/SDG/africa_regional_report_on_the_sustainable_development_goals_summary_english_rev.pdf (Accessed 09.2017).
- UNECA 2025. *"The African Water Vision for 2025 : Equitable and Sustainable Use of Water for Socio-economic Development"* Economic Commission for Africa URL-https://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/african%20water%20vision%202025%20to%20be%20sent%20to%20wwf5.pdf (Accessed 09.2017).
- UNEP & ICRAF 2006. *"Climate Change and Variability in Southern Africa: Impacts and Adaptation Strategies in the Agricultural Sector."* UNEP & ICRAF. URL http://www.the-eis.com/data/literature/Climate_change_and_variability_in_the_southern_africa.pdf (Accessed 09.2017).
- UNISDR 2015. *"Terms of Reference of the Scientific and Technical Partnership for the Implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030"*. ToR, URL-http://www.unisdr.org/files/45270_torofunisdrstpartnership.pdf. (Accessed 09.2017).

8. Appendices

Appendix I: List of Working Group Experts

- Prof. Abatan, Matthew, Pan African University Institute of Life and Earth Sciences, Nigeria
- Prof. Dr. Alcamo, Joseph M., University of Kassel Center for Environmental Systems Research, Germany
- Prof. Dr. Ardakanian, Reza, United Nations University (UNU) Institute for Integrated Management of Material Fluxes and of Resources (FLORES), Germany
- Mr Awokola, Abayomi, International Water Management Institute (IWMI), Republic of Ghana
- Prof. Dr. Ayuk, Elias, United Nations University (UNU) Institute for Natural Ressources in Africa, Cameroon
- Prof. Dr. Baghli, Lotfi, University of Tlemcen, Algeria
- Dr. Bahri, Akissa, International Water Management Institute (IWMI), Tunisia
- Prof. Bekkouche, Abdelmalek, University of Tlemcen, Algeria
- Mr. Benitez Martinez, Daniel Eduardo, German Aerospace Center (DLR), Venezuela
- Co-Chair of the Energy Working Group Mr. Prof. Dr.-Ing. Bhandari, Ramchandra, University of Applied Sciences – TH Köln, Germany
- Prof. Boko, Michel, National University of Benin, Benin
- Dr. Bolle, Friedrich-Wilhelm, Research Institute for Water and Waste Management at RWTH Aachen (FiW) e. V., Germany
- Co-Chair of the Climate Working Group Prof. Dr. Borgemeister, Christian, University of Bonn, Center for Development Research, Germany
- Frau Prof. Dr. rer. nat. Bruns, Antje, Trier University Faculty VI Regional and Environmental Sciences, Germany
- Mr. Prof. Dr. Bryniok, Dieter, Fraunhofer Institute for Interfacial Engineering and Biotechnology, Germany
- Co-Chair of the Water Working Group Prof. Dr. Buckley, Chris University of KwaZulu-Natal, Republic of South Africa
- Prof. Dr. Chaibi, Mohamed Thameur, GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)
- Prof. Cherki, Brahim, University of Abou Bekr Belkaïd, Algeria
- Dr. Egbe, Daniel Ayuk Mbi, African Network for Solar Energy e. V., Germany
- Dr. Fend, Thomas, German Aerospace Center (DLR), Germany
- Prof. Dr. Fischedick, Manfred, Wuppertal Institute, Germany
- Dr. Fonta, William, WASCAL
- Prof. Dr. Gobsch, Gerhard Ernst, Technical University Ilmenau, Institute of Physics, Germany
- Prof. Gordon, Christopher, University of Ghana Institute for Environment and Sanitation Studies, Republic of Ghana
- Dr. Hattermann, Fred, Potsdam Institute for Climate Impact Research, Germany
- Hilbig, Jens, Witten/Herdecke University, Institute of Environmental Engineering and Management, Germany
- Prof. Kadi, Lamine, University of Mostaganem, Algeria
- Co-Chair of the Energy Working Group Dr. Khellaf, Abdallah, University of Algiers, Algeria
- Dr. Koch, Hagen, Potsdam Institute for Climate Impact Research, Germany
- Dr. Laux, Patrick, Karlsruhe Institute of Technology (KIT) Institute of Meteorology and Climate Change, Germany
- Prof. Magoma, Gabriel, Pan African University Institute for Basic Sciences, Technology and Innovation, Kenia
- Mr. Prof. Dr. Mutale Joseph, University of Manchester
- Prof. Negadi Latifa, University of Tlemcen, Algeria
- Co-Chair of the Climate Working Group Dr. Oludhé, Christopher, University of Nairobi, Department of Meteorology, Kenya
- Prof. Dr. Ould, Lahoucine Cherif, University 8 May 1945 – GUELMA, Algeria
- Co-Chair of the Water Working Group Prof. Dr. Peiffer, Stefan, University of Bayreuth, Germany

- Dr. Petja, Brilliant Mareme, Water Research Commission (WRC), Republic of South Africa
- Co-Chair of the Water Working Group Prof. Dr. Rhyner, Jakob, United Nations University (UNU), Switzerland

- Prof. Ribbe, Lars, University of Applied Sciences – TH Köln Institute for Technology and Resources Management in the Tropics and Subtropics, Germany

- Prof. Dr. Runge, Erich, Technical University Ilmenau Institute of Physics, Germany

- Prof. Sebitosi, Adoniya Benaya, Stellenbosch University, Department of Mechanical and Mechatronic Engineering, Republic of South Africa

- Dr. Sedogo, Laurent, Centre on Climate Change and Land Management (WASCAL), Republic of Ghana

- Prof. Seladji, Chakib, University of Tlemcen, Algeria

- Prof. Shisanya, Christopher Allan, Kenyatta University, Kenya

- Dr. Tambo, Erick Gankam, Research Coordinator PAUWES, United Nations University (UNU), Institute for Environment and Human Security (UNU-EHS)

- Dr. Tischbein, Bernhard, University of Bonn Center for Development Research, Germany

- Mr. Toensjost, Sven Ole, University of Applied Sciences – TH Köln, Institute for Technology and Resources Management in the Tropics and Subtropics, Germany

- Mr. van der Straeten, Jonas, Technical University Berlin, Germany

- Prof. Dr. Wycisk, Peter, University of Halle, Germany

- Prof. Zebaze, Kana Martiale Gaetan, Kwara State University, Nigeria

- Prof. Zejli, Driss, National School of Applied Sciences, Marocco

Appendix II: Water Working Group Fact Sheet

1. Water and Food Security

By Brilliant Mareme Petja

a. Specific relevance of the sub-field for Africa

- Water availability guarantees long-term production of food and sustenance of livelihoods.

- Water and food security are the key challenges under climate change as both are highly vulnerable to continuously changing climatic patterns and subject to more extreme events (drought, flood).

- The majority of the easily available fresh water resources have already been highly used/depleted and there is a reduction in agricultural production globally with escalation in population and food demand.

- Population growth and changing nutrition behaviour lead to an urgent need for increasing food production, which mainly has to be achieved by raising productivity given the limitations in water resources.

- Available water resources are limited and are expected to become more variable due to climate and land use changes and will be subject to an increasing competition between different water uses and users (besides agriculture: industry, energy sector, domestic water use, ecology).

- Furthermore, irrigated agriculture is becoming increasingly important as an adaptation option; yet, currently often low use efficiency/water productivity needs improvement.

- Sustainability of integrated crop-livestock systems would be relevant for water-scarce environments particularly in southern Africa.

- Water information systems and early warning play a crucial role in avoiding or mitigating loss in the food security sector during (and prior to) times of disasters (droughts, floods, etc.).

- High importance of agriculture for economic development, for food security and livelihoods, and for ecosystem services.

b. Description of the main research questions (research potential) in the sub-field

- What options can support rainfed agriculture towards better adaptation to changing environments (rainfall forecast, crop selection and sowing dates, most suitable sites, impact of land use changes)?

- What potential does the introduction of supplemental irrigation have in terms of most suitable sites (soil, crop, and technology), appropriate timing and adapted techniques/ supportive infrastructures?
- What are the consequences of expanded and intensified irrigation in terms of impacts on the environment as well as on downstream population?
- How can the efficiency and productivity of (full) irrigation be increased and impact on the environment reduced (irrigated agriculture currently accounting for highest share of water withdrawals and severe ecological impacts) under changing and variable environments (for example: controlled deficit irrigation)?
- How can improving irrigation schedules, rehabilitating irrigation infrastructure, setting economic incentives for sustainable water use and institutional re-arrangements be combined into transdisciplinary concepts towards sustainable water management/policy?
- Which appropriate approaches to enhance water-efficient production methods and systems in agroforestry, woodlands and forestry plantations are taking into account sustainable water-based agricultural activities in rural communities and integrated water management for profitable farming systems (site-specific agricultural development)?
- How to encourage adoption of water-efficient technology and methods (crops, tillage systems, infrastructure) in agriculture and how to translate precision farming to suit rural farming for efficient fertiliser and water use (minimising groundwater pollution)?
- Which options are available for better coordination between irrigation and further agricultural inputs in order to achieve productivity gain (FAO's 'More crop per drop strategy'; sustainable intensification)?
- How can irrigation (biggest water user) be integrated in overall basin water coordination (site-specific advancing IWRM)?
- Which strategies are appropriate for putting irrigated agriculture in the context of biomass webs and production cycle assessment for the benefit of involved producers and the environment?
- How can remote sensing tools support rainfed agriculture (land use classification for large-scale planning; yield forecast to support farmers; …) and irrigated agriculture (land use; irrigation performance; …)?
- Which measures are proposed to maintain the balance between supply and demand for water in agriculture, household and industrial uses?
- What are the impacts of alternative policies and institutions on food production and food security?
- To what extent can imports of virtual water through food imports be utilised to conserve water domestically and achieve water and food security goals?
- What are the characteristics and determinants of existing water allocation mechanisms?
- What are the impacts of alternative water allocation mechanisms on farmer water use, choice of inputs, investments, productivity of water, food production and income?
- How effective are alternative water allocation mechanisms in reducing agricultural effluents and industrial pollution and protecting wetlands and other water-related ecosystems?
- How do alternative water allocation mechanisms balance the allocation of water across sectors, including agriculture, environment, domestic and industrial sectors?
- What valuation tools can be developed and utilised to inform the trade-offs among multiple uses of water and to assist stakeholders in negotiating sharing agreements?
- What are the approaches and strategies for increasing water productivity and water footprint through wise use of water in agro-processing (reuse water for irrigation)?

c. State of the art

- Available expertise in agricultural sciences, irrigation and water management, but partly refers to different constellations (combination of different climatic, bio-physical, socio-economic and institutional/political settings), which limits wide-spread utilisation.
- Limited exchange of knowledge between science, (water) administrations, commercial sector and (water) end user (farmer).
- Fair targeted cooperation between meteo and hydro services and agricultural/water management administrations could unfold a huge potential for utilisation findings (for example: information on rainfall forecast and shifts in rainy seasons).
- Lack of refinement, maintenance, and continued development of databases on meteo/hydro data in combination with agricultural responses (yield) and socio-economic drivers which could effectively support decision-making at a larger scale as well as support local communities.
- Implementation of technologies (for example in irrigation) are basically available, but hindered by socioeconomic constraints; options towards designing, adapting and assessing *"appropriate technologies"* can have a high impact

in terms of benefits for local communities (to be developed jointly by key stakeholders).

- The establishment of PAUWES with a mission to produce a critical mass of high-quality intellectual capital for Africa, and make African higher education and research attractive, globally competitive, and locally relevant in the field of water and energy sciences (including climate change).
- Current data regarding today's challenges on future water and food demands are often unreliable or inaccurate, making statistics more or less qualified guestimates.
- Insufficient development of adaptive water structures considering climate change and its impact on food security.
- Agricultural development is in favour of fast-growing and high-value cash crops for the international markets instead of subsistence and food crops for local and national markets.

d. Main challenges/current research and implementation deficits

- Reduced water supply triggered by the changing climate (recurrent droughts, heat waves, etc.).
- Inefficient use of water in irrigation.
- (Limited) availability of appropriately compiled data is a major challenge and a clear obstacle for the implementation of advanced strategies of water management in agriculture including rainfed and irrigated agriculture and watershed management.
- The implementation of strategies and supportive infrastructure needs a more structured and intensified cooperation between science, water/land administrations, commercial sectors working on land and water techniques, and (water) end-users.
- Climatic situations, socioeconomic conditions and institutional settings in Africa are very different; this partly hinders the transfer of findings; as a consequence, biophysical, socioeconomic and institutional analyses are needed and promising in identifying findings to be transferred and findings to be modified before a transfer is possible; this would enable the utilisation of rich expertise, which is available, but at the moment scattered and site-specific.

In general, transdisciplinary approaches are needed to overcome current problems, which mainly consist of insufficient consideration of the strengths as well as limitations of stakeholders mainly at the local level often leading to inappropriate solutions; due to engineering and policy track at PAUWES. With coverage of the regions across the entire continent (by students and soon by alumni), and links to administrations and the commercial sector, PAUWES has a high potential to effectively contribute to mastering these challenges.

e. Interaction with other research fields (especially the other PAUWES areas)

- Regarding the research fields identified in the October 2015 PAUWES-BMBF Workshop, links exist to all research fields in the matrix; the closest ones towards *"Basin Water Management"* (especially for integrating irrigated agriculture being the biggest water user into IWRM approaches; *"Water Governance and Economy"* (to support cost-effective and feasible combinations of technological interventions), but also towards *"Water and Environment"* (to assess the impact of agriculture on the environment).
- As mentioned above: transdisciplinary approaches with relevant stakeholders from science, administration, industry and water/land users (basin administrations, for example, Volta Basin Authority); Water Users Associations).
- As a result of mapping studies on the scientific landscape in Africa, it could be interesting to find options for cooperation, usage of available findings/tools/software and research niches for PAUWES (for example: water-food-energy nexus, engineering-policy interface).

2. Urban Water Management

By Gabriel Magoma

a. Specific relevance of the sub-field for Africa

Africa is generally water-insecure and unfortunately the available water also potentially poses environmental and health risks.

b. Description of the main research questions (research potential) in the sub-field

- What are the gaps in urban water treatment and delivery approaches?
- What are the main gaps in waste water disposal approaches that are currently in use?
- What are the limitations in the urban water legislative frameworks?
- How can water security in urban areas be improved?

c. Main challenges/current research and implementation deficits

Main challenges:

- Inadequate quality control of water treatment and delivery.
- Inappropriate waste water disposal approaches.
- Insufficient data on urban water management.
- Inadequate urban legislations on water usage.

d. Interaction with other research fields (especially the other PAUWES areas)

Urban water management is intertwined with environmental legislation/regulation and governance.

3. Basin Water Management

By Stefan Peiffer

a. Specific relevance of the sub-field for Africa

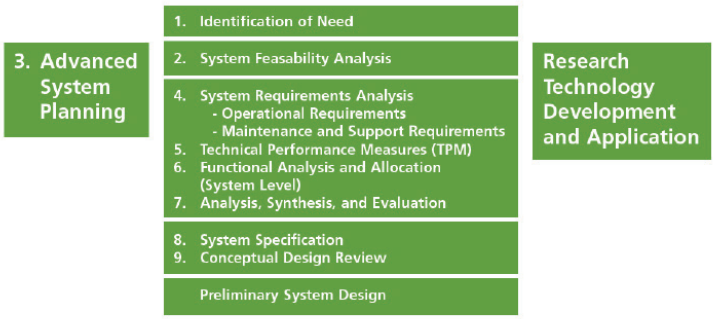
- Basin water system analysis: it would be interesting to approach the basin water as a system. The system engineering methodology is a power tool which can give us the advantages of studying all the basins as one entity with a global vision that must be integrated in complex environments.
- This approach is also participatory and all stakeholders can participate in building the man-made part of the system. Then we can talk about the integrated water system management.
- Basin water management requires information about all parts of the water cycle including evapotranspiration, rainfalls, storage, discharge, water demand for ecosystems, agriculture, energy and urban development.

Such attempts require monitoring systems (discharge), inventory of hydrogeological structures (storage), aerial land use and natural vegetation distribution (ET), meteorological network (rainfall, ET), regional planning on water demand and ecosystems services, as well as modelling tools to integrate this data.

- It appears that there are both many data gaps as well as lack of monitoring systems, inventory of water resources and water demand in Africa, hence, the need for monitoring and data processing systems including quality control is high.
- Africa's climate has not been fully understood, and consequently global and regional factors that influence the African water budgets need to be researched in greater depth (link to climate).
- There is limited expertise in Africa on short, medium and longer timescale hydrological forecasts, predictions and projections.

b. Description of the main research questions (research potential) in the sub-field

- System conceptualisation: the methodology (proposed and adapted from: Blanchard and Fabrycky, "*System Engineering and Analysis*", Prentice Hall, 1998), can be summarised as:



Identification of Need

- The success of a system product is measured initially by obtaining the satisfaction of its users (customers). The international process standards can help us to build all processes that can be used in the basin to make water in a quality and quantity that satisfies all users.
- Predicting discharge in ungauged basins.
- Inventory of ground water resources and aquifer characteristics.
- Understanding regional evapotranspiration (using remote sensing techniques).
- Understanding the role of natural ecosystems (wetlands, rain forests, etc.) for regional water budgets.
- Understanding the role of hydropower plants for regional water budgets.
- Planning of water demand for agriculture, energy, settlements, and ecosystems including stakeholders (transdisciplinary research activities).

c. State of the art

- A limited number of universities, technical colleges, research institutions and regional organisations in Africa are already working on hydrological issues, including hydrological modelling. Yet, the local capacities are financially limited as well as their expertise and infrastructure. There is need (for PAUWES) to identify these institutions as well as international activities (IAHS, FRIEND-Programme) for purposes of collaboration, networking and avoiding duplication of efforts.
- National but not basin-wide perspective.
- PAUWES should aim to become a Centre of Excellence for Africa and train the next generation of hydrologists in an interdisciplinary way (i.e. including climate change and energy issues).

d. Main challenges/current research and implementation deficits

- Data gaps; inadequate and declining data; restricted usage of data from many National Meteorological and Hydrological Services (NMHSs); formats of data often not very useful; there is much untapped historical data that needs to be rescued (among others, through digitisation); there are limited human resources to produce, analyse, interpret and disseminate hydrological data.
- Establish basin-wide management plans which requires adaptation of national standards.
- The spatial and temporal resolution of climate data is also a challenge (cf. climate fact sheets).

e. Interaction with other research fields (especially the other PAUWES areas)

- There is need for inter/multi-disciplinary research in PAUWES (e.g. nexus energy, water, food security, health).
- Undertake climate impact modelling on hydrological cycles (interdisciplinary and transdisciplinary; land use, human settlements, urbanisation, water, etc.).
- Cf. also the fact sheet on climate.

4. Water and Environment

By Stefan Peiffer

a. Specific relevance of the sub-field for Africa

- Water quality issues are a significant threat to surface and ground water with implications on health, water resources, and ecosystem functioning. Key pollutants are: nutrients (eutrophication), pesticides (human health and wild life), faecal pollution (human health). Moreover, there is significant urban pollution from various sources (leakage, contaminated sites, traffic) as well as from mining (acidity, metals).
- It appears that there is a clear lack of
  - i) Knowledge about the regional pollution patterns.
  - ii) Personnel and infrastructural capacities to survey water quality and.
  - iii) Analytical and scientific knowledge on environmental quality issues. Hence, the need for monitoring systems as well as capacity building is huge.

b. Description of the main research questions (research potential) in the sub-field

- Inventory of contamination including regional patterns.
- Development of low-cost monitoring systems using proxies for specific contamination (e. g. faecal, pesticide…).
- Degradation and natural attenuation of pollutants under African climate conditions.
- Maintenance and/or development of instrumental equipment working under high-humidity conditions.

c. State of the art

- Lack of training in state-of-the-art techniques as well as environmental quality/chemistry.

PAUWES should aim to become a Centre of Excellence for Africa and train the next generation of environmental quality engineering in an interdisciplinary approach (i.e. including methodology as well as environmental science, such as hydrology, soil science, atmospheric sciences, and ecology)

- Technical problems due to high-humidity environments and power failures.
- No IT-based data management system that allows sharing of data.

d. Main challenges/current research and implementation deficits

- Maintenance of equipment in high-humidity environments and power failures.
- Establish proxies for low-cost monitoring of environmental quality and derive a sampling as well as an action strategy in case of problems arising.
- Take measures to overcome water quality issues (stakeholder involvement).

e. Interaction with other research fields (especially the other PAUWES areas)

- Very close link to water basin management because water quantity and quality are strongly interrelated.

5. Water and Environment

By Brilliant Mareme Petja

a. Specific relevance of the sub-field for Africa

- Water is critical for development, economic growth and sustainable rural life. Therefore, issues of water quantity remain important for research investigating the balance between available water sources and the increasing demand due to population growth and settlements expansion.
- Regional monitoring of water is increasingly an important research focus particularly looking at aspects of algal blooms, for example, and land cover/land use dynamics on aquatic ecosystems which can be monitored using earth observation technology.
- Another important sub-theme is conflicts in water use that arise out of different competing sectors in a particular region (exacerbated by declining water supply because of the changing climate).

b. Description of the main research questions (research potential) in the sub-field

- What is the current water balance in a particular catchment/region and what threatens its sustainability (e.g. population growth, urbanisation, climate variability, etc.)?
- What site-specific options are available to address issues of water use efficiency?
- What is anticipated to disrupt the systems of water supply currently and in the future? What are the possible strategies?
- Mainstreaming application of earth observation technologies in addressing regional water management issues (potential).

c. State of the art

- There is need to share state-of-the-art technology on water issues/infrastructure for capacity building and cooperation – PAUWES has an opportunity to leverage relations.
- What technology can be utilised to minimise current water levels applicable and affordable to developing countries?
- Use and capacitation of earth observation technology for regional water monitoring and management should be encouraged (satellite data now mostly available at no cost).

d. Main challenges/current research and implementation deficits

- Ageing research infrastructure and lack of such infrastructure in most places.
- Inability to retain young scientists in the water sector.
- Limited cooperation among countries.
- Water infrastructure planning that does not consider changes in climate.

e. Interaction with other research fields (especially the other PAUWES areas)

- It is important to encourage cross-sectoral planning to reduce water use conflicts, i.e. incorporate IWRM, interaction with mining, industrial and agriculture sectors to encourage integrated responsibility on water management.
- Interaction with regional development initiatives that has cross-boundary implications.
- Interaction with regional/catchment management agencies.

6. Water and Food Security

By Brilliant Mareme Petja

a. Specific relevance of the sub-field for Africa

- Water availability guarantees long-term production of food and sustenance of livelihoods.
- Research should therefore focus on water use efficiency in irrigated agriculture and ability to harness water provided through climate systems in rainfed agriculture.

- Sustainability of integrated crop-livestock systems would be relevant for water-scarce environments particularly in southern Africa.
- Water information systems and early warning play a crucial role in avoiding or mitigating loss in the food security sector during (and prior to) times of disasters (droughts, floods etc.).
- Priority should be on increasing regional food security and improving the livelihoods of people in a farming community at the regional level through efficient and sustainable utilisation and development of water resources in agriculture.

b. Description of the main research questions (research potential) in the sub-field

- Encourage water-efficient production methods in relation to soil, crops and technology in rainfed and irrigation agriculture with local relevance.
- Water-efficient production methods and systems in agro-forestry, woodlands and forestry plantations.
- Sustainable water-based agricultural activities in rural communities.
- Integrated water management for profitable farming systems (site-specific agricultural development).

c. State of the art

- Encourage adoption of water-efficient technology and methods in agriculture.
- Translate precision farming to suit rural farming for efficient fertiliser and water use (minimising ground water pollution).
- Encourage planting of water-efficient crops and tillage that minimises water loss.

d. Main challenges/current research and implementation deficits

- Reduced water supply triggered by the changing climate (recurrent droughts, heat waves, etc.).
- Inefficient use of water in irrigation.

e. Interaction with other research fields (especially the other PAUWES areas)

- Increase water productivity and water footprint through wise use of water in agro-processing (reuse water for irrigation).

7. Water Economics

By Jens Hilbig

a. Specific relevance of the sub-field for Africa

- Water scarcity is one of the main global challenges over the coming decades.
- Africa is already facing numerous water-related challenges (access to water supply, adequate sanitation, food and energy production, etc.).
- Demands for fresh water will increase significantly over the next years and decades due to growing populations and economies.
- Climate change could exacerbate the problem significantly.
- Water is the ultimate constraint for sustainable development, economic growth and poverty reduction.
- Economics is the science of managing scarce resources.

b. Description of the main research questions (research potential) in the sub-field

- How to assess the economic value of the environment? Water as an economic good?
- Water efficiency: effective allocation and efficient management of water; resources Ranking of alternative uses (What is efficiency?, efficiency and equity).
- Economics of institutions (Property rights, water markets, market failure).
- Water pricing.
- Supply and demand; analysis Demand management.
- Further empirical studies and evaluation of economic models and concepts with regard to water needed.

c. State of the art

- Basic environmental economics.
- Cost-benefit analysis.
- Analysis of ecosystem goods and services.

d. Main challenges/current research and implementation deficits

- Trade-offs between social, environmental, and economic objectives.

- Establishing water pricing and policy implications of water pricing.
- Lack of financial tools to ensure sustainable water (infrastructure) financing.
- Social acceptance of economic criteria and measures.

e. Interaction with other research fields (especially the other PAUWES areas)

- Multidisciplinary issues, e.g. water-energy-food nexus or IWRM.
- Water law and policy.
- Water governance.

Appendix III: Energy Working Group Fact Sheet

1. Energy Economics and Energy Policy

By Joseph Mutale

a. Specific relevance of the sub-field for Africa

Africa is the least electrified continent. The reasons are rooted in policy and economics of electrification. Most poor communities in Africa rely on inefficient forms of energy that in many cases are harmful to human health and environmentally damaging. These forms of energy are mainly derived from biomass (firewood and charcoal) leading to rapid deforestation. The replacement of these forms of energy with clearly more sustainable forms is essential for sustainable development of these communities. To achieve this requires coherent energy policies and cost reduction of modern forms of energy.

b. Description of the main research questions (research potential) in the sub-field

- What is the impact of standards on costs of electrification?
- Can standards be relaxed to reduce costs?
- What would be the impact of relaxing voltage standards on appliance/equipment performance and ageing?
- Can use of DC be standardised to reduce costs?
- How can the costs of different electricity generation technologies (PV, min/micro hydro, bio energy, etc.) be reduced?
- How can the question of sustainability be enshrined within a holistic energy delivery system?
- How can energy development be cast in the context of integrated development with provision of essential services including food, water, shelter, health care, education and sanitation?
- What policies would best support integrated development?

c. State of the art

There are several courses and some research on renewable energy across the African continent. Many tend to focus on technical aspects of renewable energy and its use. There are not many research programmes that strongly focus on

energy economics and policy aspects of renewable energy. The issues of project financing and challenges associated with this are not well researched. Some courses cover elements such as power purchase agreements and procurement. There is a clear need to conduct research to explore alternative project development and economic models to accelerate electrification. Continuing with the status quo will not deliver the desired level of electrification to achieve significant and impactful change and still leave many people on the continent without access to modern forms of energy in their homes.

d. Main challenges/current research and implementation deficits

- Lack of skills and experience in integrated development.
- Lack of well-organised and well-resourced research support systems in most African countries.
- Apparent lack of belief amongst policy makers that research can indeed offer solutions to some intractable developmental challenges.
- Lack of research culture.
- Power & Energy research infrastructure – lack of state-of-the-art research tools and equipment.
- Lack of forums for sharing research results relevant for Africa.

e. Interaction with other research fields (especially the other PAUWES areas)

- Social sciences – community engagement in electrification projects.
- Cultural issues in electrification.
- Interplay between hydropower and utilisation of water for crop production.
- Riparian rights.
- Use of space for solar energy production versus use for crop production (could the space be used for both?)

2. Technological Development

By Lotfi Baghli

a. Specific relevance of the sub-field for Africa

Energy and its mastering are essential for any country, region or continent. For Africa, it is even more important because production facilities are few and do not cover all the needs.

Electrical energy transport and distribution also differ from region to region, particularly when we compare towns and rural regions in low-income countries.

The permanent access to this vital energy source is not guaranteed.

The industrial development and the services are largely based on the availability of electrical energy in terms of quality and continuity.

The cumulative lag with regard to energy access between Africa and European countries is considerable.

Large spaces and land access difficulties make the deployment of electrical energy expensive and difficult.

Vandalism and breach of connection standards weaken the structure and reliability of the power grid. Isolated and distant points require specific technology and energy policy (autonomy, isolated power grid, permanent islanding, battery or pumped hydroelectric energy storage).

We must conduct applied research rather than basic research. What is done in Europe or in the United States must not be conducted in Africa. The necessary means, the academic environment and the industrial R & D centres do not exist.

b. Description of the main research questions (research potential) in the sub-field

In Africa, we need applied research and a technical economic approach. Senior researchers benefit from the experience and the progress of what was carried out in Europe and the US, particularly in the field of photovoltaics, CSP and partly hydroelectrics.

The addressed themes should contain:

- Comparative studies of PV solutions nowadays and future technologies (monosilicon, polysilicon, perovskite…) including economics.
- Study and development of smart autonomous supervision stations that log sunshine, temperature, rainfall, humidity, wind direction and speed, connected to a distant database with 3G, SMS or VHF in order to gather data for the whole of Africa. Systems need to be affordable and easy to deploy and maintain.

- Build information collection centres and provide data to researchers and partners (water, climate change and others) for their own research.
- Study of daily energy storage systems and for several days for small quantities (30 kWh to 200 kWh) using batteries or pumped hydroelectric storage.
- Study of batteries, lithium-ion technology and fuel cells, their technology and algorithms of state of charge (SOC).
- Search, in partnership with Water group, for possible sites economically valuable to implant pumped hydroelectric storage systems.
- Search for possible sites to install wind farms with different region models (bush, Sahara, tropical, steppes, and ocean shore).
- Long-term research topic: HVDC technology for interconnecting African countries' power grids. DC can be a major solution for long-distance connection of power grids.
- Study of swarm of micro plants PV and wind and how they can be controlled in order to achieve the balance of power demand and power production combining classical (combined cycle, gas, coal) power plants.
- Development of optimised micro inverters of PV including GTI (Grid Tie Inverters) and autonomous inverters based on interleaved choppers. This would lead to size and weight reduction using the new high-frequency SiC based power electronics.
- Studies on using and sizing LED lighting and spreading its use in streets, building, offices and homes using a new generation of low-consumption LED bulb lamps. Moving from incandescent bulbs directly to LED bulbs without going through eco-fluorescent ones that have mercury (Hg). White LEDs have more than 200,000 hours of life, are low-cost and energy-saving.
- Research in small-scale energy harvesting (piezo, PV, walking, waves) to charge small Li-ion batteries, powered device for lighting (LED), mosquito killers (HV low/current), air cooler, occasional water pumping.
- Developing a new generation of low-cost, compact cylindrical solar cooking systems in order to produce and dispatch them in rural bush zones to avoid deforestation and consumption of wood for cooking.

c. State of the art

In African universities and engineering schools, PhD, Masters and engineer programmes are dealing with renewable energy. However, most of them are doing academic research using simulations with a lack of experiments. There is a huge need for testing the developed concepts and control algorithms on experimental benches and building prototypes.

Identifying these academic institutions is a major need. Then identify poles of excellence in each subtopic and encourage them by funding or by cooperating with the PAUWES research team avoiding duplication or reinventing the wheel.

PAUWES can be a link between African universities in the considered domain. It will set up this cooperation and proceed to build a network for researchers.

d. Main challenges/current research and implementation deficits

- Too many simulations and absence of experiments due to non-existing or expensive benches and lack of know-how to run them.
- Absence of industry cooperation with academics. There is a lack of trust from industrialists who have real problems to solve and do not need fundamental research level. The industrial needs somehow do not interest academics.
- Research whose first goal is to publish in peer reviewing journals without considering helping the local industry to solve basic problems.
- Bureaucracy overwhelming, financial mismanagement.
- No public/private investment on research projects.
- Social partners do not use public research results.
- African countries benefit from:
- Territorial availability of large spaces for testing and conducting new projects.
- High availability of primary energy sources (sun, wind and somehow water) to conduct experimental in- situ applied research experiments.

e. Interaction with other research fields (especially the other PAUWES areas)

Energy nexus and technology involve multidisciplinary research areas. Research can be conducted on different aspects. Data gathering, for example, is of interest for climate change, water and energy groups.

Building and spreading these devices on the entire continent, then collecting data and analysing them is useful for all research topics of PAUWES programmes and for health and food security.

Applied research on energy storage for small plants involves electrical technological aspects as well as fundamental and applied chemical research. Hence, a cooperation with local and foreign universities can be conducted.

Pumped Hydroelectric Energy Storage (PHES) systems cover many aspects of research in economics, geology, fluid mechanics and electrical technology. They are of great interest for both water and energy groups.

3. Energy Stakeholders and Society

By Adoniya Benaya Sebitosi

a. Specific relevance of the sub-field for Africa

Energy impacts on every aspect of society. For stable, sustainable livelihoods energy supply must be secure, accessible, affordable and environmentally sustainable. Numerous challenges such as limited resources, increased demand, skills shortages, economic hardships and climate-related constraints abound in Africa. The role of science and research is to offer solutions and interventions that will improve the quality of life. This is best achieved by access to accurate data. Public attitudes, perceptions, beliefs and knowledge have profound effects on the success (or lack) of any interventions. Moreover, it is societal choices that impact on the important aspects such as increase in demand which, in turn, impacts on security of supply as well as ease of access.

Traditional models for solutions which are typically top-down have been found to be wanting and the modern trend is to move more towards stakeholder involvement. Engagement of key stakeholders helps to identify and understand the vital issues that need to be addressed. Stakeholders include government (in particular policy makers and legislators), industry, NGOs, civil society, business and public administrators as well as other collaborating academia.

b. Description of the main research questions (research potential) in the sub-field

The process/journey of research/exploration into a subject area is what enables discovering the deep and relevant research questions as one's comprehension of the subject area evolves.

However, the following questions are pertinent and can assist as a preamble to the subsequent exploratory journey.

How complex are the issues to be addressed? (We attempt to describe the problem and its extent.)

- What processes (or interventions) are already in place (or have been tried) for resolving (or mitigating) the issues and how well are they working?
- What is the geographical location and scale of the issue?
- At what levels of societal structure is the consultation process to operate most effectively?
- What resources are available in terms of time, money and human skills?
- Will external professional facilitators or consultants need to be employed? If so, in which disciplines?
- What are the timelines and expected milestones?

c. State of the art

Traditional top-down decision-making structures entail the model that is called DAD (Decide, Announce and Defend). This can be seen as one source of a gap in trust between policy makers/implementers and society and leading to poor results. The trend is now towards DEAD (Decide, Educate, Announce and Defend). This, however, bears its own challenges. It has therefore been necessary to develop tools to tackle these challenges.

Methods and Tools[1]:

A wide variety of different methods to support participatory development is used by development partners and tailored to different tasks and situations. They include workshop-based methods and community-based methods.

Method for stakeholder consultation:

Beneficiary Assessment (BA) and Systematic Client Consultation (SCC) are techniques that focus on listening and consultation among a range of stakeholder groups.

Methods for social analysis:

Social factors and social impacts, including gender, culture, religion and race issues, among others, should be a central part of all development planning and action.
Example: participative back casting tool.[2]

d. Main challenges/current research and implementation deficits

What is involved must be understood. The processes may include policy and law making, spatial and strategic planning, resource management planning, licensing of industry and, therefore, stakeholder participation is an essential part of developing a sustainable future.

However, some concepts (such as multi-disciplinary issues) may be abstract for some students who may on occasion

be required to find solutions outside their traditional areas of discipline. In addition, there may be numerous practical field challenges with stakeholder engagement.[3]

- Stakeholders may not always want to be involved in a decision-making process.
- The necessary timelines (and/or practical pace) may fall outside the allotted course duration.
- Policies may not be in place (or updated) to take advantage of fast changing technology horizons.
- Certain powerful vested interests may frustrate participation of others.
- Certain stakeholders may also want to become involved at different stages of the process.
- Many experiences have shown that stakeholder dialogue can be messy, disjointed and even chaotic at times.
- Case example: traditional hydropower generation is currently severely affected in Eastern and Southern Africa. Worst examples are Tanzania and Zambia. Solar offers and very credible intervention, but its uptake faces challenges. Experience in Zambia reveals reluctance of individual consumers to invest in own solar power generation systems.
- Lack of modern weather data makes it hard to convince authorities to act in time.

e. Interaction with other research fields (especially the other PAUWES areas)

Energy is a multi-disciplinary field that involves all aspects of society. The student will most likely have an engineering background but will be required to have some reasonable appreciation of how society issues such as economics, politics, culture and religion will impact on the outcomes of technical interventions. It is therefore necessary to learn how to incorporate complementary components from other contributors with the diverse skills that may be necessary for a given scenario of context. For example, what is the cost analysis or environmental or cultural impact of a given solution/ intervention is almost invariably vital to the sustainability of an intervention.

4. Energy, Water, Food Security and Climate Nexus

By Driss Zejli

a. Specific relevance of the sub-field for Africa

- Electrification of the continent.
- To guarantee the food security.
- To face the scarcity of water.
- The heavy dependence of energy generation on water and the similar dependence of water treatment and distribution on energy.
- No access to an improved source of water.
- Evolution of fresh water availability over time.
- Impact of climate change on African countries.

b. Description of the main research questions (research potential) in the sub-field

- Linkage between energy, water, food, agriculture, climate change and security.
- Alternative sources of water.
- The water footprint.
- Improvement of accurate, fine-scale, site-specific data.
- Reducing the use of water through a shift to low water consuming crops.
- Rain water harvesting.
- Implementation of low-cost soil moisture and nitrogen sensors to improve irrigation efficiency and reduce fertiliser use and ground water pollution.
- Dry cooling in CSP plants.
- Solar and wind pumping for agriculture.
- Development of efficient water management practices such as alternate wetting and drying irrigation practices.
- Renewable energy powered desalination.
- Energy efficiency in building.
- Thermal characterisation of buildings.

- Establishment of a standard energy accounting system.
- Electrical Network's Modelling and Simulation.
- Smart grids.
- Optimisation methods (Artificial Neural Network method).
- Biofuels.

c. State of the art

- Very few institutions are already working on the nexus in Africa. This is the case of the WWF South Africa.
- For many years, the policy management of water and energy has been conducted in the same ministry in some countries like Cameroon, Ethiopia, Morocco, and Rwanda
- Merging of the water and electricity authorities in one agency in Morocco

d. Main challenges/current research and implementation deficits

- Lack of skills.
- Lack of data.
- Lack of networks between African universities.
- Lack of research platforms.
- Lack of real will in investing in scientific research.
- The nexus is an emerging concept.
- High degree of diversity in Africa: its main wealth (linguistic, socio-cultural, climate and resource endowments).
- Energy divide: between the continent and the rest of the world; between different regions of the continent; between exports and local consumption; in modern and efficient technologies used.

e. Interaction with other research fields (especially the other PAUWES areas)

- Climate change.
- Water.

5. Energy Resources Assessment

By Cherif Ould Lahoucine

a. Specific relevance of the sub-field for Africa

- Reliable energy resource estimates are the foundation of energy planning – this includes *"conventional"* energy sources or fossil fuels as well as renewable sources. The assessment of current and future production of fossil fuels has been undertaken for many years on different scales by using elaborate methodologies.
- However, for all the African countries, comprehensive approaches for estimating national energy production potentials from renewable energy sources are still few and often not transparent.
- For the majority of African countries, existing statistical data on energy supply and demand have a large uncertainty. Therefore, new measurements using advanced techniques are needed.
- No complete and transparent account of renewable energy potentials of African countries is freely available (despite a number of country assessments and a large amount of available raw data).

b. Description of the main research questions (research potential) in the sub-field

- How can we assess the theoretical potential of renewable energies (solar, wind, geothermal, hydro, and biomass), in each African country, in the five regions (north, east, west, central, and southern) and at the continental scale?
- How can we assess the geographical potential of renewable energies (solar, wind, geothermal, hydro, and biomass), in each African country, in the five regions (north, east, west, central, and southern) and at the continental scale?
- How can we assess the technical potential of renewable energies (solar, wind, geothermal, hydro, and biomass), in each African country, in the five regions (north, east, west, central, and southern) and at the continental scale?
- How can we assess the economic and implementation potential of renewable energies (solar, wind, geothermal, hydro, and biomass), in each African country, in the five regions (north, east, west, central, and southern) and at the continental scale?
- What are the linkages between climate change and the renewable energy potential in Africa (solar wind, hydro, and biomass)?

---

[1] The World Bank participation sourcebook

[2] Involve (2005), People & participation – How to put citizens at the heart of decision-making, Beacon Press.

Steyaert, S and Lisoir, H (2005) Participatory methods toolkit – A practitioner's manual, King Baudouin Foundation and Flemish Institute for Science and Technology Assessment

c. State of the art

- A limited number of universities, research institutions and regional organisations in Africa, as well as some international organisations are already working on Energy Resource Assessment. Among all these, IRENA is certainly the one which is deeply involved in assessing the renewable energy potential in Africa. An example of such effort is the recently published report entitled *"Estimating the Renewable Energy Potential in Africa: A GIS-based approach"*. PAUWES needs to work closely with IRENA.

- Another institution is JRC of the European Union. JRC functions as a reference centre of science and technology for the Union. This institution published many research reports on the renewable energy sector in Africa. For the assessment of RE in Africa, in 2011 they published *"Renewable Energies in Africa: current knowledge"* edited by F. Monforti. It attempts to estimate the technical potential of available resources of solar, wind, biomass and hydropower which could be economically used to provide energy for the increasing population. Connection with JRC, the UNEP, UNIDO, and the International Energy Agency is highly desirable.

- In Africa, the following institutions are deeply involved in research regarding the assessment of renewable energy potentials: Centre for Renewable and Sustainable Energy Studies CRSES (Stellenbosch University, South Africa), CDER (Algiers, Algeria).

- There were *"some"* African higher institutions offering renewable energy programmes at both the undergraduate and postgraduate levels. Masters in renewable energy are offered by about 20 African universities such as the Stellenbosch University, South Africa, University of Zimbabwe, Makerere University in Uganda, the University of Dar es Salaam in Tanzania and Mekelle University in Ethiopia, and PAUWES needs to identify all these institutions.

- Collaboration with the National Renewable Energy Laboratory (Department of Energy, in Boulder, Colorado, USA) to develop the equivalent of the Geothermal Prospector, a web-based geographic information system (GIS) application, to support resource assessment and data exploration for the U.S. Department of Energy's (DOE) Geothermal Technologies Office. The online tool provides the information needed to allow users to determine locations that are favourable to geothermal energy development.

- PAUWES should aim to become a Centre of Excellence for Africa.

d. Main challenges/current research and implementation deficits

- Data gaps; the current available data is inadequate and declining; generally with restricted usage from many National Meteorological and Hydrological Services (NMHSs); formats of data often not very useful; there is much untapped historical data that needs to be rescued (among others, through digitisation).

- In order to develop a renewable energy database for Africa, ground measurements are needed as well as the freely available open-source GIS maps. The GIS data needs to include their respective uncertainties and spatial resolutions. The measured (remote sensing) data and the GIS maps data will be compared in order to assess their corresponding accuracy. The hope is that the data, together with the corresponding national energy models, will give governments and decision makers a basis to work from when elaborating energy and cost-efficient roadmaps for the future.

- Remote sensing data are complicated (technical aspect), difficult to perform (security aspect) and generally the equipment is expensive and beyond the financial capability of the majority of African countries. GIS maps data may therefore be used for preliminary assessment of renewable energy sources whenever ground measurements are not possible (or difficult to perform).

- There are limited human resources to produce, analyse, interpret and disseminate different renewable energy data (temperature, radiation, wind speed, geothermal, biomass, etc.).

e. Interaction with other research fields (especially the other PAUWES areas)

- There is need for inter/multi-disciplinary research in PAUWES (e.g. nexus energy, water, and economy).

- Co-supervision of Master and Doctoral students in inter/multi-disciplinary research in PAUWES (agriculture, water, energy, economy, sociology).

- Exchange of professors and organisation of special lectures and workshops within different PAUWES institutes to help the cooperation to be effective.

[3] This listing is by no means exhaustive as more accurate reality will be encountered during the research process.

Appendix IV: Climate Change Working Group Fact Sheet

1. Climate Modelling, Downscaling and Prediction

By Christopher Olude

a. Specific relevance of the sub-field for Africa

- Climate information is critical for various sectorial applications (agriculture, water, energy, health, infrastructure, etc.), yet there is limited expertise in climate modelling, downscaling and prediction on the continent.
- Data is critical for climate modelling, downscaling and prediction. However, there are many data gaps in Africa hence the need for improved and enhanced data access, data rescue, digitisation and quality control.
- Africa's climate has not been fully understood, and consequently global and regional factors that influence the African climate need to be researched in greater depth.
- There is at best limited expertise in Africa on short, medium and longer timescale climate forecasts, predictions and projections.

b. Description of the main research questions (research potential) in the sub-field

- What type of climate information (downscaled/ prediction) is needed by the different sectors for their day- to-day operations and how can these be generated to suit their needs?
- How can Africa solve its climate data problems?
- What type of climate models, downscaling and prediction techniques are relevant for Africa?
- What are the global and regional factors influencing the African climate?
- How will future climate scenarios impact on the various sectors in Africa?
- What are the linkages between climate change, demography, and food and water security?
- What are the adaptation options for Africa under a changing climate?

c. State of the art

- A limited number of universities, technical colleges, research institutions and regional organisations in Africa are already working on climate modelling, downscaling and climate predictions. There is need (for PAUWES) to identify these institutions for purposes of collaboration, networking and to avoid duplication of efforts.
- Climate modelling and the provision of climate information are already being undertaken by various regional institutions in Africa such as ICPAC, ACMAD, SADC-CSC, AGRHYMET, WASCAL, SASSCAL, etc.
- Several universities on the continent, like the University of Nairobi, offer degree courses at MSc and PhD level in Climate Change Science, and PAUWES needs to identify these institutions.
- PAUWES should aim to become a Centre of Excellence for Africa.

d. Main challenges/current research and implementation deficits

- Data gaps; inadequate and declining data; restricted usage of data from many National Meteorological and Hydrological Services (NMHSs); formats of data often not very useful; there is much untapped historical data that needs to be rescued (among others, through digitisation); there are limited human resources to produce, analyse, interpret and disseminate climate data.
- Global models such as the General Circulation Models (GCMs) have limited use for/in Africa as they only provide an overview of how the climate is likely to be and in particular lack regional details. This is a major challenge and African institutions therefore need to work closely with global climate centres such as ECMWF, UK Met office, etc. to develop regional downscaled climate models that are relevant for Africa.
- The spatial and temporal resolution of climate data is also a challenge. Data outputs from GCMs are very coarse in their spatial resolution (250 x 250 km), which explains their limited applications in Africa.
- Access to re-analysis of data in Africa is also a major challenge: these are gridded data sets mostly on a 0.5 degrees spatial resolution; re-analysed climate data is very important for Africa and can be combined with remote sensing data (MODIS) for better spatial coverage. There is need for capacity building in the use of these data sets.

e. Interaction with other research fields (especially the other PAUWES areas)

- There is need for inter/multi-disciplinary research in PAUWES (e.g. nexus energy, water, food security, health).
- Undertake climate impact modelling (interdisciplinary and transdisciplinary; land use, human settlements, urbanisation, water, etc.).
- PAUWES will need to find appropriate fields of specialisation/ expertise/ excellence amongst other universities, research institutes, networks, WASCAL, SASSCAL, etc. based on its specific objective and comparative advantage.

2. Adaptation Research

By Laurent Sedogo

a. Specific relevance of the sub-field for Africa

More than 70% of the population in Africa lives in rural areas with agriculture as the main land use source of livelihood. Agriculture is dominated by a combination of semi-subsistence, rainfed cereal cropping and livestock practices, but these are under severe threat by climate change and climate variability (CC & CV). The predicted impacts of CC & CV in Africa underline food and water insecurity and negative impacts on ecosystems services such as the provision of clean water, soil health, carbon sequestration, or services related to biodiversity that will certainly negatively impact on livelihood security. On the other hand, climate predictions for West Africa are, compared to other regions worldwide, highly uncertain especially when it comes to rainfall predictions, which hinders subsequent decision-making on the local, national or regional level. Therefore, there is an urgent need for research in adaptation to CC & CV in Africa to provide policy and decision makers with sound programmes for sustainable development.

b. Description of the main research questions (research potential) in the sub-field

- Generating robust and reliable climate change projections for Africa with improved information on different scales, and reducing the uncertainties of climate change scenario prediction.
- Determining the impact of CC & CV and land use on the hydrological cycle and scenario development for adaptation, and mapping of African land cover and changes in enhanced spatial and thematic detail as compared to existing global and regional products.
- Predicting seasonal water body dynamics in Africa, and how to analyse the relation of surface water extent dynamics, land use and CC & CV.
- Identifying regions of decline or increase in vegetation cover and their relation to land use and/or CC & CV and studying the vulnerability of agricultural systems (especially rainfed cereal cultivation and pastoralism systems) and building scenarios of resilience and adaptation measures to reduce climate risks.
- What contribution of each system to food security through subsistence and market participation under CC & CV scenarios.
- Regional and national policies and institutions for CC & CV adaptation.
- Identifying/mapping vulnerable people, crops and infrastructure and adaptation measures (socio-economic, land use) for reducing damage and vulnerability to disaster; adoption studies and impact assessments of adaptation measures.
- Analysing risk and insurance concepts and safety net options and their impacts on adaptation policies.
- Resilience and continuous adaptability of the different agro-climatic zones and cultivation-area mosaics to climate variations, in relation with changing conditions of social ecological systems.
- Impact assessment framework based upon models at different scales in the context of adaptation strategies and policies.

c. State of the art

- Despite the present generation of global and regional climate models being relatively accurate in predicting temperature change over Africa, their rainfall projections are still highly uncertain.
- Land use/cover changes need to be better quantified in terms of their influence on climate-relevant biogeophysical land surface properties (essential climate variables, e.g. albedo, vegetation and leaf structure, net primary productivity).
- While models enable virtual experimentation with the most promising management options to build food security under future climatic scenarios, reliable datasets to enable adequate calibration for the most relevant crops and management options under expected climatic conditions are missing.
- Address the knowledge gap of using sciences to enhance policy making and formulation is also urgent and challenging.

d. Main challenges/current research and implementation deficits

- The need towards an increase of the capability of these models in providing useful projections for impact studies and to develop protocols and methods to generate more robust and reliable climate change projections for the 21st century accounting for the impact of future greenhouse gas, aerosols and land use/land cover dynamics.
- Quantifying and reducing the uncertainties on climate change scenarios, provide information at the regional/local level for the impact assessment and end-users community and better understand key processes and feedbacks relevant for climate change in Africa.
- Studying the impact of climate and land use on components of the hydrological cycle and on the availability of water sources (e.g. ground water and surface water) under the predicted changing conditions, and investigating the implications of such changes on water resources management.
- Testing key crops and potential management options for adaptation over a range of agro-ecological zones under CC & CV conditions.
- Research on "Policies and Institutions" in Africa is needed for better definition of adaptation strategies, including studies of institutional constraints that impede effective mainstreaming of CC programmes into sectoral development plans and strategies, research on green-economic instruments and policies, on the politics of CC adaptation policies, and to better understand how domestic resources (private and public) can be mobilised to manage CC & CV.
- Tackling challenging issues in integration including the scaling and how to (i) upscale from pixel to administrative units such as to a regional scale and (ii) determine the relevant scale to apply a specific policy or measures for promoting relevant goods and services.

e. Interaction with other research fields (especially the other PAUWES areas)

Studies on the impacts of CC & CV, land use, water resources and ecosystem services on the energy sector and impacts for sustainable development are highly needed.

3. Vulnerability Assessment

By Christopher Shisanya

a. Specific relevance of the sub-field for Africa

- Many people in Africa do not fully understand the impacts of climate change and/or how to plan for them.
- Climate change vulnerability assessment can help people review, challenge, and verify existing assumptions about climate change impacts at different scales.

b. Description of the main research questions (research potential) in the sub-field

- What are the most effective strategies for improving resilience of households to climate change?
- Which household production systems in Africa are most vulnerable to climate variability?
- How will the vulnerability of households change in the short and long term?
- What key factors make households of different livelihood strategies vulnerable?
- What adaptive strategies are available to households in Africa, and how well will they reduce vulnerability to climate change in the short and long term?
- What are the institutional options for strengthening successful local adaptation?
- What are the research and extension options for strengthening local adaptation?

c. State of the art

- Very few institutions in Africa (universities, research centres) are engaged in vulnerability assessment studies. This provides an opportunity for PAUWES to contribute towards filling this lacuna in knowledge.
- Some key universities on the continent are offering postgraduate courses (PhD & MSc) in climate change issues, with components of vulnerability assessment inbuilt in the curriculum. These universities include: University of Nairobi in Kenya, Kenyatta University, Makerere University. PAUWES needs to identify some of these key universities and enter into some arrangements to collaborate in aspects of vulnerability studies.

d. Main challenges/current research and implementation deficits

- Definitions and frameworks of vulnerability assessment: need to clearly distinguish between contextual vulnerability and outcome vulnerability.
- Measuring vulnerability: conceptual issues, measuring the exposed elements, measuring the climate stressors.
- Methodological challenges for spatial vulnerability assessments: developing acceptable spatial indices, community-based and stakeholder-driven vulnerability mapping, climate impact mapping.
- Common issues with spatial vulnerability assessments: spatial resolution and spatial and temporal scale, relationships among the indicators and components, uncertainties, validation and decision support, cartography, map illustrations and risk communication.
- The USAID-ARCC is perhaps the only project that has undertaken regional climate change vulnerability assessments.

e. Interaction with other research fields (especially the other PAUWES areas)

Now that multidisciplinary and multidisciplinarity and transdisciplinarity are currently emphasised in research agendas, it is imperative that PAUWES follows this queue and embraces the same. Departments/schools of PAUWES should be encouraged to form research teams to develop research proposals that fulfil the above mentioned current research direction.

4. Risk Assessment

By Jakob Rhyner

a. Specific relevance of the sub-field for Africa

- The knowledge, assessment, and management of environmental risks on a local, national, and regional scale are crucial for a prosperous development.
- Risks occur when hazardous processes meet with the human habitat or economy. They have different facets, including biophysical (exposition), socio-economic and political (preparedness, coping and adaptation capacities).
- Climate change will have a significant impact on the development of environmental risks. However, the attribution of changes in risk to climate change in a specific context is often difficult or even impossible, partly due to insufficient understanding of the mechanisms and partly due to missing data and statistics. It is important to improve this understanding and to provide decision makers with a better evidence base.
- The socio-economic components of risks are often related to the so-called "root causes" such as poverty, conflicts, corruption, etc. For a comprehensive risk assessment, they need to be taken into account on equal footing with the weather and climate-related factors. Therefore, any risk assessment scheme needs to draw on natural as well as social sciences.
- A variety of risk assessment schemes are available. They can be used, but need to be adapted to local and regional contexts, particularly for the application to nexus questions.
- The problem of insufficient or even deteriorating measurement, observation, and monitoring networks on the African continent is severe. Solutions need to be found, by improving ground networks at least regionally, and promote and facilitate use of remote (satellite-based) data.

b. Description of the main research questions (research potential) in the sub-field

- Application of comprehensive risk assessment methodologies. Here, "comprehensive" means taking into account bio-physical as well socio-economic context, i.e. integrating natural and social sciences, the latter particularly with regard to the root causes (see above).
- Investigate if, when, and to what extent changes of risk patterns can be attributed to climate change.
- Of particular interest are applications to complex nexus contexts, where the methods may have to be adapted on a case-by-case basis.
- Particular emphasis on adapting methodologies to contexts with poor database.
- Development of innovative climate insurance schemes and their adaptation in local and regional context.
- (Further) development of tools and handbooks for risk assessment (will support the build-up of expertise and reputation).
- Generally, the research strategy in risk assessment should be guided by and streamlined into the research strategy in the water and energy domain (see the other fact sheets).
- The Sendai Framework for Disaster Risk Reduction (SFDRR) provides the worldwide framework and is to be used as a general guideline. The research needs for the implementation of the SFDRR are set out in the UNISDR Science and Technology Roadmap: http://www.unisdr.org/files/45270_unisdrscienceandtechnologyroadmap.pdf

c. State of the art

- There is an extensive body of research for risk assessment that has meanwhile found its way into several methodologies. To mention just two.
- The World Risk Index, developed and annually published by UNU-EHS in cooperation with the Alliance development works (http://worldriskreport.org/).
- UNDP Global risk identification programme (http://www.undp.org/content/undp/en/home/ourwork/crisispreventionandrecovery/projects_initiatives/global_risk_identificationprogramme.html).
- UNISDR Science and Technology Roadmap (see section 4).

d. Main challenges/current research and implementation deficits

- (See above) mainly poor data base.
- Missing networks to be built up, with PAUWES as a leading player!

e. Interaction with other research fields (especially the other PAUWES areas)

As mentioned in section 4, the research on risk assessment should not have a life of its own but should be streamlined into the programmes of the institutes, i.e. water and energy for PAUWES and its nexus questions.

Pan African University
Institute of Water
and Energy Sciences