Session 1: Introduction

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Training program

Overview

- Day 1: General overview, group discussions
  - Overview about the study
    - General method
    - New layers for ECOWREX
  - Data challenges & Lessons learned
  - Flow estimation & Hydropower potential
  - Climate change projections

- Day 2: GIS layers, group work, practice examples
  - Hydropower classification:
    - Plant type
    - Plant size
  - Practice examples
    - Installed capacity & energy calculation
    - Water balance & climate change calculation
Introduction

Background & Objectives

• Background
  – Shortage of reliable energy supply is a critical topic in the 15 countries of ECOWAS.
  – The potential for future hydropower development is assumed to be large, but exact data are missing especially for small-scale hydropower development.
  – This study supports the energy initiatives of the “ECOWAS Centre for Renewable Energy and Energy Efficiency” (ECREEE).

• General project objectives
  – Assess the hydropower potential of all rivers in the ECOWAS region.
  – Prepare various data layers for integration into ECREEE’s online platform ECOWREX, such that the study results are readily available to the general public.
  – Identify regions/rivers that are attractive for hydropower development to direct ECREEE’s streamflow measurement initiatives.
  – This study focusses on hydropower potential for small-scale hydropower at small rivers, in addition to assessment for large rivers.
Hydropower potential

Definitions

- **Gross theoretical** hydropower potential
  Hydropower generation if all natural water flows would be utilized by 100% efficient turbines.

- **Theoretical** hydropower potential
  Rough consideration of energy losses due to turbine efficiency, hydraulic losses (penstock, etc.).

- **Technical** hydropower potential
  Also considering spillway losses due to limited design flow of turbines.

- **Economic** hydropower potential
  Also considering economic restrictions (investment costs, energy prices).

- **Exploitable** hydropower potential
  Also considering environmental and social restrictions (protected areas).
Hydropower theory

Theoretical hydropower potential of a river reach

\[ \text{Power [MW]} = \text{Flow [m}^3/\text{s}] \times \text{Height [m]} \times c \]

- **Power**: Theoretical hydropower potential [MW]
- **Flow**: Mean annual discharge in reach [m³/s]
- **Height**: Elevation difference from start to end of river reach [m]
- **c**: Constant, typically \( c = 8.5/1000 \)
Hydropower theory

Aggregation of theoretical hydropower potential

- The theoretical hydropower potential is initially computed for each river reach.

- It gives the mean annual power (in MW) that could be produced in this river reach if a hydropower plant:
  - Utilizes the full head (elevation difference) in the reach
  - Turbinates the full river discharge (no spillway losses)
  - Turbine efficiency and hydraulic losses are already roughly considered

- Aggregation of theoretical hydropower potential:
  - River: Sum of theoretical hydropower potential of all reaches along the river
  - Basin: Sum of theoretical hydropower potential of main river and all tributaries in the basin
  - Country: Sum of theoretical hydropower potential of all basins in the country
Discharge measurement in West Africa

410 discharge gauges available for this study

- Discharge (along with slope) determines the hydropower potential of a river.
- Gauges usually located at medium/large rivers.
- Hardly any gauges located at small rivers that are suitable for small-scale hydropower.
- Gauge data cover different observation periods.
- Regionalization of flow is required.

GIS mapping & water balance modelling
River network

GIS delineation of river reaches

- **Method:**
  - Hydrosheds flow direction
  - GIS processing (> 2 km² threshold for reach delineation)
  - Eliminate reaches with no discharge (in arid regions)

- **500,000 river reaches in West Africa**

- **Delineate sub-catchments**
  - 1060 sub-catchments
  - Inland: > 3000 km²
  - At coast: > 1000 km²
  - Manual adjustments at reservoirs

- **Extract river elevation from DEM**

Example for Sierra Leone
Water balance modelling

Discharge estimation for 500,000 river reaches

- **Water balance model**
  - Spatially distributed
  - Routing along river network
  - Major losses:
    - Irrigation schemes
    - Floodplains

- **Inputs**
  - Rainfall
  - Potential evapotranspiration

- **Output**
  - Mean annual discharge for each reach

- **Calibration**
  - 410 gauges used for calibration / verification of results
  - Regional patterns of model parameters
Water balance modelling

Comparison of simulated vs. observed mean annual discharge at 410 gauges

GPCC data, 1950-2010
401 gauges with available \( Q_{\text{obs}} \)
Theoretical hydropower potential
Computed for 500,000 river reaches

\[
Power \ [\text{MW}] = \ Flow \ [\text{m}^3/\text{s}] \times Height \ [\text{m}] \times c
\]
CORDEX Africa climate change analysis

2046-2065 vs. 1998-2014

Annual Precipitation

Air Temperature

Annual Runoff

Change [%]
-15.1 - -10.0
-9.9 - -5.0
-4.9 - -3.0
-2.9 - -1.0
-0.9 - 1.0
0.1 - 3.0
3.1 - 5.0
5.1 - 6.8

Change [°C]
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1

Change [%]
-46.8 - -20.0
-19.9 - -15.0
-14.9 - -10.0
-9.9 - -3.0
-2.9 - 3.0
3.1 - 10.0
10.1 - 15.0
15.1 - 20.0

Median projection out of 30 climate model runs.
Results overview

New layers for ECOWREX system

- Existing hydropower plants layer
- Climatic zones layer
- River network layer
- Sub-areas layer (Sub-catchments)
- Country reports
- Climate change (incorporated into other layers)
New layer: Existing hydropower plants

GIS point shape file

- 91 HPPs:
  - 24 large HPPs (> 100 MW)
  - 17 medium HPPs (30-100 MW)
  - 50 small HPPs (< 30MW)

- ~20 attributes (installed capacity, start year, reservoir area, etc.)

- Data sources:
  - ECOWREX, GranD, Aquastat, H&D, JICA, SHP News, World Small HPP Development Rep., Int. Water Power & Dam Yearbook, SE4ALL, online search, etc.
New layer: Existing hydropower plants

Attribute list for 91 HPPs

- Name: Name of HPP.
- Name_alt: Alternative name, if known.
- Country: Country of location of the HPP.
- ISO: Three letter country name acronym.
- Existing: Main status division (yes/no), further divided in the status attribute (see status attribute).
- Hpp_class: Capacity class according to the ECOWAS classification (small < 30MW, medium 30-100 MW, large > 100 MW).
- Status: Describes the status of the HPP in six categories: operational, under refurbishment, under construction (these three have the value Yes in the Existing attribute); identified, planned, proposed (these three have the value No in the Existing attribute).
- Lat: Latitude (decimal degrees North) of the location, snapped to river network.
- Lon: Longitude (decimal degrees East) of the location, snapped to river network.
- River: Name of the river where the HPP is located.
- River_alt: Alternative river name, if applicable.
- Year: Year of start of operation for existing HPPs. Estimated for HPPs under construction and under refurbishment.
- Dam_height: Height (m) of the main dam for existing HPPs.
- Cap_Instal: Installed capacity (MW) for operational HPPs and HPPs under refurbishment.
- Cap_Availa: Currently available capacity (MW) for operational HPPs.
- Cap_Planned: Planned capacity (MW) for HPPs under construction and under refurbishment.
- Volume: Reservoir volume (hm³) for existing HPPs.
- Lake_area: Reservoir area (km²) for existing HPPs.
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New layer: Climatic zones

GIS polygon shape file

- 6 climatic zones

- Classification
  - L’Hôte et al. (1996)
  - Based on rainfall characteristics

- GIS generalization & smoothing

- Data sources
  - Rainfall: TRMM 1998-2014
  - Air temperature: CRU 1998-2013
  - Potential evapotranspiration: CRU 1998-2013
New layer: Climatic zones

Attribute list for 6 climatic zones

- CLZ_ID: ID of climatic zone
- NAME_FR: Climatic zone denomination in French
- NAME_ENG: Climatic zone denomination in English
- PRECIP_Y: Mean annual precipitation (mm) in the period 1998-2014
- TEMP_Y: Mean annual air temperature (°C) in the period 1998-2014
- ETP_Y: Mean annual potential evapotranspiration (mm) in the period 1998-2014
- P_2035_P25: Change in future mean annual precipitation in % (2026-2045 vs. 1998-2014) for the lower quartile projection of 30 RCMs
- P_2035_P50: Change in future mean annual precipitation in % (2026-2045 vs. 1998-2014) for the median projection of 30 RCMs
- P_2035_P75: Change in future mean annual precipitation in % (2026-2045 vs. 1998-2014) for the upper quartile projection of 30 RCMs
- T_2035_P25: Change in future mean annual air temperature in °C (2026-2045 vs. 1998-2014) for the lower quartile projection
- T_2035_P50: Change in future mean annual air temperature in °C (2026-2045 vs. 1998-2014) for the median projection
- T_2035_P75: Change in future mean annual air temperature in °C (2026-2045 vs. 1998-2014) for the upper quartile projection
- E_2035_P25: Change in future mean annual potential evapotranspiration in % (2026-2045 vs. 1998-2014) for the lower quartile simulation
- E_2035_P50: Change in future mean annual potential evapotranspiration in % (2026-2045 vs. 1998-2014) for the median simulation
- E_2035_P75: Change in future mean annual potential evapotranspiration in % (2026-2045 vs. 1998-2014) for the upper quartile simulation
- P_2055_P25: Change in future mean annual precipitation in % (2046-2065 vs. 1998-2014) for the lower quartile projection of 30 RCMs
- etc.
New layer: Climatic zones

2 figures attached to each climatic zone

Air temperature data source: Climate Research Unit (University of East Anglia), CRU TS 3.22, mean 1998-2013

PET data source: Climate Research Unit (University of East Anglia), CRU TS 3.22, mean 1998-2013
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- Existing hydropower plants layer
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New layer: River network

GIS line shape file
New layer: River network

GIS line shape file

Q [m³/s]
- 0.0 - 1.0
- 1.1 - 10.0
- 10.1 - 100.0
- 100.1 - 1000.0
- 1000.1 - 6325.6
New layer: River network

GIS line shape file

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New layer: River network

Attribute list for 500,000 river reaches, part 1/2

- ARCID: ID number of reach
- TOARCID: ID number of next downstream reach
- FROMARCID: ID number of dominant upstream reach (largest inflow)
- LAT: Latitude (decimal degrees North) at end of reach
- LON: Longitude (decimal degrees East) at end of reach
- NB: ID number of sub-area
- RIVER: River name (English)
- RIVER_FREN: River name (French)
- COUNTRY_1: Country (ISO code)
- COUNTRY_2: Second country (ISO code) if reach forms international border
- AREA: Total upstream catchment area (km²) of reach
- LENGTH: Length (km) of reach
- EXRIVER: Flag indicating external river originating from another sub-area (0: local river, 1: external river)
- ELEV_US: Elevation (m) at upstream end of reach
- ELEV_DS: Elevation (m) at downstream end of reach
- ELEV_DIFF: Elevation difference (m) in reach
- SLOPE: Slope (m/m) of reach
- POWER: Theoretical hydropower potential (MW) for the period 1998-2014
- POWER_SPEC: Specific hydropower potential (MW/km) for the period 1998-2014
- PLANT_SIZE: Preferred hydropower plant size (0: none, 1: <1MW, 2: 1-30MW, 3: >30MW installed capacity)
- ...

...
New layer: River network

Attribute list for 500,000 river reaches, part 2/2

- ...  
  - Q_YEAR: Mean annual discharge (m³/s) simulated for the period 1998-2014  
  - Q_JAN: Mean monthly discharge (m³/s) 1998-2014 in January  
  - Q_FEB: Mean monthly discharge (m³/s) 1998-2014 in February  
  - Q_MAR: Mean monthly discharge (m³/s) 1998-2014 in March  
  - Q(APR: Mean monthly discharge (m³/s) 1998-2014 in April  
  - Q_MAY: Mean monthly discharge (m³/s) 1998-2014 in May  
  - Q_JUN: Mean monthly discharge (m³/s) 1998-2014 in June  
  - Q_JUL: Mean monthly discharge (m³/s) 1998-2014 in July  
  - Q_AUG: Mean monthly discharge (m³/s) 1998-2014 in August  
  - Q_SEP: Mean monthly discharge (m³/s) 1998-2014 in September  
  - Q_OCT: Mean monthly discharge (m³/s) 1998-2014 in October  
  - Q_NOV: Mean monthly discharge (m³/s) 1998-2014 in November  
  - Q_DEC: Mean monthly discharge (m³/s) 1998-2014 in December  
  - Q_2035_P25: Change in future mean annual discharge in % (2026-2045 vs. 1998-2014) for the lower quartile simulation using 30 RCM runs  
  - Q_2035_P50: Change in future mean annual discharge in % (2026-2045 vs. 1998-2014) for the median simulation using 30 RCM runs  
  - Q_2035_P75: Change in future mean annual discharge in % (2026-2045 vs. 1998-2014) for the upper quartile simulation using 30 RCM runs  
  - Q_2055_P25: Change in future mean annual discharge in % (2046-2065 vs. 1998-2014) for the lower quartile simulation using 30 RCM runs  
  - Q_2055_P50: Change in future mean annual discharge in % (2046-2065 vs. 1998-2014) for the median simulation using 30 RCM runs  
  - Q_2055_P75: Change in future mean annual discharge in % (2046-2065 vs. 1998-2014) for the upper quartile simulation using 30 RCM runs
New layer: River network

Longitudinal river profiles for all reaches/rivers
Results overview

New layers for ECOWREX system

- Existing hydropower plants layer
- Climatic zones layer
- River network layer
- Sub-areas layer (sub-catchments)

- Country reports
- Climate change (incorporated into other layers)
New layer: Sub-areas (sub-catchments)

GIS polygon shape file

GIS Hydropower Resources Mapping for ECOWAS Region

Theoretical hydropower potential for small HPP (1-30 MW inst. capacity)
New layer: Sub-areas (sub-catchments)

Attribute list for 1060 sub-areas, part 1/3

- NB: ID number of sub-area
- AREA: local size (km²) of sub-area
- PRECIP_Y: Mean annual precipitation (mm) in the period 1998-2014
- ETA_Y: Mean annual actual evapotranspiration (mm) simulated for the period 1998-2014
- RUNOFF_Y: Mean annual runoff (mm) simulated for the period 1998-2014
- TEMP_Y: Mean annual air temperature (°C) in the period 1998-2014
- P_2035_P25: Change in future mean annual precipitation in % (2026-2045 vs. 1998-2014) for the lower quartile projection of 30 RCM runs
- P_2035_P50: Change in future mean annual precipitation in % (2026-2045 vs. 1998-2014) for the median projection of 30 RCM runs
- P_2035_P75: Change in future mean annual precipitation in % (2026-2045 vs. 1998-2014) for the upper quartile projection of 30 RCM runs
- E_2035_P25: Change in future mean annual actual evapotranspiration in % (2026-2045 vs. 1998-2014) for the lower quartile simulation
- E_2035_P50: Change in future mean annual actual evapotranspiration in % (2026-2045 vs. 1998-2014) for the median simulation
- E_2035_P75: Change in future mean annual actual evapotranspiration in % (2026-2045 vs. 1998-2014) for the upper quartile simulation
- R_2035_P25: Change in future mean annual runoff in % (2026-2045 vs. 1998-2014) for the lower quartile simulation using 30 RCM runs
- R_2035_P50: Change in future mean annual runoff in % (2026-2045 vs. 1998-2014) for the median simulation using 30 RCM runs
- R_2035_P75: Change in future mean annual runoff in % (2026-2045 vs. 1998-2014) for the upper quartile simulation using 30 RCM runs
- T_2035_P25: Change in future mean annual air temperature in °C (2026-2045 vs. 1998-2014) for the lower quartile projection of 30 RCM runs
- T_2035_P50: Change in future mean annual air temperature in °C (2026-2045 vs. 1998-2014) for the median projection of 30 RCM runs
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- P_2055_P25: Change in future mean annual precipitation in % (2046-2065 vs. 1998-2014) for the lower quartile projection of 30 RCM runs
- etc.
- ...
New layer: Sub-areas (sub-catchments)

Attribute list for 1060 sub-areas, part 2/3

- POWER: Theoretical hydropower potential (MW) for the period 1998-2014 (total of all river reaches located in the sub-area)
- POW_MINI: Theoretical hydropower potential (MW) for pico/micro/mini hydropower plants (< 1 MW installed capacity) for the period 1998-2014
- POW_SMALL: Theoretical hydropower potential (MW) for small hydropower plants (1-30 MW installed capacity) for the period 1998-2014
- POW_MEDIUM: Theoretical hydropower potential (MW) for medium/large hydropower plants (>30 MW installed capacity)
- ATT_MINI: Region with theoretical hydropower potential that is attractive (0: no, 1: yes) for pico/micro/mini hydropower plants (< 1 MW installed capacity)
- ATT_SMALL: Region with theoretical hydropower potential that is attractive (0: no, 1: yes) for small hydropower plants (1-30 MW installed capacity)
- ATT_MEDIUM: Region with theoretical hydropower potential that is attractive (0: no, 1: yes) for medium/large hydropower plants (> 30 MW installed capacity)
- PLANT_TYP1: Region suitable (0: no, 1: yes) for hydropower plant type 1 (run-of-river without diversion)
- PLANT_TYP2: Region suitable (0: no, 1: yes) for hydropower plant type 2 (run-of-river with diversion)
- PLANT_TYP3: Region suitable (0: no, 1: yes) for hydropower plant type 3 (storage without diversion)
- PLANT_TYP4: Region suitable (0: no, 1: yes) for hydropower plant type 4 (storage with diversion)
- MAC_MINI: Preferred machine type for pico/micro/mini hydropower plants (< 1 MW installed capacity)
- MAC_SMALL: Preferred machine type for small hydropower plants (1-30 MW installed capacity)
- MAC_MEDIUM: Preferred machine type for medium/large hydropower plants (> 30 MW installed capacity)
- ...
New layer: Sub-areas (sub-catchments)

Attribute list for 1060 sub-areas, part 3/3

- PT_2035_25: Change in future hydropower potential in % (2026-2045 vs. 1998-2014) for the lower quartile simulation using 30 RCM runs
- PT_2035_50: Change in future hydropower potential in % (2026-2045 vs. 1998-2014) for the median simulation using 30 RCM runs
- PT_2035_75: Change in future hydropower potential in % (2026-2045 vs. 1998-2014) for the upper quartile simulation using 30 RCM runs
- PL_2035_25: Change in future hydropower potential in % (2026-2045 vs. 1998-2014) of local rivers (originating from the same sub-area) for the lower quartile simulation using 30 RCMs
- PL_2035_50: Change in future hydropower potential in % (2026-2045 vs. 1998-2014) of local rivers (originating from the same sub-area) for the median simulation using 30 RCMs
- PL_2035_75: Change in future hydropower potential in % (2026-2045 vs. 1998-2014) of local rivers (originating from the same sub-area) for the upper quartile simulation using 30 RCMs
- PT_2055_25: Change in future hydropower potential in % (2046-2065 vs. 1998-2014) for the lower quartile simulation using 30 RCM runs
- etc.
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New layer: Country reports

14 text documents with maps, tables and figures

Guinea

Theoretical hydropower potential: 5875 MW

- Theoretical potential for pico/micro/mini HPP < 1 MW: 9%
- Theoretical potential for small HPP 1-30 MW: 28%
- Theoretical potential for medium/large HPP > 30 MW: 34%
- Not suitable: 29%
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