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Intra-ACP Climate Services and Related Applications Programme – ClimSA

WORKSHOP - SADC Region

WEFE NEXUS, Climate Variability, and Environmental Monitoring

South Africa, Johannesburg, June 10^{th} – 13^{th} 2024

Joint Research Centre

WEFE Nexus in Developing Countries

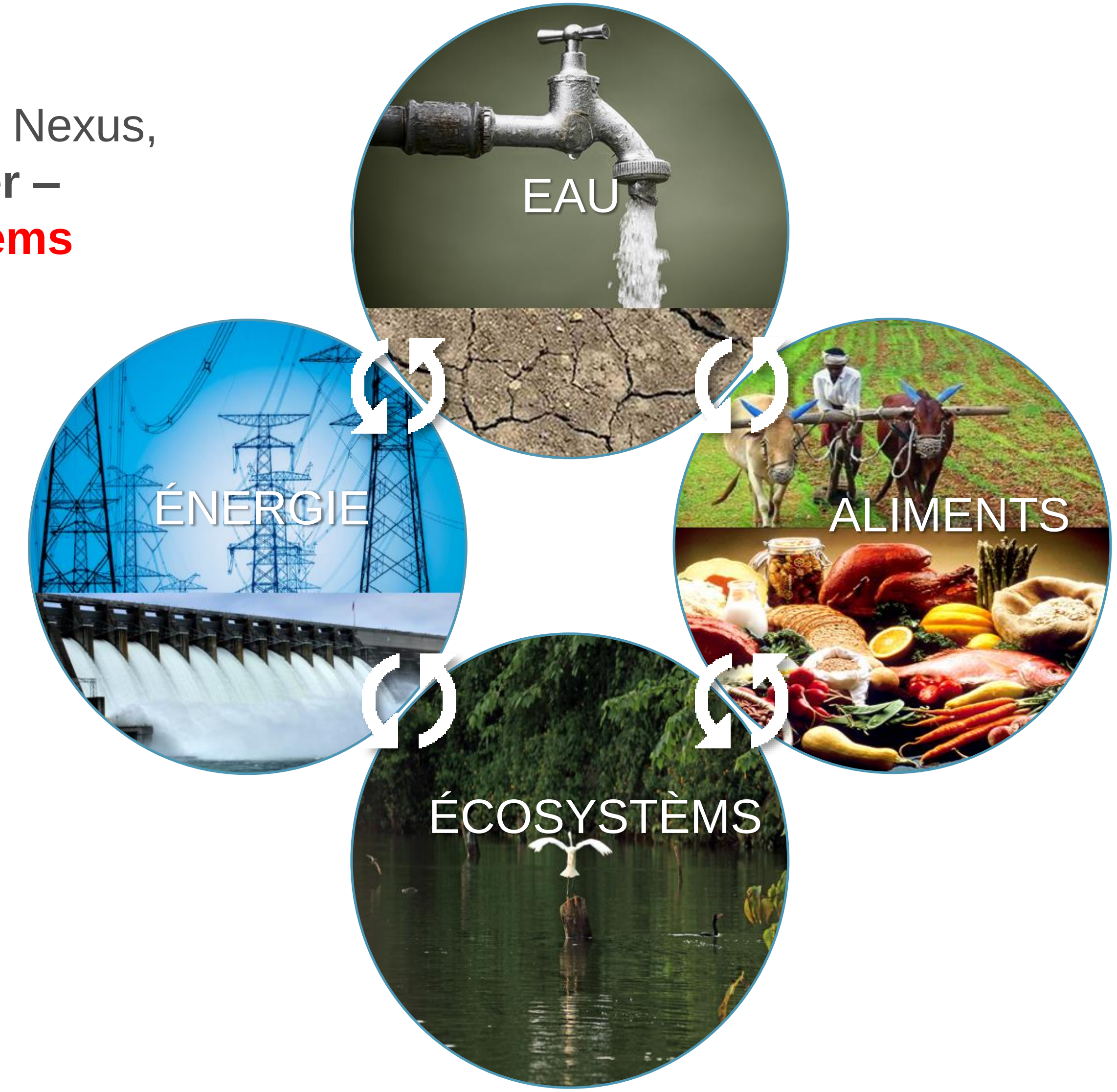
Marco PASTORI, et al.

South Africa, Johannesburg, June 10th – 13th 2024

WEFE NEXUS

Key words in a NEXUS approach:
"trade-off", compromise, synergies, efficiency, optimization, win-win.

The Water – Energy – Food Nexus, also referred to as the **Water – Energy – Food – Ecosystems** (**WEFE**) Nexus to explicitly recognize its environmental dimension



water, energy, agriculture, and natural ecosystems exhibit **strong interlinkages**

Emerged as a key framework to address complex resource and development challenges over the past 10 years.

Attempting to achieve resource security independently often endangers sustainability and security in one or more of the other sectors.

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Why Nexus and how does it differ from other approaches ?

WHY

Global and multi-sectorial crisis (food crises, cereals prices, oil petroleum higher costs, energy crisis, social issues, water crisis, climate high variability and change, uncertainty, etc.) have raised the awareness for a new holistic methodological approach

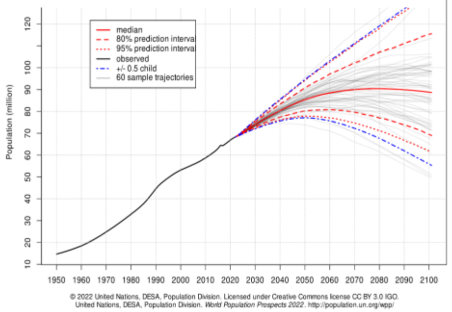
Current: Unmet **demands!**

- 2.2 billion people have no access to safe drinking water (2022) and 4 billion facing water scarcity (2016)
- 0.8 billion people have no electricity (2021)
- 2.8 billion people are food insecure (2023)
- 1.4 billion people affected by droughts (2002-2021)

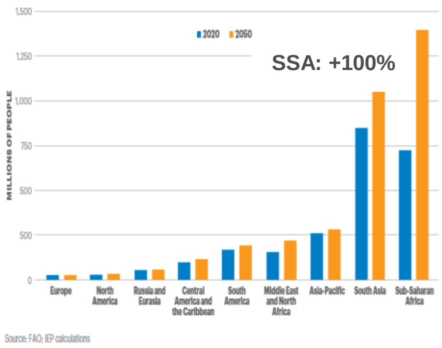
Future: **Increasing** demands!

- Due to population growth, economic development and changing consumption patterns
- The uncertainties of global change increase difficulty in meeting demands
- The food demand by 2050 will increase by 60% (1)

SOUTHER AFRICA POPULATION 2100



Food-insecure people: 2020-2050



Further general Issues:

- Food scarcity is still a major challenge
- Agriculture: still limited capability of productivity increase
- High pressure on water resources (population new habits and demands, urbanization, hydropower, irrigation and livestock, navigation, ..)
- Availability of land limited: loss of fertility, erosion, deforestation
- Strong dependency on oil and exhaustible resources
- Strong pressure on natural ecosystems
- All **tightened up** by **climate change** and **variability**

Why Nexus and how does it differ from other approaches ?

HOW

Not totally new concept

Systems analysis = understanding of **interactions i**nvolving natural resources, economic development, and livelihoods (Wichelns, 2017).

It is at the basis of many academic concepts and frameworks for attaining **sustainable use of natural resources**:

- **integrated** natural **resources management** (INRM)
- **integrated water resources management** (IWRM).
- Socio-ecological systems, coupled human-natural systems, socio-hydrology, …

But with several novelty

ADDED VALUE (WEFE and adopted approach)

- Trans-disciplinary research (**Equal importance** for **all sectors /** reconciling and **optimising** the needs associated with each resource)
- Deep-uncertainty (introduced by climate change)
- **Flexible** to adapt to **different contexts** (Multiple spatial scales)
- **Time dynamics and system complexity** (global markets, migration, …)
- Bilateral nature of sector linkages (although still mostly water-centric, at least at RB scale, as expected)
- **Policy coherence and inter-sectoral planning** (focuses on the issue of **access** to vital **resources** and the need of stakeholders)

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Why Nexus and how does it differ from other approaches ?

HOW

Why **Nexus** and how does it differ from **IWRM / GIRE**? - How it compares with **EU Consensus on Development**

COMMON ELEMENTS	IWRM / GIRE	Nexus	EU Consensus on Development
IMPROVE EFFICENCY AND SUSTAINABILITY	**WATER FOCUS**: deals primarily with the modalities for allocating this resource between competing uses	**EQUAL IMPORTANCE** for **ALL SECTORS**	Require collaborative efforts across sectors (make coordinated, accelerated and cross-sectoral efforts to end hunger: a holistic and cross-sector policy approach
Trade-offs and synergies	focus on the "**management" of water**, limited consideration of the political and economic aspects	Reconciling and optimising the needs associated with each resource	Enabling the transition to a circular economy. Transparent and accountable decision-making involving the civil society is key and common.
Access to resources (water, land, energy, food, etc.)	does not specifically address the issue of security of access to resources.	focuses on the issue of **access** to vital **resources** and the need of stakeholders.	Supporting access to land, food, water and energy avoiding any damaging effects on the environment
Spatial scale, boundaries	Normally confined at **River Basin level**	**Diversified**: global, national, bassins fluviaux, sub-basin, city	Diversified
Practice	IWRM is not, or only marginally, operationalized and put into practice. (implemented in Southern Africa)	Given the variability of issues and scales practice system not standardised. partnerships with other multilateral organisations	Strengthen their partnerships with multilateral organisations
Participatory approach	Stakeholder consultation	Stakeholder consultation. Policy and development cooperation forums	Stakeholder consultation; working more closely with all other relevant actors. greater coordination and coherence

WEFE NEXUS

"The WEF Nexus provides a holistic and integrated approach in order to secure access to water, energy and food in the long term."

Global Nexus Secretariat, 2020

- Encourages and "makes mandatory" **multidisciplinary working groups** over different thematic and cross sectorial elements along project development (*horizontal* coordination between different sectors // *vertical* coordination between different levels (local, villages, National, Regional/River Basin, International) (See working groups in the Mekrou and WEFE Senegal projects)

multi-sectoral cooperation

- Enabling Governance Dialogue: Inter-departmental involvements and dialogue across technical staff of RB authorities/Organisations/ Countries and Scientists (WORKSHOPs, HCD, Training, Webinar, Advisory boards)

policy coherence

- Raises public awareness and debate on the tradeoff of different sectors and demands

Transparency, democracy Policy legitimacy

WEFE NEXUS

"The WEF Nexus provides a holistic and integrated approach in order to secure access to water, energy and food in the long term."

Global Nexus Secretariat, 2020

- Encourages/requires **multi-stakeholder involvements** (see survey for socioeconomic needs in the Mekrou Project, Labs involvement for Water Quality task in the WEFE Senegal, Dissemination events with local population (all projects), etc.

- Ensures a **systemic approach** to environmental issues. Inherent approach, but not obvious. Water centric approaches in the past, disconnection between energy and agricultural sector, etc.)

- **Focus on efficiency**: optimal solutions must consider synergies and tradeoff ensuring "real" efficient use of natural resources (not component centric, as water optimized solution may require unsustainable use of land/energy…resources)

- It has proved (as based on our experience) its **capacity to identify intervention projects** Examples as based on our experience :
  MEKROU RB: 5 intervention projects were identified; WEFE-SENEGAL: 1 RB intervention project at the scale of the Senegal River Basin + 2 local intervention projects in the Fouta Djallon and Mali implemented by AICS + 4 research projects to improve knowledge)

trade-offs and synergies

Sustainable Development

Sustainable thinking

⇓

enabling multi sectorial intervention programmes

WEFE NEXUS

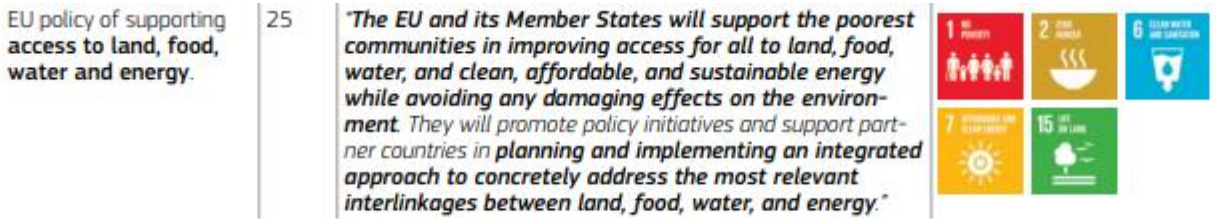
"The WEF Nexus provides a holistic and integrated approach in order to secure access to water, energy and food in the long term."

Global Nexus Secretariat, 2020

The Nexus approach is **also relevant for reaching global development goals** and supporting policy processes – such as those around the **Sustainable Development Goals (SDGs)**
A Nexus approach can therefore **act as an important enabler for different stakeholders in achieving the SDGs**

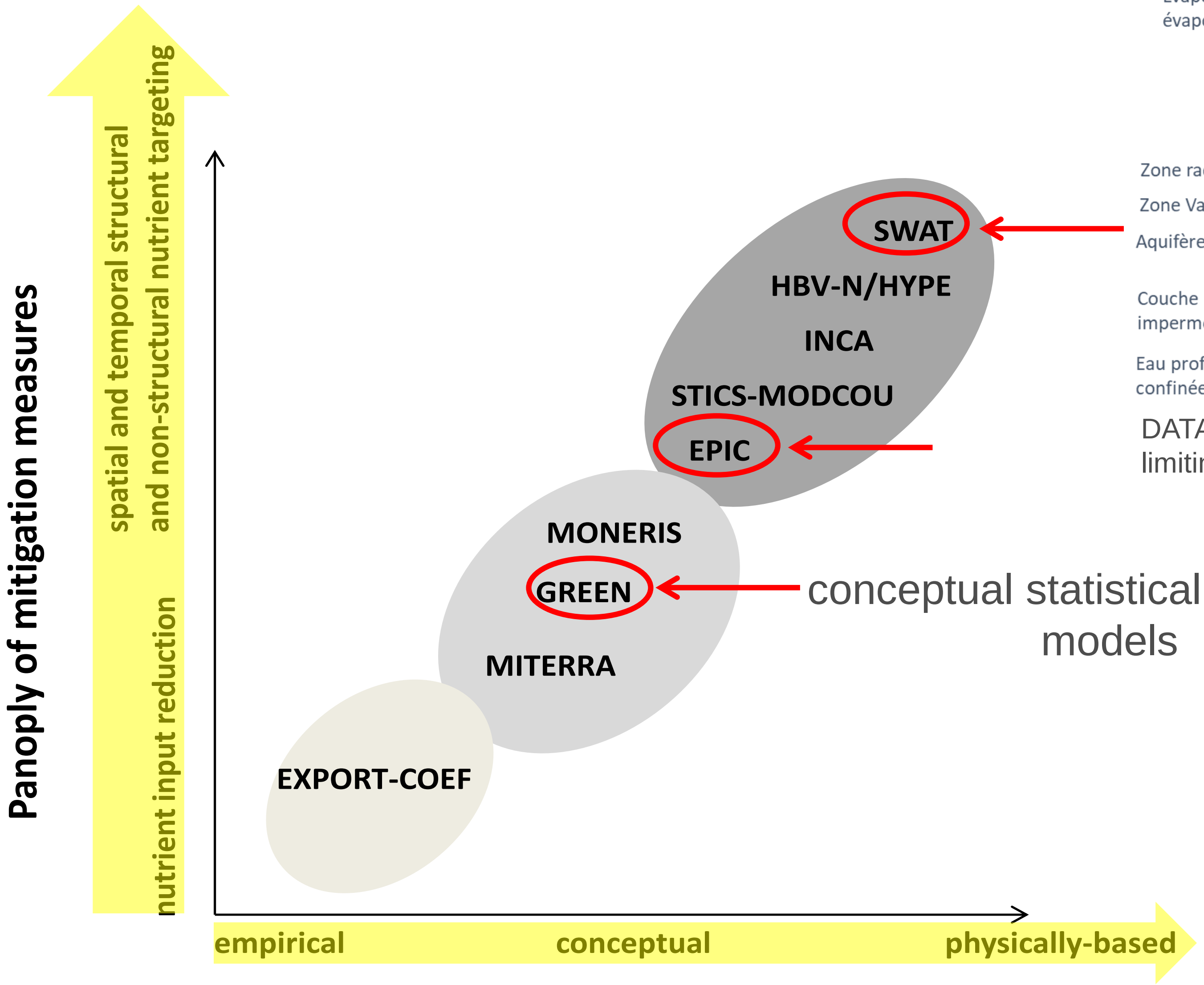
<u>Explicitly taking a WEF Nexus approach can help implementing the SDGs in the following ways:</u>

1) Support identification of **potential trade-offs** at the policy-design stage (e.g. targets related to food security, bioenergy) and consider these in policy-making processes → hence ensure that trade-offs are made transparent and will be minimized/prevented
2) Help **leverage synergies** in achieving overarching goals by supporting identification and implementation of solutions that benefit implementation of multiple SDGs → formulate policies and create incentive structures that favor such solutions
3) **Recognizing the interlinkages between the SDGs**, will ensure to pay attention to actions that meet multiple goals in a coherent way

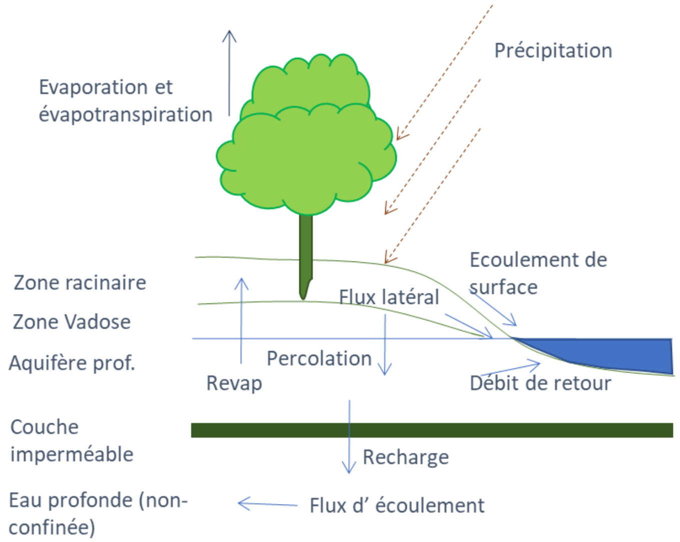


EU policy of supporting **access to land, food, water and energy**.	25	*"**The EU and its Member States will support the poorest communities in improving access for all to land, food, water, and clean, affordable, and sustainable energy while avoiding any damaging effects on the environment**. They will promote policy initiatives and support partner countries in **planning and implementing an integrated approach to concretely address the most relevant interlinkages between land, food, water, and energy**."*

WEFE and Modelling: objectives and scales

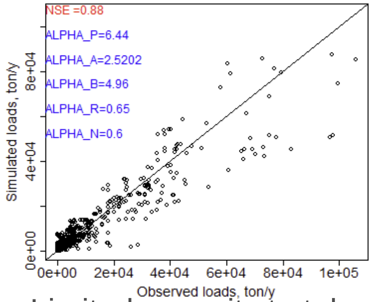


Physically based models



DATA availability at local scale is a common limiting factor / Time and resources constraints

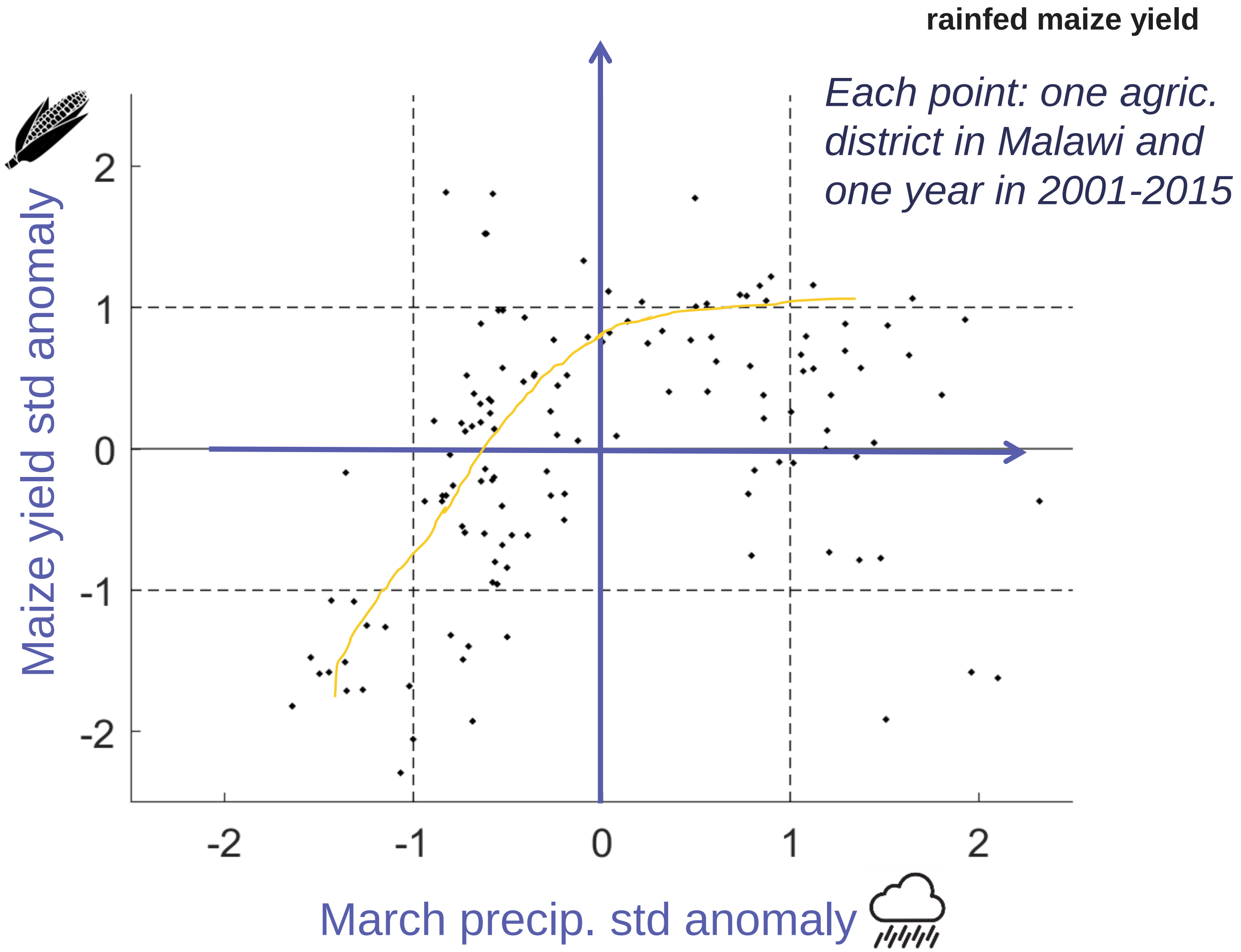
conceptual statistical regression models



Limited capacity to take into account new conditions, CC, or Nexus

Linking climate variability to socio-economic impacts

1) Infer correlations from historical records between one (or more) climate/weather index and a socio-economic index.



Note: correlations do not necessarily imply cause-effect relationships.

Anghileri, et al., 2022
https://doi.org/10.1016/j.agwat.2021.107375

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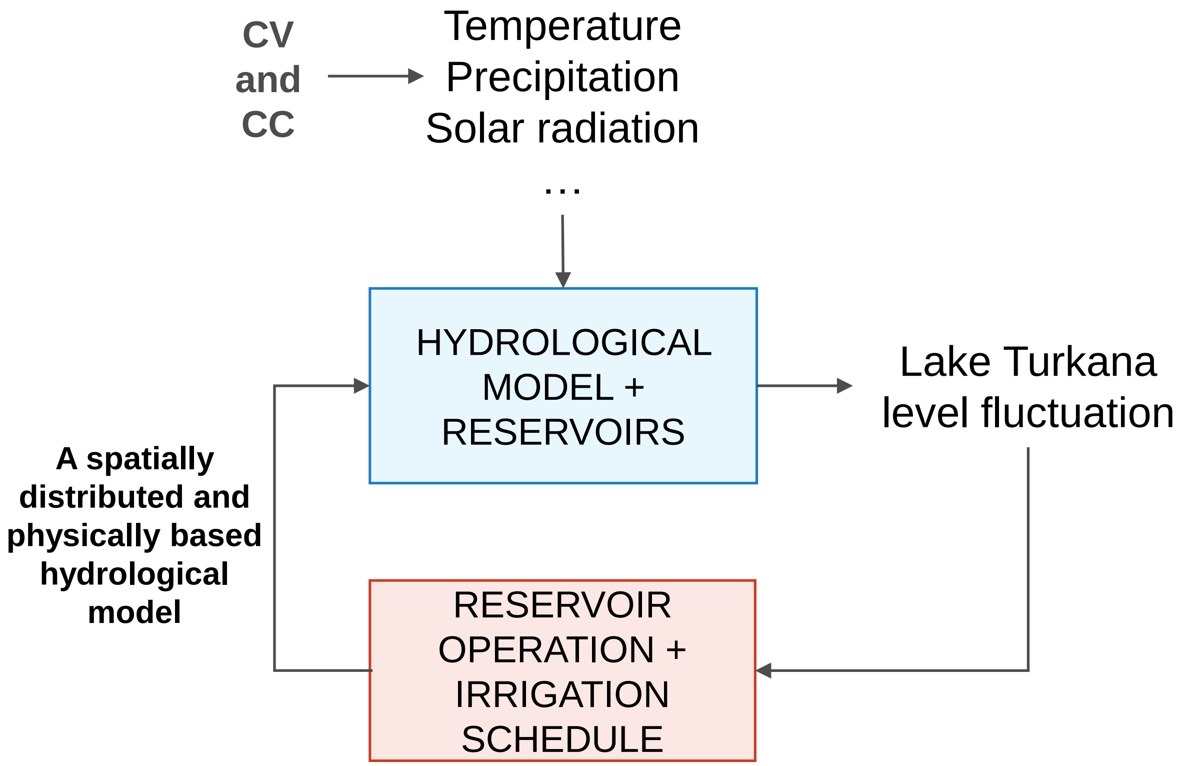
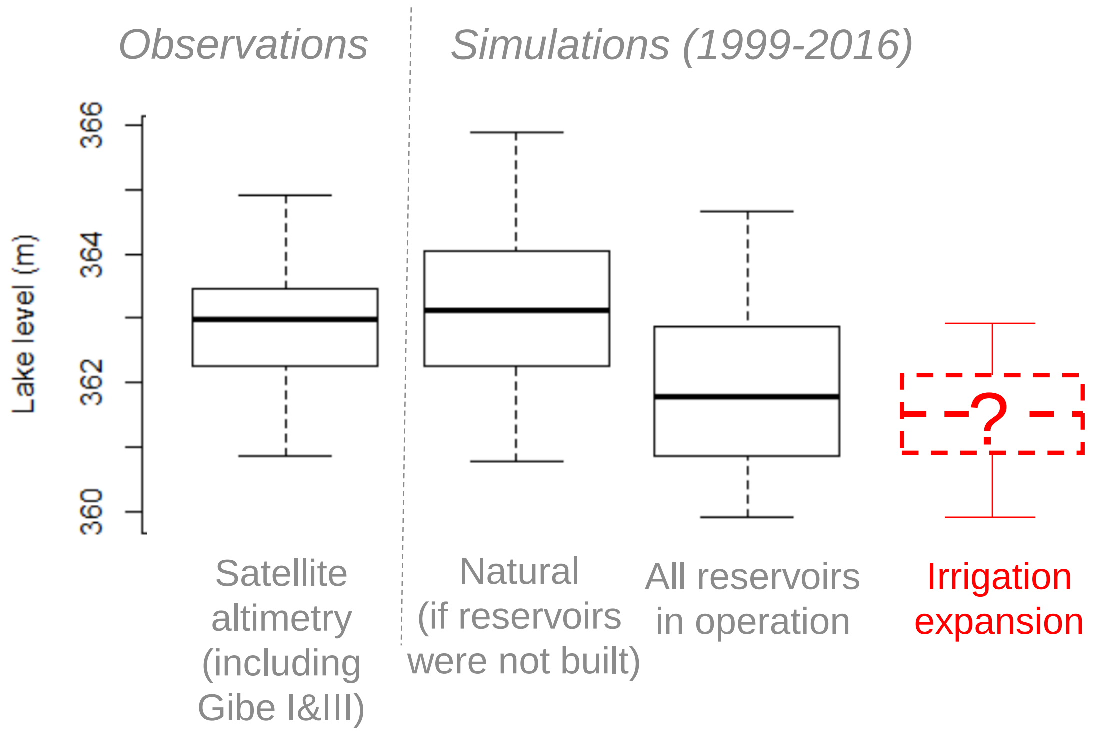
Models can **anticipate the impacts** of the interaction of human activities and CV-CC on the lake level



the model allows to simulate the lake dynamics under different hypothesis/scenarios



OUTCOMES FOR POLICY

Hydropower reservoirs can cause an average drop of 1 m in the lake level.

Anghileri, et al., AGU 2017

Why modelling the **physical system**?

The importance of physically based models

The presence of reservoirs, for example, can buffer the natural climate variability and **increase the resilience of the socio-economic activities**.

MODELLING THE WEFE NEXUS – EX1

EXAMPLES OF TRADE-OFFS, SYNERGIES AND BENEFITS

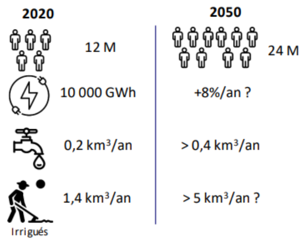
EXPEXTED BENEFITS OF A WEFE NEXUS APPROACH AND APPLICATIVE TOOL

- ***Enabling Trade-offs: limiting negative externalities***
- ***Ensuring resource efficiency for multiple resources***
- ***Political benefits***
- ***Leverage synergies***

Management of multi-purpose dams in the Senegal River Basin

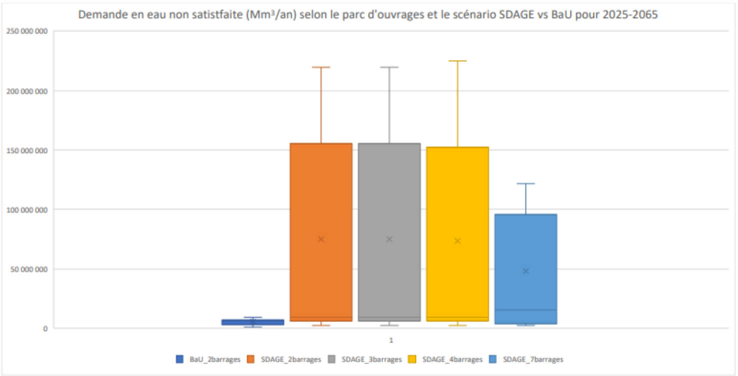
<u>Benefits and Objectives to be considered in the WEFE Nexus approach:</u>

Water storage for multiple purposes (irrigation, hydropower, navigation)
Irrigation demand in the dry season – naturally flooded agriculture
Coordinate management of water releases.
Landuse and landcover changes
Impacts on navigation services
Bank erosion



Water in the basin has been subject to increasing pressure from competing water uses.

WATER DEMANDS NOT SATISFIED MANAGEMENT + CLIMATIC SCENARIOS



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MODELLING THE WEFE NEXUS – EX2

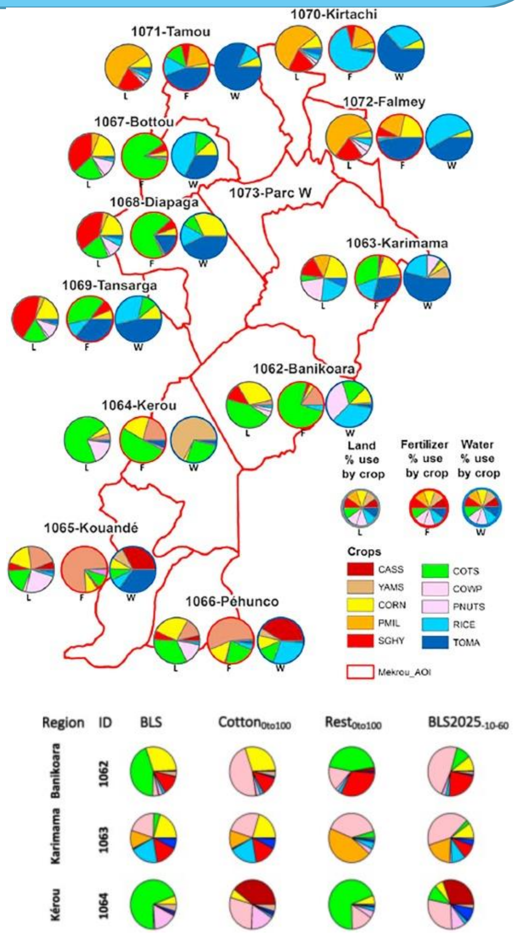
EXPEXTED BENEFITS OF A WEFE NEXUS APPROACH AND APPLICATIVE TOOL

- ***Enabling Trade-offs: limiting negative externalities***
- ***Ensuring resource efficiency for multiple resources***
- ***Political benefits***
- ***Leverage synergies***

EXAMPLES OF TRADE-OFFS, SYNERGIES AND BENEFITS

2. Implementation of the Nexus in the Merkou river basin

<u>Benefits and Objectives to be considered in the WEFE Nexus approach:</u>
WATER – water management to satisfy multiple uses;
FOOD – crop and livestock production to generate income and cover food needs and diet habits;
ecosystems preservation (W-Park and Upstream part) to
ensure services (energy-water supply, etc.), tourism and forest.
Optimal cropland allocation and fertilization-irrigation management



MODELLING THE WEFE NEXUS – EX3

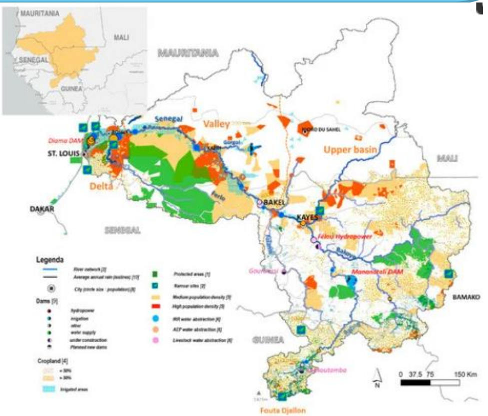
EXPEXTED BENEFITS OF A WEFE NEXUS APPROACH AND APPLICATIVE TOOL

- ***Enabling Trade-offs: limiting negative externalities***
- ***Ensuring resource efficiency for multiple resources***
- ***Political benefits***
- ***Leverage synergies***

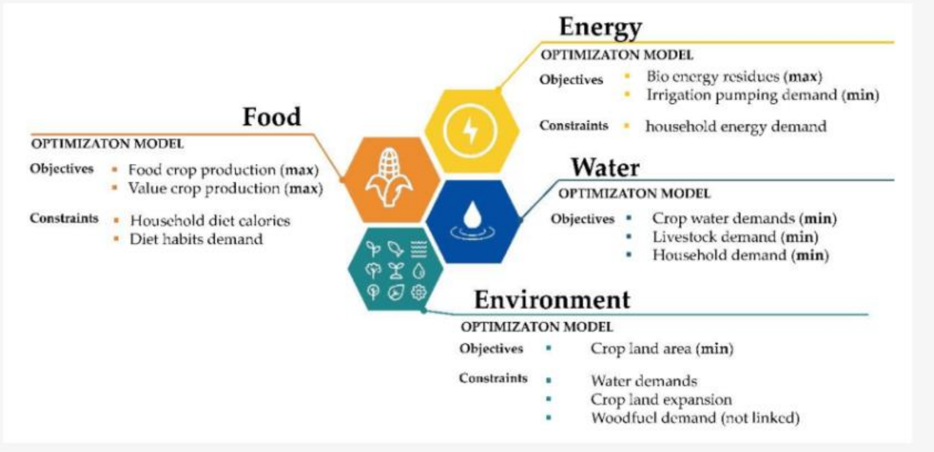
EXAMPLES OF TRADE-OFFS, SYNERGIES AND BENEFITS

2. Bioenergy in remote rural areas – a WEFE perspective

The main questions addressed in this study include:
•Which bioenergy resources are available in the Senegal river basin?
•How should the availability of agricultural residues to satisfy the energy demand from a WEFE nexus perspective be assessed?
•How do strategies that maximize bioenergy production from crop residues (and vice versa) in different agricultural settings impact food production?
•Which are the positive and negative impacts of producing bioenergy by crop residues on other WEFE aspects? These aspects include food demand and diet satisfaction cropland allocation, water demand, and the contribution of pressure on forest and savanna environments.



identification of objectives and constraints under the WEFE nexus approach. The objectives to be maximized were (F) the crop production, both for food and cash crops, and (E) the bioenergy potential from residues. While the objectives to be minimized were (W) total water demand for agriculture, (E) energy for water pumping, and (Env) crop land area.



MODELLING THE WEFE NEXUS – EX4

water scarcity is a key issue representative of arid and semi-arid regions

Small-reservoirs in Burkina FasoASSESSMENT OF MITIGATION AND ADAPTATION MEASURES TO CV - CC

Analysis of the role of small reservoirs in **buffering weather variability**

We developed **modelling tools to analyse the multi-purpose potential of the reservoirs in supporting local population needs, in terms of domestic, livestock, and agriculture and electricity needs.**

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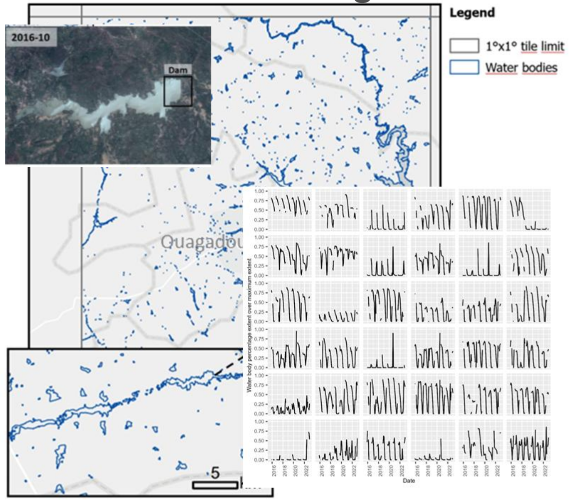
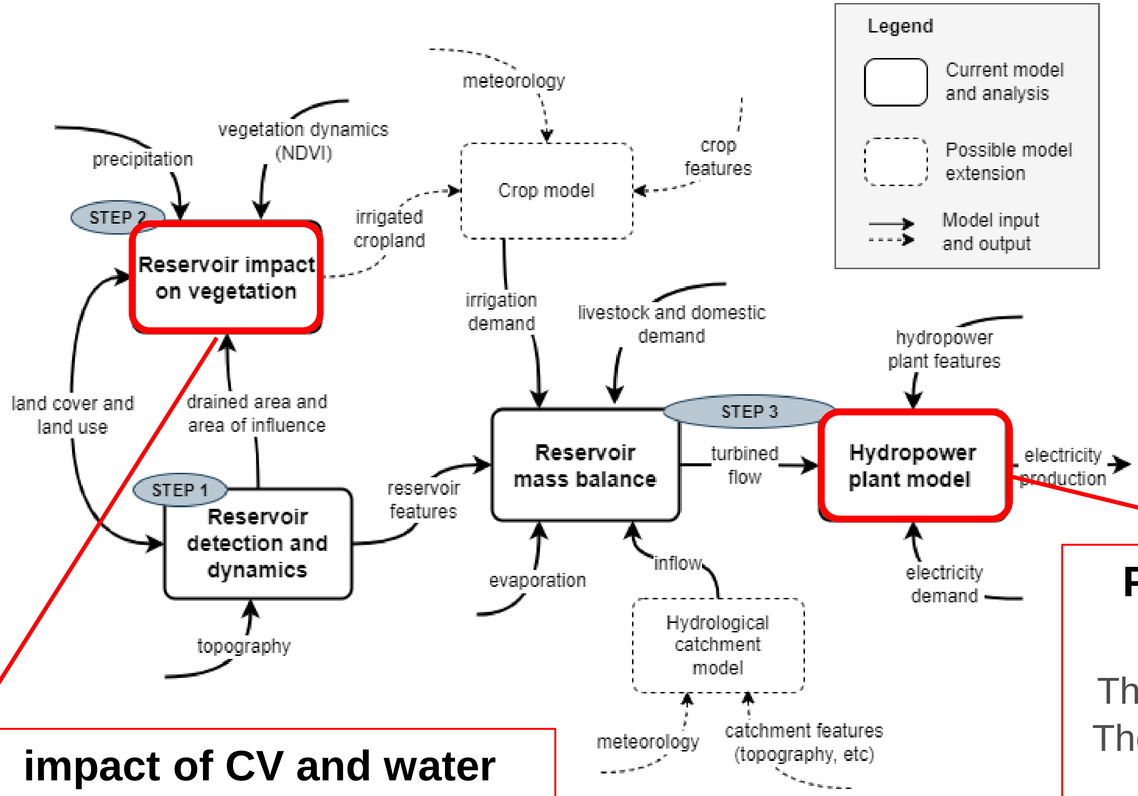
Climate variability: small-reservoirs strategy

Climate variability

WATER CHANGE AND VARIABILITY

Reservoir dynamics from remote sensing





impact of CV and water management on agricultural activities Remote sensing (NDVI) and Dynamic World Data

Promote advancement on energy access.

The maximum turbined flow are quite small. The technical potential we estimated in each reservoir would be enough to provide electricity for some households or social activities

Pastori, et al., 2024, JRC Report

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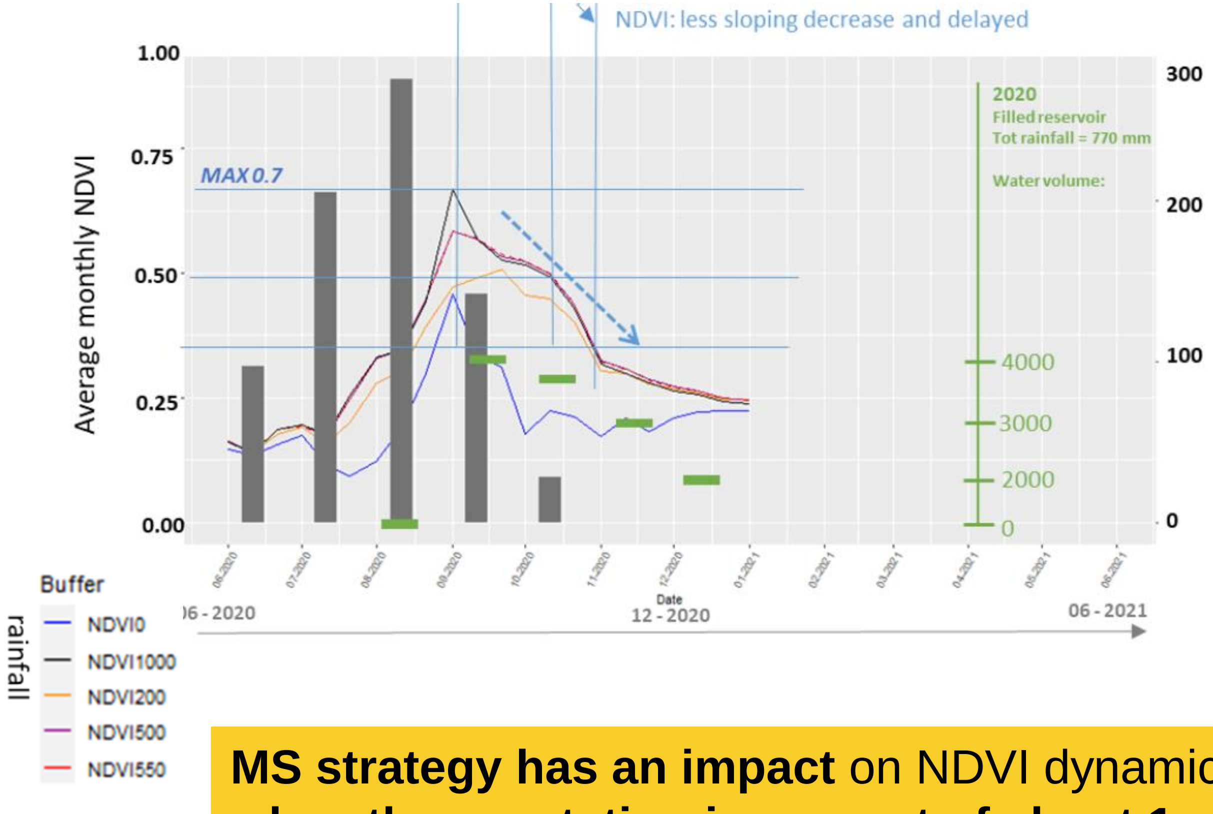
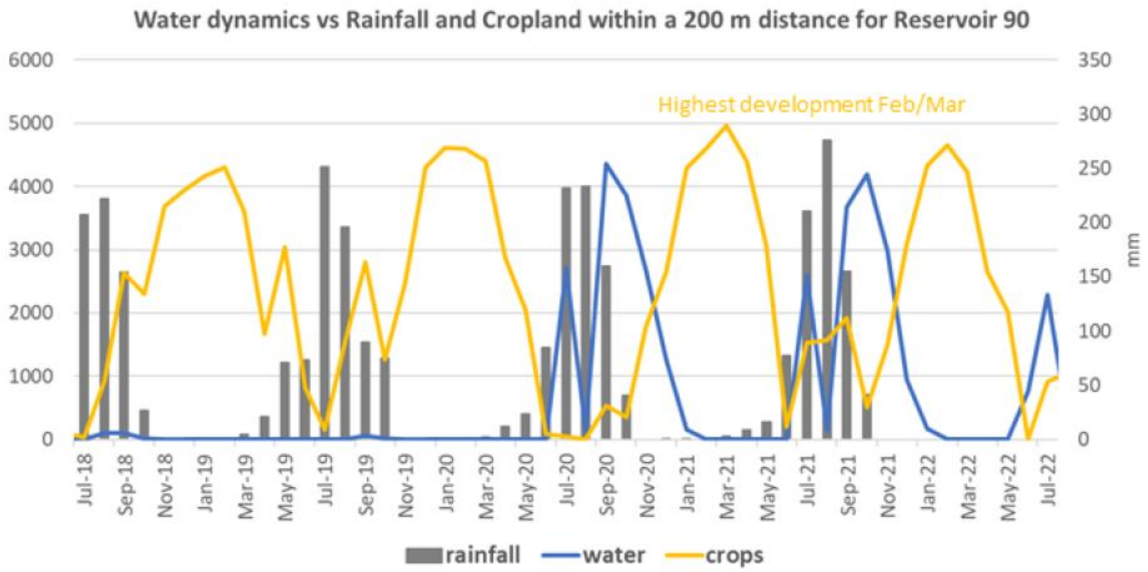
Small-reservoirs strategy: impact on agriculture





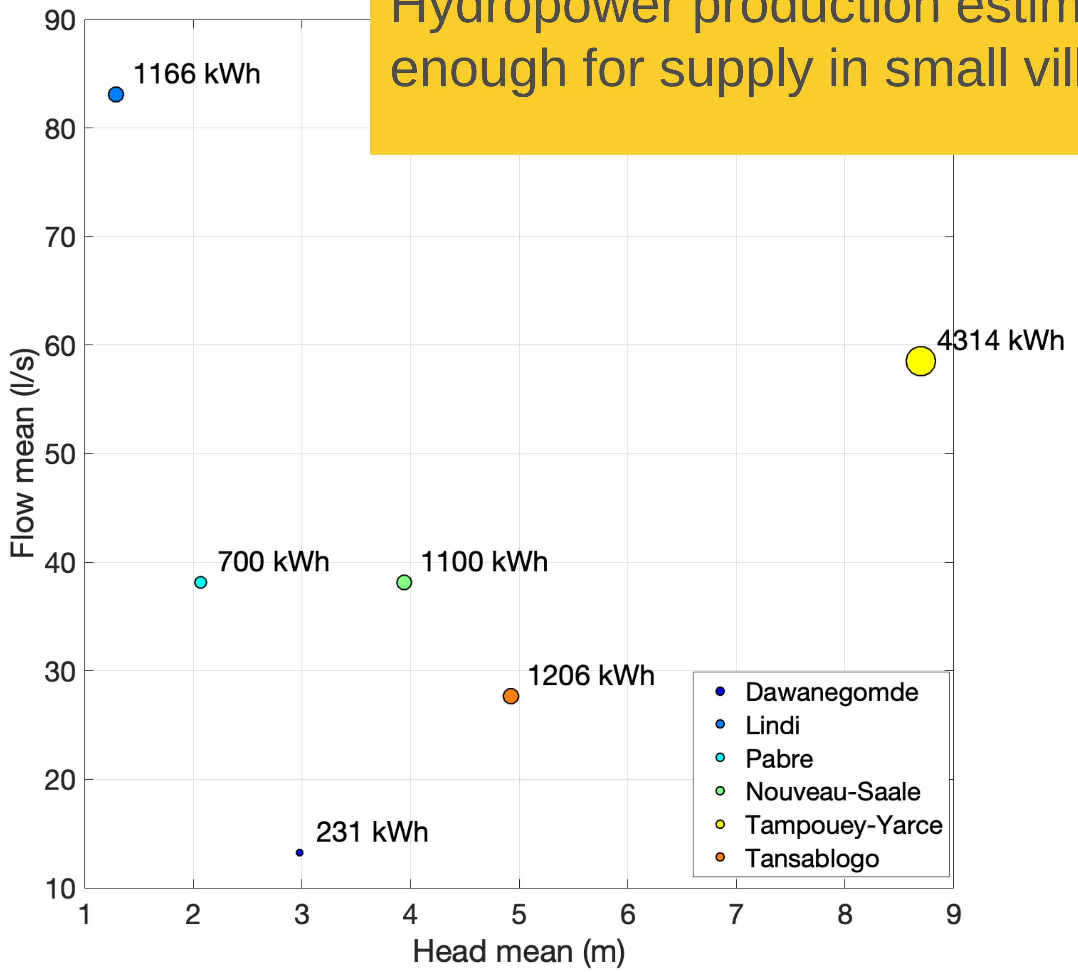
MS strategy has an impact on NDVI dynamics **extending the season when the vegetation is present of about 1 month.**

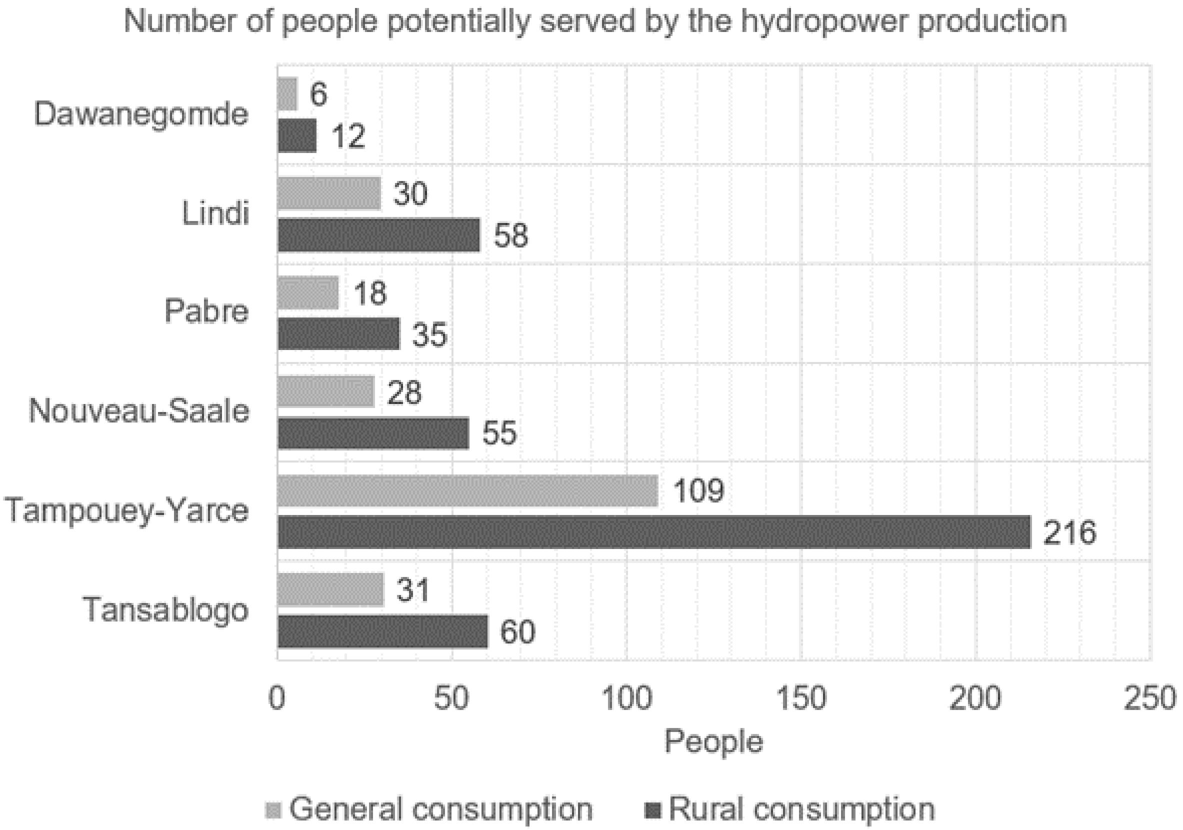
Note: Only irrigated cropland would have a development benefiting on the supplementary water availability from reservoirs management.

Pastori, et al., 2024, JRC Report

Small-reservoirs strategy: impact on energy access

Hydropower production estimate (in 6 sample reservoirs) is small, but it could be enough for supply in small villages (e.g., community house, medical devices).





Pastori, et al., 2024, JRC Report

WEFE NEXUS in Developing Countries

LESSON LEARNED

DATA

The issue of DATA is **well known in Africa** but it is also **emphasized by WEFE Nexus** requirements or more generally by the need of **multidisciplinary and multi scale (temporal and spatial) data**. (**Issues**: limited recognition of global data (such as FAO, statistics, etc.), access to data restrictions, transboundary agreement needed, data quality and standards, lack of data democracy. Data harmonization procedure to be developed and agreed with stakeholder and local experts. Data analysis transparency

Identified adaptation strategies:

- **Shared validation of regional/global data** (remote sensing) **+ Survey data** (t/r constraints!)
- **Pre-project data identification** can be useful (the preparation of fill-in metadata tables supported the process
- Process to reach **agreement** among riparian countries specifically to **identify data sharing policies and harmonization issues** (both among countries and WEFE sectors)
- **Advance with Data Analysis** (methods and Tool), **modelling with ready available data** and update data layer (results will be demonstrative but same activities may be not possible or will require a novel setup after the project, see for ex. Model Calibration)

PARTECIPATORY APPROACH AND CO-DEVELOPMENT

Participatory approach is not novel and not specific to the WEFE. **However**, this aspect is even **more key when a multidisciplinary approach** (as WEFE) is adopted. Need that **different experts contribute to the development and support the co-understanding** of process simplification and feedback approaches.

- **Involvements of multidisciplinary experts in the development of tool and data analysis**. It is key to discuss and agree on data integration into models.
- **ensure transparency** to establish confidence in the results. The assumptions and inputs used in the model and scenario analyses should be clearly documented and open to review by stakeholders and experts in the field
- it is essential to **acknowledge the limitations** of the models and **create realistic expectations** to avoid potential misinterpretations of the results
- ensure **open source and free software**

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WEFE NEXUS in Developing Countries

LESSON LEARNED

DECISION SUPPORT TOOLS

Issues: WEFE Nexus complexity may require **complex models**; This is needed somehow to take into account several sectors and scenarios. **There is a need for simple models, quick and producing results transferable**

<u>Identified adaptation strategies</u>:

- Integration in the tool (e,g E-Nexus) of **2 type of modules** (component specific usually required Input Data, Validation calibration, Expert involvements) and Meta Model for Optimisation
- Organize **<u>multisectorial scientific and training sessions</u>** even for thematic models (as reported in the WEFE project the participation of energy expert to agriculture or hydrological scientific seminar has ensured comprehension and appropriation of tool outputs
- for the identification of experts and technician to be involved in scientific seminars it is key to clarify the profile required and to ask the countries for their identification and assignment
- **develop tools and data analysis in parallel with planning demand** (for example Mekrou and **E-Water analysis adapted to the request arising from CaSSE, SDAGE** and PMPI) **+** As different ways of multi model integration (WEFE Nexus methods) are possible (fully integration, meta model, external link, etc.) the implementation plan should be agreed by all experts
- fully holistic models are not necessarily required. A soft-coupling of models is preferable at the more practical level qualitative modelling approaches can help map the WEFE system and locate priorities and trade-offs to be discussed and negotiated afterwards.

DISSEMINATION

<u>Issues</u>:Communication language (technical) may be an issues as not all experts/stakeholders/ policy makers may have same understanding of both project and problems in the basin. Request for more formal agreement of communication roles has been pointed out.

- Formal agreement about communication role and strategy
- Increase alternative ways to standard Reporting, Scientific Papers and Web Platform → see Radio/TV broadcast for Mekrou and for Intervention Projects in the WEFE Senegal…..
- ……………………..

GOVERNANCE

<u>Issues</u>: **concerted agreement on projects requirements**, outcomes (Nexus projects): time and resource demanding.
Financing mechanisms are pointed out as not appropriate
Needed comprehensive collaboration between entities such as **working networks or platforms** supported by multi sector policies, protocols, and procedures.

- The National cooperation frameworks developed under climate change or on IWRM, if they exist in a country, can be easily reused within the NEXUS approach and governance structures could be appropriated to define and implement Nexus solutions.
- focus on river basin scale for approaching and implementing the Nexus: indeed transboundary cooperation framework or river basin institutions could also embed the Nexus dialogue and cooperation between WEFE stakeholders.

WEFE NEXUS Case studies
a more in-depth analysis

1. SPECIFIC FOCUS ON AGRICULTURE AND BIOENERGY: A cropland-energy-water-environment assessment of **bioenergy potential**

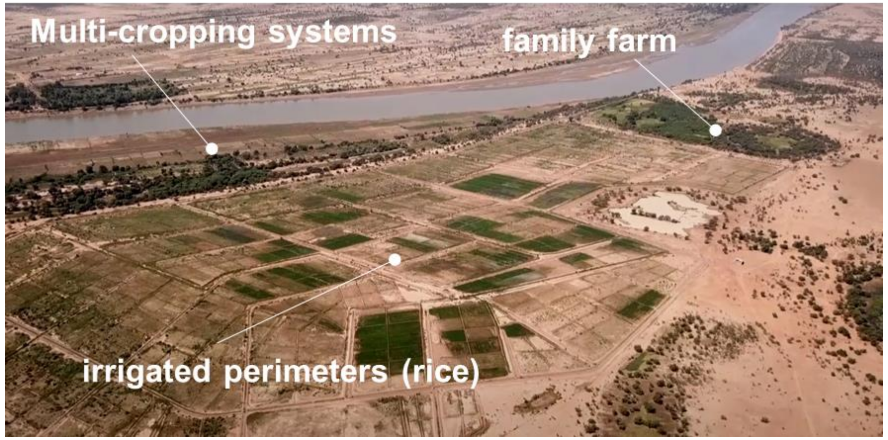
2. RIVER BASIN FOCUS – WATER DEMAND AND USES at river basin level: A cropland and water allocation

3. **The importance of linking CV (and CC) with their impacts on agriculture systems:** An analysis for major rainfed cropping systems (My colleague Patricia)

WEFE Nexus and identification of optimal solutions

Bioenergy potential of crop residues: A cropland-energy-water-enviroment assessment in the Senegal river Basin

1.SPECIFIC FOCUS ON AGRICULTURE AND BIOENERGY



Pastori, M.; Udias, A.; Cattaneo, L.; Moner-Girona, M.; Niang, A.; Carmona-Moreno, C. Bioenergy Potential of Crop Residues in the Senegal River Basin: A Cropland–Energy–Water-Environment Nexus Approach. *Sustainability* **2021**, *13*, 11065. https://doi.org/10.3390/su131911065

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WEFE Nexus and identification of optimal solutions

Bioenergy potential of crop residues: A cropland-energy-water-enviroment assessment in the Senegal river Basin

AGRICULTURE AND BIOENERGY CHALLANGES

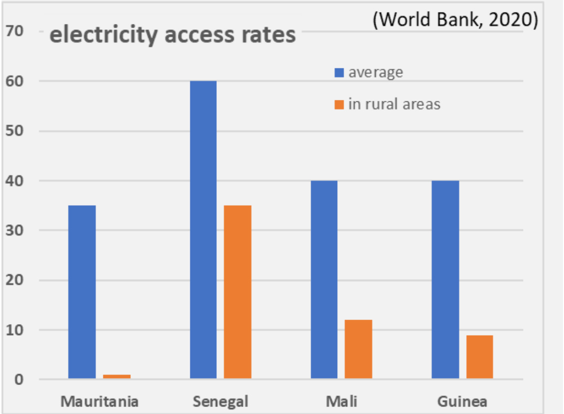
- **access to energy services** is a priority for sustainable economic development, **especially in rural areas where limited access to energy services is accompanied by and directly linked to the other components such as food security and agricultural, water-demand, and environmental aspects**

- support actions are needed to meet the United Nations' goal of achieving universal access to affordable, reliable, and modern energy services for all by 2030

- **Alternatives to fossil-fuel energy** sources would **reduce the impact on natural resources (wood)** and would pursue political and economic goals through promoting under-utilized and domestically available resources. In Countries highly dependent on biomass sources (such as savannah, forest, and agriculture) biomass is intensively used but with methods that are poorly efficient and that pose a health risk. **+ Forest Degradation**

- **Growing Demands**: **Climate change and climate variability will also impact biomass**, exacerbating the pressure on this limited resource.
The increasing need for land and water resources to meet the demand for food, poverty, and low efficient farming and livestock practices, also lead to changes in vegetation cover, loss of genetic and interspecific diversity, and reduced habitat integrity for wildlife

EX. IN THE SENEGAL RIVER BASIN



In rural areas, these figures are much lower:
9, 12, <1 and **35%** for Guinea, Mali, Mauritania and Senegal respectively.

Wood fuel production: +14% 2000-2018 in WA

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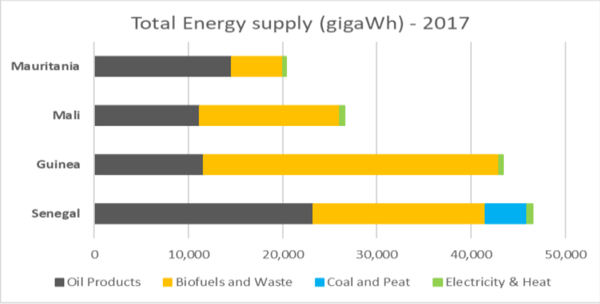
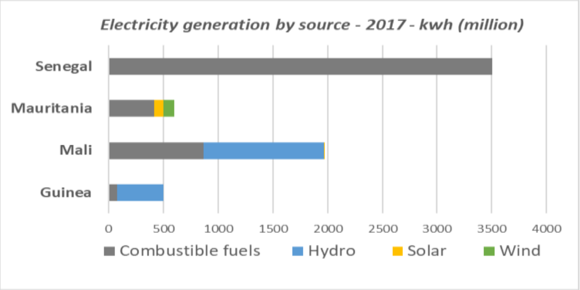
WEFE Nexus and identification of optimal solutions

Bioenergy potential of crop residues: A cropland-energy-water-enviroment assessment in the Senegal river Basin





CROP RESIDUES: OBJECTIVE AND CONTEXT

- **biomass residues**, which is locally produced and often close to demand (**spec. in rural areas**), **could be used in tandem with hydropower and photovoltaic (PV) systems to balance the power system** affected by the variable nature of solar energy.

- **Energy potentials from agricultural residues and agro-industrial residues could be explored for present and future energy needs**. Several studies have explored the potential of using crop residues to partially satisfy energy requirements, avoiding some common biofuel issues
  Specifically, in regions with a dominant agricultural sector, the advantages of valorising such resources, without impacting land use or introducing negative effects on crop availability and markets, have been pointed out

- **Optimization methods**: A multi-objective optimization approach can provide a better understanding to assess bioenergy potential together with complex interlinkages required by the WEFE nexus

WEFE Nexus and identification of optimal solutions

Bioenergy potential of crop residues: A cropland-energy-water-enviroment assessment in the Senegal river Basin

SPEFICIF OBJECTIVES

OPTIMISE BIOENERGY IN A WEFE CONTEXT: support decision making on the **allocation of agricultural land** for **food** and bioenergy production

HOW: integrate a bioenergy crop residue potential estimation model with an optimization method that assess the impact of alternative agricultural and cropland management scenarios at river basin level, **by simultaneously favouring food self-sufficiency capacity and environmental benefits.**

The use of the nexus approach, which integrates various environmental factors, is instrumental to identify optimal land-energy strategies and provide decision makers with greater knowledge of the potential multiple benefits while **minimizing trade-offs of the new solutions such as those connected to farmers' needs, local energy demand, and food and land aspects.**

WEFE Nexus and identification of optimal solutions

Bioenergy potential of crop residues: A cropland-energy-water-enviroment assessment in the Senegal river Basin

The case study: the Senegal River basin

- **Agriculture contribution to GDP is 38%.** Cereals (like sorghum, fonio, millet, and maize) are the dominant crop types, accounting for about 51% of the total harvested area. Maize represents 8% of the total area. Other important crops are oil crops (16%), pulses (12%), rice (7%), and cotton (6%).
- Even if irrigated cropping systems are low-diffused in the basin (<1% in Guinea and Mali, 15% in Senegal, and 25% in Mauritania), **agriculture accounts for 70 % of the total global freshwater withdrawals**, making it the largest user of water. **Cropland expansion** in the river basin is also **increasing** by an average annual growth rate of **4%** between 2005 and 2016
- **Competition** across pastoral (14 M livestock UBT), irrigated and rainfed (and recession) farming; **Water demand** for irrigation is 1400 Mm^3 and about 113 Mm^3 for livestock
- **Food demand** mainly supplied by rainfed agriculture (78% of total food); and small farmers rely on recession (decrue) agriculture for food, more and more threaten by hydropower development
- **Environment:** 8 Ramsar sites and 55 000 km^2 of protected; land degradation and erosion (poor soil fertility management; landuse change (deforestation, land abandonment, water abstraction in wetlands, salt infiltration); water quality is affected by (heavy metals) pollution and by a rapid increase in the prevalence of water-borne diseases, as impacted by river flow alteration.
- **Transboundary dimension**: Development priorities may differ between countries: while upstream countries (Mali, Guinea) are highly interested in hydropower services, downstream countries prioritize food production and someway ecosystem services in the Delta and river valley.

WEFE Nexus approach, modelling and optimization

Soutenir les connaissances sur les différents thèmes
Comprendre les interactions et les réactions

- *Analysis of existing documents*
- *identify available tools and data*

EVIDENCE

- Inventory of current status
- Identification of Development Priorities

NEXUS Assessment

- Understanding climate variability
- Understanding the water balance/quality
- Understanding the energy balance
- Understanding Food security issues
- Understanding ecosystems

Understand the WEFE Interactions

Identification of collaboration & Points of interests across sectors

NEXUS Policy dialogue

Scenarios

Strategic Framework for WEFE Nexus Development

Solutions Nexus

Development measures and Investments

Dialogue

scenario development, expert and stakeholder engagement, identification of Nexus Solutions de scenarios

ref.
Position Paper on WEFE NEXUS and SDGs, 2019

MODULE Opti - BIOENERGIE

ENexus tool

DATA harmonization and Digitalisation

GIS, DB, field survey, bibliography, Open DATA

Thematic modelling

Hydro: SWAT / LISFLOOD
Agri: GISEPIC
Energy: Bioenergy Model and PIV
Climate: SPI, L-Moments
Quality: SWAT, GREEN

Optimization of conflicting objectives

MOO methods: single objective, multi objective, water vs bioenergy, crop land allocation, crop management optimization, water demands assessment

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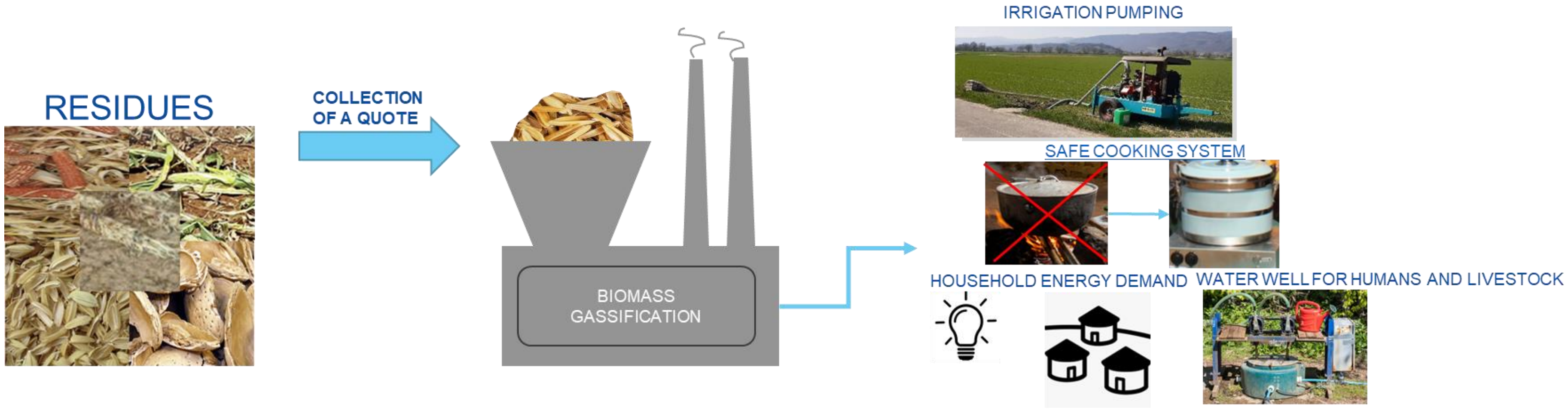
The Bioenergy electricity potential model

- The spectrum of biomass to energy solutions involves **a wide range of materials and technologies.**
- When it comes to **generating electricity**, the most competitive and commercially **available** processes are combustion and gasification.
- Other studies have identified **gasification** as **the most promising technology for converting solid biomass to electricity on a small scale** (**less than 100 kW**) [RHC Platform, AA.VV., 2014]
- In rural and remote off-grid villages, **decentralised power generation** using distributed energy resources is considered the most important strategic solution to energy problems.



We have calculated the requirements in terms of residues, plant production and surface area to feed a **600 kW CHP plant**, knowing that a 600 kWe CHP plant **operating for 7500 hours/year** can potentially produce **4500 MWh/year of electricity**

P_{tot} = Total residues available ($Yield_{cr} * Dry_{cr} * AREA_{cr} * RPR_{cr} * RECF_{cr}$)

$$EnPot_{cr} = Yield_{cr} * Dry_{cr} * AREA_{cr} * RPR_{cr} * RECF_{cr} * LHV_{cr} * EPE$$

- $EnPot_{cr}$: Energy elec. Potential (MWh/yr)
- cr: crop residue type
- $Yield_{cr}$: Crop productivity (tons/ha), for a specific cropping season
- Dry_{cr}: Dry yield conversion for residues
- $AREA_{cr}$: Crop harveted area (ha), specific to rainfed and irrigated cropping systems
- RPR_{cr}: Factor for residue production: crop-specific residue to product ratio (g/g))
- $RECF_{cr}$: Factor for residues availability as a fraction of total production (for the collection for energy production)
- LHV_{cr}: Lower heating value: crop residue heating value (MJ/kg)
- EPE: Efficiency conversion factor (depending on energy technology conversion efficiency). A reference efficiency factor of 17% was applied, based on a fixed bed gasifier coupled to an Otto engine

ADAPTABLE TO ANY REGIONS

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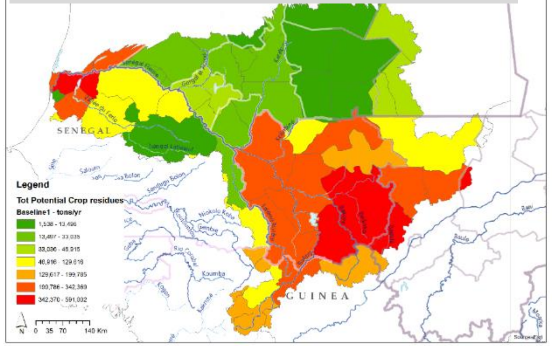
The Bioenergy electricity potential model

OUTCOMES / RESULTS

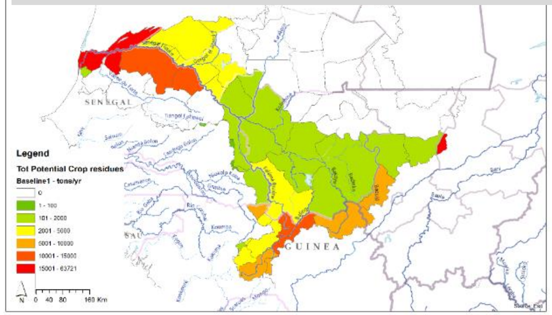
Estimation of cultural residues
TOTAL BY REGION – SPATIAL AND TEMPORAL AVAILABILITY

this type of energy strategy is efficient and can realistically be applied in rural areas, as there is normally no provision for the movement, transport and storage of residues for such small installations

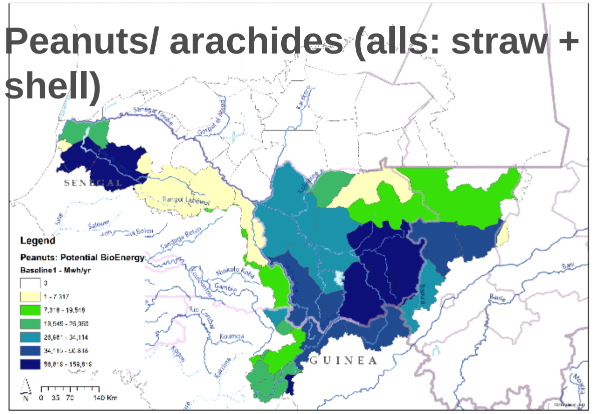
résidus de culture potentiels: tot (tonnes / an)

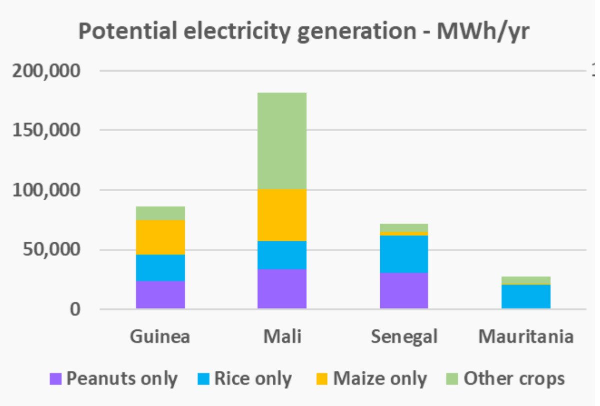


résidus de culture potentiels: riz - paille (tonnes / an)

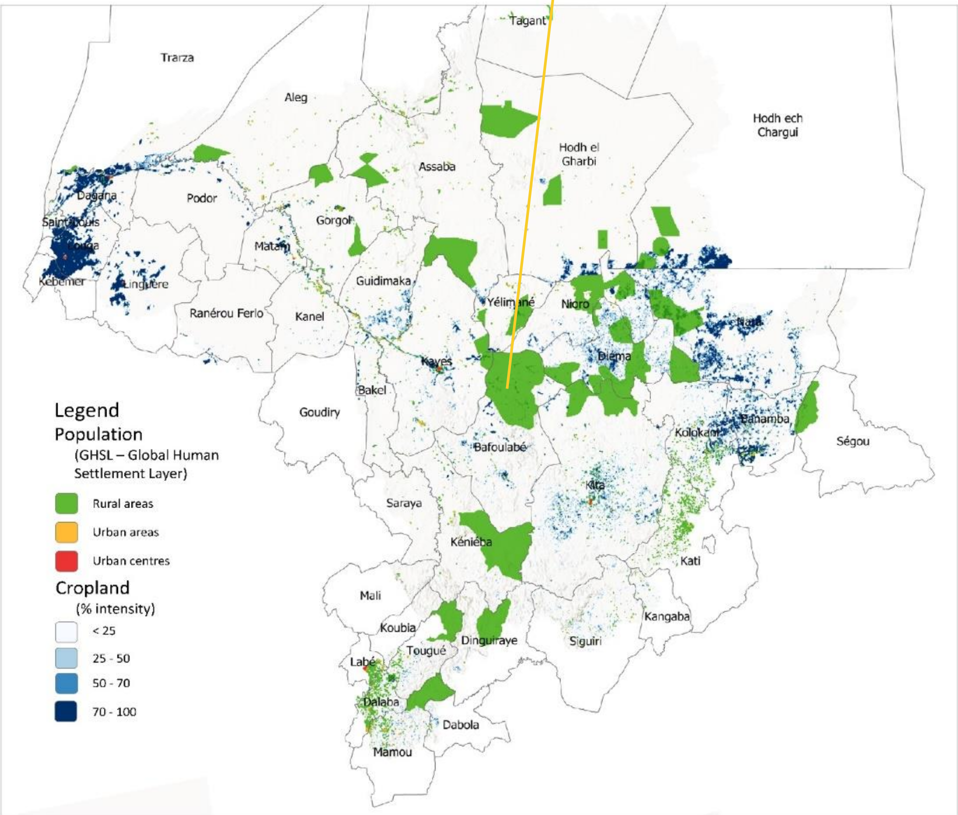


Peanuts/ arachides (alls: straw + shell)





RURAL POPULATION AND CROPLAND OVERLAY



The Optimization module: objectives and constraints

The Multi Objective Optimisation

EXAMPLE of Analysis and results

The objective of the optimisation modelling is to determine the most appropriate land and water allocations by optimising crop and bioenergy production, while taking into account the food self-sufficiency of the local regional demand in the Senegal River basin

- In the optimization process **several objectives can be optimized simultaneously**; this is a key capability of the approach, but it should be also pointed out that the concurrent use of more objective can make more complex the interpretation of the results
- The analysis of optimization consider the need to analysis the bioenergy production in a WEFE Nexus context. To this sco… and constraints have been selected:

List of WEFE Nexus component and related objectives for the optimization of bioenergy production in the Senegal river basin.

- ✓ W (Eau) : Minimize total irrigation water demand;
- ✓ E (En.): Maximize total bioenergy potential from crop residues;
- ✓ E (En.): Minimize total irrigation pumping energy demand
- ✓ F (Ali) : Maximize total food production;
- ✓ E (Env): Minimize crop land area

Energy

OPTIMIZATON MODEL

Objectives
- Bio energy residues (**max**)
- Irrigation pumping demand (**min**)

Constraints
- household energy demand

Food

OPTIMIZATON MODEL

Objectives
- Food crop production (**max**)
- Value crop production (**max**)

Constraints
- Household diet calories
- Diet habits demand

Water

OPTIMIZATON MODEL

Objectives
- Crop water demands (min)
- Livestock demand (min)
- Household demand (min)

Environment

OPTIMIZATON MODEL

Objectives
- Crop land area (min)

Constraints
- Water demands
- Crop land expansion
- Woodfuel demand (not linked)

OPTIMIZATION CONFIGURATION

DATA AND CONSTRAINTS (stakeholder)

different cropping systems (irrigated, rainfed, …), irrigation surfaces, crop specific water requirements, pumping heads (energy), water abstraction limit; Minimum quantity to be maintained to satisfy food demand and farmers needs); energy demand; pumping energy demand

SPATIAL APPROACH

Freedom of movement of crops and resources within the rive basin and riparian countries (all movements allowed, only a quote, only within the country, etc.)

CROPLAND ALLOCATION SIMILARITY

set up the % of variation vs the current (baseline) cropland allocation at regional or national level. For example 100 means that areas of all crops within the region optimized can change completely (within the same total cropland) and potentially several crops can be totally replaced by others

SELECTION OF OBJECTIVES

The Multi Objective Optimisation

Design of Optimization Modelling

KEY DATA AND ASSESSMENT TO CONFIGURE THE OPTIMISATION

WATER AND LAND DEMAND ESTIMATION AS IMPACTED BY CV – CC - GROWTH

Irrigation energy demand

Energy requirements for irrigation (and livestock) for pumping and in general for water movement

$$EnD_{Irr} = PumpEff * THead * \mathrm{IRRfrac} * \mathrm{WatReq} * 10^{6}$$

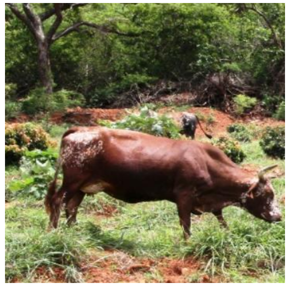
Population household energy demand

$$PopEnDem_r = Pop_r * HH\_EnHab_r$$

Energetic demand by households as kwh_capita

	2016	2025
Guinea	140	182
Mali	78	102
Mauritania	302	393
Senegal	298	387

Agriculture water demand (irrigation and livestock) and demand for land required by animal (forage)



$$WatDem_c = AREA_c * IRRf_c * WatReqbyha_c$$

$$WatLivDem_i = DailyDem_i * TotNUBT_i * 365 * 10^{-3}$$

demande annuelle en forage (tons)

$$ForDemDry_i = TotNUBT_i * Daysdry * DailyFor$$

Population food demand

The Multi Objective Optimisation

The Optimization module: objectives and constraints

SETUP OF OBJECTIVES AND COSTRAINTS

Design of Optimization Modelling

- Process based on co-development with local experts and stakeholders

OBJECTIFS D'OPTIMISATION ⟷ CONSTRAINTS D'OPTIMISATION

ENERGY

- Bio energy residues (max) — Objs
- Irrigation pumping demand (min)
- household energy demand — Cons

production de bioénergie

$$maximize \sum_r \sum_c (XR_{rc} * YieldR_{rc} + XI_{rc} * YieldI_{rc}) * EnPot_c$$

$$EnPot_c = RPR_c * RECF_c * LHV_c * EPE_c$$

Potentiel calorique des aliments

FOOD

- Objs: Food crop production (max)
- Cons: calories de régime
- Habitudes en matière de régime alimentaire

Production minimale de nourriture

$$\sum_c Pop * FSQ\_Hab_c \quad \forall\ c\ in\ C$$

$$\sum_r (XR_{rc} * YieldR_{rc} + XI_{rc} * YieldI_{rc}) \geq \sum_r MinProd_{rc} \ \forall\ c\ in\ C$$

Extension des terres cultivées

WATER

- Demande en eau des cultures (min)
- Demande du bétail (min)
- Demande des ménages (min)

Demande en eau des cultures

$$Minimize \sum_c \sum_r (XI_{rc} * WatReqbyHa_{rc})$$

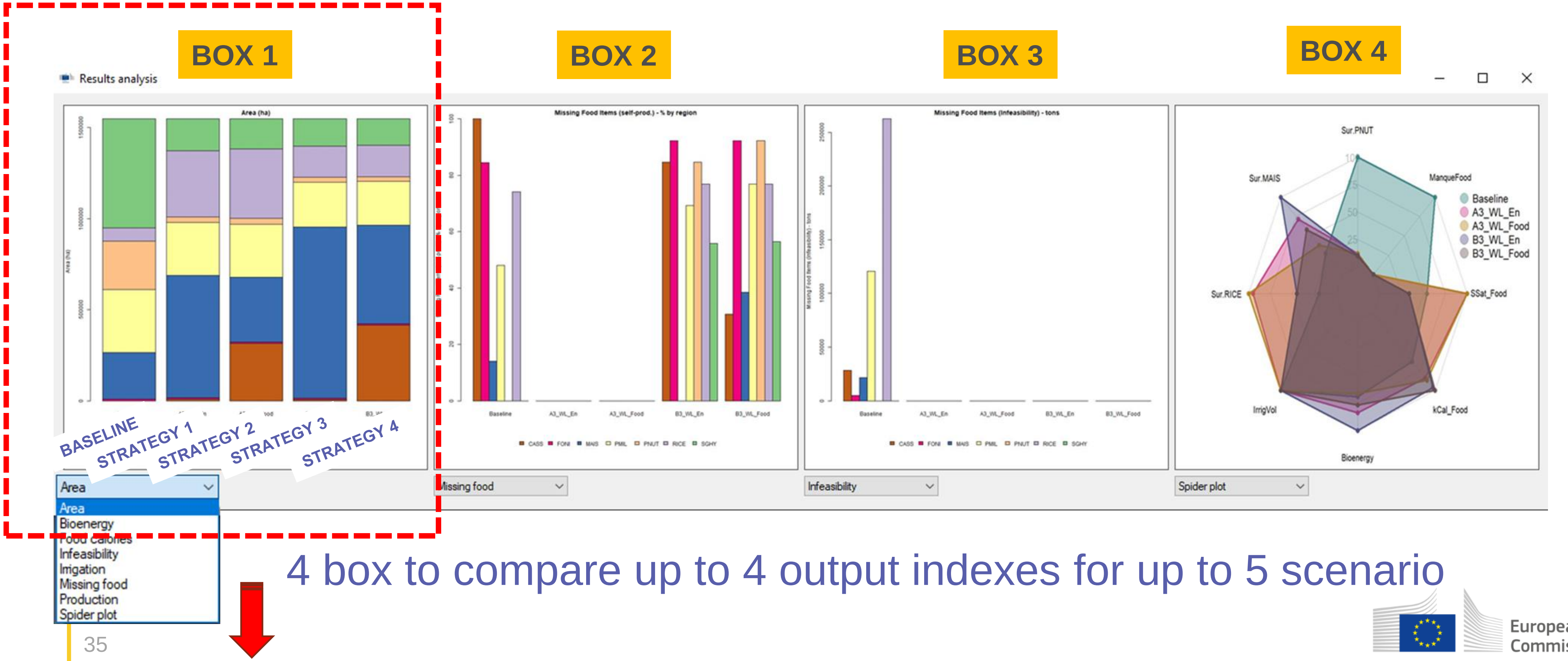
Demande en eau du bétail

Disponibilité de l'eau pour l'irrigation

$$\sum_c (XI_{rc} * WatReqbyHa_{rc}) \leq WaterAvail_r \ \forall\ r\ in\ R$$

The Multi Objective Optimisation

PROVISON OF OUTPUTS FOR STAKEHOLDERS : COMPARE SCENARIOS



4 box to compare up to 4 output indexes for up to 5 scenario

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The Multi Objective Optimisation

PROVISON OF OUTPUTS FOR STAKEHOLDERS : COMPARE SCENARIOS

EXAMPLE - CROPLAND ALLOCATION ANALYSIS

INPUT DATA section: editing, verification, update

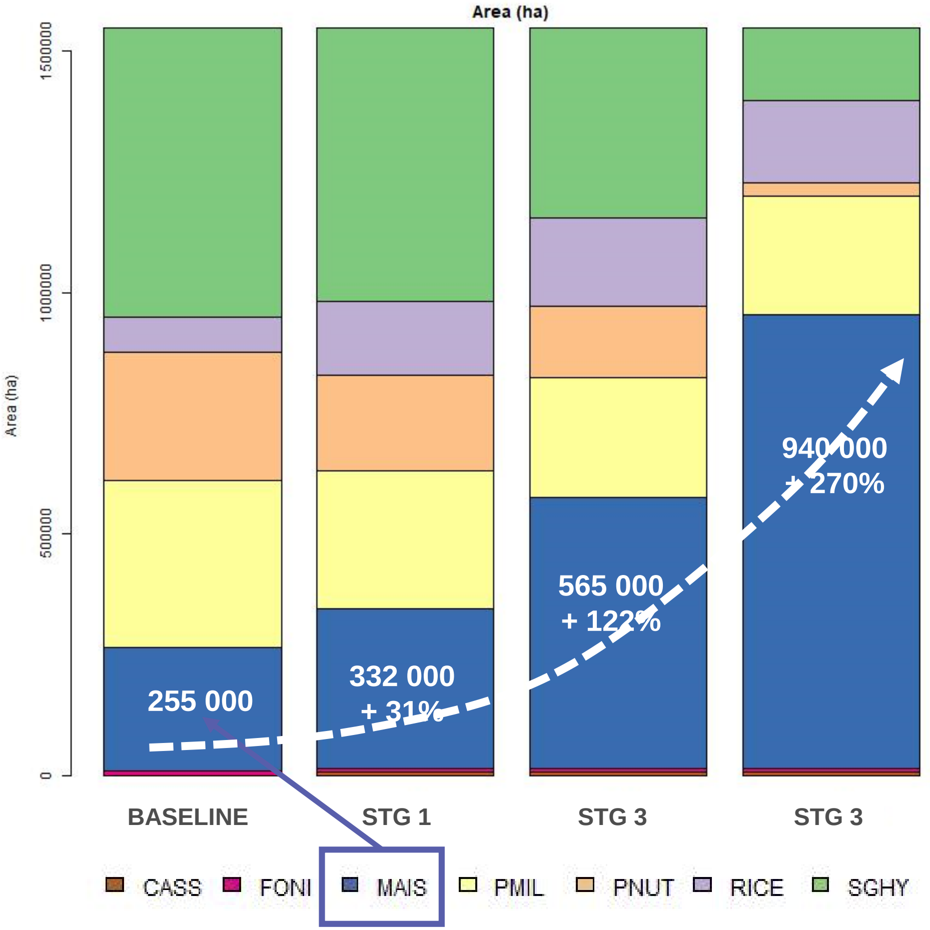
- **AGRI** - crop surfaces for different cropping systems (irrigated, rainfed, …), crop yields,
- **WATER** - irrigation surfaces, crop specific water requirements, pumping heads (energy), water abstraction limit;
- **FOOD** - Minimum production by crop (quantity to be maintained to satisfy food demand and farmers needs);
- Diet habits; crop food calories contribution;
- **ENERGY** – population (household) energy demand; pumping energy demand
- **MODEL** - model coefficients and scenarios (increasing rates , changes of productivity, change of arable land scenario, increasing of water abstraction)

DIFFERENT CONSTRAINTS AND SPATIAL SCALES

OPTIMISATION OBJETIVES

STRATEGY	SPATIAL APPROACH	VARIATION LIMIT	STRATEGY TARGETS	OPTIMIZATION OBJ
1	LINKED	5	WATER+LAND	ENERGY
2	LINKED	20	WATER+LAND	ENERGY
3	LINKED	50	WATER+LAND	ENERGY

- Only variation limit is changing
- The increasing of this limit results in «more freedom» for the optimizer in changing the allocation of total cropland to the different crops



Each crop specific variable is showed with different colors

FOR EXAMPLE FOR MAIS

The optimizer, under these conditions, focus on the expansion of maize crop

Trends for other crops

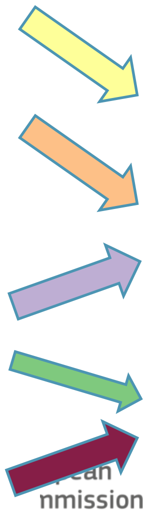
MILLET

PEANUTS

RICE

SORGHUM

CASSAVA



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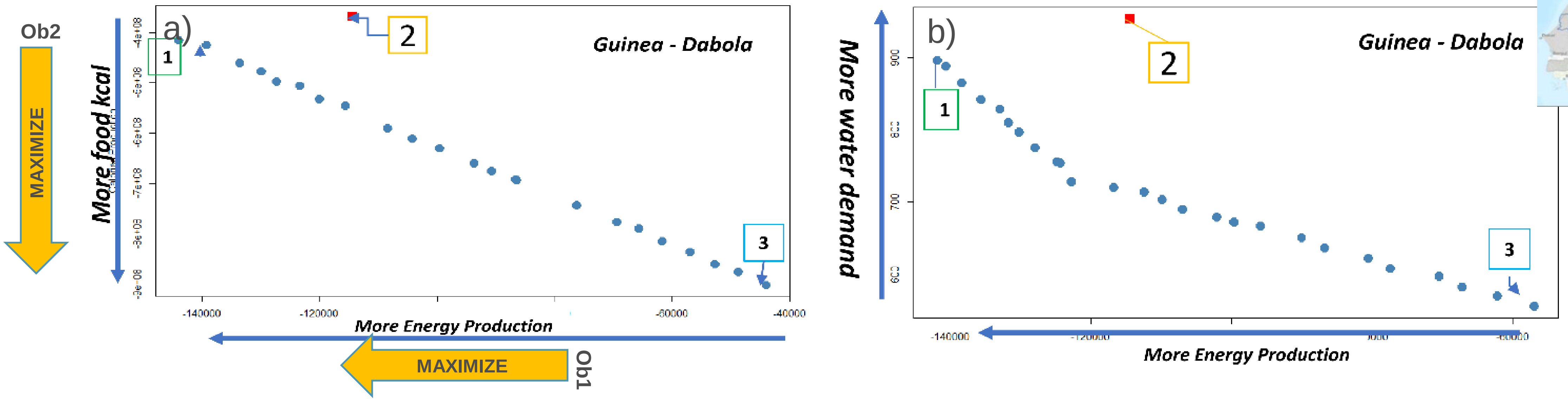
PROVISON OF OUTPUTS FOR STAKEHOLDERS :
<u>Pareto front solutions</u>: Trade-offs between different objectives



- The figure shows the **Pareto frontier**, formed by the **compromise of effective strategies between (i) the selected WEFE targets and (ii) the capacity to produce bioenergy from crop residues**
- **There is not a single solution** but a **<u>series of optimal alternative solutions</u>**
- Graphic Interpretation: two solutions (1,3) are the opposite ones (top left and bottom right) in the Pareto maximizing one of the two optimized objectives. The solution corresponding to the current distribution of cultivated land (2, red square) is also shown to highlight the difference with the optimized solutions.

WEFE NEXUS Case studies
a more in-depth analysis

1. SPECIFIC FOCUS ON AGRICULTURE AND BIOENERGY: A cropland-energy-water-environment assessment of **bioenergy potential**

2. RIVER BASIN FOCUS – WATER DEMAND AND USES at river basin level: A cropland and water allocation

3. **The importance of linking CV (and CC) with their impacts on agriculture systems:** An analysis for major rainfed cropping systems (My colleague Patricia)

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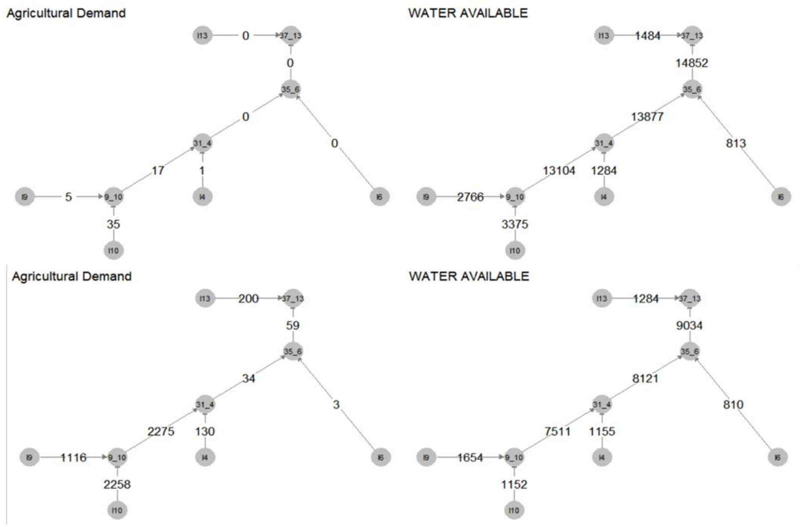
WEFE Nexus and identification of optimal solutions

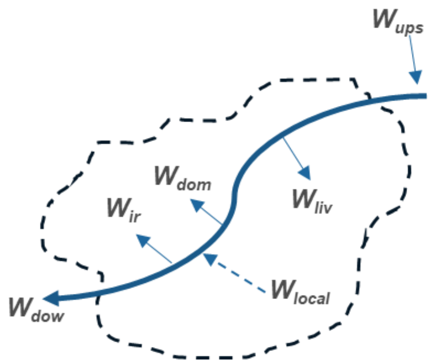
A cropland-energy-water-enviroment assessment in the Senegal river Basin

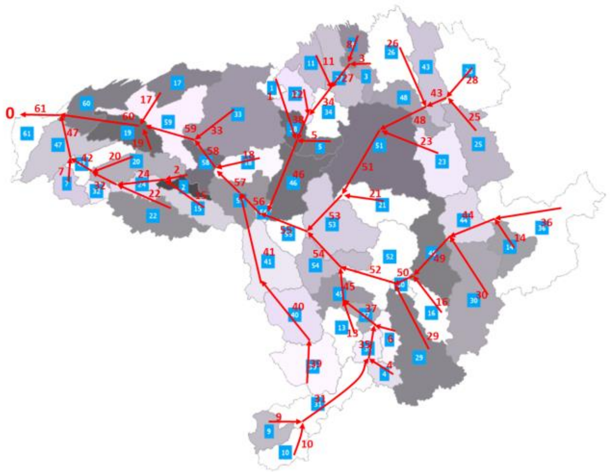
2. RIVER BASIN FOCUS – WATER DEMAND AND USES at river basin level: A cropland and water allocation

BASELINE

OPTIMAL







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The Multi Objective Optimisation
RIVER BASIN APPROACH FOR WATER ROUTING

WATER DEMAND ALLOCATION AT RIVER BASIN LEVEL - CHALLANGES

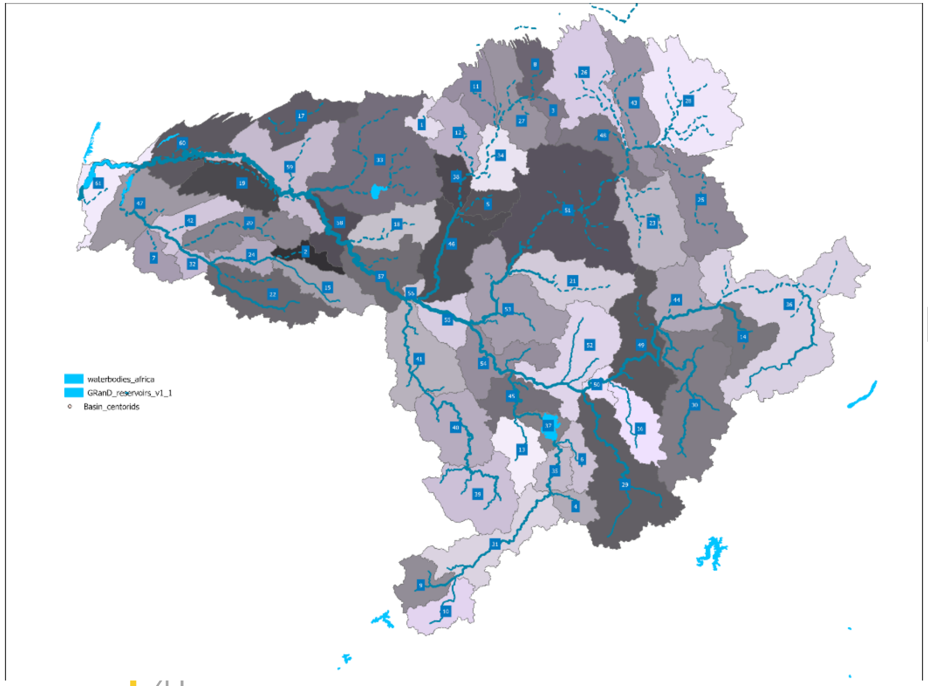
- ✓ **Take into account hydrological dynamics, river water flows, river routing and water transfers**
- ✓ **Improve the assessment of water demand accounts and the impact of changes in downstream water use (distribution of water demand across the river)**
- ✓ **Enhance the multi consideration of WEFE components at basin level (take into account the impact of the proposed strategy on other sectors, upstream and downstream)**
  - WATER / EAU: irrigation + (water needs of livestock and households)
  - FOOD: diets and eating habits + economic benefits for farmers
  - ENERGY: Bioenergy (as already developed) + hydropower target minimum production

Different management alternatives are possible: which are the most EFFECTIVE, the most SUSTAINABLE and their impact on other sectors?

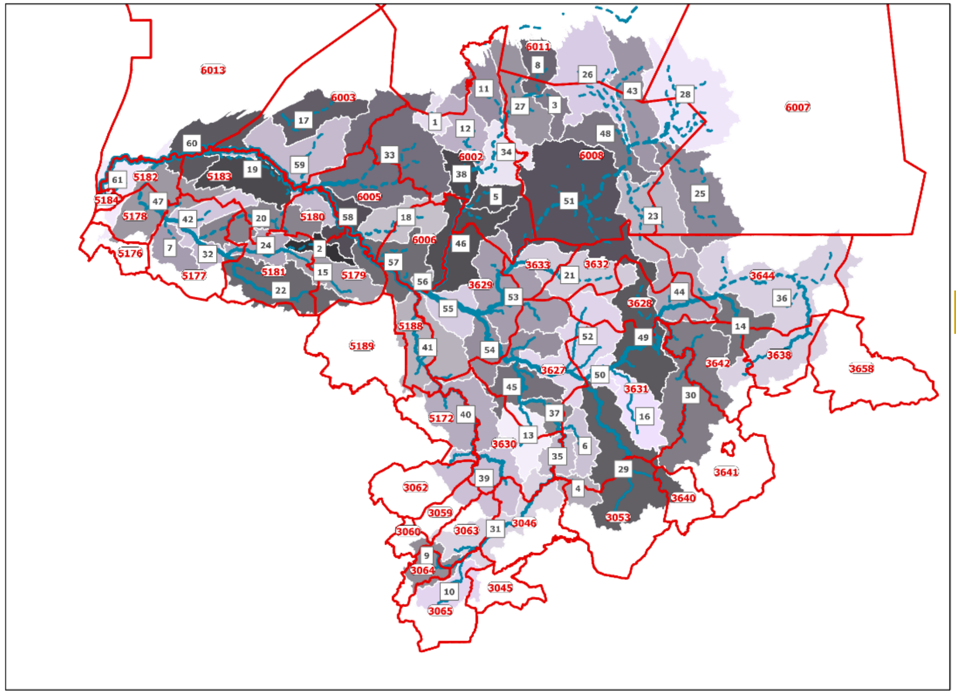
The Multi Objective Optimisation

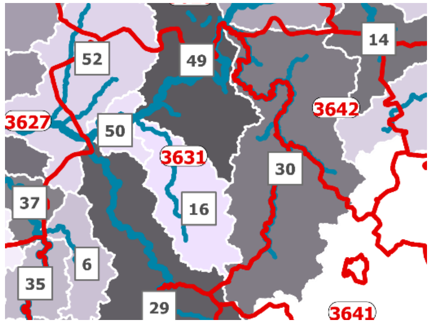
DIFFERENT SPATIAL AGGREGATION SCALES

Basins:
61 basin versants tel que dérivé par une simplification de la procédure d'accumulation de flux de SWAT



Administrative regions:
43 communes administratives appartenant (à l'intersection ou principalement à l'intérieur) au bassin du fleuve Sénégal
https://gadm.org/





SIMULATION UNITS

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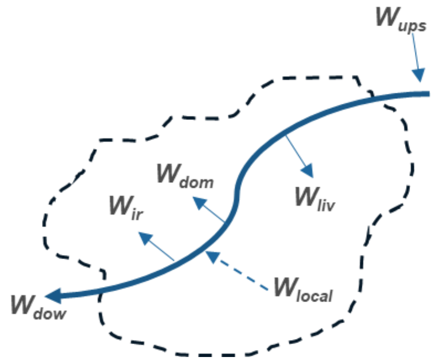
The Multi Objective Optimisation

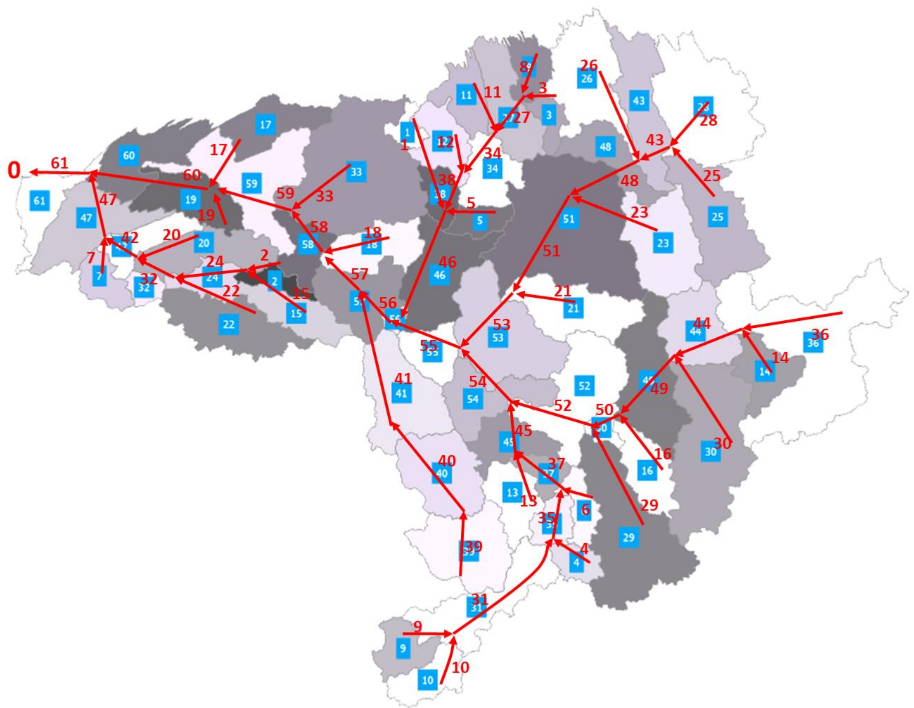
HYDROLOGICAL MODEL

Bilan hydrique (dans chaque subbasin)

$$W_{dow} = W_{ups} + W_{local} + W_{ir} + W_{liv} + W_{dom}$$

$$W_{ir} = \sum_{r}\sum_{c} XI_{rc} * WatDem_{rc}$$





Objectifs d'optimisation

$$maximize \sum_r \sum_c [(XRL_{rc} * YieldRL_{rc}) * SellPrices_{rc} - XRL_{rc} * AgrCostRL_{rc}] +$$
$$\sum_r \sum_c [(XRH_{rc} * YieldRH_{rc}) * SellPrices_{rc} - XRH_{rc} * AgrCostRH_{rc}] +$$
$$\sum_r \sum_c [(XI_{rc} * YieldI_{rc}) * SellPrices_{rc} - XI_{rc} * AgrCostI_{rc}]$$

Indicateur du stress environnemental sur les eaux de surface

$W_{dow} = W_{flow}$ = *le flux dans chaque unité spatiale du bassin versan*

$W_{flow} > W_e$

Subscripts
r: Region
c: Crop

Variables de décision
XRLrc: Surface d'agriculture pluviale pour la culture c dans la région r
XRHrc: Surface d'agriculture pluviale pour la culture c dans la région r
XIrc: Surface d' agriculture irriguée pour la culture c dans la région r

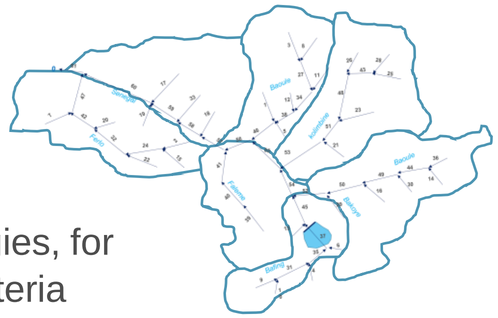
Paramètres
W_{dow} : water resources transferred to downstream the watershed
W_{ups} : water resources transferred from uptstream of the watershed
W_{local} : total water resources produced within the watershed
W_{ir} : irrigation water use (agricultural water demand)
W_{liv} : livestock water use
W_{dom} : domestic water use
W_e : environmental flow for ecosystems
$WatDem_{rc}$: Agricultural water demand pour la culture c dans la region r

Other possible constraints to be specified:

- Share of agricultural water consumed in each country
- Relationship (% to be saved) between water arriving from upstream and water continuing downstream.
- Production and share of different agricultural systems (rain-fed, high-input, subsistence, irrigated, etc.)

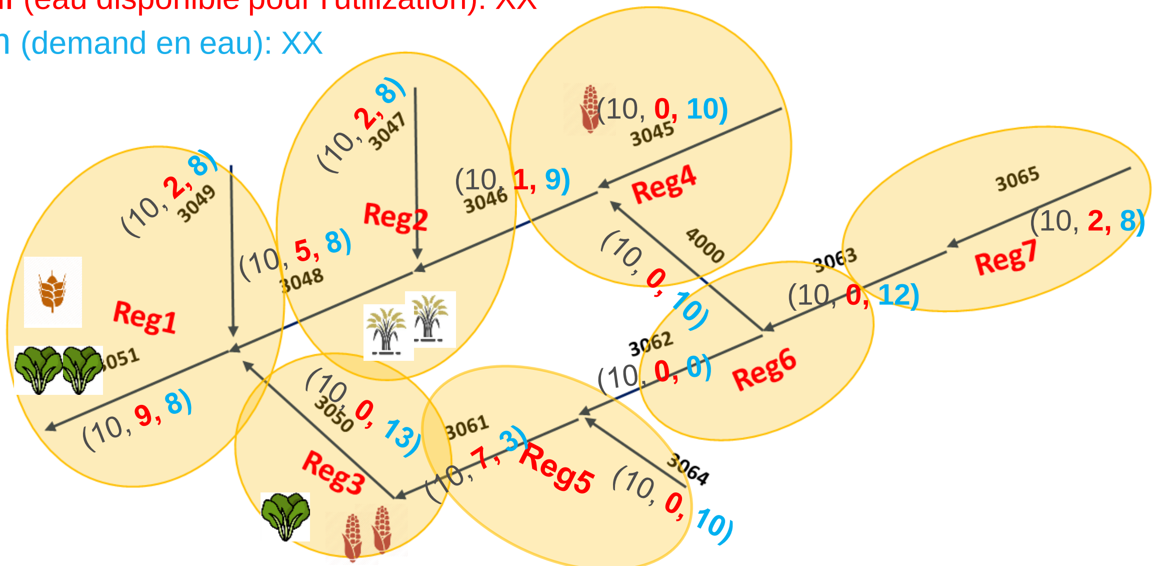
The Multi Objective Optimisation

HYDROLOGICAL MODEL

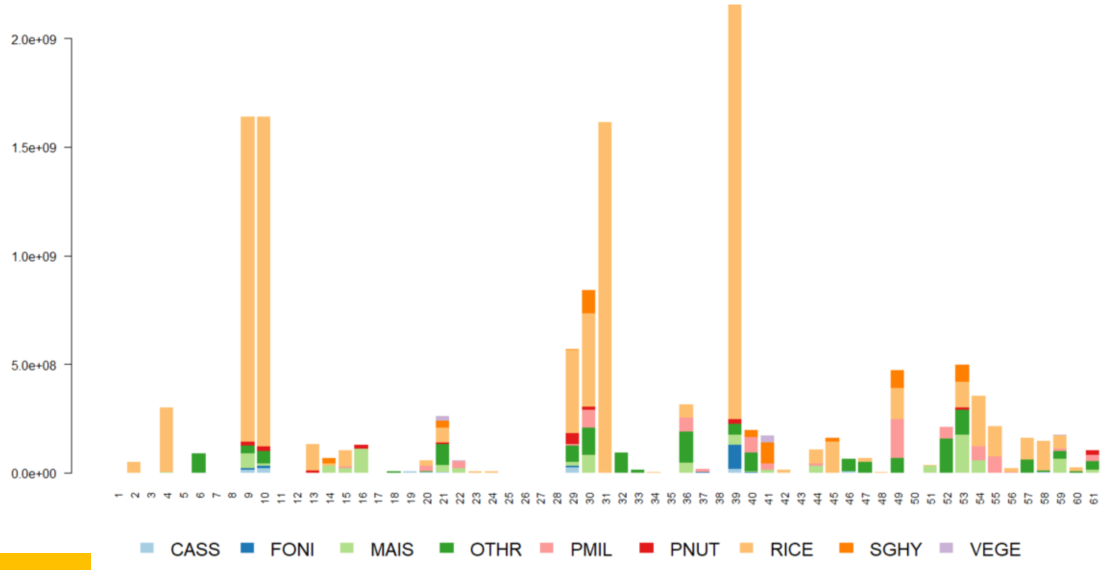


How it works: It proposes several effective solutions (MOO, Multi Objective Optimisation), with alternative strategies, for example, increasing the use of irrigation in certain areas of the basin and reducing it in others (by considering multi-criteria aspects).

freshW (quantité d'eau de rivière): XX
Wavail (eau disponible pour l'utilization): XX
Wdem (demand en eau): XX



Water demand **in each sub-basin as a function of crop management (each colour corresponds to a crop system).**



different solutions for the distribution of cultivated land for each region

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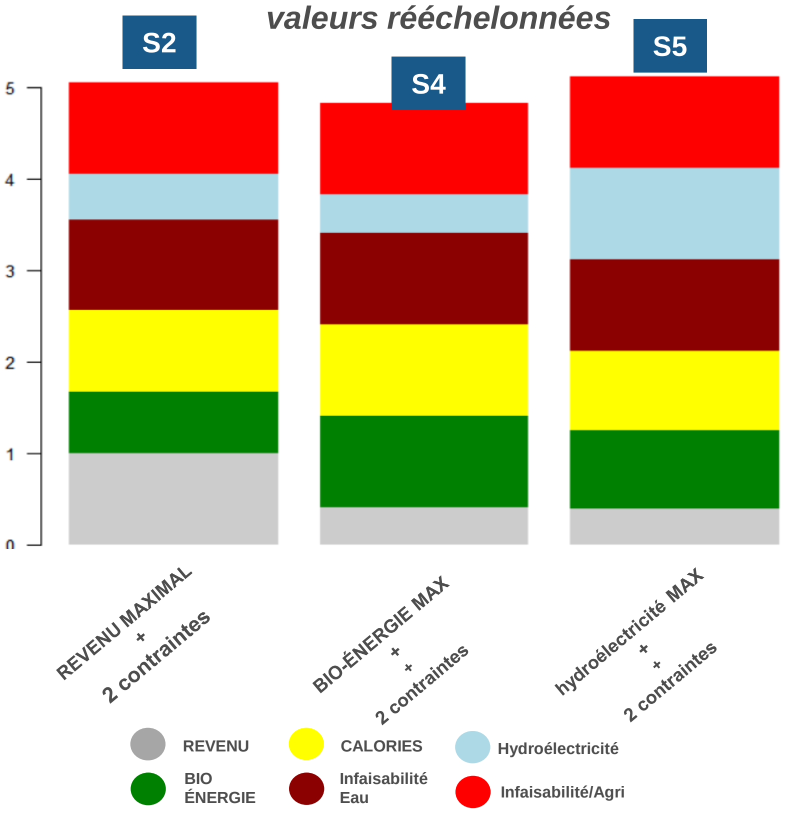
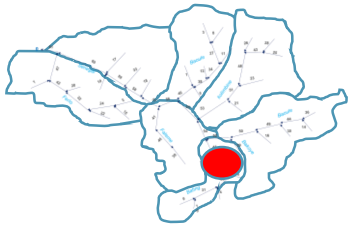
The Multi Objective Optimisation

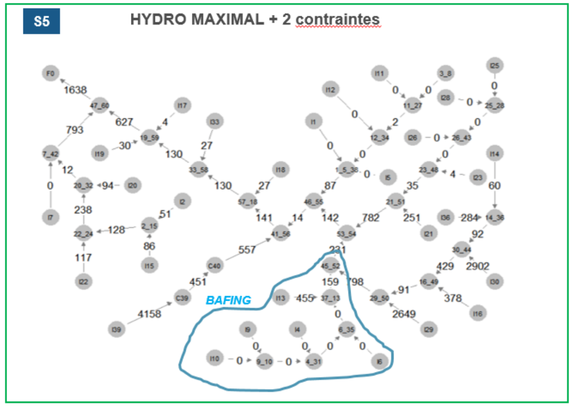
Influence of taking hydroelectricity into account in the selection of management strategies. Consideration of available water in the basin and minimum production constraints

- **Maximising water storage and use for hydroelectricity** (volume at Manantali)
- Option: Maximise bioenergy production





Demande en eau pour l'agriculture



- **Water availability constraints**
- **Satisfying food demand**

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Conclusion and perspectives

Possible questions

- Comparison of different **crop production strategies**, taking into account **multiple objectives simultaneously (economic, environmental and food)**
- **Optimisation of water used for irrigation**, **hydropower, etc.** both at transboundary basin level or national and regional level
- Assessment of specific development scenarios for **increasing demand for irrigation water and impacts on other sectors (as a mitigation/adaptation option to CV and CC)**
- Identification of minimum levels of reduction in agricultural production required to ensure water availability in specific river basin areas (**environmental flow**)
- **Analysis of water demand increase/reduction strategies**
- Assessment of **water use efficiency in different regions / sectors** (water distribution and allocation)

Conclusion and perspectives

- A key aspect to be considered is the **practical transferability of the proposed solutions** and their **acceptance**. In the case that decision-makers only support strategies that are very similar to the current strategy, as shown in the results section, the required constraint still ensures the achievement of an important bioenergy production increase and the complete food demand satisfaction by local production, at least for the riparian regions of Guinea and Senegal.
    - For example: **the regional self-satisfaction capacity** (**limited movements at the regional level**) remains a desirable objective, both for reasons of transport and storage cost, potential difficulties in crop transportation, and as a strategic method to ensure food security for farmers
- **Food demand**: Other aspects that could potentially affect food crop insecurity, such as post-harvest losses, limited accessibility to markets, lack of infrastructure for food transport and storage, and crop failures because of local and seasonal conditions (not considered currently)
- **Financial feasibility** is finally a key element, which is even more complex and which should be assessed at a local scale depending on the national economy and the incentive frameworks of each of the four countries.
- **the environmental impact** of new strategies and more specifically the potential benefit
- **Optimisation**: Importance of optimisation model configuration by **co-iterative process** together with **local experts (forms sectors), stakeholders and decision makers**. Data harmonisation across sectors, definition of objectives formulations + formulation of constraints (limiting optimisation space but ENSURING solution acceptance)

WEFE NEXUS Case studies a more in-depth analysis

1. SPECIFIC FOCUS ON AGRICULTURE AND BIOENERGY: A cropland-energy-water-environment assessment of **bioenergy potential**

2. RIVER BASIN FOCUS – WATER DEMAND AND USES at river basin level: A cropland and water allocation

3. **The importance of linking CV (and CC) with their impacts on agriculture systems:** An analysis for major rainfed cropping systems (My colleague Patricia)

Thank you

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